1 VEDLEGG

Id	Navn	Utarbeidet av	Dato	Ant. sider
Felles vedleggsrapporter				
V0.01	Miljømål og akseptkriterier for tiltak ved U-864	DNV GL AS	2014	18
V0.02	Design av tildekking og kontroll av utlegging	DNV GL AS, NGI	2014	80
V0.03	Geoteknisk vurdering av stabilitet ved tildekking	DNV GL AS	2014	9
V0.04	U-864 2013 Soil survey -Geotechnical Report (NGI)	NGI	2013	199
V0.05	Technical Note, Submarine Wreck U-864. Capping of wreck and contaminated seabed. Evaluation of soil consolidation and increased capping height (Geopartner)	GeoPartner Marin AS	2014	15
V0.06	Submarine Wreck U-864. Effect of consolidation on shear strength	NGI	2014	12
V0.07	Tokt 3a (7 rapporter)	DOF Subsea, NGI, FRAMO, Admiral Consulting, NIVA	2014	229
V0.08	Vurdering av organisering av prosjektet	Risk Management Institute as	2014	18
V0.09	Spesifisering av methyleringsforsøk (Norge + USA)	DNV GL AS, NIVA, Texas Tech University	2014	14
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V0.11	Miljøovervåkningsprogram	DNV GL AS	2014	36
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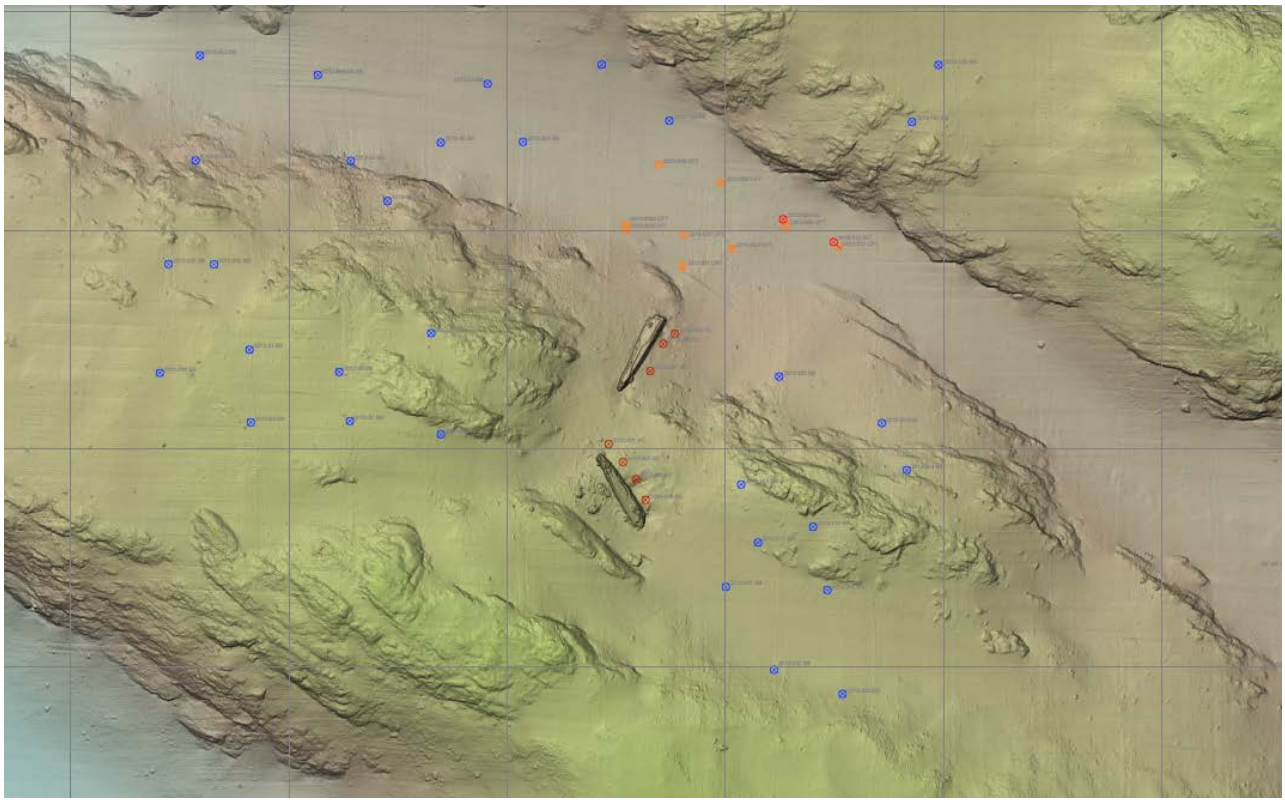
Vedlegg V0.01

MILJØTILTAK VED VRAKET AV U-864

Miljømål og akseptkriterier for tiltak ved U-864

DNV GL AS



Kilde : Kystverket

Project name: Miljøtiltak ved vraket av U-864
Report title: Miljømål og akseptkriterier for tiltak ved U-864

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Dato: 12.5.2014

Gjengivelse av deler av dette vedleggsdokument som kan føre til mistolkning er ikke tillatt

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1 GENERELT

For håndteringen av U-864 er det utarbeidet miljømål og akseptkriterier. Akseptkriteriene skal være til hjelp for å styre operasjonen slik at den holder seg innenfor de miljømål som er satt.

Regjeringen vedtok i 2012 å gå videre med to alternativer i et forprosjekt basert på rangeringen i KVU (konseptvalgutredningen) og KS1 (kvalitetssikring av konseptvalget). I bestillingen fra FKD (Nærings- og fiskeridepartmentet) til Kystverket fremgår det at det skal gjennomføres forprosjektering av følgende alternative løsninger for miljøtiltak ved vraket av U-864:

- Tildekking av vrak og forurenset havbunn (Alt. 1 i KVU)
- Heving av last og tildekking av vrak og forurenset havbunn (Alt. 3 i KVU).

I dette dokumentet beskrives miljømål og akseptkriterier under tiltaket, for sluttkontroll og for langtidsovervåking.

Miljømål og akseptkriterier er de samme uansett hvilket tiltak som velges. Dette understreker at kravene til miljøet er overordnet og ikke er styrt av hvilket tiltak som velges.

I forbindelse med utarbeidelsen av den første utgaven av dokumentet ble det i 2009 holdt møter med Miljødirektoratet (da SFT), Bellona, Norges Naturvernforbund, Norges Miljøvernforbund, World Wide Fund For Nature (WWF) og Greenpeace. Videre ble det avholdt et møte den 28.4.2009 hvor dokumentet ble presentert for Mattilsynet, Nasjonalt institutt for ernærings- og sjømatforskning (NIFES), Havforskningsinstituttet, Folkeaksjonen på Fedje, Fedje kommune, Fiskeri og havbruksnæringens landsforening (FHL) og Norges Fiskarlag – Fiskerlaget Vest.

Møtene ga mange gode innspill og disse ble vurdert og implementert i dokumentet (versjon 1, 26.1.2010).

Som bakgrunn til dette dokumentet har også DNVs rapport til Kystverket i 2008 /1/ vedrørende tiltak ved U-864 vært brukt. Her ble det foreslått et overvåkingsprogram for de ulike tiltaksalternativene tilknyttet U-864.

For å kontrollere om de satte akseptkriteriene har riktig størrelse i forhold til mulig spredning av kvikksølv er det også utført modellberegninger /2/.

1.1 Miljømål

Det er etablert et overordnet miljømål og i tillegg et miljømål for tiltaket:

Overordnet miljømål:
Tiltaket skal medføre at kvikksølvnivået i sjømat, i vannsøylen og i overflatesediment fra dette området vil være på samme nivå som er typisk for den nordlige delen av Nordsjøen.

Overholdelse av dette miljømålet dokumenteres gjennom langtidsovervåkingen, se kapittel 5.

Miljømål for selve tiltaket:
Tiltaket skal utføres slik at det gir minst mulig spredning av kvikksølv til omgivelsene.

Begrepet *minst mulig* er definert av akseptkriteriene for operasjonen som er diskutert i dette dokumentet. Minst mulig spredning inkluderer olje fra vraket og fra utstyret som benyttes i operasjonen.

Kommentar til miljømål:
Fedje og U-864 ligger i den nordlige delen av Nordsjøen på 60 grader 45 minutter N. Grensen mellom Nordsjøen og Norskehavet ligger på 62 grader N.

I 2013 kom Stortingsmelding nr. 37 (2012–2013) *«Helhetlig forvaltning av det marine miljø i Nordsjøen og Skagerrak» (forvaltningsplan). Forvaltningsplanens oppgave er å «legge til rette for verdiskaping gjennom bærekraftig bruk av ressurser og økosystem-tjenester i Nordsjøen og Skagerrak og samtidig opprettholde økosystemenes struktur, virkemåte, produktivitet og naturmangfold. Forvaltningsplanen er derfor et verktøy både for å tilrettelegge for verdiskaping og for å opprettholde miljøverdiene i havområdet».*

I kapittel 8 i Stortingsmeldingen angis hvilke mål som settes for forvaltningen av Nordsjøen og Skagerrak. Av spesiell betydning for denne saken er målene for forurensning:

«Konsentrasjonen av helse- og miljøfarlige kjemikalier og radioaktive stoffer i miljøet skal bringes ned mot bakgrunnsnivået for naturlig forekommende stoffer, og tilnærmet null for menneskeskapte forbindelser. Utslipp og tilførsler av helse- og miljøfarlige kjemikalier eller radioaktive stoffer fra virksomhet i Nordsjøen og Skagerrak skal ikke bidra til overskridelser av disse nivåene.

Utslipp og bruk av kjemikalier som utgjør en alvorlig trussel mot miljøet i de norske havområdene skal kontinuerlig reduseres med mål om å stanse utslippene innen 2020.

Utslipp og tilførsler av forurensende stoffer til Nordsjøen og Skagerrak skal ikke føre til helseskader eller skader på naturens evne til produksjon og selvfornyelse.»

2 KRAV TIL UTFØRENDE ENTREPRENØR

Miljøkrav til utførende entreprenør skal sammenstilles i et dokument og foreligge før oppstart. Dette dokumentet godkjennes av Kystverket/Prosjekteier. Følgende skal inngå i entreprenørens dokumentasjon:

- Entreprenøren skal utarbeide en plan for overvåking av spredning av forurensning.
- Entreprenøren skal utarbeide et dokument med alle relevante bakgrunnsverdier for miljøovervåking under operasjonen. Disse verdiene skal måles før noen aktiviteter har begynt på stedet.
- Entreprenøren skal beskrive utstyr som skal brukes for overvåking, lagring og overføring av resultater fra overvåkingen.
- En beskrivelse av hvordan overvåkingsutstyr skal kalibreres skal utarbeides. All kalibrering skal dokumenteres.
- Entreprenør skal utarbeide en plan for avbøtende tiltak i tilfelle det skjer en uønsket spredning av forurensning.
- Alle laboratorieanalyser skal være akkreditert og ha relevante deteksjonsgrenser, hvis praktisk mulig.

Videre er det satt krav til entreprenøren under selve tiltaket:

- Overvåking av spredning av forurensning skal utføres basert på det dokument som entreprenøren utarbeider i forkant av operasjonen og som er godkjent av Kystverket.
- Spredning av forurensning (partikkelbundet og vannløselig) skal ligge innenfor de akseptkriterier som er gitt av oppdragsgiver (Kystverket) for alle trinn i operasjonen. *Akseptkriterier gis i dette dokumentet.*
- Hvis det under pågående overvåking avdekkes spredning av kvikksølv utover akseptkriteriene skal <u>alle operasjoner stoppes</u>. *Akseptkriterier gis i dette dokumentet.*
- Hvis operasjonen er blitt stoppet på grunn av uakseptabel spredning, skal årsaken til spredningen klarlegges og rettes på før operasjonen starter opp igjen.

3 AKSEPTKRITERIER UNDER TILTAKET

For selve tiltaket legges følgende akseptkriterier til grunn:

Turbiditet:
På målestasjonene skal den gjennomsnittlige turbiditeten i tiltaksperioden over en periode på 20 minutter maksimalt være 5-10 enheter (målt som FTU eller NTU)[1] høyere enn målte bakgrunnsverdier[2]. Overskrides dette på en eller flere målere skal operasjonen stoppes og årsaken til spredningen klarlegges og rettes på før operasjonen starter opp igjen. Unntak fra dette akseptkriteriet kan aksepteres hvis:

- *Det er en risiko for at liv kan gå tapt og/eller det er en risiko for negativ effekt på helsen til involvert personell.*
- *Det oppstår en værsituasjon som gjør at det vil være en uakseptabel risiko for personell og materiell å utføre operasjonen (manøvrering av skip og utstyr).*

Kvikksølv i vann:
I forbindelse med at operasjonen stoppes skal kvikksølvkonsentrasjonen i vannsøylen måles. For å få starte opp operasjonen igjen må kvikksølvkonsentrasjon i vannsøylen ikke overskride 0,7 µg/l. Denne konsentrasjonen kan aksepteres for en kort periode (opp til 30 minutter), etter det må den ikke overstige 0,05 µg/l, ellers må operasjonen stoppes igjen.

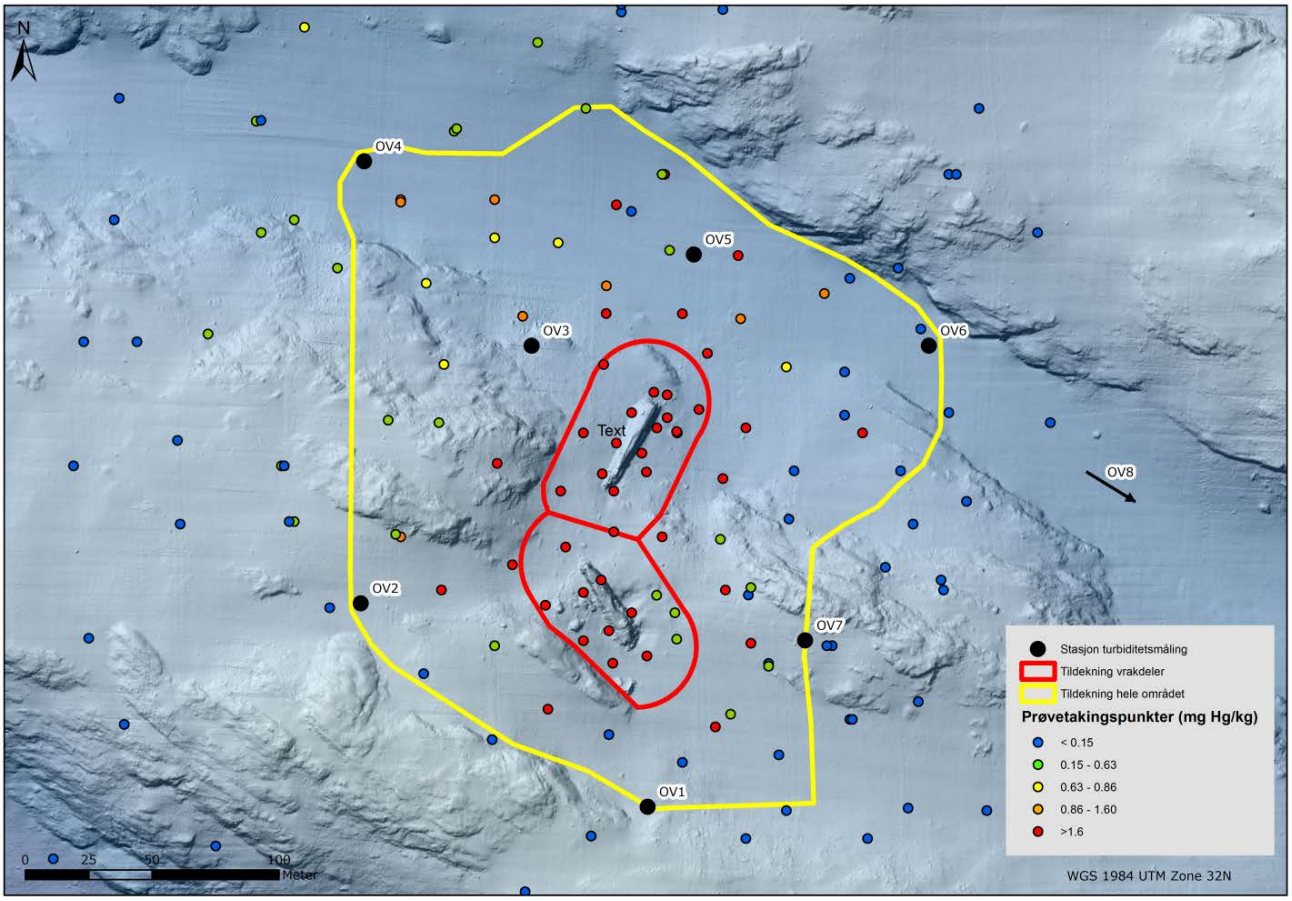
Olje i vann:
Ved synlig olje på vannoverflaten av betydning[3] skal tiltak iverksettes (oljelenser, absorbenter, skimmere etc.[4]).

Total spredning av kvikksølv (miljøgiftbudsjett):
Et krav til valg av tiltak er at det ikke skal medføre at det spres mer enn maksimalt 30 kg kvikksølv utenfor tiltaksområdet under gjennomføring av tiltaket. Dette tilsvarer 10 års spredning av kvikksølv uten tiltak (nåværende situasjon).

3.1 Begrunnelse og utførelse

Turbiditetsmålinger i vannsøylen
Turbiditet er et indirekte mål på partikkelkonsentrasjonen i sjøen og er en vanlig målemetode for tiltak i sjø som kan medføre oppvirvling og spredning av partikler og miljøgifter. Turbiditetsmålinger er best egnet som stoppkriterium fordi det er mulig å måle turbiditet online. Forslag til plassering av stasjoner for turbiditetsmålinger i vannsøylen er vist i Figur 1.

[1] FTU = Formazine Turbidity Unit, NTU = Nephelometric Turbidity Unit
[2] Bakgrunnsverdier vil bli malt før gjennomføring av tiltaket og lagt ved dette dokumentet
[3] Se beskrivelse av begrepet «av betydning» i kap 3 side 12
[4] Skimmere som tar tynnere oljer bør brukes (erfaring fra tømmingen av Blücher)



Figur 1: Forslag til plassering av stasjoner for turbiditetsmålinger.

De fleste stasjoner for turbiditetsmålinger er plassert i ytterkant av tiltaksområdet. Disse er plassert slik fordi hensikten er å overvåke at spredning ikke foregår ut av tiltaksområdet. Videre må ikke måleutstyret komme i konflikt med selve operasjonen. Målingene er foreslått utført 3 m og 10 m over sjøbunnen.

I tillegg er det planlagt en referansestasjon 500 m sørøst for vraket (se Figur 1). Denne ligger oppstrøms i forhold til den dominerende strømretningen og antas å være utenfor det området som forventes å bli påvirket av tiltaket.

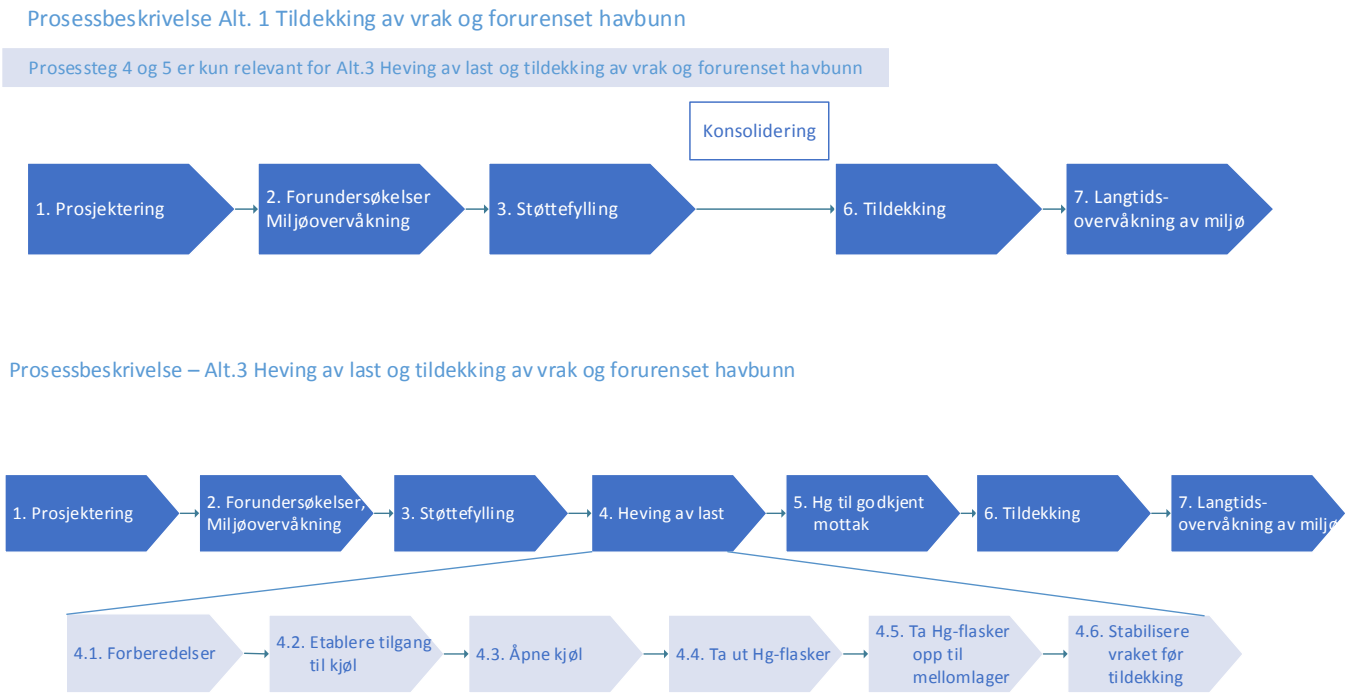
Dette gir til sammen 16 prøvepunkter. Målerne kan måle kontinuerlig eller ved gitte frekvenser under tiltaket. Det skal gjøres bakgrunnsmålinger på samtlige stasjoner før tiltaket starter.

Akseptkriteriet for turbiditetsmålingene skal baseres på bakgrunnsmålinger gjennomført i en periode minimum en måned før tiltaket påbegynnes. Målingene gjennomføres så nært opp til starten av tiltaket som mulig. Bakgrunnen for dette er at turbiditeten vil variere naturlig gjennom året, hvilket betyr at målinger gjennomført lenge før tiltaket starter, ikke nødvendigvis er representative for den perioden tiltaket gjennomføres.

Akseptkriteriet for turbiditet baseres på tidsintegrerte målinger i måleperioden som spesifisert. Tidsintegrerte målinger bør velges for å få et bilde av om det foregår en økning av partikkelkonsentrasjonen i sjøen over tid.

Akseptkriterier for turbiditet for de forskjellige aktivitetene i prosjektet

Figur 2 nedenfor viser de ulike aktivitetene i prosjektet for de to alternativene (alternativ 1: Tildekking av vrak og forurenset havbunn og alternativ 3: Heving av last og tildekking av vrak og forurenset havbunn).



Figur 2: Aktiviteter for alternativ 1 (tildekking) og alternativ 3 (heving av last og tildekking) i U-864 prosjektet.

Det vil være to akseptkriterier knyttet til turbiditet under tiltaket:

- ***10 FTU over målt bakgrunnsverdi for aktiviteter hvor operasjonen innebærer inngrep i sjøbunnen***
- ***5 FTU over målt bakgrunnsverdi for øvrige aktiviteter***

Akseptkriteriene er høyeste tillatte turbiditet når målte bakgrunnsverdier er overskredet, og overskridelsen skal maks. være for en periode på 20 minutter. Perioden på 20 minutter måles fra det tidspunkt hvor en enkeltverdi har overskredet bakgrunnsverdien.

Nedenfor er de forskjellige aktivitetene og tilhørende akseptkriterier beskrevet mer i detalj for de ulike fasene av operasjonen, med henvisning til for hvilke tiltaksalternativer de gjelder:

1. Prosjektering (begge alternativ)

Prosjektering av tiltak og eventuelle miljøovervåkingsprogram.

2. Forundersøkelser, Miljøovervåkning (begge alternativ)

Forundersøkelser for tiltaket. Miljøovervåkning: Utplassering av målestasjoner og måling av bakgrunnsverdier som vil være grunnlaget for målinger under tiltaket.

3. Støttefylling (begge alternativ)

Etablering av støttefylling for å unngå utrasing av skråning og vrak.

Akseptkriteriet er 10 FTU over målt bakgrunnsverdi, over en periode på maks. 20 minutter.

4. Heving av last (kun alternativ 3)

Hevingen av kvikksølvet innebærer også inngrep i sjøbunnen for å kunne komme til lasten.

Akseptkriteriet er 10 FTU over målt bakgrunnsverdi, over en periode på maks. 20 minutter.

5. Hg til godkjent mottak (kun alternativ 3)

Kvikksølvet transporteres til et godkjent (endelig) mottak.

6. Tildekking (begge alternativ)

Tildekking av hele det forurensede området. Tildekkingen skal foregå med rene masser og med en utleggingsmetode som gir liten oppvirvling. En må uansett regne med noe oppvirvling av partikler.

Akseptkriteriet er 5 FTU over målt bakgrunnsverdi, over en periode på maks. 20 minutter.

7. Langtidsovervåkning av miljø (begge alternativ)

Langtidsovervåkning skal følge opp miljøtilstanden etter tiltaket. Her vil det bli målt andre parametere enn turbiditet.

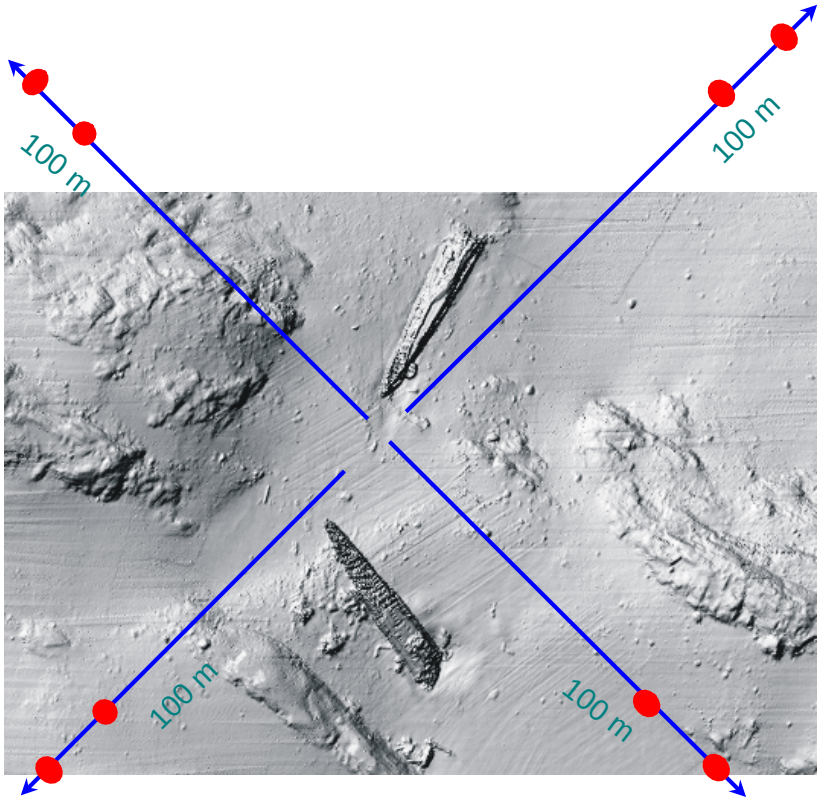
Kvikksølvkonsentrasjon i vannsøylen

For å oppnå en god beskyttelse av miljøet under tiltaket er det satt som krav at kvikksølvet i sjøvannet ikke skal gi noen toksiske effekter. Dette tilsvarer tilstandsklasse II "God" i Miljødirektoratets klassifiseringssystem /3/. Det betyr at konsentrasjonen av kvikksølv i vannsøylen ikke skal overstige 0,048 µg/l (avrundes til 0,05 µg/l).

For korte perioder under operasjonen (opp til 30 minutter) kan høyere konsentrasjoner av kvikksølv i vannsøylen aksepteres. Akseptabel verdi bør være på et nivå der korte perioder med denne vannkonsentrasjonen av kvikksølv ikke medfører økt dødelighet på fisk som tilfeldigvis er i området under tiltaket. Det anbefales her å bruke en verdi på 0,7 µg/l. Verdien er basert på LC_{50} (konsentrasjonen med 50 % dødelighet i forsøk) for fisk, hvor fisken er eksponert for denne dosen i 4 dager i laboratoriet /4/.

For å gi et bilde av hva en kvikksølvkonsentrasjon på 0,7 µg/l tilsvarer, så vil et "basseng" på 30 000 m^2 og 150 m dybde med denne konsentrasjonen gi en total kvikksølvmengde på 3 kg. Dette kan for eksempel sammenlignes med den beregnete og analyserte årlige utlekkingen på 3-4 kg kvikksølv fra de 30 000 m^2 forurensede sedimentene i dag /5/.

For løpende overvåking av kvikksølv i vannsøylen under tiltaket er det foreslått at vannprøvetaking foretas i transekt som inkluderer hovedstrømretningen. Prøvene tas i fire hovedretninger (nordøst, nordvest, sørvest og sørøst), slik det er vist i Figur 3.



Figur 3: Forslag til plassering av stasjoner for vannprøvetaking

Foreslått avstand for stasjonene er 100, 200 og 300 m fra vraket i hver retning. Vannprøvene foreslås tatt på 3 og 10 m over bunnen. Dette gir 24 prøvepunkter til

sammen. Vannprøver skal tas ved faste intervaller, en gang per dag når tiltak pågår. Det skal gjøres en bakgrunnsmåling på samtlige stasjoner før tiltaket starter.
En vannprøve vil kunne brukes for å raskt kunne bekrefte/avkrefte om det foreligger en spredning av kvikksølv over akseptkriteriet og eventuelt behov for å iverksette korrigerende tiltak.

I forkant av tiltaket bør det gjøres en vurdering av om det også er mulig å anslå kvikksølvmengden i vann (bundet til partikler) basert på turbiditetsmålinger. Erfaringsmessig er imidlertid dette vanskelig.

Olje i vann
Vrakdelene kan fortsatt inneholde olje fremst i form av drivstoff (diesel). Et krav er at spredningen av olje fra vraket og operasjonsutstyret skal minimaliseres.
Oljespill vil best kunne detekteres ved visuell overvåking. Ved synlig olje på vannoverflaten av betydning skal tiltak iverksettes. Med oljeutslipp av betydning menes utslipp som ikke er tillatt etter forurensningsloven § 7. Utstyr som trengs for å stoppe spredning av olje (oljelenser, absorbenter, skimmere etc.) skal finnes på fartøy på stedet.

Total spredning av kvikksølv (miljøgiftbudsjett)
I tillegg til kontroll av overskridelser av turbiditet og kvikksølv i vann er det en begrensning på hvor mye kvikksølv som kan spres utenfor tiltaksområdet. Ved at kvikksølvet spres utenfor tiltaksområdet vil det bli tilført i et område hvor det ikke er planlagt å utføre tiltak og derved utgjøre en miljøbelastning. Grensen for tiltaksområdet er vist på Figur 1. For hele tiltaket får det ikke spres mer enn maksimalt 30 kg kvikksølv utenfor tiltaksområdet. Den årlige spredningen på nåværende tidspunkt uten tiltak fra tiltaksområdet er ca. 3-4 kg pr. år /5/. Det vil si at grensen som er satt for spredning av kvikksølv under tiltaket tilsvarer spredningen i løpet av ca. 10 år uten tiltak (nåværende situasjon). Spredningen vil bli estimert ved hjelp av vannprøvene som tas i løpet av tiltaket. Basert på vurderingene i forkant av tiltaket vil det bli bestemt om også turbiditetsmålinger skal brukes for å anslå spredningen (se ovenfor).

Håndtering av overskridelser av akseptkriterier for turbiditet, kvikksølv-konsentrasjon i vannsøylen under tiltaket og total spredning
Ved overskridelse av akseptkriteriet (mistanke om uakseptabel spredning) skal entreprenøren stoppe operasjonen og klarlegge årsaken til spredningen. Vannprøve skal tas der hvor overskridelsen har funnet sted og spredningsreduserende tiltak skal iverksettes. Det er kvikksølvinnholdet i vannprøven som bestemmer om en får starte opp igjen (se ovenfor).
Hvis konsentrasjonen av kvikksølv ikke er under 0,05 µg/l innen 30 minutter etter overskridelsen skal årsaken dokumenteres og det skal utarbeides en ny strategi som sørger for at årsaken til overskridelsen av akseptkriteriet er fjernet/endret.

For den totale spredningen lages det et miljøbudsjett med en maksimal spredning pr. døgn. Viser det seg at det spres mer enn dette, må arbeidene stoppes og det utarbeides nye arbeidsrutiner som reduserer spredningen slik at en ikke overskrider den totale rammen.

I en krisesituasjon; for eksempel hvor det blir varslet meget dårlig vær må Kystverket/ Prosjekteier gjøre en total vurdering hvor liv og helse må veies mot miljø. I en slik situasjon kan det være bedre å la operasjonen fortsette, til tross for en overskridelse av akseptkriteriene. I en slik situasjon bør tiltaksområdet revurderes for å sikre at tiltaket tilfredsstiller akseptkriteriene etter tiltak.

4 AKSEPTKRITERIER FOR SLUTTKONTROLL ETTER TILTAKET

For sluttkontrollen av entreprenørens arbeid legges følgende akseptkriterier til grunn for sjøbunnen etter tildekking:

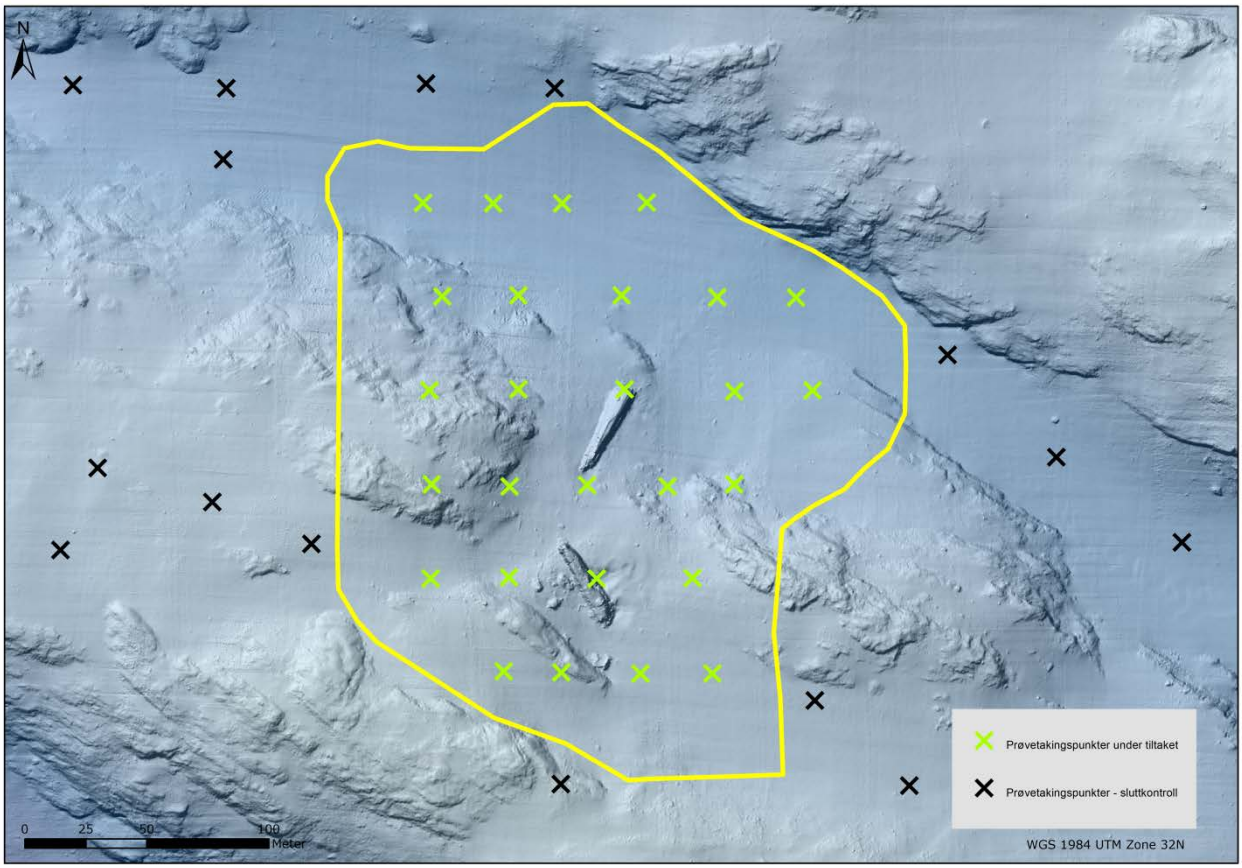
- ***Ved sluttkontrollen skal konsentrasjonen av kvikksølv i det øverste sedimentlaget (2 cm) ikke overstige 0,63 mg/kg (klasse II – god).***
- ***Tildekkingen kontrolleres slik at 100 % av tiltaksområdet skal være tildekket. Arealer rundt vrakdelene skal være tildekket med planlagt tykkelse og minst 90 % av øvrige areal skal være dekket til med fastsatt tykkelse på dekklaget.***

4.1 Begrunnelse og utførelse

Ved sluttkontrollen skal kilden til spredning av kvikksølv være fjernet eller tildekket. Det betyr at det må settes krav til renhet i sedimentene. Kravet er at sedimentene ikke skal ha noen toksiske effekter. Dette tilsvarer en kvikksølvkonsentrasjon på maksimalt 0,63 mg/kg, tilsvarende tilstandsklasse II (god) i Miljødirektoratets klassifiseringssystem /3/. Prøvene som analyseres bør være fra de øverste 2 cm av sedimentene (laget under erosjonslaget der hvor det er tildekket) hvor det er risiko for spredning og bioturbasjon (gravende virksomhet av dyr som lever i sedimentene). Som ekstra kontroll bør det også tas prøver fra et dypere lag, forslagsvis 2-5 cm.

For sluttkontrollen av utført arbeid av entreprenør tas sedimentprøver i et rutenett slik det er foreslått i Figur 4. I størrelsesorden 30-40 prøver tas som 3 replikate prøver og analyseres som en blandprøve. På alle stasjoner foreslås at kvikksølvinnholdet analyseres og på 10 av stasjonene er også analyse av porevann foreslått.

For tildekkingen kan kontroll av tykkelse på dekklaget gjøres ved en kombinasjon av akustiske målinger (før og etter tildekking), ROV og ved avlesing av målepinner på sjøbunnen. Sluttkontrollen skal utføres etter at dekklaget (sand eller lignende) er lagt på men <u>før</u> det erosjonsbeskyttende laget (grov grus eller pukk) er lagt på.



Figur 4: Illustrasjon av plassering og antall prøvetakingsstasjoner for sluttkontroll sediment. Grønne kryss representerer stasjoner innenfor planlagt tiltaksområde mens svarte kryss representerer stasjoner utenfor tiltaksområdet.

5 AKSEPTKRITERIER FOR LANGTIDSOVERVÅKING ETTER TILTAKET

Etter at tiltaket er utført vil det være behov for akseptkriterier for langtidsovervåkingen både for vannsøylen, sedimentene og for biota (primært fisk og krabber):

- ***Etter tiltaket skal kvikksølvkonsentrasjonen i vannsøylen ikke overstige bakgrunnskonsentrasjon i nordlige deler av Nordsjøen, både i åpne havområder og kystnære områder.***
- ***Etter tiltaket skal konsentrasjonen av kvikksølv i vannprøver fra det øverste sedimentlaget (2 cm) ikke overstige 0,05 µg/l (klasse II – god).***
- ***Etter tiltaket skal 100 % av tiltaksområdet skal være tildekket. Arealer rundt vrakdelene skal være tildekket med planlagt tykkelse og minst 90 % av øvrige areal skal være dekket til med fastsatt tykkelse på dekklaget.***
- ***Etter tiltaket skal konsentrasjonen av kvikksølv i fiskefilet og krabber være på samme nivå som er typisk for nordlige deler av Nordsjøen, både i åpne havområder og kystnære områder og ikke overstige EUs grenseverdi (0,5 mg/kg våt vekt). En eventuell reduksjon av kvikksølvkonsentrasjon i fisk og krabber vil ta noe tid og må følges opp med overvåkingsdata.***

Kvikksølvkonsentrasjon i vannsøylen

Etter tiltaket (dager) forventes kvikksølvkonsentrasjonen i vannsøylen å være på samme nivå som i åpne havområder og kystnære områder i nordlige deler av Nordsjøen

For overvåking av kvikksølv i vannsøylen etter tiltaket er det foreslått vannprøvetaking på de samme stasjonene som under tiltaket, se kapittel 3, samt fra etablerte overvåkingsbrønner i området.

Kvikksølvkonsentrasjon i sedimentene

Etter tiltaket skal kilden til spredning av kvikksølv være fjernet eller tildekket. Kravet er at kvikksølvinnholdet i sedimentet ikke skal medføre noen toksiske effekter, dvs. det samme krav som ved sluttkontrollen. Det er imidlertid uegnet å ta sedimentprøver fra tildekkede områder, det kan skade tildekkingen. Isteden etableres overvåkingsbrønner hvor det tas vannprøver fra tildekkingslaget. Vannprøvene som analyseres tas fra de øverste 2 cm av tildekkingen (under erosjonslaget) hvor det er risiko for spredning og bioturbasjon (gravende virksomhet av dyr som lever i sedimentene).

Det foreslås å ta vannprøver i samme rutenett som er brukt for sluttkontroll (30-40 stasjoner), se Figur 4 i kapittel 4. På alle stasjoner analyseres kvikksølvinnholdet i vannprøver. Prøvene tas ved faste intervaller, forslagsvis en gang i året i de første årene. Konsentrasjonen av kvikksølv i vannprøvene skal ikke overstige 0,05 µg/l (klasse II – god).

Kontroll av tykkelsen på dekklag
Kontroll av tykkelse på dekklaget kan gjøres ved en kombinasjon av akustiske målinger (sammenligne med tidligere undersøkelser), ROV og ved kontroll av de på forhånd utsatte målepinnene på sjøbunnen.

Kvikksølvkonsentrasjon i biota
Etter tiltaket skal kvikksølvkonsentrasjonen i biota (fisk og krabbe) undersøkes. I fisk undersøkes fileten og i krabber undersøkes klokjøtt og krabbesmør. NIFES foreslår at organismene samles inn i tre områder /6,7,10/. I tillegg er det foreslått at det fiskes nord og sør i kyststrømmen. Prøvene tas ved faste intervaller, forslagsvis en gang i året i de første årene. Det vil være en viss responstid (år) før det kan måles en eventuell reduksjon i kvikksølvkonsentrasjonen i fisk og krabber, se også /9/.

Vedrørende grenseverdier/akseptkriterier så viser NIFES /6,7.10/ i sine undersøkelser av fisk i området rundt U-864 til EUs grenseverdier /8/. EUs grenseverdi (EC 2001/466) for kvikksølv i fiskefilet er 0,5 mg/kg våtvekt. Noen få arter har fått en grenseverdi på 1,0 mg/kg våtvekt (for eksempel uer, kveite og steinbit). Det foreslås at EUs grenseverdi legges til grunn som et foreløpig akseptkriterium for både fisk og krabber. Da det kan forventes høyere nivåer av kvikksølv i fisk i kystnære områder (kyststrømmen) bør nivåer av kvikksølv i fisk fanget i kyststrømmen inkluderes som referanse når bakgrunns-konsentrasjon i nordlige deler av Nordsjøen vurderes.
Endelig vurdering av akseptabelt innhold av miljøgifter i fisk og krabber foretas av Mattilsynet med bistand fra den norske Vitenskapskomiteen for mattrygghet (VKM). Mattilsynet forholder seg til internasjonalt aksepterte grenseverdier. Ut i fra disse grense-verdiene og innholdet i fisk og krabber vil de vurdere hvilke tiltak som skal gjennomføres. Tiltak kan være omsetningsforbud eller kostholdsråd.

Tid som langtidsovervåkingen skal pågå
Miljøovervåkningsprogrammet som er beskrevet strekker seg ut over tiltakets varighet og Kystverkets ansvarsperiode som foreslås satt til 5 år. Etter denne perioden vil videre miljøovervåkning, basert på en revisjon av det skisserte program for oppfølging av tiltaksområdet for U-864, måtte inngå i Miljødirektoratets totale nasjonale program for miljøovervåkning.

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About DNV GL

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Vedlegg V0.02

MILJØTILTAK VED VRAKET AV U-864

Design av tildekking og kontroll av utlegging

DNV GL AS

Project name: Miljøtiltak ved vraket av U-864
Report title: Design av tildekking og kontroll av utlegging

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Dato: 12.5.2014

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APPENDIX 1: Modellering for design av tildekkingslag for tildekking av U-864 og forurensede sedimenter omkring vraket. Teknisk notat 20130288-01-TN utarbeidet av NGI.

KONKLUDERENDE SAMMENDRAG

I denne rapporten er tildekkingsalternativet (alternativ 1) for U-864 beskrevet. Rapporten følger opp arbeidet som ble presentert i DNV-rapport 23916-11 "*Salvage of U864 - Supplementary studies - Study no. 11: Assessment of future spreading of mercury for the capping alternative*" som ble levert til Kystverket i 2008. I denne nye rapporten er det foreslått en mer detaljert design av tildekkingen og av arbeids-utførelsen. Hensikten med dette er at en skal ha et godt grunnlag for å gjøre en kostnadsberegning for tiltaket.

Målet for tildekkingen er at alle områder hvor kvikksølvforurensningen av sjøbunnen overskrider 0,63 mg/kg sediment skal tildekkes. Basert på alle sedimentanalysene som er utført av sjøbunnen, er dette området estimert til 47 000 m^2.

Design av tildekkingen er utarbeidet for de to vrakdelene av U-864 og for de øvrige forurensede områdene. I hovedalternativet er det foreslått at en baserer tiltaket på en tildekking med mineralske masser (sand, grus etc.).

	Like ved vraket (adveksjonslag: fin subbus)	Resten av forurenset område
Erosjonslag	20 cm	20 cm
Bioturbasjonslag	15 cm	15 cm
Adveksjonslag	(220 – 90 – 15 cm*) = 115 cm	(40 – 15 cm*) = 25 cm
Kjemisk isolasjonslag	90 cm	5 cm
Sum tildekking uten usikkerhet	**240 cm**	**65 cm**
Tillegg for blandingslag	10 cm	10 cm
Tillegg for å ta hensyn til usikkerhet ved utlegging	40 cm	40 cm
Total tykkelse av tildekkingen	**290 cm**	**115 cm**

Som det fremgår av tabellen foreslås vrakdelene tildekket med en tykkelse på 2,9 m og øvrige områder med en tykkelse på 1,15 m.

Selve utleggingen av masser bør utføres med konvensjonelt tilgjengelig utstyr i markedet så langt dette er mulig.

1 INNLEDNING

1.1 Bakgrunn

I denne rapporten er tildekkingsalternativet (alternativ 1) for U-864 beskrevet.

Rapporten følger opp arbeidet som ble presentert i DNV-rapport 23916-11 "*Salvage of U864 - Supplementary studies - Study no. 11: Assessment of future spreading of mercury for the capping alternative*" som ble levert til Kystverket i 2008. I denne nye rapporten er det foreslått en mer detaljert design av tildekkingen og av arbeids-utførelsen. Hensikten med dette er at en skal ha et godt grunnlag for å gjøre en kostnadsberegning for tiltaket.

1.2 Hensikten med tildekkingen

Tildekkingen av vraket etter U-864 har som formål å redusere risiko knyttet til kvikksølv i vraket og i sedimentet utenfor vraket. Dette oppnås ved å redusere tilgjengeligheten av dette kvikksølvet (Hg), (både elementært Hg, ionisk Hg og metylkvikksølv) i over-flaten av sjøbunnen etter tildekking. Basert på delrapport om miljømål og aksept-kriterier for tiltak ved U-864 (DNV GL, 2014a) er oppnåelsen av dette beskrevet som at konsentrasjon i sediment i de øverste 2 cm av sjøbunnen etter tildekkingen (før plassering av erosjonslag) skal være mindre enn 0,63 mg/kg. Dette tilsvarer tilstandsklasse II ifølge Miljødirektoratets veileder for klassifisering av miljøkvalitet i fjorder og kystfarvann (Miljødirektoratet, 2007).

Tykkelsen med tildekkingsmasse der diffusjonstransport dominerer Hg-transporten beregnes slik at disse kravene tilfredsstilles.

Tildekkingslaget må dessuten oppfylle følgende funksjoner:

- Hindre at tildekkingslaget eroderer
- Hindre at bølger og vannstrøm fører til vesentlig adveksjon i tildekkingsmassene
- Ta høyde for
    - At deler av det forurensede sedimentet blandes med tildekkingsmassen ved utlegging
    - At deler av tildekkingsmassen konsoliderer etter tildekking
    - At det er noe usikkerhet i tykkelsen som faktisk blir lagt ut i forhold til designtykkelse.

Den overordnete hensikten med overvåkingen av tildekkingsoperasjonen er:

1. Kontroll under tildekkingen som muliggjør korrigerende tiltak under utplasseringen, slik at planlagt sluttresultat kan oppnås.
2. Sluttkontroll av hele tiltaket. Kontrollere at tildekkingen er som designet med hensyn på tykkelse, sammensetning og utstrekning.

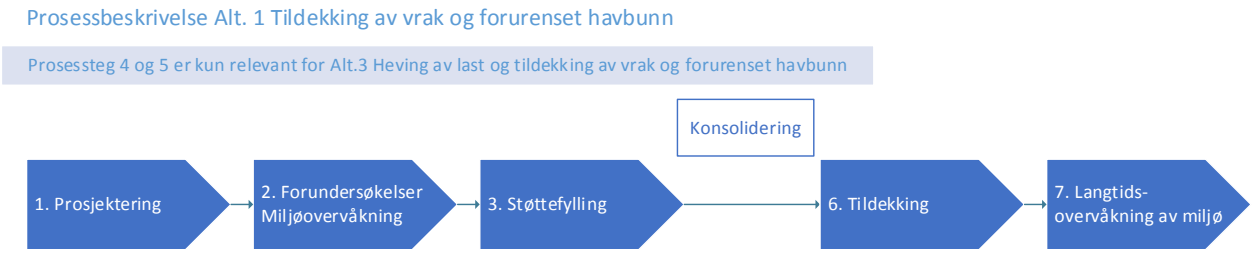
Tildekking kontrolleres slik at 100 % av tiltaksområdet skal være tildekket og arealer rundt vrakdelene skal være tildekket med planlagt tykkelse og minst 90 % av øvrige areal skal være dekket til med fastsatt tykkelse på dekklaget.

Overvåkingen inkluderer både fysisk og kjemisk kontroll som beskrevet nærmere i de følgende kapitlene i denne rapporten.

Det vises til delrapport som omhandler overvåking av tiltaket som helhet (DNV GL, 2014b) og delrapport som omhandler akseptkriterier (DNV GL, 2014a)

1.3 Prosessbeskrivelse for tildekkingen

Figuren nedenfor beskriver de arbeidsprosesser som er vurdert å være nødvendige for å dekke til vraket av U-864. Rekkefølgen som er vist i figuren antas å være nødvendig for at alle operasjonene skal bli mest mulig vellykkede og gi minst mulig spredning av forurensning under arbeidet med tildekking. Prosessteg 4 og 5 omhandler fjerning av last (kvikksølv). De er kun relevante for tiltaksalternativ 3 (heving av kvikksølvlast) men ikke for dette alternativet (alternativ 1, tildekking). Heving av kvikksølvlast er utredet i egne delutredninger.



1.4 Bidragsytere til denne rapporten

Hovedarbeidet med denne rapporten er utført av:

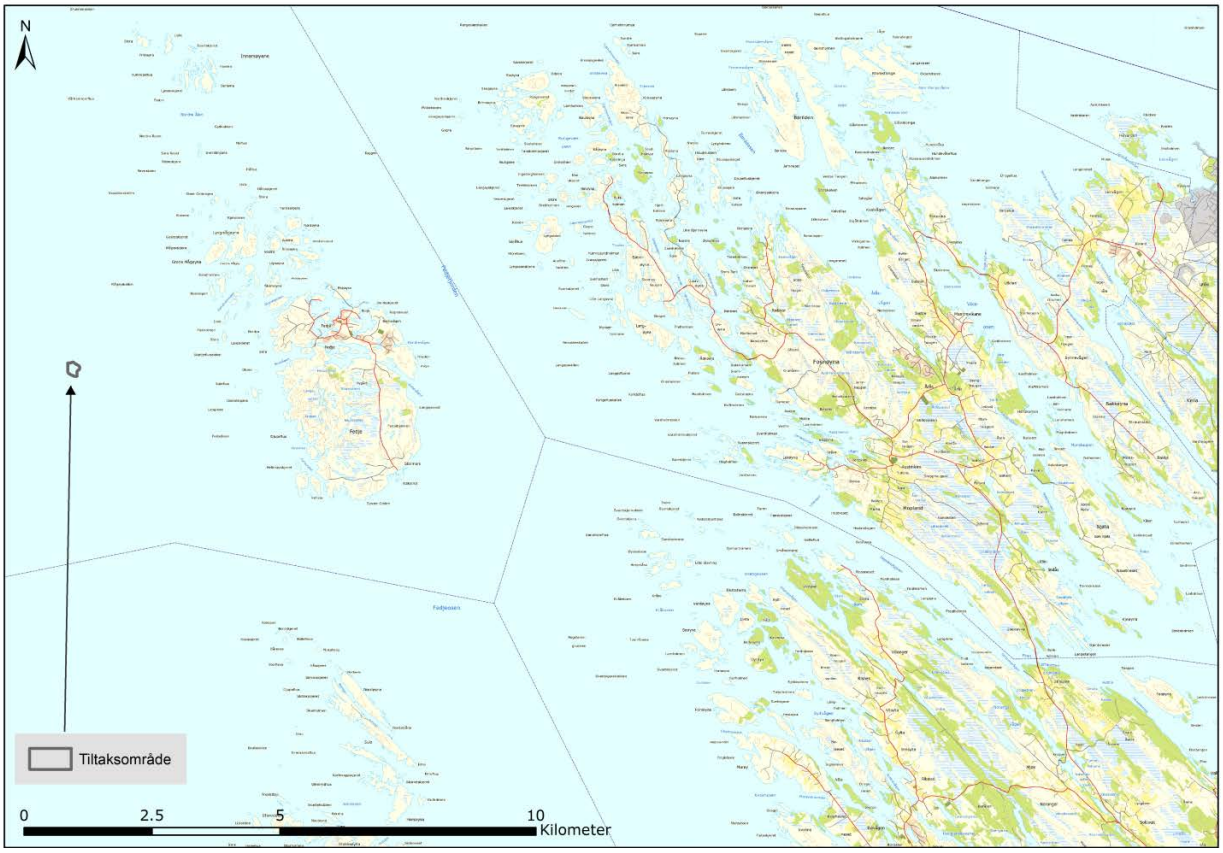
- Dr. Espen Eek, Norges Geotekniske Institutt
- Cand scient. Thomas Møskeland, DNV GL AS
- Dr. Jens Laugesen (Ansvarlig), DNV GL AS
- M.Sc. Aase Holsen, DNV GL AS

Rapporten har siden vært gjennomgått og revidert av:

- Professor Danny Reible, TexasTech University (USA)
- Dr. Mike Palermo, Mike Palermo Consulting (USA)
- Dr. Joe Jersak, SAO Environmental Consulting AB (Sverige)

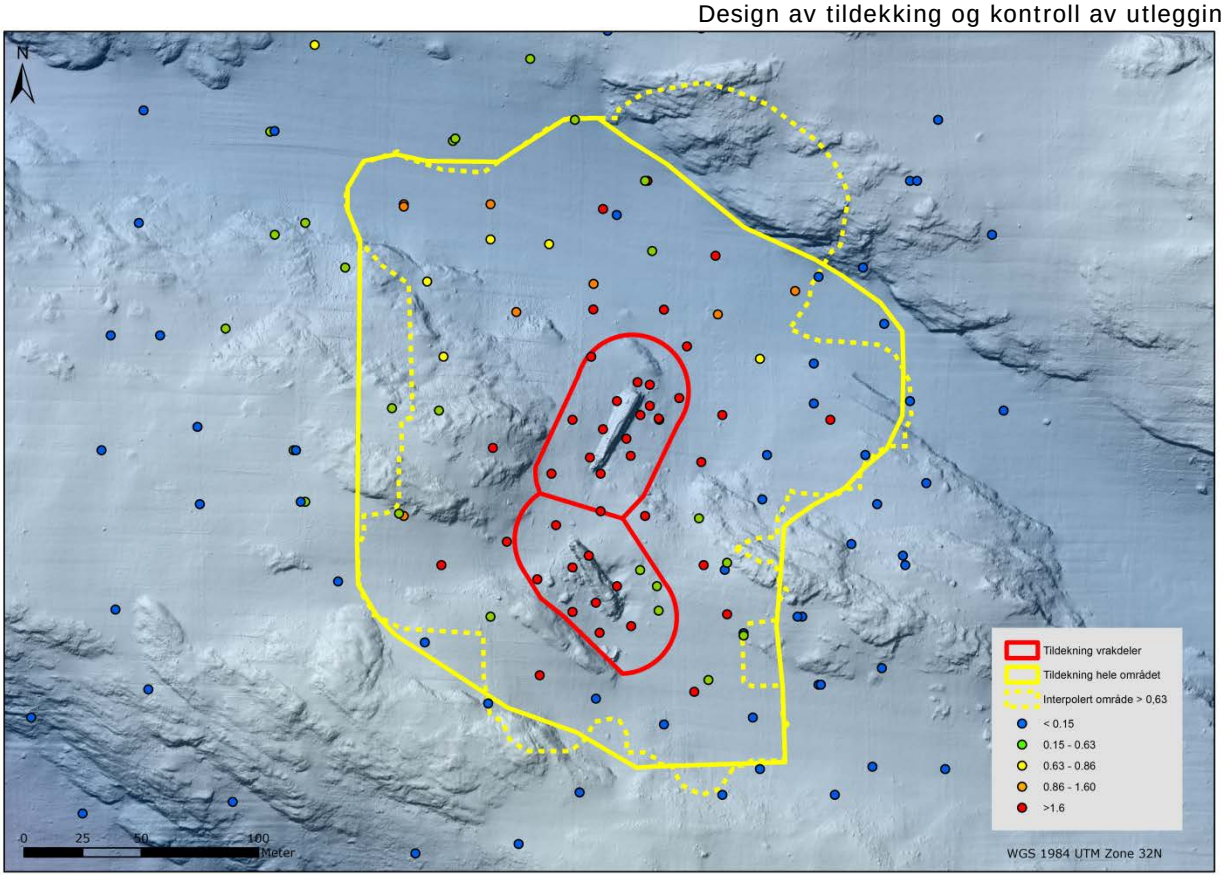
2 AREAL SOM SKAL TILDEKKES

Figur 1 viser området utenfor Fedje i Hordaland hvor vrakdelene av U-864 ligger på ca. 150 m dyp.



Figur 1: Tiltaksområdet hvor vraket av U-864 ligger er ca. 2 nm (3,7 km) utenfor Fedje.

Det er tatt en rekke sedimentprøver rundt U-864. Prøvene er analysert for å avdekke innhold av kvikksølv. Basert på analysene er det utført en interpolering av resultatene hvor sedimentene er inndelt i forhold til tilstandsklasser for kvikksølv, se Figur 2.



Figur 2: Analyser av kvikksølv fra overflatesedimenter rundt U-864 med fargeinndeling i henhold til Miljødirektoratets tilstandsklasser for forurensede sedimenter (veileder TA 2229/2007). Stiplet gul linje viser GIS interpolert avgrensning for tiltaksmål 0,63 mg Hg/kg. Heltrukken gul linje viser manuelt tilpasset avgrensning til topografi (47 000 m^2) av område som foreslås tildekket. Rød linje viser område rundt vrakdelene som foreslås tildekket med ekstra tykt lag.

Størrelse på tiltaksareal for kvikksølvforurenset sjøbunn vil variere avhengig hvilke tiltaksklasse som settes som tiltaksmål. I tabell 1 er de forskjellige tiltaksarealene oppgitt, som det fremgår av tabellen vil et strengere tiltaksmål gi et større tiltaksareal.

Tabell 1: Størrelse på tiltaksareal basert på hvilken tilstandsklasse som settes som tiltaksmål. Beregning basert på interpolering av data fra sedimentundersøkelser.

Tilstandsklasse kvikksølv	**Areal m^2**
Tiltaksmål: Tilstandsklasse 2 (areal med konsentrasjon > 0,15 mg Hg/kg saneres)	227 600
Tiltaksmål: Tilstandsklasse 3 (areal med konsentrasjon > 0,63 mg Hg/kg saneres)	47 000
Tiltaksmål: Tilstandsklasse 4 (areal med konsentrasjon > 0,86 mg Hg/kg saneres)	41 500
Tiltaksmål: Tilstandsklasse 5 (areal med konsentrasjon > 1,6 mg Hg/kg saneres)	30 700

Målsetningen i prosjektet er å sanere alle sedimenter som har en forurensning som ligger høyere enn tilstandsklasse II.

Det betyr at akseptkriteriet (miljømålet) er 0,63 mg Hg/kg og at det utføres tiltak hvor sedimentene er i tilstandsklasse III, IV og V. Det gir et saneringsareal på 47 000 m^2 sjøbunn (se Figur 2). Dette arealet kan bli justert etter detaljprosjektering og etter at eventuelle andre aktiviteter på vraket er gjennomført.

3 FUNKSJONSKRAV TIL TILDEKKINGEN

Innkapslingen (tildekking/eller *capping* på engelsk) av U-864 og de forurensede sedimentene omkring vraket vil bygges opp av inerte løsmasser basert på naturlige mineralske produkter slik som sand, grus, og stein. Alternativt kan også lag inkluderes som består av bearbeidede materialer som har til hensikt å gi tildekkingen spesielle ønskede egenskaper, slik som særlig god bindingsevne for Hg eller lav gjennomstrømningsevne for vann.

Valgt design for innkapsling av vraket og forurensingen innebærer at det fylles løsmasser over vraket.

Designet av tildekkingen over vraket og forurenset sediment består av forskjellige lag som har følgende overordnede funksjoner:

1. Beskytte selve tildekkingslaget mot erosjon.
2. Hindre at utlekking av kvikksølvforurensing gir konsentrasjoner i overflaten av tildekkingen som overskrider miljømålet.
3. Ekstra lag som skal ta høyde for innblanding av rene tildekkingsmasser i sedimentet og usikkerhet i tykkelse ved konstruksjon.

I tillegg inngår det i designet en motfylling nedenfor skråning der tildekkingen plasseres for å beskytte vraket og tildekkingslaget mot utglidning. Denne motfyllingen er beskrevet tidligere (NGI, 2006) og også i andre deler av dette forprosjektet og omhandles derfor ikke her.

For at tildekkingen skal oppfylle funksjon 1) " Beskytte selve tildekkingslaget mot erosjon" må den øverste delen av tildekkingen bestå av masser som ikke eroderes ved de strømhastighetene som kan forventes i området.

For at tildekkingen skal oppfylle funksjon 2) "Hindre utlekking" må tildekkingen ha følgende mer spesifikke funksjoner:

- Hindre at bunnlevende dyrs omblanding av massene på sjøbunnen fører til økt transport av Hg gjennom tildekkingen,
- Hindre at bølger og vannstrøm fører til økt transport av Hg gjennom tildekkingen på grunn av adveksjon i deler av tildekkingen,
- Kjemisk isolere kvikksølvforurensingen slik at transport gjennom tildekkingen ikke gir overskridelse av miljømålet (konsentrasjon <0,63 mg Hg/kg i overflatesedimentet).

Funksjon 3) «ekstra lag» i tildekkingsdesignet er viktig for at usikkerhet knyttet til konstruksjonen av tildekkingslaget ikke skal føre til at konstruert tykkelse blir mindre enn designet tykkelse. For å ivareta dette vil tildekkingen designes med en overtykkelse

tilsvarende usikkerheten i konstruksjonen. Følgende usikkerheter er vurdert som viktige og tatt med i denne overtykkelsen:

- At deler av det forurensede sedimentet blandes med tildekkingsmassen ved utlegging.
- At det kan forekomme avvik i tykkelsen som faktisk blir lagt ut i forhold til designtykkelse.

3.1 Andre hensyn i designet

Vraket er i dag antatt å være fylt av vann og noe luft. Svekkelser i konstruksjonen ved torpederingen av U-864 og korrosjon etter dette fører til at skrogets styrke svekkes med tiden. Tildekking over vraket vil føre til en større belastning på skroget enn det som er i dag. Disse forholdene vil føre til at skroget gir etter når korrosjon har svekket styrken i skroget slik at den er mindre enn lasten fra tildekkingen. Det er sannsynlig at deler av det ytre profilskroget gir etter under tildekkingen. Det indre trykkskroget er imidlertid laget for å tåle store trykk. Det innebærer at det sannsynligvis vil gå lang tid før dette gir etter. Ved en slik sammensynkning av vraket vil tildekkingsmassene som ligger over vraket synke inn i dette. Ved et slikt forløp kan tildekkingen over deler av forurensningen bli mindre enn det opprinnelige designet.

Dette kan håndteres på følgende måter:

1. En sammensynkning av vraket hindres ved å fylle masser inn i vraket før tildekking.
2. Tildekking repareres dersom nødvendig etter en sammensynkning av vraket. Dette forutsetter overvåkning av tildekkingen med tanke på å observere når vraket synker sammen.
3. Det dekkes til med nok masse slik at tilstrekkelig beskyttelse over vraket sikres etter en sammensynkning.

Det er i dette designet forutsatt at dette håndteres med metode 2).

4 DESIGN AV TILDEKKINGSLAG

En innkapsling (tildekkingen) må designes. I dette kapitlet er det gitt en oppsummering av den design og modellering som er utført for å bestemme hvilke materialer som bør inngå og hvilken tykkelse de bør ha for en tildekking.

Det understrekes at det før et prosjekt kan utføres også må foretas en detalj-prosjektering av tildekkingen hvor det kan være behov for en del justeringer.

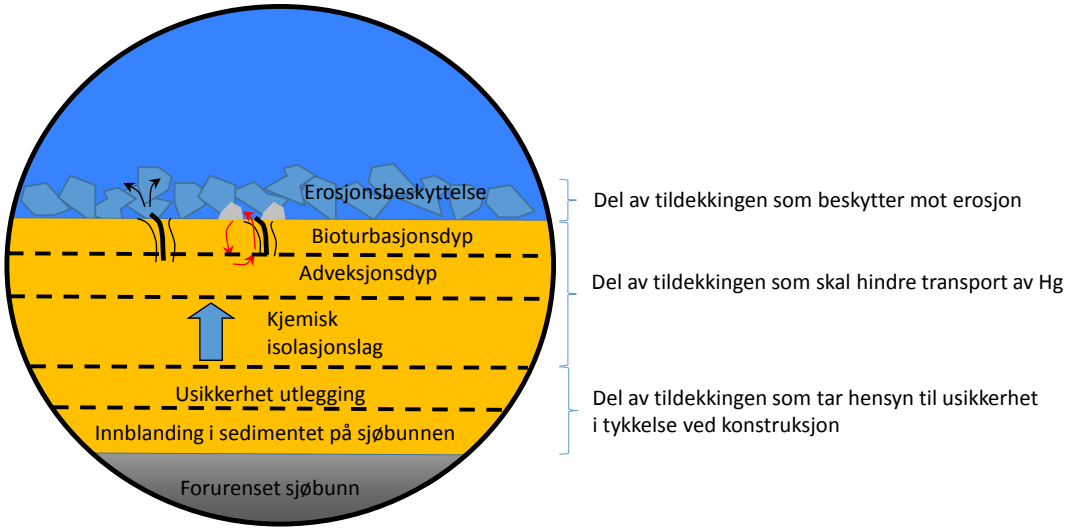
Det er to områder med tildekking som må designes:

1. Områder hvor selve vrakdelene tildekkes
2. Øvrige kvikksølvforurensede områder som må tildekkes

I Appendix 1 er det gitt en uttømmende bekrivelse av hvordan design og modellering av tildekkingslag er utført.

4.1 Cap-Design

Figur 3 illustrerer overordnet tildekkingsdesign over forurensningen i og ved vraket av U-864 med de lagene som skal ivareta ulike funksjoner i denne tildekkingen og dermed utgjør designet.



Figur 3: Illustrasjon av designlag i tildekkingen av forurensningen i og ved vraket av U-864.

Følgende tildekkingslag må designes:

- Erosjonsbeskyttelse
- Bioturbasjonslag
- Adveksjonslag
- Kjemisk isolasjonslag
- Blandingslag

- + Usikkerhet i utleggingen (kompensere med ekstra masser)

Det er i denne prosjekteringen benyttet sikkerhetsfaktorer og konservative vurderinger som gir et design som er mer konservativt enn det som er vanlig ved tildekking av forurenset sediment.

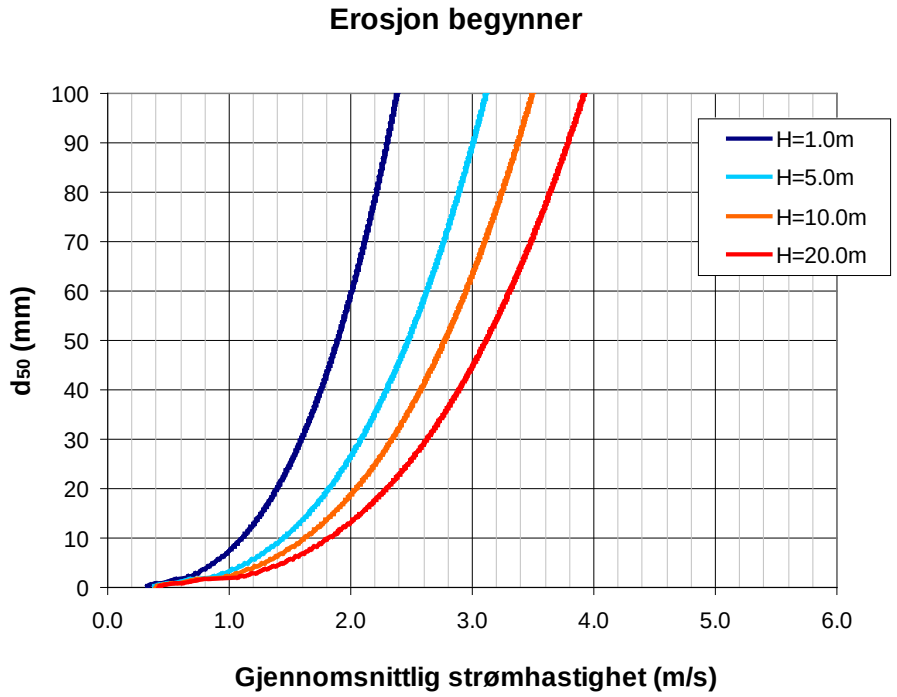
Dette er gjort fordi det i dette prosjektet ansees som vesentlig å etablere tilstrekkelig sikkerhetsmargin for at tiltaket beskytter miljøet mot forurensingen i området like ved vraket.

De moderat forurensede sedimentene i de øvrige områdene utenfor de mest forurensede områdene like ved vraket skal også dekkes til. Her viser prøvene en lavere konsentrasjon enn like ved vraket. Dette innebærer at det kan benyttes et tynnere kjemisk isolasjonslag. Det er likevel benyttet samme konservative designprinsipper som ved tildekking like ved vraket. Risiko knyttet til spredning herfra er mindre kritisk fordi konsentrasjonen og mengden kvikksølv er mye mindre enn i og ved vraket.

4.2 Erosjonsbeskyttelse

For at kravet skal oppfylles om at tildekkingslaget skal beskyttes mot erosjon, må den øverste delen av tildekkingen ha en kornstørrelse som ikke eroderer under de strøm-forholdene som kan forventes i området. Strømmålingene som ble utført over 79 dager høsten 2005 viste at maksimumsstrømmen i målingene som var gjort på 3–20 m over bunnen var 0,73 m/s (NIVA, 2006).

Inntil flere data foreligger er det konservativt antatt at det kan forekomme strøm-hastigheter på maksimalt 2 m/s langs sjøbunnen ved vraket. I følge Figur 4 (basert på van Rijn (1993), tilsvarende Hjulstrøms diagram) så vil masser med en kornstørrelse tilsvarende d_{50} >60 mm (50 % av materialet passerer en sikt med åpning på 60 mm) være tilstrekkelig som erosjonsbeskyttelse. Dette er basert på å bruke maksimal strømhastighet (2 m/s) nær bunnen (H = 1 m) i Figur 4. Tykkelsen av dette laget er skjønnsmessig satt til 3 x d_{50} ~ 20 cm.



Figur 4: Kurver som indikerer partikkelstørrelse (d_{50}) som kan eroderes som funksjon av gjennomsnittlig strømhastighet over et gitt avstand til bunnen (H). Hentet fra NGI-rapport 20021244-4 (NGI 2005), modifisert etter van Rijn (1993).

Konklusjon: Erosjonslagets tykkelse settes til 20 cm i hele tiltaksområdet (konservativt).

4.3 Bioturbasjonslag

Organismer som lever på sjøbunnen kan grave seg ned i sedimentet. Det er imidlertid vanlig å anta at den delen av sedimentet der det skjer en aktiv blanding av sedimentene er mindre enn 10 cm tykk (Miljødirektoratet 2012).

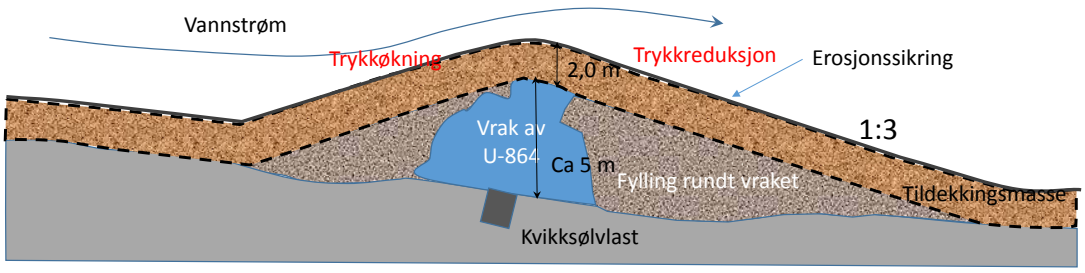
Konklusjon: Bioturbasjonslagets tykkelse settes til 15 cm i hele tiltaksområdet (konservativt).

4.4 Adveksjonslag

Adveksjonslag over vrakdelene

Trykkforskjellene som dannes av vannstrømmen over fyllingen over vraket kan gi adveksjon (strømning av vann) i tildekkingen.

Størrelsen på trykkforskjellene og permeabiliteten i tildekkingsmassene vil bestemme hastigheten av denne adveksjonen (se Figur 5).



Figur 5: Illustrasjonen viser eksempel på trykkforskjeller som kan oppstå som følge av vannstrøm over tildekket vrak.

For å sikre seg mot adveksjon som følge av trykkforskjeller over vraket er det basert på transportberegninger utført av NGI (teknisk notat 20130288-03-TN) anbefalt at en trenger et 220 cm tykt lag med mineralske masser. I dette laget kan også bioturb-asjonslaget (15 cm) og det kjemiske isolasjonslaget (90 cm) inngå slik at nødvendig tykkelse på selve adveksjonslaget over vraket blir 115 cm.

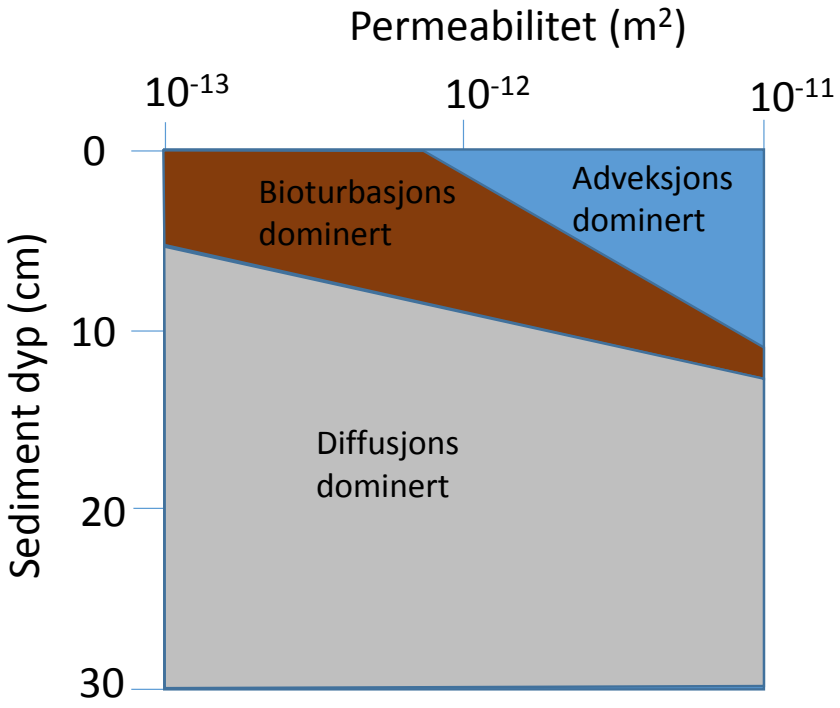
For at adveksjonlaget skal oppnå en hydraulisk ledningsevne på lavere enn 10^{-4} cm/s må det bestå av masser med d_{10} < 0,01 mm (betyr at 10 % av materialet er mindre enn 0,01 mm). Det betyr at materialet i hele tildekkingen bør bestå av subbus med mye finstoff (0 – 2 eller 0 – 4 mm).

Et alternativ for å oppnå en tilstrekkelig reduksjon av adveksjonstransporten i isolasjonslaget er å bruke et tynnere og tettere lag enn subbus som er det anbefalte alternativet. Velger en for eksempel et adveksjonslag med bare 10 cm tykkelse må det bestå av materialer som har permeabilitet lavere enn 10^{-15} m^2 (hydraulisk ledningsevne $<10^{-6}$ cm/s). Det mest egnede materialet for et slikt lavpermeabelt lag er derfor sannsynligvis leirbaserte materialer, se kapittel 6. Det er generelt liten erfaring med utlegging av finkornige masser på store dyp og for leire er det ekstra utfordringer på grunn av de kohesive egenskapene (klebrig) til leiren. Dette må evt. vurderes nærmere i detaljert design av tildekkingslaget.

Adveksjonslag i øvrige områder

I øvrige områder vil det kunne oppstå trykkforskjeller og dermed adveksjon omkring mindre ujevnheter (1–50 cm) som steiner i erosjonslaget. Flere studier har vært utført for å dokumentere hvilken effekt dette har på utveksling av stoffer mellom sediment og

vannet over. Figur 6 viser skjematisk hvilket dyp denne effekten forventes basert på Huettel og Webster (2001).



Figur 6: Illustrasjon av prosesser som påvirker porevannstransport i sediment som funksjon av permeabilitet og sedimentdybde. Fra Huettel and Webster 2001, og referanser i denne.

Dette studiet indikerer at bare de øverste 10 cm av permeable sedimenter (sandige) var påvirket av adveksjon. Andre studier har sett effekt av adveksjon som følge av trykkforskjeller på sedimentoverflaten forårsaket av strømning over ujevnheter på sjøbunnen ned til 25 cm (Rutger van der Loeff 1980).

For å være sikker på at det kjemiske isolasjonslaget ikke påvirkes av adveksjon gjøres det en konservativ antakelse om at adveksjon kan påvirke de øverste 25 cm av sediment (tilsvarende den største effekten i disse to studiene). Deretter benyttes det en sikkerhetsfaktor på 1,5 som innebærer et lag på 40 cm.

Massene i bioturbasjonslaget kan bygges opp med samme type masser som adveksjonslag slik at tykkelse avsatt til adveksjonslaget kan settes til 40 cm minus tykkelse av bioturbasjonslag (15 cm), 40 cm – 15cm = 25 cm.

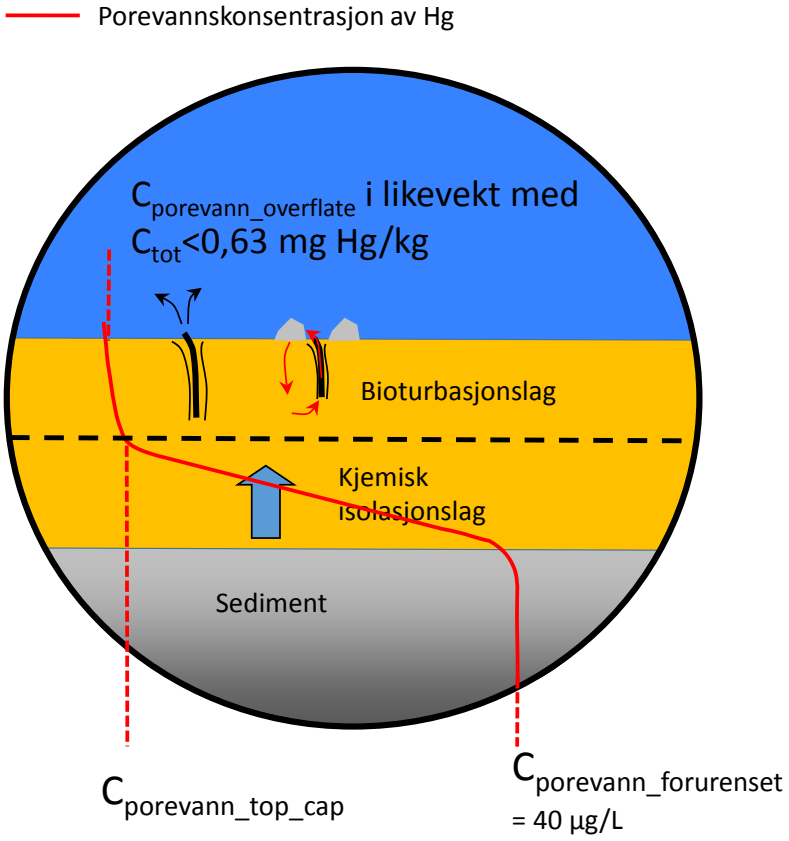
Massene bør ha en hydraulisk ledningsevne som er mindre enn 10^{-2} cm/s. Dette kan oppnås ved å bruke sandige masser eller subbus med en del finstoff med d_{10} < 0,1 mm.

Konklusjon: Adveksjonslagets over vrakdelene settes til 115 cm (konservativt). I resten av det forurensede området settes adveksjonslagets tykkelse til 25 cm (konservativt).

4.5 Kjemisk isolasjonslag

I det kjemiske isolasjonslaget, det vil si den delen av tildekkingslaget som ikke påvirkes av bioturbasjon eller vannstrøm og trykkforskjeller, vil diffusjon være den viktigste mekanismen for transport av kvikksølv.

Isolasjonslaget designes til å begrense hastigheten av kvikksølvdiffusjon gjennom tildekkingen. Dette vil begrense hvor mye kvikksølv som kan tilføres overflate-sedimentet der bunnfauna lever og dermed bidra til å minimere hvor mye som lekker ut fra tildekkingen til vannet over. Transporten gjennom tildekkingen styrer dermed kvikksølvkonsentrasjonen på sjøbunnen etter tildekking.



Figur 7: Illustrasjon av konsentrasjonsgradient og transport av Hg gjennom tildekking som er utgangspunktet for modellering av transport gjennom det kjemiske isolasjonslaget og bioturbasjons-dypet. I denne modelleringen ser man bort fra de andre lagene, mens i den konstruerte tildekkingen vil alle lagene være tilstede og ytterligere hindre for transport av Hg gjennom tildekkingen.

Før noe kvikksølv kan lekke gjennom tildekkingen vil tildekkingsmassene binde opp kvikksølv, mens det etableres en konsentrasjonsgradient gjennom tildekkingen som styrer utlekkingen på veldig lang sikt ("steady state"). Tiden det tar før kvikksølvet har fylt opp bindingskapasiteten i tildekkingen kan være på flere tusen år (DNV 2008). Tykkelsen på tildekkingen er beregnet slik at den skal oppfylle kravene til å beskytte overflatesedimentet (<0,63 mg/kg i de øverste 2 cm) også etter at bindingskapasiteten

i tildekkingen er brukt opp. I denne fasen er det den forlengede diffusjonsveien gjennom tildekkingen som begrenser transporten og dermed konsentrasjonen i overflate sedimentet.

Tykkelse som tilfredsstiller miljømålet er beregnet med en analytisk modell utviklet av Prof. Danny Reible ved Texas Tech University (Lampert og Reible, 2009). Det er antatt en kvikksølvkonsentrasjon på 40 µg/L i porevannet når det er i kontakt med rent kvikksølv. I områder hvor det er kvikksølvforurenset sediment (men ikke rent kvikksølv) er det antatt en kvikksølvkonsentrasjon på 2 µg/L i porevannet. Disse konsentrasjonene er de samme som ble benyttet til beregning av transport i tidligere utredninger av tildekkingsalternativet (DNV 2008). En kvikksølvkonsentrasjon på 40 µg/L tilsvarer konsentrasjonen i vann i likevekt med rent kvikksølv, mens 2 µg/L er om lag som konsentrasjonene målt i porevannet i forurensede sedimentprøver fra like ved vraket (NIVA 2005).

Denne antakelsen er konservativ siden 2 µg/L er målt i de mest forurensede sedimentene, og konsentrasjonen i porevannet i resten av området sannsynligvis er mye lavere. Resultatene av disse beregningene er oppsummert i Tabell 2.

Tabell 2: Tykkelse kjemisk isolasjonslag

	Konsentrasjon i porevann= 40 µg/L	Konsentrasjon i porevann = 2 µg/L
Tykkelse nødvendig i det kjemiske isolasjonslaget for å hindre utlekking og dermed forurensing av de øverste 2 cm som overskrider miljømålet (0,63 mg/kg)	87 cm	5 cm

Konklusjon: Det kjemiske isolasjonslagets tykkelse over vrakdelene settes til 90 cm (konservativt). I resten av det forurensede området settes det kjemiske isolasjonslagets tykkelse til 5 cm (konservativt).

4.6 Blandingslag

Det er skjønnsmessig antatt at ved forsiktig utlegging av tildekkingsmassene vil disse blandes inn i sedimentet under i en sone som tilsvarer 2 – 3 x største kornstørrelse på tildekkingsmassene. Kornstørrelsen for massene som benyttes antas å være mindre enn 3 cm. Designtykkelsen på blandingssonen kan derfor antas å være mindre enn 10 cm.

Blandingsdypet tilsvarer den tykkelsen nederst i tildekkingen som ikke kan forventes å ha noen vesentlig effekt fordi forurensede sedimenter er fysisk blandet inn i tildekkingsmassene.

Konklusjon: Blandingslagets tykkelse settes til 10 cm i hele tiltaksområdet (konservativt).

4.7 Usikkerhet ved utlegging

Et ekstra lag som skal ta høyde for usikkerhet i tykkelsen i tildekkingslaget ved utleggingen er viktig for at tykkelsen ikke blir mindre enn designet tykkelse.

Usikkerheten ved utlegging er basert på erfaring fra utlegging av fyllinger i forbindelse med utlegging av rørledninger offshore. Her viser erfaring en typisk høydeforskjell på 30 cm mellom furene som dannes ved utlegging med rør ned til bunnen. Betydelig vanndyp og kupert topografi gjør at usikkerheten kan øke noe. Ujevnheten kan forventes å minke med tiden. Dette reduserer effekten av usikkerheten i overdekning med tiden. For å ta høyde for usikkerheten og mulig avvik fra design under konstruksjonen av tildekkingen er det derfor valgt å bruke en tykkelse på 40 cm. Avhengig av erfaring med den metoden for utlegging av tildekingsmasse som velges og planlegging av dette så kan denne tykkelsen bli større eller mindre.

Konklusjon: Usikkerheten ved utlegging settes til 40 cm i hele tiltaksområdet (konservativt).

4.8 Anbefalt tildekkingsdesign

Tabell 3 viser designet av tildekkingens tykkelse over vraket og forurenset sediment.

Tykkelse av tildekkingslaget som skal hindre utlekking av kvikksølv er 240 cm for det mest forurensede området over og like ved vraket, og 65 cm i resten av det forurensede området. For å ta hensyn til innblanding i bunnsedimentene og toleransegrenser for utleggingsoperasjonen er det i tillegg estimert usikkerhetsmargin som legges til tildekkingstykkelsen. Total forventet tykkelse av tildekkingslaget, inkludert denne usikkerheten, er 290 cm like ved vraket og 115 cm i det øvrige området.

Modellberegninger av transport av kvikksølv i tildekkingslaget viser at utlekkingshastigheten forventes å bli redusert med mer enn 99 % med en slik tildekking.

Tabell 3: Tildekkingsdesign med passiv tildekking

	Like ved vraket (adveksjonslag: fin subbus)	Resten av forurenset område
Erosjonslag	20 cm	20 cm
Bioturbasjonslag	15 cm	15 cm
Adveksjonslag	(220 – 90 – 15 cm) = 115 cm*	(40 – 15 cm*) = 25 cm
Kjemisk isolasjonslag	90 cm	5 cm
Sum tildekking uten usikkerhet	**240 cm**	**65 cm**
Tillegg for blandingslag	10 cm	10 cm
Tillegg for å ta hensyn til usikkerhet ved utlegging	40 cm	40 cm
Total tykkelse av tildekkingen	**290 cm**	**115 cm**

* Beregnet ved å trekke fra 90 cm tykkelse for det kjemiske isolasjonslaget og 15 cm tykkelse for bioturbasjonslaget.

Ved beregning av mengde masser må det også innberegnes et tap av masse ut av tildekkingsområdet. Dette vil være avhengig av mengde finstoff i massene, strøm-forholdene og hvor langt over sjøbunnen massene slippes ut. Ekstra masser nødvendig for å dekke tap av masser er ikke tatt med i tabellen over.

Tykkelsen av tildekking vil få konsekvenser for størrelse og utforming av motfyllingen nedenfor vraket. Det må derfor bestemmes et toleranseintervall som den totale oppfyllingshøyden inkludert fyllinger omkring vraket og tildekkingen må holdes innenfor. Oppfyllingshøyden beregnes slik at tildekkingen tilfredsstiller både de miljøtekniske kravene til tildekkingstykkelse og krav til geoteknisk stabilitet lokalt og globalt.

4.9 Håndtering av usikkerhet knyttet til funksjon

Tildekkingen som er beskrevet for vrakdelene og øvrige områder er basert på konservative antakelser:

- Det er lagt til grunn høye konsentrasjoner i porevannet
- Det tas hensyn til adveksjon i tildekkingen som kan forårsakes av strømning over tildekkingen
- Det er lagt til ekstra sikkerhetsmargin i tykkelsen av lagene for å være sikker på at de oppfyller den tiltenkte funksjonen. En tykkelse på 290 cm over vraket er betydelig større enn de fleste tildekkingslag som er benyttet i andre kjente prosjekter.

5 PRØVETILDEKKING

I forbindelse med etablering av motfylling (se kapittel 3 og NGI (2006)) er det mulig å utføre en prøvetildekking med de materialer som er foreslått å inngå i tiltaket for passiv tildekking. Hensikten er da å bruke samme fartøy for prøvetildekkingen som brukes for motfyllingen.

Ved prøvetildekking velges det ut et område på sjøbunnen som ligger utenfor tiltaksområdet som defineres som testområdet. Testområdet bør ha følgende egenskaper:

- Det bør ligge på omtrent samme dybde som vrakdelene (150 m dyp)
- Bunnforholdene bør være omtrent tilsvarende det faktiske tiltaksområdet
- Massene legges i en terrenghelning på ca. 1:3 som tilsvarer den helning som massene er planlagt å bli plassert i ved ubåtvrakene.
- Testområdet bør være i størrelsesorden 50 x 50 m (2 500 m^2)

Prøvetildekkingen vil da foregå i følgende rekkefølge (tilsvarende som planlagt for selve tiltaket):

1. Utlegging av et 10 cm tykt blandingslag bestående av sand på de 2 500 m^2 som utgjør testområdet (ca. 250 m^3)
2. Utlegging av et 90 cm tykt kjemisk isolasjonslag bestående av sand på testområdet (ca. 2 250 m^3)
3. Utlegging av et 130 cm tykt bioturbasjons- og adveksjonslag av subbus på testområdet (ca. 3 250 m^3)
4. Utlegging av et 20 cm erosjonslag av grus/pukk på testområdet (ca. 500 m^3)

I prøvetildekkingen legges det ikke ut 40 cm ekstra for å kompensere for usikkerhet ved utleggingen. Hensikten er å se hvor store avvik en får i forhold til designtykkelsen for å få et anslag på reell usikkerhet ved utleggingen.

Utleggingen tilstrebes å foregå med samme fremdrift som fullskala tildekkingen. Det som er spesielt vesentlig er tiden som subbuslaget ligger eksponert før erosjonslaget utplasseres.

Oppfølgingen bør gi svar på størrelsen på tapet av materiale som legges ut, samt lagenes integritet og tykkelse.

Til oppfølgingen av tiltaket bør det brukes en kombinasjon av akustisk oppmåling av sjøbunnen (sonar), målepinner og ROV, samt at det tas kjerneprøver av tildekkingen.

I tillegg til utprøving av den foreslåtte passive tildekkingen er det også mulig å teste ut utlegging av andre materialer som leire og aktiv karbon.

6 ALTERNATIVE TILDEKKINGSMATERIALER

I tillegg til den anbefalte løsningen med tildekking med inerte eller passive materialer der virkemåten er å forlenge diffusjonsveien for kvikksølv fra forurensningen på sjøbunnen og ut i vannet, kan det også designes tildekking der massene i deler eller hele tildekkingen har egenskaper som øker effekten av tildekkingen.

To viktige typer aktive tildekkingsmasser kan være aktuelle ved tildekking av U-864:

- Masser med lav permeabilitet
    - Alternativ for adveksjonslaget basert på leirbaserte tetningsmaterialer (se kapittel 4.4).
- Masser med høy sorbsjonskapasitet for kvikksølv
    - Et lag med masser med høy sorbsjonskapasitet for kvikksølv vil binde kvikksølv som diffunderer fra forurensningen i vraket og inn i tildekkingslaget og kan dermed øke tiden før gjennombrudd av kvikksølv gjennom tildekkingslaget.
    - Aktuelle materialer som kan brukes i en slik aktiv tildekking er:
        - Aktivt kull
        - Leirbasert materiale med sulfid-grupper bundet til leiren

Felles for alle materialene som skal benyttes til tildekkingen og motfyllinger er at de må være rene og tilfredsstille Miljødirektoratets tildekkingsveileder (Miljødirektoratet 2006).

Tildekkingsdesign med aktiv tildekking

Dersom det brukes aktive materialer som beskrevet ovenfor i tildekkingen vil disse kunne erstatte deler av lagene i tildekkingsdesignet med passive materialer.

Dersom det skal benyttes aktive materialer må det stilles krav til dokumentasjon av funksjonalitet og til at det ikke gir uønskede bieffekter. Slike krav kan stilles som en del av anbudsprosessen eller det kan gjennomføres et pilotprosjekt der prekvalifiserte materialer eller tildekkingsdesign testes under like forhold.

En aktiv tildekking som binder kvikksølv vil ikke redusere utlekkingshastigheten ved "steady state", når hele tildekkingen er i likevekt med den konsentrasjonsgradienten som transporten gjennom tildekkingen gir. En slik tildekking gjør at det tar svært lang tid til en slik "steady state"-tilstand oppstår og dermed tiden til det i det hele tatt kan komme Hg gjennom tildekkingen (>>1000 år). Over så lang tid kan geologiske endringer påvirke området der forurensingen ligger noe som uansett vil være vanskelig å inkludere i designet. På bakgrunn av dette kan det argumenteres for at et slikt lag med masser med høy sorbsjonskapasitet for Hg kan erstatte det meste av det kjemiske isolasjonslaget.

Et aktivt lag vil kunne legges ut som et 5 – 20 cm lag der tykkelsen bestemmes av hvordan laget skal legges ut. Dersom laget legges ut sydd inn i geotekstiler vil dette

kunne være så tynt som 5 cm, hvis det legges ut som granulære masser vil laget sannsynligvis måtte være 10 – 20 cm og med 10 cm beskyttelseslag bestående av sandige masser mellom adveksjonslaget og det aktive laget. Dette gir en anslått tykkelse av det (aktive) kjemiske isolasjonslaget på 15 – 30 cm.

Dersom aktivt kull eller andre materialer som inneholder organiske materialer skal benyttes, må kravet i Miljødirektoratets tildekkingsveileder om maksimum 0,5 % TOC i tildekkingsmaterialet sees bort fra, men det må da dokumenteres at det organiske materialet i tildekkingsmaterialet er inert og ikke brytes ned. Dette er viktig både for å unngå gassdannelse i tildekkingen og for å hindre økt metylering av kvikksølv.

Tabell 4 viser at den totale tildekkingstykkelsen kan reduseres med 85 – 160 cm ved å bruke alternative (aktive) tildekkingsmaterialer.

Tabell 4: Anbefalt (passiv) tildekkingsdesign like ved vraket sammenlignet med: lavpermeabelt lag ved vraket (alt. A), aktive lag like ved vraket (Alt. B) og sorbsjonslag like ved vraket (Alt. C). Tykkelse er bare beregnet for området nærmest vraket med utgangspunkt i 40 µg/L Hg i porevannet.

	Kun passiv tildekking (anbefalt)	*Alt. A:* *Lav-permeabelt lag (leirbasert adveksjonslag)*	*Alt. B:* *Aktiv tildekking med sorpsjon av Hg*	*Alt. C:* *Lav-permeabelt lag og sorbsjons-materiale*
Erosjonslag	20 cm	*20 cm*	*20 cm*	*20 cm*
Bioturbasjonslag	15 cm	*15 cm*	*15 cm*	*15 cm*
Adveksjonslag	(220 – 90 – 15 cm*) = 115 cm	*10 cm (leire) + 20 cm beskyttelse*	*(220 – 15 – 15 cm)* = 190 cm*	*10 cm (leire) + 20 cm beskyttelse*
Kjemisk isolasjonslag	90 cm	*90 cm*	*15 cm*	*15 cm*
Sum tildekking uten usikkerhet	**240 cm**	***155 cm***	***240 cm***	***80 cm***
Tillegg for blandingslag	10 cm	*10 cm*	*10 cm*	*10 cm*
Tillegg for å ta hensyn til usikker-het ved utleggingen	40 cm	*40 cm*	*40 cm*	*40 cm*
Total tykkelse av tildekkingen	**290 cm**	***205 cm***	***290 cm***	***130 cm***

7 BESKRIVELSE AV PLASSERING AV TILDEKKINGSMASSER

Det forutsettes at samme strategi for plassering av tildekkingsmasser kan brukes uansett hvilket tildekkingsalternativ som velges. Det er i denne beskrivelsen forutsatt at det tildekkes med mineralske masser (passiv tildekking), som beskrevet i kapittel 4. Endelig valg av løsning må fremkomme som resultat av detaljert design.

7.1 Hensikt med plassering av tildekkingsmasser

Hensikten med plasseringen av tildekkingsmassene er å tildekke vrakdelene og kvikksølvforurenset sjøbunn rundt U-864.

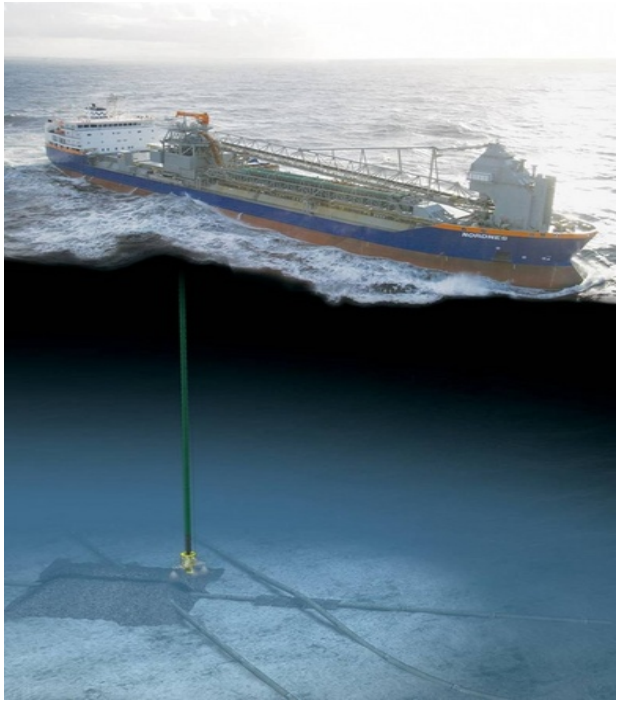
Merknad: For alternativet med heving av last vil det i forkant bli lagt et beskyttende lag på bunnen langs kjølen der hvor man vil gå inn for å hente ut kvikksølvet. Det vil være enten en geotekstilduk eller et sandlag. Hensikten er å beskytte dette området mot spredning av kvikksølvforurensede sedimenter under selve tiltaket.

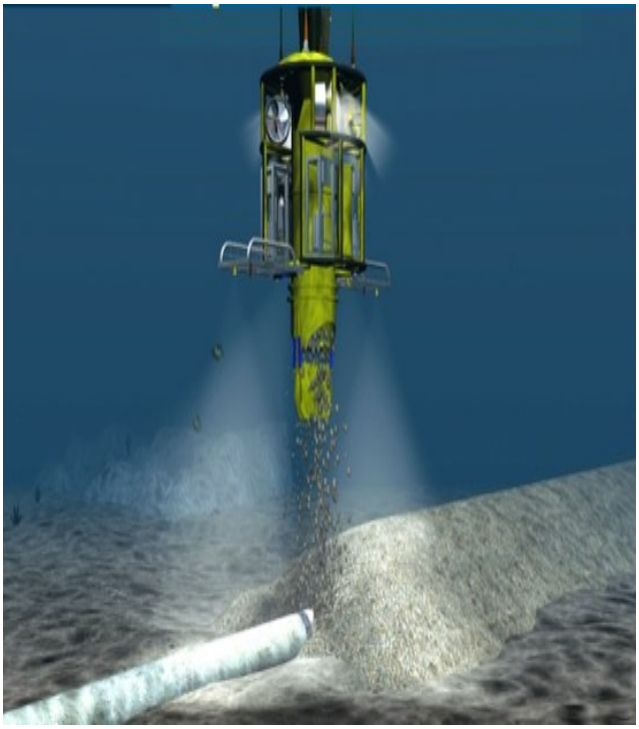
7.2 Utstyr til plasseringen av tildekkingsmasser

Ved valg av utstyr for tildekkingen bør det legges vekt på å bruke eksisterende og kjent teknologi. Det finnes i dag fartøyer i markedet for bl.a. tildekking av rørledninger på store dyp og lignende oppgaver. Slikt utstyr har kapasitet til å transportere forholdsvis store mengder masser fra kai på fastlandet og ut til vrakstedet.

På Figur 8 er det vist et eksempel på et fartøy som utfører slik tildekking. Disse fartøyene kan føre masser ned til over 1 000 m vanndyp og kan frakte over 20 000 tonn masser. Fartøyet er utstyrt med et fleksibelt nedløpsrør og i enden av nedløpsrøret er en diffusor. Diffusor er utformet slik at en får en jevn og kontrollert fordeling og plassering av massene på sjøbunnen under utlegging.

Bruk av fartøyer med fleksibelt nedløpsrør behøver noe tilpasning for å være effektive til tildekking av store arealer da de i hovedsak er beregnet for nøyaktig tildekking av rørledninger. På engelsk kalles de for "Fallpipe vessels" og baserer seg i stor grad på at massene faller til bunns ved egen tyngde. De egner seg for nøyaktig plassering av materialet.





Figur 8: Øverst: Fartøy som brukes for tildekking av rørledninger. Figur til venstre viser fartøyet og nedføringsrøret. Figur til høyre viser en detalj av selve diffusoren som er i enden av nedføringsrøret og som fordeler massene på sjøbunnen. Fra www.vanoord.com. Nederst: En trailing suction hopper dredger (TSHD). Fra: www.theartofdredging.com

En annen mulighet er å bruke en «trailing suction hopper dredger» (TSHD) med tilpasset utstyr for å spre massene utover bunnen (se Figur 8 nederst). Denne kan også hente materialet selv i nærområdet hvis det finnes aktuelle steder med tilgjengelige masser på sjøbunnen. En kombinasjon av fartøy med fleksibelt nedløpsrør og TSHD kan

være et godt alternativ. Fallpipe kan arbeide nøyaktig på begrenset område mens TSHD kan dekke de store arealene.

7.3 Rekkefølge på utleggingen

Tildekkingen er det siste som skjer på stedet. Det vil si at alle aktiviteter som kan medføre spredning av forurensning (kvikksølvforurenset sediment) skal være avsluttet. Den eneste aktiviteten i forkant av tildekkingen som medfører utlegging av masser er motfyllingen i skråningen for å hindre utglidning av forseksjonen.

I de følgende to delkapitlene er rekkefølgen på tildekking nærmest vraket og i resten av det kvikksølv-forurensede området beskrevet. Det forurensede området er definert ved at sjøbunn skal tildekkes, der hvor tilstandsklasse 2 for kvikksølv (0,63 mg Hg/kg) i det øverste laget er overskredet(DNV GL, 2014a). De oppgitte tykkelsene tar utgangspunkt i en passiv tildekking. Hvilken tykkelse som trengs for andre typer tildekkingsmasser er oppgitt i det foregående kapitlet.

7.3.1 Rekkefølge på tildekking nærmest vraket

Rekkefølgen på tildekkingen nærmest vraket er følgende:

1. Først legges blandingslaget ut på hele tildekkingsområdet. Blandingslaget består av sand eller lignende og har en tykkelse på 10 cm. Det utføres en nøyaktig oppmåling og kontroll av laget før en fortsetter med tildekkingen. Blandingslaget kontrolleres og må være rent før videre tildekking kan fortsette.
2. Deretter legges lag med sand på til sammen 90 cm (kjemisk isolasjonslag). Dette legges ut i flere lag (minimum 3). Etter utlegging av hvert lag utføres en kontroll og oppmåling av laget før en går videre.
3. Etter dette legges lag på til sammen 130 cm med fin subbus (bioturbasjonslag og adveksjonslag). Dette legges ut i flere lag. Etter utlegging av hvert lag utføres en kontroll og oppmåling av laget før en går videre.
4. Til slutt legges erosjonslaget på 20 cm som består av grus/pukk eller lignende.

Dette gir en samlet tykkelse på 250 cm. I tillegg legges det inn en usikkerhetsmargin på 40 cm for å ta hensyn til usikkerhet i utplasseringen. Total tykkelse på tildekkingen blir da 290 cm over vrakdelene, inkludert tillegg for usikkerhet (for mer detaljer, se kapittel 4.8).

7.3.2 Rekkefølge på tildekking i resten av det forurensede området

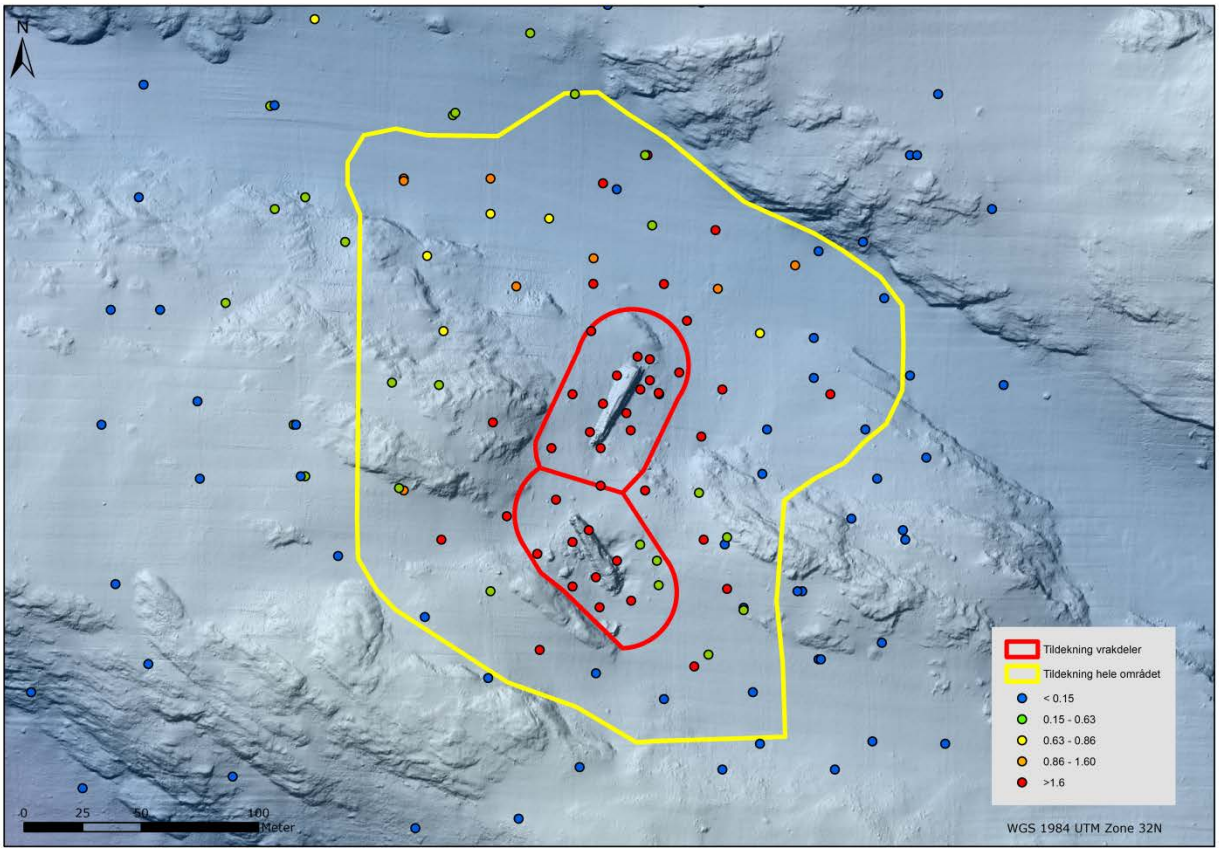
Rekkefølgen på tildekkingen i resten av det forurensede området er følgende:

1. Først legges blandingslaget ut på hele tildekkingsområdet. Blandingslaget består av sand eller lignende og har en tykkelse på 10 cm. Det utføres en nøyaktig oppmåling og kontroll av laget før en fortsetter med tildekkingen.
2. Deretter legges lag på til sammen 45 cm med sand eller fin subbus (adveksjonslag, bioturbasjonslag og kjemisk isolasjonslag). Dette legges ut i flere lag (minimum 2). Etter utlegging av hvert lag utføres en kontroll og oppmåling av laget før en går videre.
3. Til slutt legges erosjonslaget på 20 cm som består av grus/pukk eller lignende.

Det gir en samlet tykkelse på 75 cm. I tillegg legges det inn en usikkerhetsmargin på 40 cm for å ta hensyn til usikkerhet i utplasseringen. Total tykkelse på tildekkingen blir da 115 cm i resten av det forurensede området, inkludert tillegg for usikkerhet (for mer detaljer, se kapittel 4.8).

Utleggingen av diffusjonslaget foreslås å foregå fra spesialfartøy som kan føre ned massene til nær sjøbunnen (1-5 m over) for å sikre en kontrollert utlegging. Massene føres ned gjennom et fleksibelt nedføringsrør med en diffusor nederst, se kapittel 7.2.

Kontroll av tildekkingstykkelser bør utføres med ekkoloddmålinger, målestaver, SPI-kamera (Sediment Profile Imaging) etc. Metoder for slik kontroll er nærmere beskrevet i kapittel 8.



Figur 9: Kart som viser alle analyser av kvikksølv i overflatesediment inndelt i tilstandsklasser. Areal innenfor gul linje er 47 000 m2 og viser sedimenter som ligger over tiltaksmålet (0,63 mg Hg/kg sediment) og som tildekkes med 1,15 m masser. Areal i det røde området (nærmest vraket) dekkes til med 2,90 m masser.

7.4 Kornstørrelse på dekkmateriale

Kornstørrelsen på erosjonslaget er anslått til d_{50} >30 mm, med minste kornstørrelse på 10 mm og største kornstørrelse på 60 mm.

Veileder TA-2143/2005 fra SFT (nå Miljødirektoratet) inneholder krav til kornstørrelse for diffusjonslaget (her kalt «filter») i forhold til de underliggende sedimentene:

«Tildekkingsmassene skal tilfredsstille flere krav som til dels er motstridende. For best mulig effekt med hensyn på å hindre fremtidig forurensningsspredning ved diffusjon fra sedimentet som skal tildekkes, bør tildekkingsmassen være forholdsvis finkorning. Tildekkingsmassene må også ha en kornfordeling som hindrer sammenblanding av massene. Samtidig må tildekkingsmaterialet ha tilstrekkelig permeabilitet (evne til å slippe gjennom vann) til å tillate en viss drenasje av porevann fra det underliggende sedimentet. Forurensede, finkornige marine sedimenter (leire og silt) er vanligvis løst lagret. Enhver tildekking – naturlig eller kunstig – vil gi sammenpressing av disse sedimentene og dermed et midlertidig økt poretrykk. Dette poretrykket vil redusere den geotekniske stabiliteten og er derfor ikke ønskelig. For å redusere overtrykket, bør masser for tildekking av finkornige sedimenter ha noe høyere permeabilitet

enn de forurensede sedimentene, men tildekkingsmassen må ikke være så grovkorning at en også risikerer utvasking av finstoff fra sedimentet gjennom tildekkingen. Det kan derfor i enkelte tilfeller være ønskelig å legge på tildekkingen i flere omganger.

Siden tildekkingslaget normalt ikke er utsatt for store trykkforskjeller og vannstrømmer vil vi anbefale følgende relasjon:

$2*d_{15}$ *(sediment)* $< d_{15}$ *(filter)* $< 5*d_{85}$ *(sediment)*

Hvor: d_{15} *og* d_{85} *er den korndiameteren som 15 %, henholdsvis 85 % (vekt) av kornene er mindre enn.*

Disse verdier leses ut av kornfordelingskurvene for materialene.

Kravet d_{15} *(filter)* $< 5*d_{85}$ *(sediment) sikrer mot utvasking av finstoff gjennom tildekkingslaget mens kravet*

$2*d_{15}$ *(sediment)* $< d_{15}$ *(filter) skal sikre at tildekkingslaget har tilstrekkelig permeabilitet til å hindre overtrykk i sedimentet».*

Det siste kravet må kanskje fravikes i og med at permeabiliteten skal begrenses.

Tilsvarende anbefalte relasjoner bør også brukes for forholdet mellom diffusjonslaget og erosjonslaget.

Til massene som skal brukes i adveksjonslaget må den hydrauliske ledningsevnen være mindre enn 10^{-4} cm/s. Dette kan oppnås ved å bygge opp dette laget slik at det består av masser med $d_{10} < 0{,}01$ mm.

7.5 Andre krav til dekkmateriale

I tillegg til kornstørrelse inneholder tildekkingsveilederen fra Miljødirektoratet (2006) andre forslag til krav til masser til bruk for tildekking av forurensede sedimenter.

Massene skal være rene og ikke overskride akseptverdier for totalinnhold av de forbindelser som er oppgitt i veilederen, se Tabell 5.

Tabell 5: Trinn 1 vurdering. Akseptverdier for totalinnhold av forbindelser i tildekkingsmaterialet (mg/kg ts), ref. Miljødirektoratet (2006).

Parameter	**Oppmudrede**	**Andre masser**
Totalt organisk karbon (TOC)	10 000 (1 %)	5 000 (0,5 %)
Arsen	Jfr. tilstandsklasse II for metaller og organiske miljøgifter generelt SFT TA-1467/1997 *(nå TA-2229/2007)*	20
Bly		60
Kadmium		1
Kopper		100
Krom		70
Kvikksølv		0,63
Nikkel		50
Sink		150
Jern		ingen verdi
Mangan		ingen verdi
Sum PAH 16		2
Benzo(a)pyren		0,05

Andre krav som stilles i veilederen er:

Kornfordeling

Tildekkingsmassenes kornfordeling skal bestemmes iht. NS 8005. Masser med større innhold av materiale < 0,075 mm enn 5 % og/eller med belegg på større partikler, skal våtsiktes.

Permeabilitet

Permeabiliteten av tildekkingsmasser skal bestemmes. Det kan vanligvis bestemmes med tilstrekkelig nøyaktighet ved beregning ut fra kornfordelingskurven, jfr. vedlegg B i veilederen. For finkornede materialer (silt/leire) kan permeabiliteten om ønskelig bestemmes ved ulike geotekniske laboratorieforsøk.

Densitet og korndensitet

Forventet densitet etter når tildekkingsmassen er lagt ut. Kan bestemmes i laboratorium. Korndensitet bestemmes vanligvis iht. NS 8012.

Egnethetsvurdering basert på fysiske egenskaper

For å fastslå tildekkingsmaterialets egnethet må de fysiske egenskapene til tildekkingsmaterialet vurderes i forhold til tilsvarende egenskaper i de forurensede sedimentene, samt de lokale sjø- og bunnforhold, anleggstekniske forhold.

De krav som stilles til massene skal imøtekommes ved etablering av et godkjenningsregime for masser som alle masser som skal utplasseres skal gjennomgå.

7.6 Konsolidering/setninger

Ved tildekking med mineralske masser som sand og grus vil tildekkingslaget raskt konsolidere og dette forventes ikke utgjøre noe problem. Derimot vil vekten av tildekkingslaget kunne gi setninger på selve sjøbunnen.

7.7 Avslutning

Etter tildekking må det utføres kontroll av at tykkelsen er i henhold til de krav som er stilt. Dette kan gjøres ved å foreta en nøyaktig oppmåling av sjøbunnen før og etter tildekkingen, og kontrollere tykkelsen ved å utføre differansemålinger. Typisk utstyr for slike målinger vil være sonar/multistråle ekkolodd (se kapittel 8).

7.8 Håndtering av usikkerheter ved utlegging

Følgende faktorer vurderes som de viktigste usikkerhetene i forbindelse med utlegging av tildekkingen:

- Areal som må tildekkes – bør kunne vurderes forholdsvis nøyaktig da det er tatt mange sedimentprøver.
- Volum av masser (volum av tildekkingsmasser og motfyllingsmasser) – det finnes et godt kartmateriale slik at dette kan vurderes med god nøyaktighet
- Egnede dekkmasser – så langt vurdert basert på erfaringer fra andre prosjekter, materiale bør også testes på laboratorium samt på stedet
- Kontroll av tildekkingstykkelse – er beskrevet (målestaver, SPI-kamera og sonar/ekkolodd) men bør også testes ut, da det ikke tidligere er gjort tilsvarende på så store dyp
- Setninger – beregnes av geotekniker men kan også måles når motfyllingen er lagt ut, motfyllingen er forventet å bli lagt ut i god tid før tildekkingen starter
- Tildekking av vraket – vraket vil på et eller annet tidspunkt synke sammen, tildekkingen er så tykk at den skal tåle dette, avbøtende tiltak bør imidlertid være på plass

8 KONTROLL AV TILDEKKINGEN

8.1 Fysisk kontroll

Den viktigste fysiske parameteren som må overvåkes under og etter tildekkingen er tykkelsen på tildekkingslaget. Kornstørrelse i materiale i tildekkingen og poretrykks-oppbygging under tildekkingen bør også inngå i overvåkingen.

8.1.1 Målestaver

Målestaver som settes ut i området før tildekkingen starter brukes til å lese av visuelt hvor mye tildekkingsmasse som er lagt ut der målestaven står. Målestavene settes gjerne ut i et på forhånd definert mønster og kan leses av flere ganger underveis og når utfyllingen er avsluttet. Avlesningen gjøres gjerne med ROV.

Følgende faktorer må håndteres ved bruk av målestaver:

- Målestavene kan velte som følge av utlegging av tildekkingsmasse på disse. Målestavene må derfor plasseres slik at de står tilnærmet vinkelrett på sjøbunnen gjennom hele utplasseringen av tildekkingslaget. En robust plassering av disse kan være særlig utfordrende dersom sjøbunnen er ujevn og dersom målestavene skal være svært lange for å måle stor mektighet av tildekking. Like ved vraket kan mektigheten på tildekkingen bli opptil 7 m.
- Dårlig sikt under utlegging av tildekkingen kan gjøre det vanskelig å lese av målestavene
- Målestaver gir overvåkning av tykkelse kun der de er plassert og gir ingen informasjon mellom stavene. Av erfaring vet man at avvik i utførelsen av en tildekking kan være svært lokal.
- Konflikt med andre operasjoner på eller ved vraket

Målestaver er benyttet for kontroll av tildekkingstykkelse ved andre prosjekter med tildekking av forurensede sedimenter blant annet ved tildekkingen av deponerte mudrede masser ved Malmøykalven i indre Oslofjord. Den overordnede konklusjon fra dette prosjektet var at denne metoden fungerer hvis det eksisterer et godt system for avlesning, merking, loggføring (id for hver stav og skala) og generell oppfølging.

Antall målestaver og plassering må koordineres med entreprenør slik at det ikke oppstår konflikt med andre operasjoner på vrakdelene. I utgangspunktet er det tenkt rundt 40 målestaver i tiltaksområdet. Da dette er punktmålinger så er et relativt høyt antall målestaver nødvendig for å fange opp variasjon i utlagt tykkelse. Målestaver i kombinasjon med ROV undersøkelser og ekkoloddmålinger ansees som en god kombinasjon i forhold til kontroll på tykkelser og utbredelse av tildekkingsmaterialet.

I størrelsesorden 10 målestaver konstrueres slik at de også kan fungere som prøve-takingsbrønner. Dette for å gjøre det mulig å overvåke kvikksølvkonsentrasjonene over isolasjonslaget (dvs. under erosjonslaget) i et langtidsperspektiv (se Kapittel 10).

Brønnene må designes slik at det kan benyttes ROV til å ta prøvene.

8.1.2 Ekkoloddmålinger

Geofysiske målinger er en egnet metode for å måle vanndypet, i praksis overgangen mellom sjøbunnen og vannsøylen. Bruk av ekkolodd (multistråle) er en konkret relevant metode. Fordelen er at metoden dekker hele tiltaksområdet med stor oppløselighet. Det bør kjøres tette linjer som dekker hele tiltaksområdet og undersøkelsen bør designes slik at usikkerheten i målingene minimaliseres.

Slike målinger kan med fordel kombineres med andre typer målinger som eksempelvis målestaver for å korrigere for feilkilder i målingene.

Bruk av ekkoloddmålinger bør planlegges nøye i forhold til formålet slik at unøyaktigheten i målingene sees i sammenheng med hva som ønskes oppnådd. Eksempelvis må ikke målingenes usikkerhet være større enn tykkelsen på lagene som skal kontrolleres. Følgende feilkilder må håndteres ved ekkoloddmålinger:

- Type teknologi/ekkolodd (multistråle, enkeltstråle)
- Posisjoneringsfeil som overføres direkte til dybderegistreringen
- Båtens bevegelser (rull, hiv, kurs og stampfeil)
- Feil i sensorens posisjon
- Feil i dypgående
- Tidsfeil: En tidsfeil mellom navigasjonssystemet og ekkoloddet overføres direkte til en posisjonsfeil for dybderegistreringen
- Lydprofilen: Måling av lydfart er avgjørende og må bestemmes hver gang det gjøres målinger
- Feil i ekkolodd
- Inntrengningsdybden. Avhengig av bunnens beskaffenhet, eksempelvis fjell, leire
- Vannstandsfeil

Kontraktør bør oppgi hvordan målingene er tenkt gjennomført samt usikkerhetene i disse. Opplysningene bør verifiseres av tredjepart, eksempelvis Kartverket.

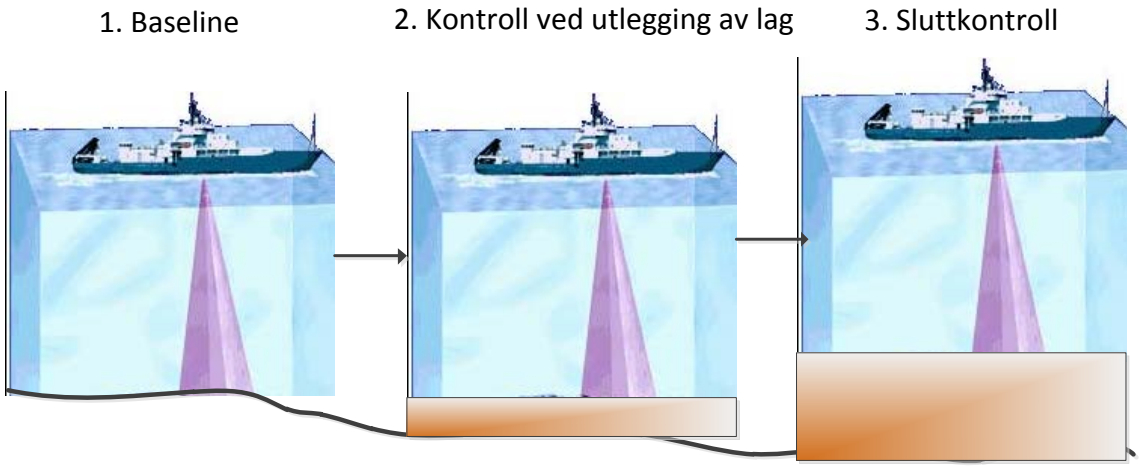
Andre feilkilder er relatert til setninger av sjøbunn og tildekkingsmasse som:

- Setninger i sjøbunnen vil kunne registreres som en mindre heving av sjøbunnen enn mengde utlagt masse skulle tilsi. Dette kan da tolkes som en tynnere tildekking selv om tykkelsen er korrekt.
- Setninger i tildekkingsmassene vil registreres som tynnere tildekking med ekkoloddet en hva som faktisk er tilfellet

Generelt må strategien for målingene inkludere:

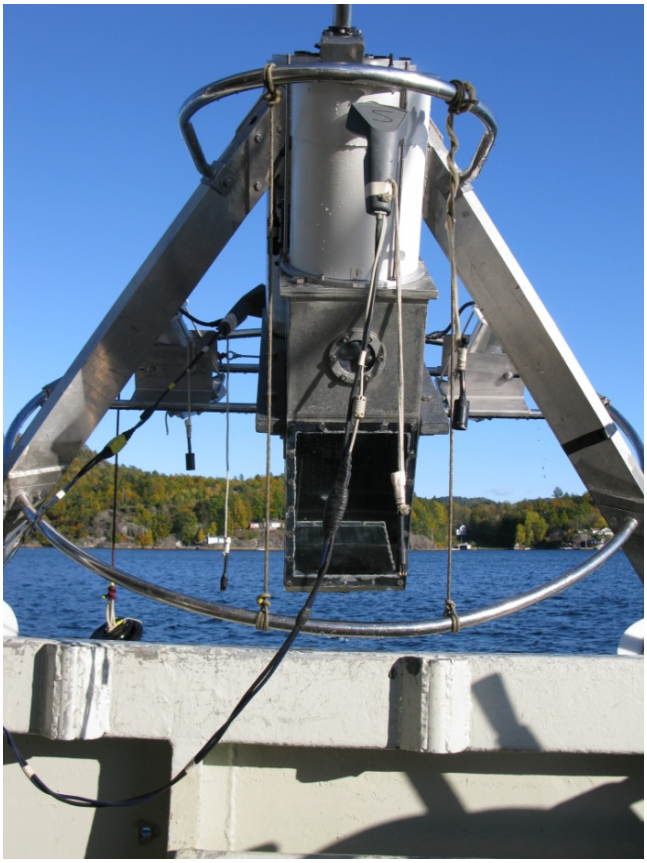
- Oppmåling av tiltaksområdet før tiltaket starter (baseline). Målingene før tiltaket starter skal være av høy og samme kvalitet som målingene som planlegges under og etter tiltaket
- Oppmålinger etter utlegging av ulike lag, altså underveis i tiltaket, som kontroll på at utlekkingen er i henhold til design.
- Oppmålinger ved sluttføring av tiltaket som dokumentasjon på at tykkelsen er i henhold til design
- Loggføring og distribusjon av resultater

I tillegg er ekkoloddmålinger et nyttig verktøy for entreprenør. Dette kan gi nyttig informasjon om fremdrift og kvalitet i det daglige.



8.1.3 Sediment Profiling Imaging (SPI)

Sedimentprofil kamera (sediment profile imaging (SPI)) er en kamera prisme som montert på en tripod kan penetrere sjøbunnen og fotografere et profil av sjøbunnen gjennom en pleksiglassplate i prismet. SPI-kamera har vært mye brukt til å karakterisere økologisk tilstand på sjøbunnen, og har i den senere tid også vært noe brukt til å dokumentere tykkelsen til relativt tynne lag med tildekking. SPI kamerat kan penetrere sjøbunnen og ta et profilbilde av de øverste 20-30 cm av sedimentet og bruken begrenser seg derfor til tildekkingslag med noen få desimeters tykkelse.



Figur 10: Venstre: Tripod med SPI-kamera. Høyre: SPI-bilde av tildekkingslag fra Opticap tynntildekkingsfelt (www.niva.no)

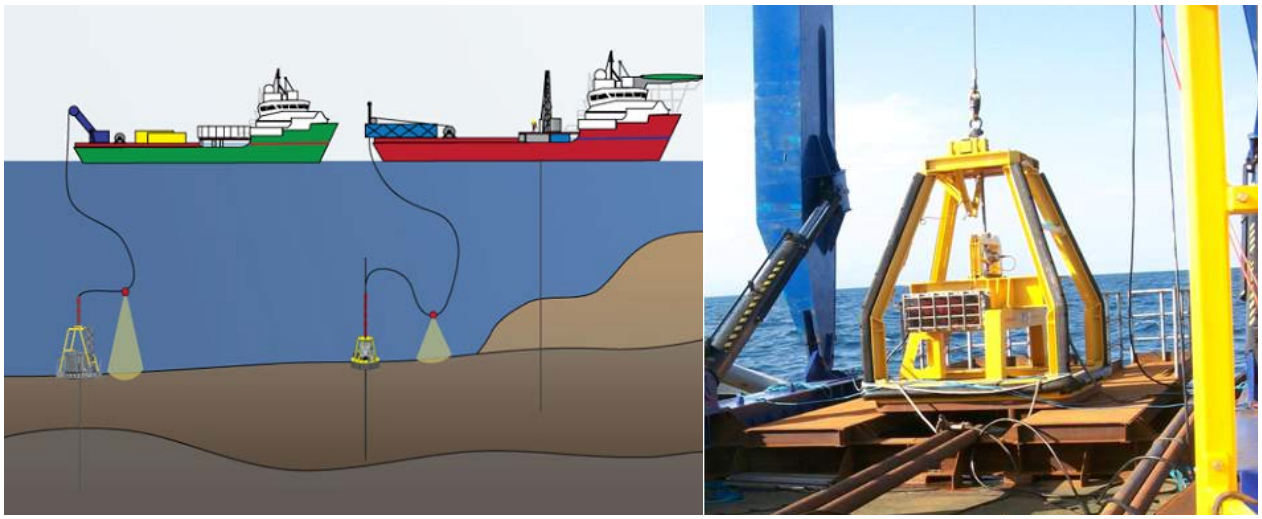
Metoden kan derfor brukes til å kontrollere tykkelsen av de første lagene med tildekking som legges ut ved U-864, dersom tildekkingen blir lagt ut i tilstrekkelig tynne lag. For tildekkingslag som er tynnere enn 15 cm, ansees denne metoden som mer nøyaktig en målestaver. Bruk av SPI kamera kan benyttes som stikkprøver og kan gjøres på ikke planlagte punkter i motsetning til målestaver som bare kan brukes på forhånd planlagte punkter.

Hovedproblemet med denne metoden er at den ikke kan brukes til å kontrollere tykkelsen av ferdig utlagt tildekking fordi den da blir for tykk. SPI-kamera kan imidlertid være en nyttig metode for å kontrollere at de første lagene med tildekking gir forventet tykkelse.

- Måling med SPI-kamera gir bare punktmålinger og ingen informasjon mellom disse punktene. Målingen kan likevel gjøre relativt tett og derfor gi relativt god oppløsning ved behov.
- Grove masser og stein eller bart fjell under tildekkingen kan gjøre det vanskelig å penetrere tildekkingslaget eller sjøbunnen under tildekkingen.

8.1.4 Cone Penetrating Testing (CPT)

"Cone Penetration testing" (CPT) er en mye brukt metode i geotekniske undersøkelser der en spiss (cone) presses ned i grunnen mens spissmotstand registreres. I CPT-målinger er det vanlig å måle poretrykk og sidefriksjon på spissen som presses ned i grunnen, i tillegg til spissmotstand. De ulike parameterne som registreres brukes til å skille ulike typer masser i grunnen og kan derfor kanskje brukes til å skille tildekkings-massen fra underliggende sjøbunn. Dette forutsetter at det er tilstrekkelig forskjell i egenskapene til sedimentet i sjøbunnen og tildekkingsmassen og at disse kan registreres med CPTen. Sannsynligheten for at massene som vil bli brukt som tildekkingsmasser vil være tilstrekkelig forskjellig fra sedimentet på sjøbunnen er stor.



Figur 11: Prinsipp for bruk av CPT med sjøbunnsramme,. Venstre: eksempel på sjøbunnsramme for CPT.

CPT er ofte konstruert for å presse spissen 3 m ned i grunnen i ett dytt. Dersom det skal måles dypere enn dette må det enten brukes en CPT-med lengre stang eller så må det bores gjennom det testede laget før en ny test kan starte.

- Denne metoden gir også bare punktmålinger av tykkelse, men som for SPI-kamera kan oppløsningen forbedres ved å bruke CPTen i mange punkter.
- CPTen vil få problemer med å penetrere gjennom hele tildekkingslaget dersom massene er for grove eller for tett lagret. Problemer med at CPT-spissen skades under testingen kan være et problem i for grove masser.

8.1.5 Poretrykksmålinger

Når lasten på sjøbunnen økes ved at motfyllingsmasse og tildekkingsmasse legges på sjøbunnen, vil kornene i sedimentet under de utfylte massene pakkes tettere slik at det fører til økt trykk i porene mellom kornene (poretrykksoppbygging). En slik poretrykks-oppbygging kan redusere styrken i jorden der poretrykket øker og dermed stabiliteten til tildekkingslaget.

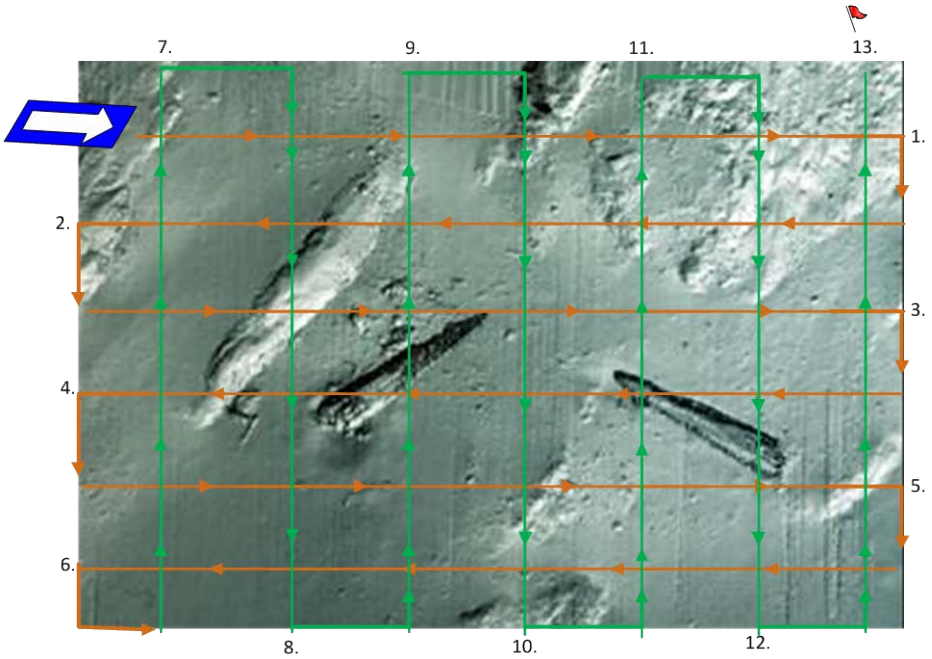
Poretrykksmålere kan derfor plasseres i grunnen under tildekkingen for å overvåke denne poretrykksoppbyggingen og for å kunne avbryte tildekkingen dersom stabiliteten svekkes slik at den ikke lenger er tilfredsstillende. Poretrykksmålerne utstyres med dataoverføring til land for online overvåkning av utviklingen. Antall poretrykksmålere og design bør vurderes av geotekniker.

8.1.6 ROV

ROV vil sannsynligvis være operativ under hele operasjonen og kan benyttes til å kontrollere utleggingen av dekkmassene. Den primære hensikten med å bruke ROV er en generell visuell inspeksjon av overflaten, eksempelvis undersøke at det ikke er hauger med tildekkingsmasse men at massene er lagt relativt homogent ut på overflaten. ROV kan benyttes ved ulike faser av tildekkingen, eksempelvis ved å undersøke under utlegging og som sluttkontroll. I tillegg er det mulig å utstyre ROV med andre typer sensorer ved behov.

Det foreslås at ROV undersøkelsene baseres på et grid med relativt tette linjer mellom. Gridet trenger ikke være forhåndsdefinert eller likt hver gang da det ansees som hensiktsmessig å ha en tildels tilfeldig tilnærming til transektlinjene innenfor tiltaks-området.

Det må planlegges en loggføring av eventuelle avvik som minimum inneholder en beskrivelse av avviket og koordinater. En konseptskisse er vist under.



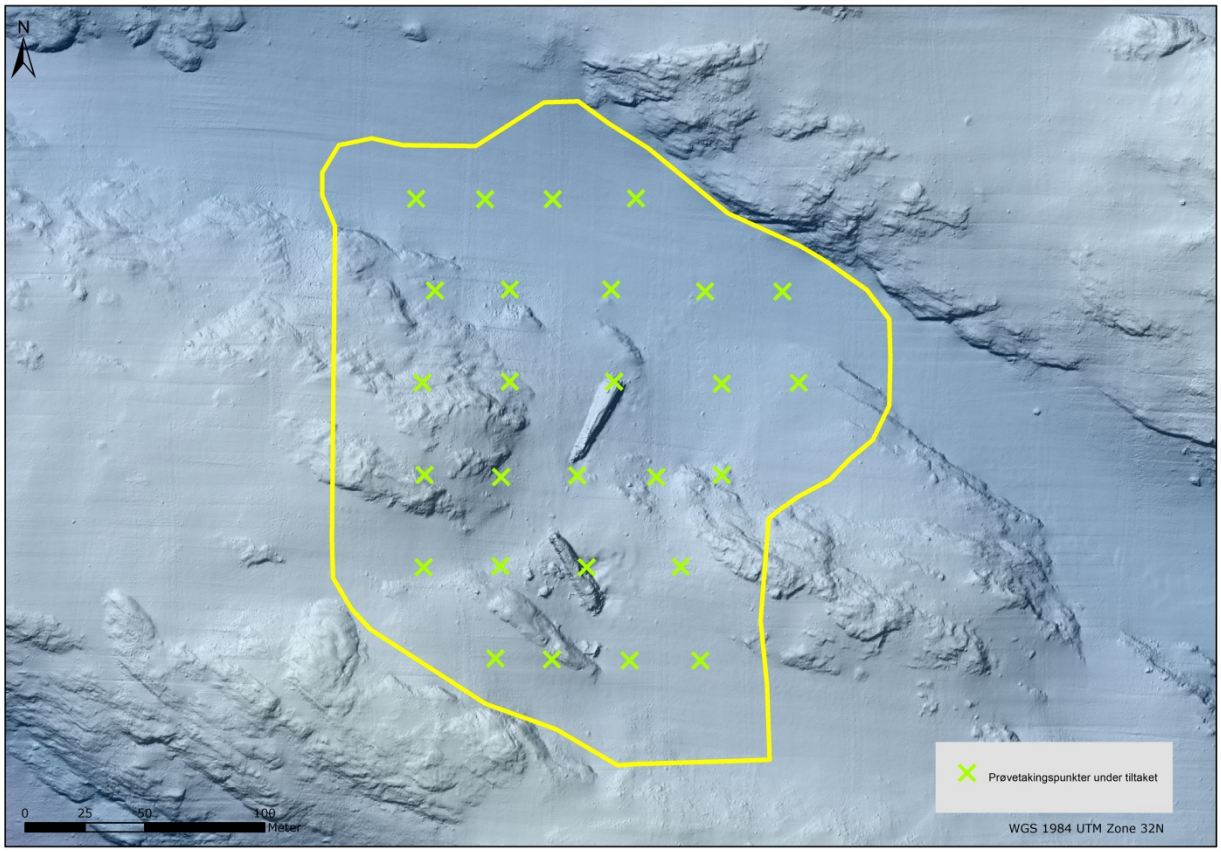
Figur 12: Konseptskisse for grid for ROV.

8.2 Kjemisk kontroll

8.2.1 Kontroll under tiltaket

Det anbefales å ta prøver av overflatesediment for å måle konsentrasjonene av kvikksølv i utlagte tildekkingsmasser. Det foreslås følgende strategi:

- Første prøvetakingsrunde gjøres etter at entreprenør anser seg ferdig med blandingslaget, som en verifikasjon på at overflaten er ren.
- Prøvene tas i et grid med 25-30 stasjoner, se Figur 13 som eksempel.



Figur 13: Forslag til grid for prøvetaking av overflatesediment i forbindelse med kontroll under tiltaket.

- Prøvene tas fortrinnsvis med en corer eller grabb og de øverste 0-2 cm analyseres for Hg.
- Akseptkriteriet er satt til 0,63 mg Hg/kg som tilsvarer klasse II (Miljødirektoratet 2007).

Nærmere informasjon om akseptkriterier under og etter tiltaket er gitt i delutredning V0.01 «Miljømål og akseptkriterier for tiltak ved U-864 (DNV GL, 2014a)

9 SLUTTKONTROLL AV TILTAKET

Sluttkontroll av tiltaket foreslås basert på følgende tre hovedaktiviteter:

1. Akustisk oppmåling av hele tiltaksområdet
2. Avlesing av målestaver
3. Prøvetaking av overflatesediment og porevann

9.1 Akustisk oppmåling

Når tiltaket er ferdig gjøres en ny akustisk måling som en kontroll på at planlagt tykkelse og utbredelse (areal) på tildekkingslaget er oppnådd. Dette gjøres ved å sammenlikne med referansedataene (før tiltaket startet). Disse avsluttende målingene er også et utgangspunkt for å følge eventuelle endringer i dekklaget over tid.

9.2 Avlesning av målestaver

Avlesning av etablerte målestaver utføres også helt til slutt som en kontroll på at planlagt tykkelse og utbredelse på tildekkingslaget er oppnådd. Disse dataene kan sammenstilles med den akustiske oppmålingen.

9.3 Prøvetaking av overflatesediment og porevann

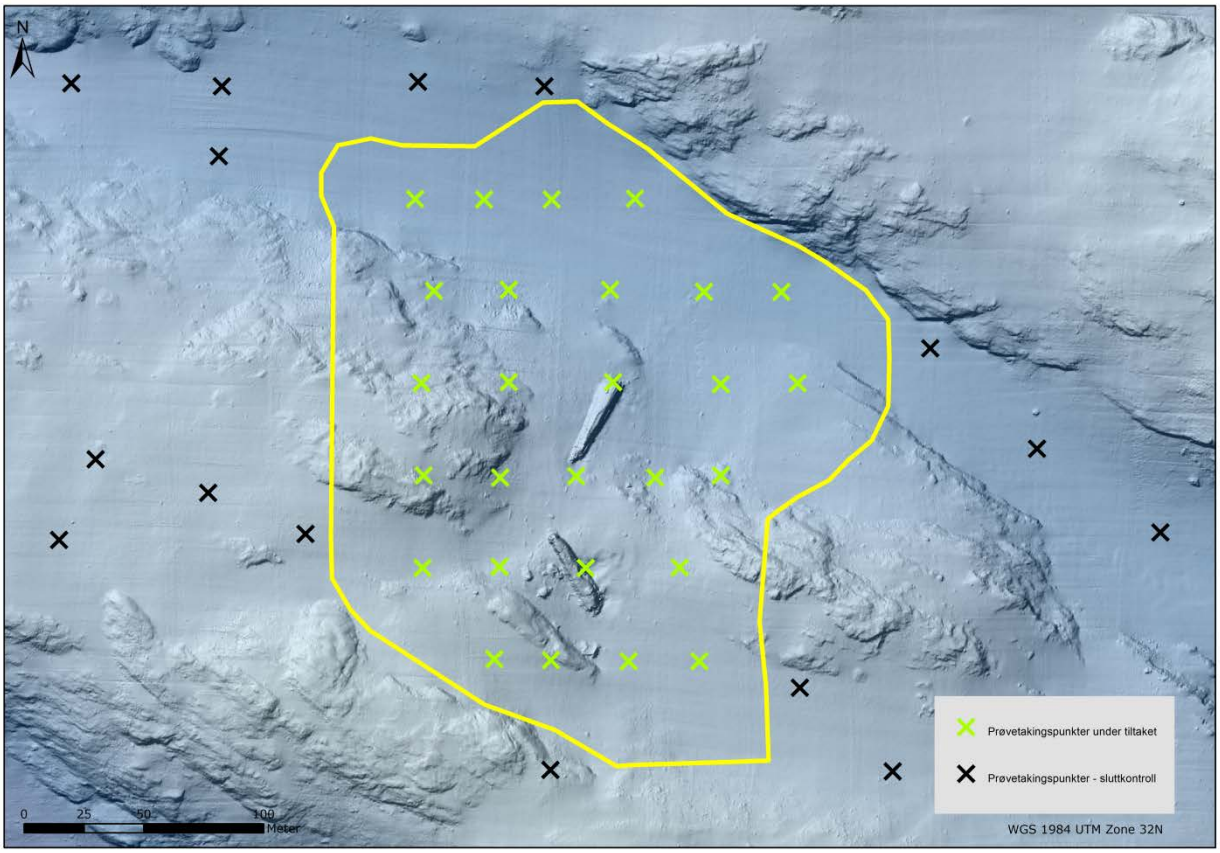
Prøvetaking av overflatesediment og porevann gjøres som en kontroll på konsentrasjoner av kvikksølv i endelig topplag av sedimentet. Denne type prøvetaking er tidligere beskrevet i DNV (2008). Denne prøvetakingen må gjøres <u>før</u> etableringen av erosjonslaget.

Et forslag til prøvetakingsstrategi for sediment er å etablere 25-30 stasjoner innenfor tiltaksområdet i et grid. I tillegg bør det tas prøver utenfor tiltaksområdet som en sjekk på eventuelle områder som kan ha blitt kontaminert som følge av tiltaket (eksempelvis spredning av forurenset sediment fra graving/mudring utover tiltaksområdet), i størrelsesorden 15-20 prøver bør tas utenfor tiltaksområdet. Prøvetakingsstasjoner er illustrert i Figur 14. Detaljert antall og plassering av prøvetakingspunktene spesifiseres i et detaljert overvåkingsprogram. Nøyaktig plassering av prøvetakingsstasjonene må gjøres i felt basert på der det er mulig å ta prøver. Eksempelvis er det vanskelig å ta prøver i områder med relativt grovt sediment (sand) eller hardbunn.

Prøvene tas med en grabb eller kjerneprøvetaker. Denne type prøver kan tas både fra båt eller ved bruk av ROV. Ved bruk av ROV er kjerneprøvetaking mest relevant.

Tre replikate prøver fra hver stasjon kan analyseres som en blandprøve. Det tas prøver av overflatelaget (0-2 cm) og et dypere lag, eksempelvis 2-5 cm.

Antall porevannsprøver kan være færre enn antall sedimentprøver. Et utgangspunkt er at 10 av sedimentstasjonene også prøvetas for porevann. Fra disse stasjonene tas det ut separate sedimentprøver (størrelsesorden 500 g våtvekt) fra sjiktet 0-5 cm. Porevannet kan tas ut i laboratorium ved eksempelvis under trykk med inert gass og filtrering (0,45 µm) eller ved sentrifugering. Prøvene kan analyseres både for elementært kvikksølv (Hg) og metylkvikksølv).



Figur 14: Illustrasjon av plassering og antall prøvetakingsstasjoner for sluttkontroll av sediment. Grønne kryss representerer stasjoner innenfor planlagt tiltaksområde mens svarte kryss representerer stasjoner utenfor tiltaksområdet.

10 LANGTIDSOVERVÅKING

Langtidsovervåking er også beskrevet i DNV (2008) og DNV GL (2014a og 2014b). Hensikten med langtidsovervåkingene er primært:

- Overvåke effekten av tiltaket over tid
- Overvåke tildekkingslagets integritet

10.1 Overvåke effekten av tiltaket over tid

Overvåkingen kan inkludere følgende aktiviteter:

- Overvåking av kvikksølvinnholdet i fisk og krabbe
- Overvåking av kvikksølvkonsentrasjoner i etablerte brønner
- Overvåking av utviklingen av bunnfaunen

10.1.1 Overvåking av kvikksølvinnholdet i fisk og krabbe

Overvåkingsprogrammet bør baseres på tidligere undersøkelser av NIFES (2006). Relevante arter for overvåkingen er torsk (kysttorsk), brosme, lange og uer, som er arter tidligere undersøkt av NIFES. Prøvetakingsstrategien bør legges opp av NIFES men den bør kunne sammenliknes med tidligere undersøkelser. I utgangspunktet bør fangstene gjøres i 3 områder (beskrevet i NIFES 2013):

- Område 0 => i nærheten av vraket
- Område 1 => 1 nautisk mil nord for vraket
- Område 2 => 2 nautiske mil nord for vraket

I tillegg anbefales prøvetaking relativt lang unna vraklokaliteten, henholdsvis nord og sør i kyststrømmen. Det kan være verdifullt å se på nivåer i mer kystnære områder som en referanse.

I utgangspunktet bør det fanges in ca. 25 individer av hver art fra hvert område. I tidligere undersøkelser er det analysert på individer. Det anbefales å følge samme strategi i langtidsovervåkingen men hvis resultatene viser relativt lave konsentrasjoner kan omfanget med hensyn på antall arter, antall analyser og antall prøvetakingslokaliteter vurderes på nytt.

I tidligere undersøkelser er det analysert på filet. Det bør vurderes å inkludere analyse på lever i analyseprogrammet.

I forbindelse med prøvetakingen bør minimum følgende dokumenteres:

- Art
- Vekt (kg)
- Analyse matriks (lever, filet, klokjøtt, krabbesmør)
- Vekt av prøvematerialel

- Fangstdato
- Gjennomsnittlig dyp på fangststed
- Fangstmetode (tråling, line, annet)
- Fiskelengde, carapax bredde (krabbe)
- Området for fangst (angi koordinater og vist på kart)
- Sykdomstegn.
- Beskrivelse av eventuelle abnormaliteter

10.1.2 Overvåking av kvikksølvinnholdet i etablerte brønner

Det er foreslått å etablere 10 brønner som muliggjør prøvetaking av vann over isolasjonslaget, se kapittel 8.1.1 Det tas vannprøver fra disse brønnene hvert år de 5 første årene. Det bør tas i størrelsesorden 10 l vann fra hver brønn. Prøvene filtreres i laboratorium og det analyseres for kvikksølv og metylkvikksølv på filtratet (partiklene) og vannfasen. Avhengig av resultatene kan frekvensen av prøvetakingen justeres etter de fem første årene.

10.1.3 Utvikling av bunnfauna

Etter at tiltaket er avsluttet kan bunnen i tiltaksområdet karakteriseres som hardbunn (erosjonslaget på toppen). Det betyr at det er hardbunnsorganismer som først vil etablere seg i området. Over tid vil bunnforholdene sannsynligvis endre seg i tråd med de rådene strømforholdene på lokaliteten, det vil si at mer finpartiklulært materiale vil legge seg over erosjonslaget. Dette gir på sikt muligheter for at bløtbunnsorganismer kan etablere seg.

Det anbefales å følge utviklingen av bunnfaunaen. Det er rimelig å anta at bunnen i tiltaksområdet vil være dominert av hardbunnsorganismer de første årene før en overgang til en bunn mer dominert av bløtbunnsorganismer. Utviklingen av bløtbunnsfaunaen kan derfor skyves lenger frem i tid. Det kan også vurderes å måle innholdet av kvikksølv i hardbunnsorganismer hvis det lar seg praktisk gjennomføre å samle inn tilstrekkelig materiale. En slik undersøkelse for hardbunnsorganismer kan gjøres ved bruk av ROV samtidig som prøvetakingen av vann fra brønnene.

10.2 Overvåke tildekkingslagets integritet

Hensikten med langtidsovervåking av tildekkingslaget er overordnet å kontrollere at funksjonen til tildekkingen er som forventet og at masser ikke eroderer bort. En slik overvåking muliggjør reparasjon og vedlikehold av tildekkingen samt at konsekvensene en eventuell sammensynkning av skroget har på dekklaget kan dokumenteres slik at nødvendige tiltak kan iverksettes.

Overvåkingen av tildekkingslagets integritet over tid er prinsipielt den samme som de elementer beskrevet for overvåkingen av selve tildekkingsoperasjonen, som beskrevet i denne rapporten. Følgende overvåkingselementer er relevante:

- Ekkoloddmålinger av tiltaksområdet => se Kapittel 8.1.2
- Prøvetaking av vann fra etablerte brønner i tildekkingslaget => se Kapittel 8.1.1
- ROV undersøkelser => se Kapittel 8.1.6
- Avlesing av målestaver => se Kapittel 8.1.1

10.3 Oppsummering langtidsovervåking

Når det gjelder frekvensen av langtidsovervåkingen er det foreslått en tentativ plan som er vist i Tabell 6.

Tabell 6: Plan for langtidsovervåking, antall målinger og frekvens

	Tildekkingslagets integritet			Effekten av tiltaket		
År etter avsluttet tiltak	**Avlesning av målestaver**	**Ekkolodd oppmålinger**	**ROV under-søkelse**	**Fisk og krabbe**	**Kvikk-sølv i vann fra brønner**	**Bunnfauna[1)]**
1	Ca 40 stk	Tiltaksområdet	Tiltaks-området	NIFES program	Ca 10 brønner	Ja => ROV
2	Ca 40 stk	Tiltaksområdet	Tiltaks-området	NIFES program	Ca 10 brønner	Ja => ROV
3	Ca 40 stk	Tiltaksområdet	Tiltaks-området	NIFES program	Ca 10 brønner	Ja => ROV
4	Ca 40 stk	Tiltaksområdet	Tiltaks-området	NIFES program	Ca 10 brønner	Ja => ROV
5	Ca 40 stk	Tiltaksområdet	Tiltaks-området	NIFES program	Ca 10 brønner	Ja => ROV
Hvert 5. år[2)]						

[1)] De første årene er det forventet hardbunnsorganismer
[2)] Frekvens og omfang etter de 5 første årene er avhengig av resultatene fra de 5 første årene med overvåking.

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APPENDIX 1

Modellering for design av tildekkingslag for tildekking av U-864 og forurensede sedimenter omkring vraket

Teknisk notat 20130288-01-TN utarbeidet av NGI.

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Modellering for design av tildekkingslag for tildekking av U-864 og forurensede sedimenter omkring vraket

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Kontroll- og referanseside

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1 Bakgrunn

NGI har som underleverandør til DNV GL bistått Kystverket i utarbeidelsen av forprosjektet for offentlig anskaffelse i forbindelse med planlegging av tiltak mot forurensing fra ubåtvraket U-864.

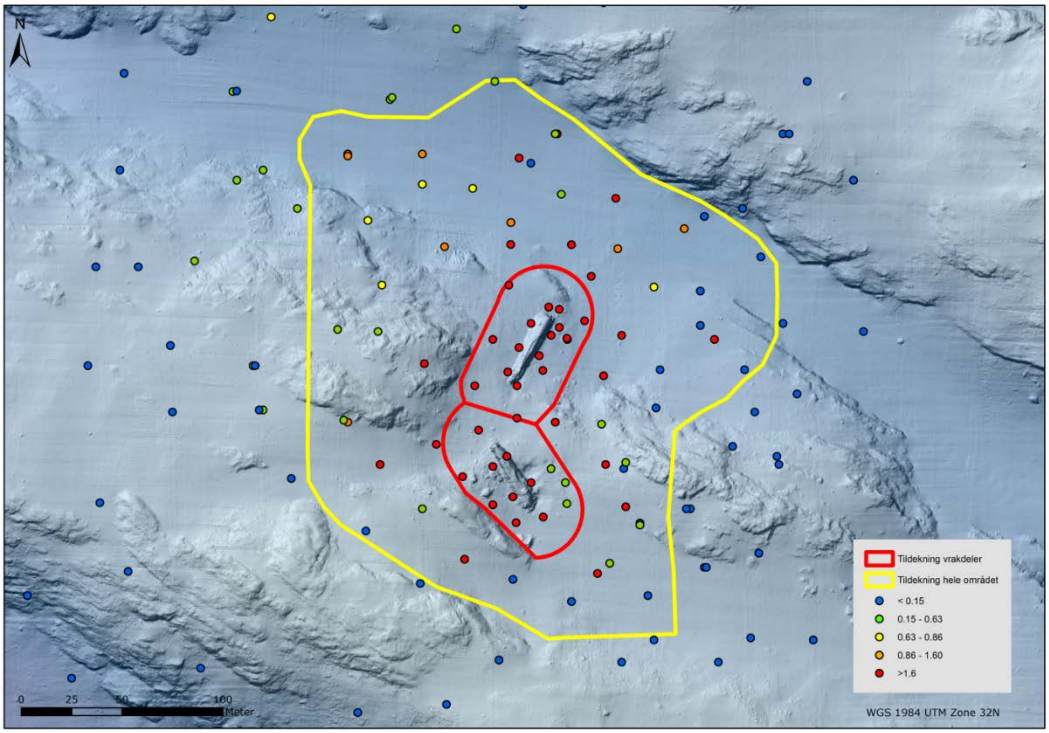
Dette notatet beskriver design av tykkelse på tildekkingen av U-864 og kvikksølv-forurenset sediment utenfor vraket.

Vurderingene bygger blant annet på følgende dokumenter:

- Guidance for Subaqueous Dredged Material Capping (Palermo et al. 1998).
- Anbefalinger ved prosjektering av tildekking av forurenset sediment (NGI 2005).
- Salvage of U864 - Supplementary studies - Study No. 11: Assessment of future spreading of mercury for the capping alternative (DNV 2008).
- Miljømål og akseptkriterier for tiltak ved U-864 (DNV GL 2014).

2 Funksjonskrav til tildekkingen

Innkapslingen (tildekking/eller *capping* på engelsk) av vraket etter U-864 vil ha som formål å redusere risiko knyttet til kvikksølv (Hg) i vraket og i sedimentet utenfor vraket. Dette oppnås ved at tildekkingen isolerer forurensingen og dermed reduserer tilgjengeligheten av kvikksølv (både elementært Hg, ionisk Hg og metylkvikksølv) i overflaten av ny sjøbunnen etter tildekking. Basert på Notat om Miljømål og akseptkriterier for tiltak ved U-864 (DNV GL 2014), er oppnåelsen av dette beskrevet som at totalkonsentrasjon av Hg i sediment i de øverste 2 cm av sjøbunnen etter tildekkingen skal være mindre enn 0,63 mg Hg/kg. Dette tilsvarer klasse II ifølge Miljødirektoratets Veileder for klassifisering av miljøkvalitet i fjorder og kystfarvann (Miljødirektoratet 2007). Figur 1 viser området som skal dekkes til.



Figur 1. Oversikt over analyser av kvikksølv i overflatesediment inndelt i tilstandsklasser (Miljødirektoratet 2007). Gul linje avgrenser området med sedimenter som ligger over tiltaksmålet (0,63 mg Hg/kg sediment). Arealet innenfor de røde linjene er området der tildekkingen over vrakdelene vil ligge.

Det er tatt utgangspunkt i at tildekkingen av U-864 og de forurensede sedimentene omkring vraket i hovedsak vil bli bygget opp av inerte løsmasser basert på naturlige mineralske produkter slik som sand, grus og stein eller knuste mineralske masser (passiv tildekking). Det kan også inkluderes lag som består av bearbeidede materialer som har til hensikt å gi tildekkingen spesielle ønskede egenskaper, slik som særlig god bindingsevne for Hg eller lav permeabilitet (gjennomstrømbarhet).

Designet av tildekkingen over vraket og forurenset sediment består av forskjellige lag som har følgende overordnede funksjoner:

1. Beskytte selve tildekkingslaget mot erosjon.
2. Hindre at utlekking av kvikksølvforurensing gir konsentrasjoner i overflaten av tildekkingen som overskrider miljømålet.
3. Ekstra lag som skal ta høyde for innblanding i forurenset sediment og usikkerhet i tykkelse ved konstruksjon.

I tillegg inngår det i designet en motfylling nedenfor der tildekkingen plasseres for å beskytte vraket og tildekkingslaget mot utglidning. Denne motfyllingen er beskrevet

tidligere (NGI 2006) og også i andre deler av dette forprosjektet. Følgelig omhandles ikke dette her.

Designet av tildekkingen basert på å oppfylle funksjonene beskrevet over, vil gi en minimum tykkelse for tildekkingen. Basert på stabiliteten i området vil det i prosjekteringsfasen også være nødvendig å stille krav til maksimum tykkelse av tildekkingen.

Dette notatet beskriver design av tildekkingen av vraket og forurensede sedimenter ved U-864 i henhold til funksjonene 1 – 3 over.

For at tildekkingen skal oppfylle funksjon 1 " Beskytte selve tildekkingslaget mot erosjon" må den øverste delen av tildekkingen bestå av masser som ikke eroderes ved de strømhastighetene som kan forventes i området.

For at tildekkingen skal oppfylle funksjon 2 "Hindre utlekking" må tildekkingen ha følgende mer spesifikke funksjoner:

- Hindre at bunnlevende dyrs omblanding av massene på sjøbunnen fører til økt transport av Hg gjennom tildekkingen,
- Hindre at bølger og vannstrøm fører til økt transport av Hg gjennom tildekkingen på grunn av adveksjon i deler av tildekkingen,
- Isolere kvikksølvforurensingen slik at transport (med diffusjon) gjennom tildekkingen ikke gir overskridelse av miljømålet (konsentrasjon <0,63 mg Hg/kg i overflatesedimentet).

Funksjon 3 i tildekkingsdesignet er viktig for at usikkerhet knyttet til konstruksjonen av tildekkingslaget ikke skal føre til at konstruert tykkelse blir mindre enn designet tykkelse. For å ivareta dette designes tildekkingen med en overdimensjonert tykkelse tilsvarende usikkerhet i konstruksjonen. Følgende usikkerhet er vurdert som viktig og tatt med i denne overdimensjonert tykkelsen:

- At deler av det forurensede sedimentet blandes med tildekkingsmassen ved utlegging,
- At det kan forekomme avvik i tykkelsen som blir faktisk lagt ut i forhold til designet tykkelse.

2.1 Andre hensyn i designet

Vraket er i dag antatt å være fylt av vann og noe luft. Svekkelser i konstruksjonen ved torpederingen av U-864 og korrosjon etter dette fører til at skrogets styrke svekkes med tiden. Tildekking over vraket vil føre til en større belastning på skroget enn det som er i dag. Disse forholdene vil føre til at skroget gir etter når korrosjon har svekket styrken i skroget slik at den er mindre enn lasten fra tildekkingen. Det er sannsynlig at deler av det ytre profilskroget gir etter under tildekkingen. Det indre trykkskroget er imidlertid laget for å tåle store trykk, noe som betyr at det sannsynlig-

vis vil gå lang tid før dette gir etter. Ved en slik sammensynkning av vraket vil tildekkings-massene som ligger over vraket synke inn i dette og tildekkingen kan bli mindre over deler av forurensningen enn det opprinnelige designet.

Dette kan håndteres på følgende måter:

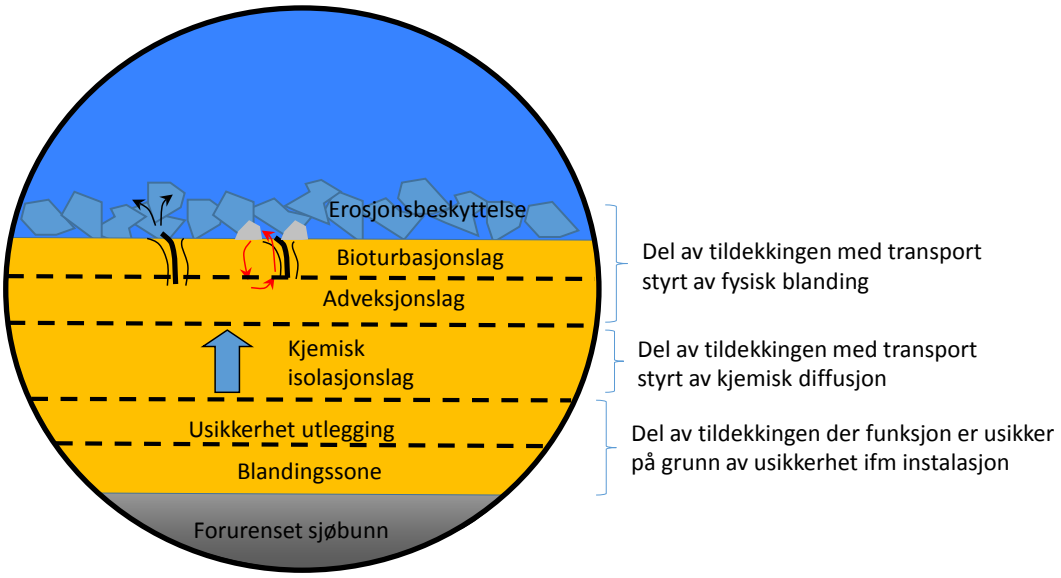
1. Sammensynkning hindres ved å fylle masser inn i vraket før dette tildekkes.
2. Tildekking repareres dersom nødvendig etter en sammensynkning av skroget. Dette forutsetter overvåkning av tildekkingen med tanke på å observere når skroget synker sammen.
3. Det dekkes til med nok masse over vraket slik at tilstrekkelig beskyttelse sikres etter en sammensynkning.

Det er her forutsatt at en sammensynkning av skroget håndteres med metode 2.

3 Tildekkingsdesign

3.1 Overordnet tildekkingsdesign

Figur 2 illustrerer overordnet tildekkingsdesign over forurensingen i og ved vraket av U-864 med de lagene som skal ivare ta ulike funksjoner i denne tildekkingen.

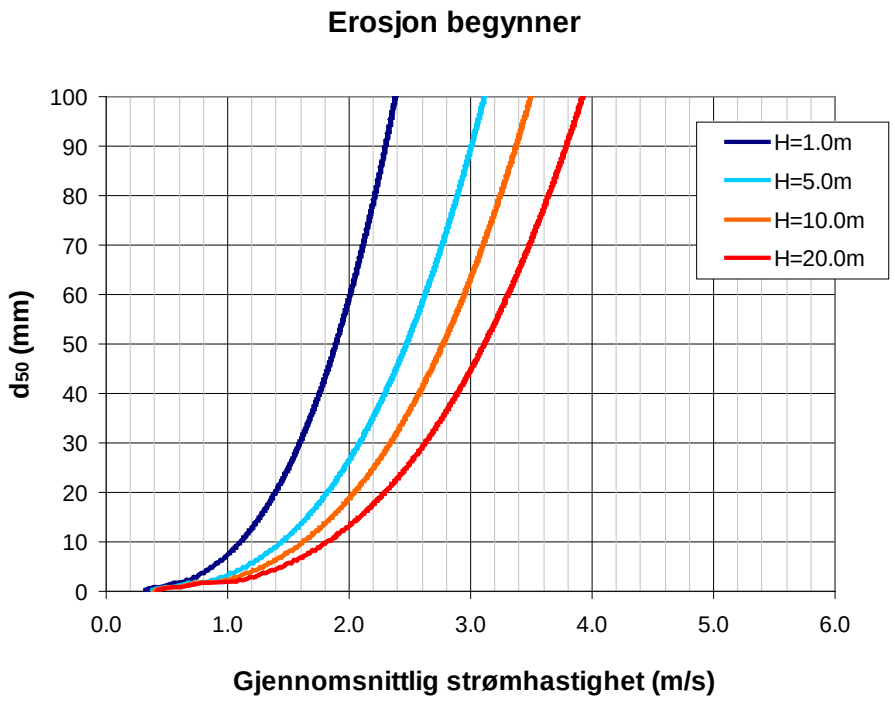


Figur 2. Illustrasjon av designlag i tildekkingen av forurensingen i og ved vraket av U-864.

3.2 Erosjonsbeskyttelse

For at tildekkingen skal oppfylle funksjon 1 og ikke erodere bort, må den øverste delen av tildekkingen ha en kornstørrelse som ikke eroderes under de strømforholdene som kan forventes i området. Strømmålinger som ble gjort over 79 dager (10. september til 28. november) i 2005 viste at maksimumsstrømmen i målingene som var gjort på 3 – 20 m over bunnen var 0,73 m/s, gjennomsnittshastighet var fra 0,1 – 0,2 m/s (NIVA 2006).

Inntil flere data foreligger, er det konservativt antatt at det kan forekomme strømhastigheter på maksimalt 2 m/s langs sjøbunnen ved vraket. I følge Figur 3 (basert på van Rijn (1993), tilsvarende Hjulstrøms diagram) så vil masser med en kornstørrelse tilsvarende d_{50} > 60 mm (50% av materialet passerer en sikt med åpning på 60 mm) være tilstrekkelig som erosjonsbeskyttelse. Maksimal strømhastighet (2 m/s) nær bunnen (H = 1 m) ligger til grunn i Figur 3. Tykkelsen av dette laget er skjønnsmessig satt til 3 x d_{50} ~ 20 cm.



Figur 3. Kurver som indikerer partikkelstørrelse (d_{50}) som kan eroderes som funksjon av gjennomsnittligstrømhastighet over et gitt avstand til bunnen (H). Hentet fra NGI-rapport 20021244-4 (NGI 2005), modifisert etter van Rijn (1993).

Konklusjon erosjonsbeskyttelse:
Erosjonsbeskyttelsen bør bestå av et lag på minimum 20 cm med mineralske masser med d_{50} > 60 mm

3.2.1 Ytterligere Krav til kornfordeling

I tillegg til kravet om d_{50} > 60 mm må tildekkingsmassene bygges opp slik at det ikke er fare for utvasking av finstoff mellom lag i tildekkingen med ulik kornfordeling og mellom tildekkingslaget og opprinnelig sediment. I følge Miljødirektoratet sin Tildekkingsveileder (Miljødirektoratet 2006), skal massene tilfredsstille krav til filteregenskaper gitt ved:

$$d_{15(\text{tildekking})} < 5 \times d_{85(\text{sediment})}$$

Det samme forholdet gjelder mellom erosjonslaget og tildekkingslaget under dette.

$$d_{15(\text{erosjonslag})} < 5 \times d_{85(\text{tildekking_bioturbasjon/adveksjon})}$$

Hvor: d_{15} og d_{85} er den korndiameteren som 15 %, henholdsvis 85 % (vekt) av kornene er mindre enn.

3.3 Bioturbasjonslag

Organismer som lever på sjøbunnen kan grave seg ned i sedimentet. Det er imidlertid vanlig å anta at den delen av sedimentet der det skjer en aktiv blanding av sedimentene er mindre enn 10 cm tykk (Miljødirektoratet 2012). Konservativt brukes 15 cm som tykkelse av dette laget.

Konklusjon bioturbasjonslag:
Bioturbasjosnlaget bør bestå av et lag på minimum 15 cm med mineralske masser.

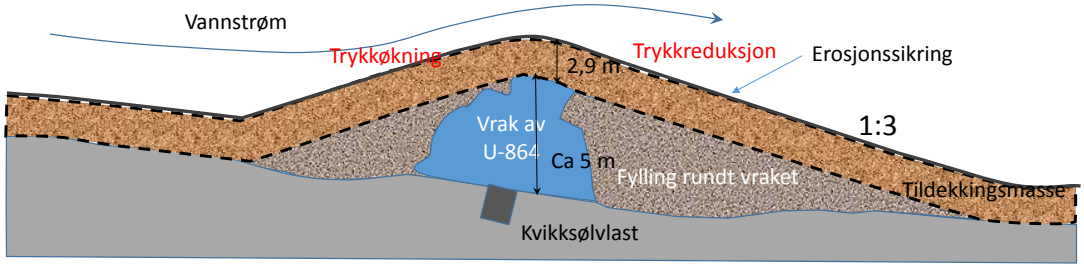
3.4 Adveksjonslag

Bølger, strøm over ujevnheter i sjøbunnen og tidevann kan skape trykkforskjeller inne i tildekkingsmassene og dermed adveksjon. Bølger vil sjelden og derfor i liten grad påvirke vannbevegelser på dette dypet. To nivåer av ujevnheter vil kunne skape trykkforskjeller i tildekkingen av U-864:

- Fyllingen over vrakdelene vil danne en forhøyning i landskapet som vil være en hindring vannet må strømme over. Når strømmende vann presses over denne forhøyningen vil dette danne trykkforskjeller mellom oppstrømssiden og nedstrømssiden av denne haugen. Denne trykkforskjellen vil føre til adveksjon gjennom deler av tildekkingen (se Figur 4).
- Små ujevnheter på overflaten av tildekkingslaget gir lokale trykkforskjeller og lokale strømning. Steinene som skal utgjøre erosjonslaget vil danne slike ujevnheter.

Trykkforskjeller over fylling rundt vraket

Trykkforskjellene som dannes av vannstrømmen over fyllingen over vraket kan gi adveksjon i tildekkingen. Størrelsen på trykkforskjellene og permeabiliteten i tildekkingsmassene vil bestemme hastigheten av denne adveksjonen. Vann-bevegelsene inne i tildekkingen vil ha en vertikal komponent og kan dermed øke transporthastigheten av kvikksølv gjennom tildekkingen.



Figur 4. Illustrasjonen viser eksempel på trykkforskjeller som kan oppstå som følge av vannstrøm over tildekket vrak. Tykkelse på tildekkingen vist i eksempelen er 2,9 m, se Tabell 2 for detaljer).

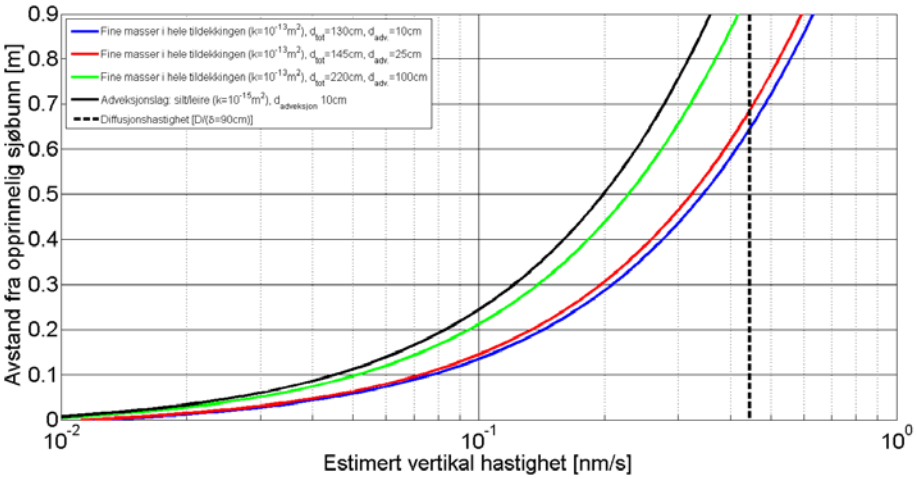
Trykkforskjellen (Δp) over fyllingene rundt vrakdelene er beregnet med ligningen:

$$\Delta p \approx \frac{1}{2} c_D \rho U_0^2 = 20\ Pa$$

Der formfaktoren, C_D. er lik 1, ρ er vannets tetthet (1027 kg/m^3), u er strømhastighet ved bunnen (konservativt estimat av gjennomsnittsstrøm er 0,2 m/s). En ekstrem hendelse med høy vannstrøm langs bunnen kan føre til erosjon og betydelig skade på tildekkingen. For planlegging av erosjonsbeskyttelse må det derfor tas hensyn til slike ekstreme situasjoner og derfor anbefales det at erosjonsbeskyttelsen minst skal tåle en strømhastighet på 2 m/s. Transport i tildekkingen som følge av adveksjon, indusert av strømning over ujevnheter, vil påvirkes av ekstrem strømhastighet bare i det korte tidsrommet disse pågår, gjennomsnittlig strømhastighet er derfor mer representativ for denne effekten. Ved vurdering av adveksjon i tildekkingen brukes derfor 0,2 m/s som kriteriet for hvilken trykkforskjell kan dannes og som vil være styrende for transporten over tid. Dette er en konservativ gjennomsnittshastighet og vurderes som konservativt nok. Dette gir en trykkforskjell over forhøyningen på 20 Pa. Det er videre antatt at denne trykkforskjellen virker over en avstand på 5 m (konservativt).

Denne trykkforskjellen er lagt inn i en modell for strømning i porøse medium der permeabilitet og tykkelse av de ulike lagene i tildekkingen er lagt inn og den vertikale strømningen (adveksjonen) som trykkforskjellen forårsaker er beregnet. Ulike adveksjonslag med ulik tykkelse og permeabilitet (k) er lagt inn i modellen for å se hva som er nødvendig for å redusere effekten av trykkforskjellen slik at transport med adveksjon er mindre enn transporten med diffusjon gjennom det kjemiske

isolasjonslaget. Når dette er oppfylt vil design av tildekkingens tykkelse kunne gjøres basert på at transport med diffusjon er eneste transport mekanisme gjennom det kjemiske isolasjonslaget i tildekkingen. Beregningene av adveksjonen i tildekkingslaget er nærmere beskrevet i et eget notat (NGI teknisk notat 20130288-03-TN).



Figur 5. Vertikal strømningshastighet i isolasjonslaget med ulike materialer i adveksjonslaget: 10 cm leirbasert tetningslag ("Clay liner") (k= 10^{-15} m^2 = 10^{-6} cm/s) vises som heltrukken svart linje, Adveksjon ved bruk av fin subbus (k= 10^{-13} m^2 = 10^{-4} cm/s) i hele tildekkingen (adveksjonslag + kjemisk isolasjonslag) total tykkelse på 130 cm (blå linje), 145 cm (rød linje) og 220 cm (grønn linje).

Figur 5 viser beregnet vertikal strømningshastigheter i tildekkingslaget sammenlignet med diffusjonshastigheten gjennom isolasjonslaget (v_D):

$$v_D = \frac{D}{L}$$

Der D er diffusjonskoeffisienten for Hg i tildekingslaget og L er diffusjonsveien (her L = 90 cm, tykkelse av isolasjonslag, se avsnitt 3.5).

Adveksjonslag like ved vraket og ved bruk av fin subbus

Beregningene viser at adveksjonen kan reduseres slik at adveksjonstransporten i det kjemiske isolasjonslaget blir mindre enn diffusjonstransporten dersom isolasjonslaget og adveksjonslaget til sammen utgjør et 220 cm tykt lag med masser med permeabilitet lavere enn 10^{-13} m^2 som tilsvarer en hydraulisk ledningsevne på 10^{-4} cm/s. Dette kan oppnås ved å bygge opp dette laget slik at det består av masser med d_{10} < 0,01 mm (betyr at 10% av materialet er mindre enn 0,01 mm). For å oppnå dette må materialet i hele tildekkingen bestå av subbus med mye finstoff (knuste masser i fraksjonene 0 – 2 eller 0 – 4 mm). Dette forutsetter at disse massene kan legges ut på en slik måte at tapet av finstoff under utleggingen og etter utleggingen før erosjonsbeskyttelsen er på plass blir minst mulig.

Selv om finstoffinnholdet skulle bli redusert under utleggingen vil en tildekking bygget opp med adveksjonslag som beskrevet her fortsatt være konservativt. Tildekkingen vil fortsatt begrense adveksjonen inne i tildekkingen og sørge for at diffusjon blir den styrende transportmekanismen. Adveksjonen som eventuelt dominerer i øvre del av tildekkingen vil dessuten gi en beskjeden transport sammenlignet med dagens situasjon der forurensningen er direkte eksponerte for frie vannmasser. Dette betyr at det ligger en betydelig margin i designet i forhold til å oppnå miljømålet med hensyn på konsentrasjon i de øverste 2 cm av sedimentet og med hensyn på utlekking til vannet over tildekkingen. Dette betyr også at tykkelsen kanskje kan reduseres dersom det gjøres mer detaljerte beregninger av generte trykkforskjeller og strømning i tildekkingen. Bruken av et tykt lag med subbus som adveksjonsbeskyttelse gir også den fordelen at dette er en mer finknust variant av de samme massene som er aktuelle å bruke i resten av tildekkingen og som derfor kan legges ut med samme fartøy og om lag samme metode som resten av tildekkingen.

Adveksjonslag like ved vraket -alternativ med bruk av leirbasert tetningslag

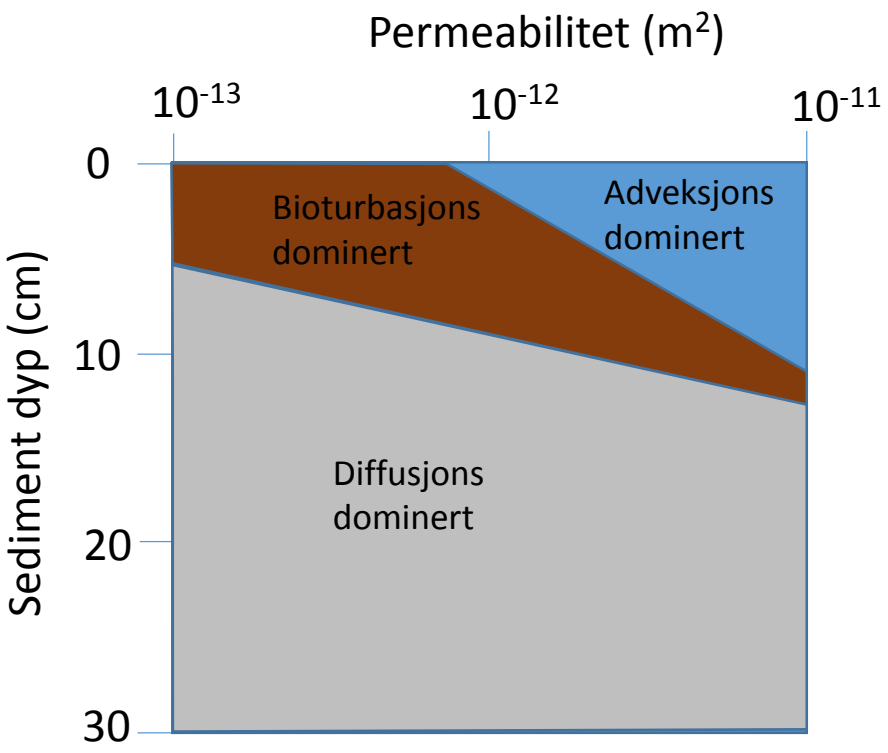
Tilstrekkelig reduksjon av adveksjonstransporten i isolasjonslaget kan også oppnås med et adveksjonslag bestående av et 10 cm tykt lag med materialer som har permeabilitet lavere enn 10^{-15} m^2 (hydraulisk ledningsevne $<10^{-6}$ cm/s). Dette er en permeabilitet som bare oppnås med masser med betydelig finstoffinnhold, for eksempel silt eller morene masser. Det vil sannsynligvis være betydelige utfordringer knyttet til å legge ut et jevnt lag med slike masser på 150 m vanndyp og med de rådende strømforholdene i området. For å få lagt ut et slikt lavpermeabelt lag er det derfor sannsynligvis nødvendig å legge ut bearbeidede leirmaterialer som brukes som tetting i deponier og som også tidligere er brukt i forbindelse med tildekking av forurensede sedimenter. Slike bearbeide leirmaterialer kan legges ut som bentonitt membraner (geosyntetiske clay liners) der bentonittleire er plassert mellom to geotekstiler som legges ut som en membran. Bearbeidede leirbaserte materialer kan også legges ut som ulike typer pellets.

Bearbeidede leirbaserte produkter oppnår størst tetningseffekt (lavest permeabilitet) når disse sveller under et mottrykk av overliggende masser. En utfordring knyttet til en del leirbaserte produkter er at disse sveller mindre i saltvann enn i ferskvann. Det finnes imidlertid materialer som kan gi lavere hydraulisk ledningsevne enn 10^{-6} cm/s også i saltvann. Et slikt leirbasert tetningslag vil måtte dekkes over med tildekkingsmasser for å holde porøsiteten (og dermed permeabiliteten) lav og for å beskytte laget mot erosjon av finstoff i leiren. Hvor lav permeabilitet som kan oppnås må uansett dokumenteres før denne typen tetningsmasser brukes i adveksjonslaget.

Fordelen med å lage adveksjonslaget med et leirbasert materiale er at dette kan gi et lavpermeabelt lag med relativt liten tykkelse. Utlegging av matter/duk kan imidlertid bli en omfattende operasjon som kan kreve bruk av et eget ROV-fartøy for dette. Leirbaserte tettingsmateriale lagt ut som pellets kan sannsynligvis legges ut med samme type fartøy som vil legge ut resten av tildekkingsmassen og er derfor det mest realistiske alternativet dersom leirbasert tetning skal brukes.

Adveksjonslag i resten av forurenset området utenfor vrakområdet

Vannstrøm omkring mindre ujevnheter slik som steiner og andre ujevnheter i erosjonslaget vil også generere trykkforskjeller og dermed adveksjon i tildekkingen under disse ujevnhetene. Flere studier har dokumentert hvilken effekt dette har på utveksling av stoffer mellom sediment og vannet over. Figur 6 viser skjematisk hvilken dybde denne effekten forventes basert på Huettel og Webster (2001).



Figur 6. Illustrasjon av prosesser som påvirker transport i sediment som funksjon av permeabilitet og sediment dybde. Fra Huettel and Webster 2001, og referanser i denne.

Dette studiet indikerer at bare de øverste 10 cm av permeable sedimenter (sandige) var påvirket av adveksjon. Andre studier har sett effekt av adveksjon som følge av strømning over ujevnheter på sjøbunnen ned til 25 cm (Rutger van der Loeff 1980).

For å være sikker på at det kjemiske isolasjonslaget ikke påvirkes av adveksjon antas det at adveksjon kan forekomme i de øverste 25 cm av sediment (tilsvarende den største effekten i disse to studiene). Deretter benyttes det en sikkerhetsfaktor på 1,5 som gir et lag på 40 cm. I områdene der det ikke bygges opp en forhøyning i landskapet er det derfor vurdert å være tilstrekkelig med et adveksjonslag på 40 cm med hydraulisk ledningsevne som er mindre enn 10^{-2} cm/s. Dette kan oppnås ved å bruke sandige masser eller subbus med en del finstoff med $d_{10} < 0{,}1$ mm.

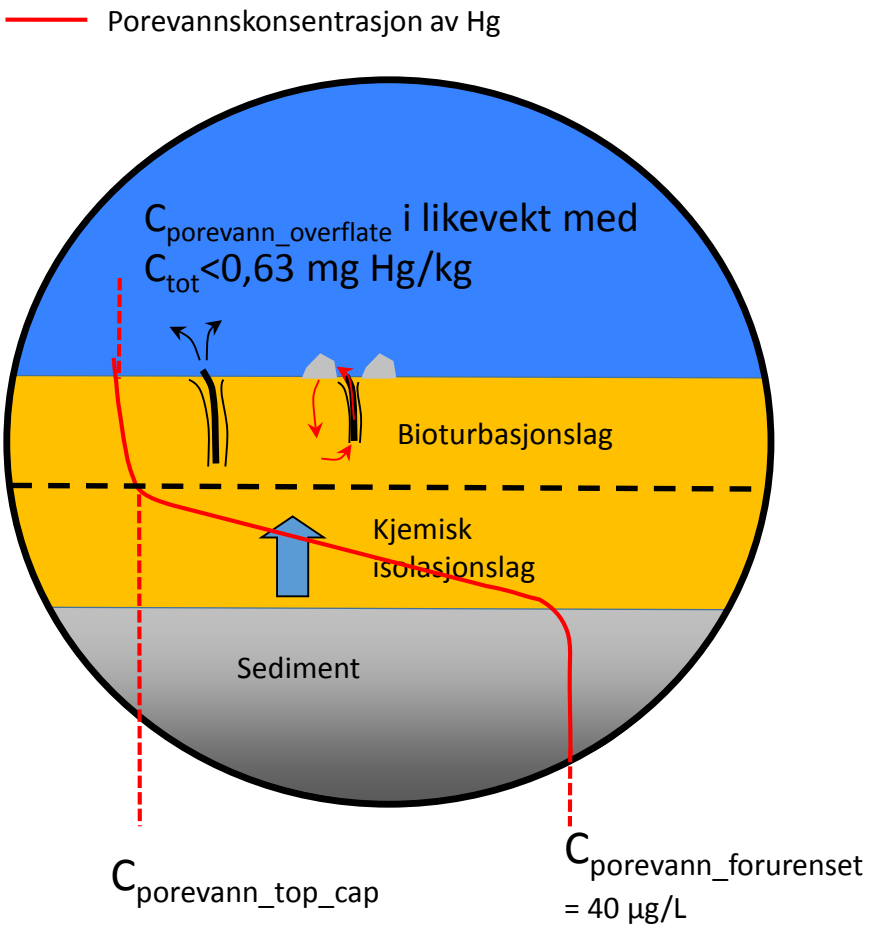
Erosjonsbeskyttelseslaget vil sannsynligvis være for grovt for å tilfredsstille kravene til permeabilitet i adveksjonslaget, mens massene i bioturbasjonslaget godt kan bygges opp med det samme type masser som adveksjonslag slik at tykkelse avsatt til adveksjonslaget kan settes til 40 cm minus tykkelse av bioturbasjonslag (15 cm), 40 cm – 15cm = 25 cm.

Konklusjon adveksjonslaget:
For tildekkingen som ligger over vrakdelene anbefales det at bioturbasjonslaget, adveksjonslaget og det kjemiske isolasjonslaget bygges opp med samme type rene masser med hydraulisk ledningsevne som er mindre enn 10^{-4} cm/s (subbus med mye finstoff for eksempel 0 – 2 mm). Dette laget bør til sammen ha en tykkelse på 220 cm. Det vil si at tykkelsen avsatt til adveksjonslaget kan settes til 220 cm – 15cm – 90 cm (se avsnitt 3.5) = 115 cm

Alternativt kan samme effekt oppnås med et 10 cm tykt lavpermeabelt lag (hydraulisk ledningsevne < 10^{-6} cm/s) som beskyttes og belastes med 55 cm masser over (20 cm erosjonsbeskyttelse, 15 cm bioturbasjonslag + 20 cm ekstra masser i adveksjonslaget).

I tildekkingen i de øvrige områdene anbefales det at adveksjonslaget og bioturbasjonslaget bygges opp med samme type masser (0 – 2 mm eller 0 – 4 mm) og til sammen har en tykkelse på 40 cm. Det vil si at tykkelsen avsatt til adveksjonslaget kan settes til 40 cm – 15cm = 25 cm.

3.5 Beregning av tykkelse kjemisk isolasjonslag



Figur 7. Illustrasjon av konsentrasjonsgradient og transport gjennom tildekking som er utgangspunktet for modellering av transport gjennom det kjemiske isolasjonslaget og bioturbasjonsdypet. I denne modelleringen ser man bort fra de andre lagene.

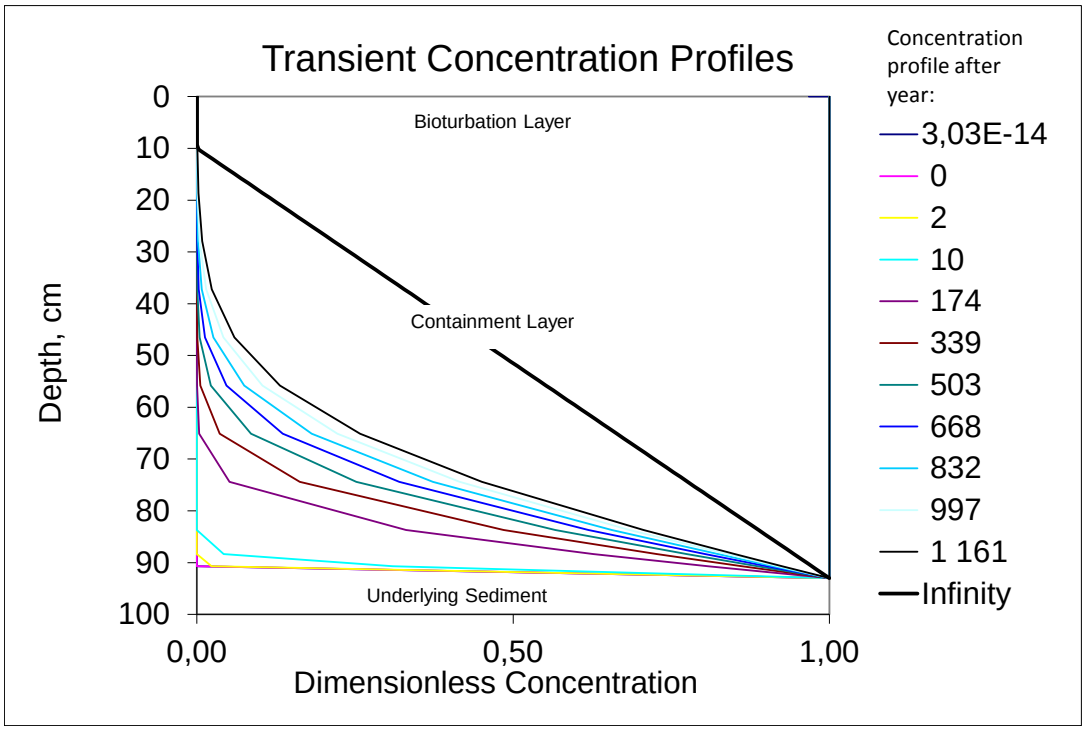
I den delen av tildekkingslaget som ikke påvirkes av bioturbasjon eller vannstrøm og trykkforskjeller vil diffusjon være den viktigste mekanismen for transport av Hg (det kjemiske isolasjonslaget). Hastigheten av Hg-diffusjon gjennom tildekkingen vil bestemme hvor mye Hg som tilføres overflatesedimentet der bunnfauna lever og hvor mye som lekker ut fra tildekkingen til vannet over. Transporten gjennom tildekkingen styrer dermed kvikksølvkonsentrasjonen på ny sjøbunn etter tildekking.

Før noe Hg kan lekke gjennom tildekkingen vil tildekkingsmassene binde opp Hg, mens det etableres en konsentrasjonsgradient gjennom tildekkingen som styrer utlekkingen på veldig lang sikt ("*steady state*") som vist i Figur 8. Tiden det tar før kvikksølvet har fylt opp bindingskapasiteten i tildekkingen kan ta mer enn tusen år (DNV 2008). Tykkelsen på tildekkingen er beregnet slik at den skal oppfylle kravene til å beskytte overflatesedimentet (<0,63 mg Hg/kg i de øverste 2 cm) også etter at

bindingskapasiteten i tildekkingen er brukt opp. I denne fasen er det bare den forlengede diffusjonsveien gjennom tildekkingen som begrenser transporten og dermed konsentrasjonen i overflatesedimentet.

Tykkelse av det kjemiske isolasjonslaget som er nødvendig for å tilfredsstille miljømålet er beregnet med en analytisk modell utviklet av Prof. Danny Rieble, nå ved Texas Tech University (Lampert og Reible, 2009). Transport gjennom det kjemiske isolasjonslaget og gjennom et tilnærmet homogent lag med bioturbasjon på 10 cm er beregnet slik at miljømålet skal være oppfylt av gjennomsnitts-konsentrasjonen i bioturbasjonslaget, det vil si < 0,63 mg Hg/kg fra 5 cm og opp. Tykkelsen på 10 cm er konservativt både sammenlignet med design tykkelse på bioturbasjonslaget på 15 cm og miljømålet som gjelder de øverste 2 cm.

Det er beregnet nødvendig tykkelse for området like ved vraket (innenfor røde linjer i Figur 1) ved å anta en konsentrasjon i porevannet på 40 µg/L, som tilsvarer likevekt med rent Hg. I sedimentet utenfor dette området, men innenfor tiltaksområdet (mellom gul og rød linje i Figur 1) er det forutsatt en konsentrasjon av Hg i porevannet på 2 µg/L. Disse konsentrasjonene er de samme som ble benyttet til beregning av transport i tidligere utredninger av tildekkingsalternativet (DNV 2008). En kvikksølvkonsentrasjon på 40 µg/L kan forekomme i sediment som er i direkte kontakt med Hg, mens 2 µg/L er om lag som konsentrasjonene målt i porevannet i forurensede sedimentprøver fra området like ved vraket (NIVA 2005). Antakelsene ovenfor er derfor konservative for begge områdene. Konsentrasjonen av Hg i porevannet i området utenfor det mest forurensede området forventes å være mye lavere enn 2 µg/L.



Figur 8. Estimerte konsentrasjonsgradienter i tildekkingslaget (konsentrasjon som funksjon av dyp i tildekkingen ("Depth") på ulike tidspunkt etter en tildekking, figur fra modellering med sorbsjonskoeffisient (K_d-verdi) = 200 for tildekkingsmassen. Dette er et konservativt (lavt) estimat for K_d for passive materialer, slik som sand eller subbus.

Resultatene av disse beregningene av nødvendig tykkelse der diffusjon styrer transporten er oppsummert nedenfor og inngangsparametere og øvrige resultater er vist i vedlegg A.

I området nær vraket der det er antatt en konsentrasjon av Hg i porevannet på 40 µg/L vil et kjemisk isolasjonslag på 90 cm redusere transporten av Hg slik at konsentrasjonen på den nye sjøbunnen etter tildekking holder seg lavere enn miljømålet på 0,63 mg/kg. I området utenfor det mest forurensede området ved vraket, der konsentrasjonen er anslått til å være < 2 µg/L, vise modelleringen at 5 cm tildekking er tilstrekkelig for å overholde miljømålet.

Konklusjon kjemisk isolasjonslag:
I området nær vraket anbefales det et kjemisk isolasjonslag på 90 cm mineralske masser.
I området utenfor dette anbefales det å bruke et kjemisk isolasjonslag på 5 cm mineralske masser.

3.6 Ekstra tykkelse for å ta hensyn til usikkerhet i konstruksjon

Funksjon 3 i tildekkingsdesignet er viktig for at usikkerhet knyttet til konstruksjonen av tildekkingslaget ikke skal føre til at konstruert tykkelse blir mindre enn designet tykkelse.

Erfaring fra utlegging av fyllinger i forbindelse med utlegging av rørledninger offshore er at høyde forskjellen mellom furene som dannes ved utlegging med rør ned til bunnen er 30 cm. Dette tilsvarer usikkerheten i utlegging med denne metoden. Betydelig vanndyp og kupert topografi gjør at usikkerheten kan øke noe, mens ujevnheten sannsynligvis vil minke med tiden. Basert på dette er det valgt å bruke en tykkelse på 40 cm for å ta høyde for usikkerheten og avvik fra designet under utlegging av tildekkingen. En tykkelse på 40 cm er et estimat, men kan bli større eller mindre avhengig av entreprenørens erfaring med den metoden for utlegging av tildekkingsmassene.

Konklusjon usikkerhet ved konstruksjon av tildekkingen:
Det er lagt til 40 cm tykkelse i designet for å ta hensyn til usikkerhet ved konstruksjon av tildekkingen.

3.7 Blandingssone mellom sediment og tildekking

Det er skjønnsmessig antatt at ved forsiktig utlegging av tildekkingsmassene vil disse blandes inn i sedimentet under i en sone som tilsvarer 2 – 3 ganger største kornstørrelsen. Kornstørrelsen for massene som benyttes antas å være mindre enn 30 mm. Tykkelsen på blandingssonen antas derfor å være mindre enn 10 cm. Blandingssonen tilsvarer den tykkelsen nederst i tildekkingen som ikke kan forventes å ha noen vesentlig effekt fordi forurensede sedimenter er fysisk blandet inn i tildekkingsmassene.

Konklusjon blandingssone mellom sediment og tildekking:
Det er brukt en tykkelse på 10 cm for blandingssonen mellom sediment og tildekking.

4 Anbefalt tildekkingstykkelse med tildekking med mineralske masser

Tabell 1 viser anbefalt tildekkingstykkelse over vraket og forurenset sediment.

Tykkelse av tildekkingslaget som skal hindre utlekking av Hg er 240 cm for det mest forurensede området over og like ved vraket og 65 cm i resten av det forurensede området. I tillegg er det estimert tykkelser knyttet til usikkerhet i konstruksjon og blandingsdybden. Total forventet tykkelse av tildekkingslaget, inkludert denne

usikkerheten, er 290 cm like ved vraket og 115 cm i det øvrige området. Modellberegninger av transport av Hg i tildekkingslaget viser at utlekkingshastigheten forventes å bli redusert med mer enn 99% med en slik tildekking.

Tabell 1. Tildekkingsdesign med passiv tildekking

	Like ved vraket (adveksjonslag: fin subbus)	**Resten av det forurenset området**
Erosjonslag	20 cm	20 cm
Bioturbasjonslag	15 cm	15 cm
Adveksjonslag	(220 – 90 – 15 cm*) = 115 cm	(40 – 15 cm*) = 25 cm
Kjemisk isolasjonslag	90 cm	5 cm
Sum tildekking uten usikkerhet	**240 cm**	**65 cm**
Blandingslag	10 cm	10 cm
Usikkerhet plassering	40 cm	40 cm
Total tykkelse av tildekkingen	**290 cm**	**115 cm**

* 15 cm tykkelse i bioturbasjonslaget, 90 cm isolasjonslag

5 Alternativt tildekkingsdesign med aktive tildekkingslag

I tillegg til en tildekking med inerte eller passive materialer der virkemåten er å forlenge diffusjonsveien for Hg fra forurensningen på sjøbunnen og ut i vannet, kan det også designes tildekking der massene i deler eller hele tildekkingen har egenskaper som øker effekten av tildekkingen:

- Masser med lav permeabilitet
    - Det er alternativene for adveksjonslaget basert på leirbaserte tetningsmaterialer (se avsnitt 3.4)
- Masser med høy sorbsjonskapasitet for Hg
    - Et lag med masser med høy sorbsjonskapasitet for kvikksølv vil binde kvikksølv som diffunderer fra forurensningen i vraket og inn i tildekkingslaget og kan dermed øke tiden før gjennombrudd av kvikksølv gjennom tildekkingslaget.
    - Aktuelle materialer som kan brukes i en slik aktiv tildekking er:
        - Aktivt kull
        - Leirbasert materiale med sulfid-grupper bundet til leiren

Felles for alle materialene som skal benyttes til tildekkingen og motfyllinger er at de må være rene og tilfredsstille Miljødirektoratets tildekkingsveileder (Miljø-direktoratet 2006). Dersom det skal brukes aktivt kull eller andre materialer som inneholder organiske materialer må kravet i denne veilederen om maksimum 0,5 % TOC i tildekkingsmaterialet sees bort fra, men det må da dokumenteres at det organiske materialet i tildekkingsmaterialet er inert og ikke brytes ned. Dette er viktig både for å unngå gassdannelse i tildekkingen og for å hindre økt metylering av kvikksølv.

Dersom det skal benyttes aktive materialer må det stilles krav til dokumentasjon av funksjonalitet og til at de ikke gir uønskede bieffekter. Slike krav kan stilles som en del av anbudsprosessen eller det kan gjennomføres et pilotprosjekt der prekvalifiserte materialer eller tildekkingsdesign testes under like forhold.

Dersom det brukes aktive materialer som beskrevet ovenfor i tildekkingen vil disse kunne erstatte deler av lagene i tildekkingsdesignet med passive materialer.

En aktiv tildekking som binder Hg vil ikke redusere utlekkingshastigheten ved "*steady state*", når hele tildekkingen er i likevekt med den konsentrasjonsgradienten som transporten gjennom tildekkingen gir. En slik aktiv tildekking gjør at det tar svært lang tid til en slik "*steady state*"-tilstand oppstår og dermed tiden til det i det hele tatt kan komme Hg gjennom tildekkingen (>>1000 år). Over så lang tid kan geologiske endringer påvirke området der forurensingen ligger. På bakgrunn av dette kan det argumenteres for at et slikt lag med masser med høy sorbsjonskapasitet for Hg kan erstatte det meste av det kjemiske isolasjonslaget. Et aktivt lag kunne legges ut som et 5 – 20 cm lag der tykkelsen bestemmes av hvordan laget skal legges ut. Dersom laget legges ut sydd inn i geotekstiler vil dette kunne være så tynt som 5 cm, hvis det legges ut som granulære masser vil laget sannsynligvis måtte være 10 – 20 cm og med 10 cm beskyttelseslag bestående av sandige masser mellom adveksjonslaget og det aktive laget. Dette gir en anslått tykkelse av det (aktive) kjemiske isolasjonslaget på 15 – 30 cm.

Tabell 2. Tildekkingsdesign med aktive lag like ved vraket; lavpermeabelt og sorbsjonslag. Tykkelse er bare beregnet for området nærmest vraket med utgangspunkt i 40 µg/L Hg i porevannet.

	Kun passiv tildekking	**Lav-permeabelt lag (Leirbasert adveksjonslag)**	**Aktiv tildekking med sorpsjon av Hg**	**Lav-permeabelt lag og sorpsjons-materiale**
Erosjonslag	20 cm	20 cm	20 cm	20 cm
Bioturbasjonslag	15 cm	15 cm	15 cm	15 cm
Adveksjonslag	(220 – 90 – 15 cm)* = 115 cm	10 cm (leire) + 20 cm beskyttelse	(220 – 15 – 15 cm)* = 190 cm	10 cm (leire) + 20 cm beskyttelse
Kjemisk isolasjonslag	90 cm	90 cm	15 cm	15 cm
Sum tildekking uten usikkerhet	**240 cm**	**155 cm**	**240 cm**	**80 cm**
Blandingslag	10 cm	10 cm	10 cm	10 cm
Usikkerhet plassering	40 cm	40 cm	40 cm	40 cm
Total tykkelse design	**290 cm**	**205 cm**	**290 cm**	**130 cm**

* 220 cm er tykkelse til bioturbasjonslag + adveksjonslag + kjemisk isolasjonslag. Bioturbasjonslaget og kjemiskisolasjonslag trekkes i fra for å få tykkelse som må legges inn i design som tykkelse til adveksjonslaget.

Den totale tildekkingstykkelsen kan reduseres med 85 – 160 cm ved å bruke lavpermeabel tetting og aktiv tildekking. Tildekking med aktivt kjemisk isolasjonslag gir ingen effekt på tykkelsen alene fordi summen av tykkelsen av adveksjonslaget og det kjemiske isolasjonslaget fortsatt må være 220 cm. Sammen med et leirbasert adveksjonslag gir det mulighet for reduksjon av total tykkelse av tildekkingen.

6 Vurdering av usikkerhet knyttet til tildekkingen

Det er i denne vurderingen av nødvendig tildekking benyttet sikkerhetsfaktorer og konservative vurderinger som gir et design som er mer konservativt enn det som er vanlig ved tildekking av forurenset sediment. Dette er gjort fordi det i dette prosjektet ansees som kritisk å beskytte miljøet mot forurensingen i området like ved vraket. De moderat forurensede sedimentene utenfor de mest forurensede områdene like ved vraket skal også dekkes til. Her er det basert på utførte sedimentundersøkelser brukt en lavere Hg-konsentrasjon enn like ved vraket som fører til tynnere kjemisk isolasjonslag, men det er likevel benyttet det samme konservative designet som ved tildekking like ved vraket.

Tildekkingen som er beskrevet i dette notatet er også konservativ ved å anta høye konsentrasjoner i porevannet, ved at det tar hensyn til adveksjon i tildekkingen som

kan forårsakes av strømning over tildekkingen og ved at lagene har blitt gitt ekstra tykkelse for å være siker på at de oppfyller den funksjonen de skal ha. En tykkelse på 290 cm over vraket er betydelig større enn de fleste tildekingslag som er benyttet i andre prosjekter.

I forhold til forbruk av masse må det også beregnes et tap av masse ut av tildekkingsområde. Dette vil være avhengig av mengde finstoff i massene, strømforholdene og hvor langt over sjøbunnen massene slippes ut. Ekstra masser nødvendig for å dekke tap av masser er ikke estimert her.

Den totale tykkelsen av tildekking vil få konsekvenser for størrelse og utforming av motfyllingen nedenfor vraket. Det må derfor bestemmes et toleranseintervall som den totale oppfyllingshøyden inkludert fyllinger omkring vraket og tildekkingen må holdes innenfor, slik at tildekkingen tilfredsstiller både de miljøtekniske kravene til tildekkingstykkelse og krav til stabilitet lokalt og globalt.

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Vedlegg A - Modellering av diffusjonstransport gjennom tildekkingen

Innhold

1 Innledning 2
2 Inndata til modellering av tildekking på det mest forurensede området 3
3 Inndata til modellering av tildekking på forurensede område lenger unna vraket 5

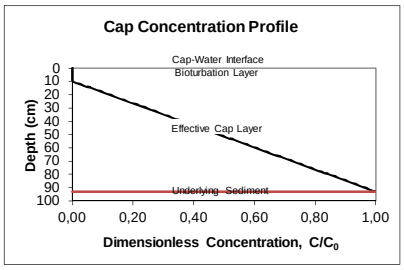
1 Innledning

Tykkelse som tilfredsstiller miljømålet er beregnet med en analytisk model utviklet av Prof. Danny Rieble ved Texas Tech University (Lampert og Reible, 2009). Det er beregnet nødvendig tykkelse ved å anta en konsentrasjon i porevannet i kontakt med rent kvikksølv på 40 µg/L og i området omkring der sedimentet er forurenset men der det ikke er rent kvikksølv på 2 µg/L. Disse konsentrasjonene er de samme som ble benyttet til beregning av transport i tidligere utredninger av tildekkingsalternativet (DNV 2008). En kvikksølvkonsentrasjon på 40µg/L tilsvarer konsentrasjonen i vann i likevekt med rent kvikksølv, mens 2 µg/L er om lag som konsentrasjonene målt i porevannet i forurensede sediment prøver fra like ved vraket (NIVA 2005). For denne beregningen er det antatt en Kd-verdi i det kjemiske isolasjonslaget på 200 L/kg, som tilsvarer det som kan forventes i inerte sand og grus masser. I bioturbasjonslaget er det brukt en Kd-verdi på 100 000 L/kg. Dette er det som er målt i sedimentet i området og tilsvarer verdien som benyttes i risikovurderinger av forurensede sedimenter (Miljødirektoratet (2012) Veileder for risikovurdering av forurenset sediment. TA-nummer 2802/2011.).

2 Inndata til modellering av tildekking på det mest forurensede området

ACTIVE CAP DESIGN MODEL
including steady state design model from Lampert and Reible (2008)*
Version 3.12
2008-01-07

Instructions: This spreadsheet determines concentrations and fluxes in a sediment cap at steady-state worksheet 1), unsteady state (worksheet 2), assuming advection, diffusion, dispersion, bioturbation, deposition/erosion, sorption onto colloidal organic matter, and boundary layer mass transfer. An active cap layer with enhanced sorption is considered by converting to an equivalent conventional cap thickness.Depth is defined from the cap-water interface. A constant deposition rate can be entered but is not allowed to result in a net contaminant velocity <0 (relative to the changing cap-water interface) . The cells in blue are input cells; these can be changed for the design of interest. DO NOT CHANGE THE CELLS IN RED(or the spreadsheet will not function properly). A second worksheet calculates the transient profiles for a semi-infinite case. The third worksheet title "array" allows the user to create an array of outputs for a given input (e.g. to study different compounds for a given site).



Contaminant Properties

Contaminant	Hg		
Organic carbon partition coefficient, log K_{oc}	7,0	log L/kg	
Colloidal organic carbon partition coefficient, logK_{DOC}	6,63	log L/kg	
Water diffusivity, D_w	8,8E-06	cm^2/s	Konservativt, ca 5.7e-6 ved 10 C
Cap decay rate (porewater basis), λ_1	0,00	yr^{-1}	
Bioturbation layer decay rate (porewater basis), λ_2	0,00	yr^{-1}	

Sediment/Bioturbation Layer Properties

Contaminant pore water concentration, C_0	40	ug/L	
Biological active zone fraction organic carbon, $(f_{oc})_{bio}$	0,01		
Colloidal organic carbon concentration,ρ_{DOC}	0	mg/L	
Darcy velocity, V	0	cm/yr	
Depositional velocity, V_{dep}	0	cm/yr	
Bioturbation layer thickness, h_{bio}	10	cm	
Pore water biodiffusion coefficient, D_{bio}^{pw}	0	cm^2/yr	
Particle biodiffusion coefficient, D_{bio}^{p}	5	cm^2/yr	4 - 32 cm2/
Boundary layer mass transfer coefficient, k_{bl}	0,75	cm/hr	
Effective retardation factor in sediment	100000		

Active Layer Properties

Layer thickness	0,0	cm
Ratio of effective diffusion in active layer to conventional layer	1,00	
Equivalent active layer thickness (steady state equivalent)	0,0	cm
Effective Partition Coefficient	10000000	L/kg
Active adsorbent loading	3,91	kg/m^2/cm
Effective retardation factor, active layer	312	
Equivalent sandy cap thickness (transient equivalent)	0,00	cm

Conventional Cap Properties

Depth of specific interest below cap-water interface, z	5	cm	
Fraction organic carbon at depth of interest, $f_{oc}(z)$	0,01		
Conventional cap placed depth	93	cm	10 cm bioturbasjonslag resten isolasjonslag (83 cm)
Cap materials -granular (G) or consolidated silty/clay (C)	G		
Cap consolidation depth	0	cm	
Underlying sediment consolidation due to cap placement	0	cm	
Porosity, ε	0,4		
Particle Density, ρ_P	2,6	g/cm^3	
Fraction organic carbon, $(f_{oc})_{eff}$	0,00002		
Effective sand cap thickness, h_{sand}	93,0	cm	
Steady state equivalent cap thickness, h_{cap}	93	cm	
Transient equivalent cap thickness, h_{equiv}	93		
Chemical isolation layer partition coefficient	200,0	L/kg	

Steady State Model Equations

$$C_1 = \frac{C_{bio}e^{-Pe_1/2} - C_0 e^{-\beta}}{2\sinh\beta}\exp\left[\left(\frac{Pe_1}{2}+\beta\right)\frac{h_{cap}-z}{h_{eff}}\right] + \frac{C_0 e^{\beta} - C_{bio}e^{-Pe_1/2}}{2\sinh\beta}\exp\left[\left(\frac{Pe_1}{2}-\beta\right)\frac{h_{cap}-z}{h_{eff}}\right]$$

$$Pe_1 = \frac{Uh_{eff}}{D_1} \qquad Da_1 = \frac{\varepsilon\lambda_1 h_{eff}^2}{D_1} \qquad \beta = \sqrt{\frac{Pe_1^2}{4} + Da_1}$$

$$C_2 = \frac{C_{bl}e^{-\frac{Pe_2}{2}} - C_{bio}e^{-\gamma}}{2\sinh\gamma}\exp\left[\left(\frac{Pe_2}{2}+\gamma\right)\frac{h_{bio}-z}{h_{bio}}\right] + \frac{C_{bio}e^{\gamma} - C_{bl}e^{-\frac{Pe_2}{2}}}{2\sinh\gamma}\exp\left[\left(\frac{Pe_2}{2}-\gamma\right)\frac{h_{bio}-z}{h_{bio}}\right]$$

$$Pe_2 = \frac{Uh_{bio}}{D_2} \qquad Da_2 = \frac{\varepsilon\lambda_2 h_{bio}^2}{D_2} \qquad \gamma = \sqrt{\frac{Pe_2^2}{4} + Da_2}$$

$$C_{bio} = \frac{C_o \frac{Pe_2}{Pe_1} e^{\frac{Pe_1}{2}} \beta \sinh\gamma}{\frac{Pe_2}{Pe_1}\beta\cosh\beta\sinh\gamma + \gamma\sinh\beta\cosh\gamma - \frac{\gamma^2\sinh\beta}{\left(Sh + \frac{Pe_2}{2}\right)\sinh\gamma + \gamma\cosh\gamma}}$$

$$C_{bl} = \frac{C_0 e^{\frac{Pe_1+Pe_2}{2}}}{\left(\frac{Pe_1}{2} + \frac{Pe_1 Sh}{Pe_2}\right)\frac{\sinh\beta\cosh\gamma}{\beta} + \left(\frac{Pe_2}{2} + Sh\right)\frac{\cosh\beta\sinh\gamma}{\gamma} + \frac{Pe_1\gamma\sinh\gamma\sinh\beta}{Pe_2\beta} + \cosh\beta\cosh\gamma}$$

Output-Steady State Model

Pore water concentration at depth, $C(z)$	0,006	ug/L	
Solid concentration at depth of interest, $W(z)$	625,0	ug/kg	
Average bioturbation layer loading, $(W_{bio})_{avg}$	625	ug/kg	
Flux to overlying water column,J	394	$ug/m^2/yr$	
Cap-bioturbation interface concentration,C_{bio}/C_0, C_{bio}	0,02 %	0,0065	ug/L
Cap-water interface concentration, C_{bl}/C_0, C_{bl}	0,01 %	0,0060	ug/L
Average bioturbation concentration,$(C_{bio})_{avg}/C_0$, $(C_{bio})_{avg}$	0,02 %	0,0063	ug/L
Time to containment breakthrough,$t_{adv/diff}$	1,64E+03	yr	

Dimensionless Parameters

Chemical isolation layer Peclet no.,Pe_1	0,00
Chemical isolation layer Damkohler no.,Da_1	0,00
β = SQRT(Pe_1^2/4+Da)	0,00
Bioturbation layer Peclet no., Pe_2	0,00
Bioturbation layer Damkohler no.,Da_2	0,00
γ = SQRT(Pe_1^2/4+Da)	0,003
Sherwood number at interface, Sh	0,1
Equivalent ratio of active layer thickness to sand layer	1,0

Other Parameters

Chemical isolation layer depth,h_{eff}	83	cm
Chemical Isolation Layer Retardation Factor, R_1	312,4	
Bioturbation layer retardation factor, R_2	156000	
Effective advective velocity (>=0), U	0	cm/yr
Dispersivity, α	1,51	cm
Chemical isolation layer diffusion/dispersion coeff.,D_1	82	cm^2/yr
Bioturbation layer diffusion/dispersion coeff.,D_2	780082	cm^2/yr
Characteristic advection time-cap layer, t_{adv}	2,59E+12	yr
Characteristic diffusion time-cap layer, t_{diff}	1644,5	yr
Characteristic reaction time-cap layer, t_{decay}	infinite	yr

*Lampert, D.J. and Reible, D.D. 2008. "An Analytical Modeling Approach for Evaluation of Capping of Contaminated Sediments," Soil & Sediment Contamination, (in press).

3 Inndata til modellering av tildekking på forurensede område lenger unna vraket

ACTIVE CAP DESIGN MODEL
including steady state design model from Lampert and Reible (2008)*
Version 3.12
2008-01-07

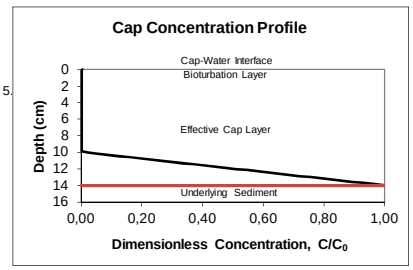
Instructions: This spreadsheet determines concentrations and fluxes in a sediment cap at steady-state worksheet 1), unsteady state (worksheet 2), assuming advection, diffusion, dispersion, bioturbation, deposition/erosion, sorption onto colloidal organic matter, and boundary layer mass transfer. An active cap layer with enhanced sorption is considered by converting to an equivalent conventional cap thickness.Depth is defined from the cap-water interface. A constant deposition rate can be entered but is not allowed to result in a net contaminant velocity <0 (relative to the changing cap-water interface) . The cells in blue are input cells; these can be changed for the design of interest. DO NOT CHANGE THE CELLS IN RED(or the spreadsheet will not function properly). A second worksheet calculates the transient profiles for a semi-infinite case. The third worksheet title "array" allows the user to create an array of outputs for a given input (e.g. to study different compounds for a given site).

Contaminant Properties

Contaminant	Hg		
Organic carbon partition coefficient, log K_{oc}	7,0	log L/kg	
Colloidal organic carbon partition coefficient, logK_{DOC}	6,63	log L/kg	
Water diffusivity, D_w	8,8E-06	cm^2/s	Konservativt, ca 5.
Cap decay rate (porewater basis), λ_1	0,00	yr^{-1}	
Bioturbation layer decay rate (porewater basis), λ_2	0,00	yr^{-1}	

Sediment/Bioturbation Layer Properties

Contaminant pore water concentration, C_0	2	ug/L	
Biological active zone fraction organic carbon, $(f_{oc})_{bio}$	0,01		
Colloidal organic carbon concentration,ρ_{DOC}	0	mg/L	
Darcy velocity, V	0	cm/yr	
Depositional velocity, V_{dep}	0	cm/yr	
Bioturbation layer thickness, h_{bio}	10	cm	
Pore water biodiffusion coefficient, D_{bio}^{pw}	0	cm^2/yr	
Particle biodiffusion coefficient, D_{bio}^{p}	5	cm^2/yr	4 - 32 cm2/
Boundary layer mass transfer coefficient, k_{bl}	0,75	cm/hr	
Effective retardation factor in sediment	100000		



Active Layer Properties

Layer thickness	0,0	cm
Ratio of effective diffusion in active layer to conventional layer	1,00	
Equivalent active layer thickness (steady state equivalent)	0,0	cm
Effective Partition Coefficient	10000000	L/kg
Active adsorbent loading	3,91	kg/m^2/cm
Effective retardation factor, active layer	318	
Equivalent sandy cap thickness (transient equivalent)	0,00	cm

Conventional Cap Properties

Depth of specific interest below cap-water interface, z	5	cm	
Fraction organic carbon at depth of interest, $f_{oc}(z)$	0,01		
Conventional cap placed depth	14	cm	10 cm bioturbasjonslag resten isolasjonslag (4 cm)
Cap materials -granular (G) or consolidated silty/clay (C)	G		
Cap consolidation depth	0	cm	
Underlying sediment consolidation due to cap placement	0	cm	
Porosity, ε	0,4		
Particle Density, ρ_P	2,6	g/cm^3	
Fraction organic carbon, $(f_{oc})_{eff}$	0,00002		
Effective sand cap thickness, h_{sand}	14,0	cm	
Steady state equivalent cap thickness, h_{cap}	14	cm	
Transient equivalent cap thickness, h_{equiv}	14		
Chemical isolation layer partition coefficient	200,0	L/kg	

Steady State Model Equations

$$C_1 = \frac{C_{bio}e^{-Pe_1/2} - C_0 e^{-\beta}}{2\sinh\beta}\exp\left[\left(\frac{Pe_1}{2}+\beta\right)\frac{h_{cap}-z}{h_{eff}}\right] + \frac{C_0 e^{\beta} - C_{bio}e^{-Pe_1/2}}{2\sinh\beta}\exp\left[\left(\frac{Pe_1}{2}-\beta\right)\frac{h_{cap}-z}{h_{eff}}\right]$$

$$Pe_1 = \frac{Uh_{eff}}{D_1} \qquad Da_1 = \frac{\varepsilon\lambda_1 h_{eff}^2}{D_1} \qquad \beta = \sqrt{\frac{Pe_1^2}{4}+Da_1}$$

$$C_2 = \frac{C_{bl}e^{-\frac{Pe_2}{2}} - C_{bio}e^{-\gamma}}{2\sinh\gamma}\exp\left[\left(\frac{Pe_2}{2}+\gamma\right)\frac{h_{bio}-z}{h_{bio}}\right] + \frac{C_{bio}e^{\gamma} - C_{bl}e^{-\frac{Pe_2}{2}}}{2\sinh\gamma}\exp\left[\left(\frac{Pe_2}{2}-\gamma\right)\frac{h_{bio}-z}{h_{bio}}\right]$$

$$Pe_2 = \frac{Uh_{bio}}{D_2} \qquad Da_2 = \frac{\varepsilon\lambda_2 h_{bio}^2}{D_2} \qquad \gamma = \sqrt{\frac{Pe_2^2}{4}+Da_2}$$

$$C_{bio} = \frac{C_o \frac{Pe_2}{Pe_1} e^{\frac{Pe_1}{2}} \beta\sinh\gamma}{\frac{Pe_2}{Pe_1}\beta\cosh\beta\sinh\gamma + \gamma\sinh\beta\cosh\gamma - \frac{\gamma^2\sinh\beta}{\left(Sh+\frac{Pe_2}{2}\right)\sinh\gamma+\gamma\cosh\gamma}}$$

$$C_{bl} = \frac{C_0 e^{\frac{Pe_1+Pe_2}{2}}}{\left(\frac{Pe_1}{2}+\frac{Pe_1 Sh}{Pe_2}\right)\frac{\sinh\beta\cosh\gamma}{\beta} + \left(\frac{Pe_2}{2}+Sh\right)\frac{\cosh\beta\sinh\gamma}{\gamma} + \frac{Pe_1\gamma\sinh\gamma\sinh\beta}{Pe_2\beta} + \cosh\beta\cosh\gamma}$$

Output-Steady State Model

Pore water concentration at depth, $C(z)$	0,006	ug/L		
Solid concentration at depth of interest, $W(z)$	624,6	ug/kg		
Average bioturbation layer loading, $(W_{bio})_{avg}$	625	ug/kg		
Flux to overlying water column,J	394	$ug/m^2/yr$		
Cap-bioturbation interface concentration,C_{bio}/C_0, C_{bio}	0,32	%	0,0065	ug/L
Cap-water interface concentration, C_{bl}/C_0, C_{bl}	0,30	%	0,0060	ug/L
Average bioturbation concentration,$(C_{bio})_{avg}/C_0$, $(C_{bio})_{avg}$	0,31	%	0,0062	ug/L
Time to containment breakthrough,$t_{adv/diff}$	4,02E+00	yr		

Dimensionless Parameters

Chemical isolation layer Peclet no.,Pe_1	0,00
Chemical isolation layer Damkohler no.,Da_1	0,00
β = SQRT(Pe_1^2/4+Da)	0,00
Bioturbation layer Peclet no., Pe_2	0,00
Bioturbation layer Damkohler no.,Da_2	0,00
γ = SQRT(Pe_1^2/4+Da)	0,003
Sherwood number at interface, Sh	0,1
Equivalent ratio of active layer thickness to sand layer	1,0

Other Parameters

Chemical isolation layer depth,h_{eff}	4	cm
Chemical Isolation Layer Retardation Factor, R_1	317,6	
Bioturbation layer retardation factor, R_2	158600	
Effective advective velocity (>=0), U	0	cm/yr
Dispersivity, α	0,08	cm
Chemical isolation layer diffusion/dispersion coeff.,D_1	79	cm^2/yr
Bioturbation layer diffusion/dispersion coeff.,D_2	793079	cm^2/yr
Characteristic advection time-cap layer, t_{adv}	1,27E+11	yr
Characteristic diffusion time-cap layer, t_{diff}	4,0	yr
Characteristic reaction time-cap layer, t_{decay}	infinite	yr

*Lampert, D.J. and Reible, D.D. 2008. "An Analytical Modeling Approach for Evaluation of Capping of Contaminated Sediments," Soil & Sediment Contamination, (in press).

Kontroll- og referanseside/
Review and reference page

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Vedlegg V0.03

MILJØTILTAK VED VRAKET AV U-864

Geoteknisk vurdering av stabilitet ved tildekking

DNV GL AS

Project name: Miljøtiltak ved vraket av U-864

Report title: Geoteknisk vurdering av stabilitet ved tildekking

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Gjengivelse av deler av dette vedleggsdokument som kan føre til mistolkning er ikke tillatt

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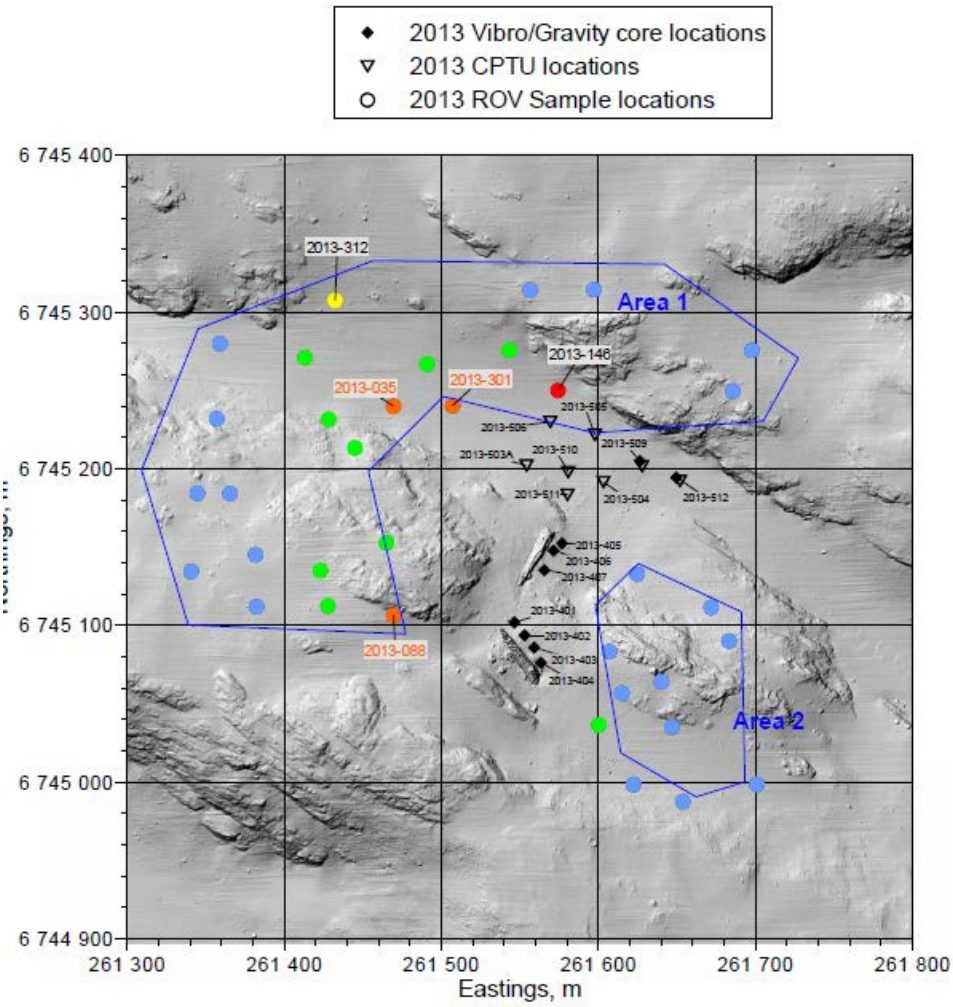
1 GEOTEKNISK VURDERING AV STABILITET VED TILDEKKING

I Januar 2013 ble det utført nye grunnundersøkelser rundt U-864. Blant annet ble det tatt grunnundersøkelser tett inntil de to vrakdelene og i «dalen» nord øst for vrakdelene. Det ble tatt både «gravity core» prøver og «CPT» prøver (Cone Penetration Test).



Figur 1 Grunnundersøkelser utført 2013, NGI.

Resultatene av de nye undersøkelsene er sammenliknet med eksisterende undersøkelser. Det henvises til følgende dokumenter:

- "Submarine Wreck U-864. Encapsulation of Wreck and Capping of Contaminated Seabed. Geotechnical Design and Guidelines for Installation.» som ble utarbeidet av GeoPartner i 2007. NGI report, "U-864 2013 Soil survey -Geotechnical Report", Document No.: 20120738-01-RDate: 17 April 2013,Revision/Rev. date: 0

En sammenstilling av grunnundersøkelser er utført av NGI og det kan konkluderes med at det ikke er grunnlag for å endre lagdeling eller styrkeprofil som ble lagt til grunn da Geopartner utførte stabilitetsvurderinger i 2007.

Det konkluderes videre med at de jordskjelvtekniske beregningene som ble utført i 2007 er konservative.

Det har vært stilt spørsmål i media hvorvidt tildekking vil være intakt dersom ankere slippes ukontrollert over tildekkingslaget eller om det skulle oppstå en forkastningssone (jordskjelv) gjennom tildekkingsområdet. Begge hendelser er svært lite sannsynlige, og det konkluderes med at tildekkingslag av sand (ikke kohesivt materiale) vil ha en «selvreparerende effekt», ved at vertikale kanter ikke er stabile og sand (ikke kohesivt materiale) vil falle ned i sprekker/grøfter.

I 2007 ble det ikke tatt høyde for en effekt av konsolidering ved lagvis utlegging av sandfyllingen. Uansett valg av tiltak, så er det en klar anbefaling at en støttefylling bør legges ut uavhengig av om tiltak med eller uten heving av last blir utført.

NGI og DNVGL anbefaler å legge ut et 7 meter tykk støttefylling i «dalen» som ligger nord øst for vrakdelene og la leira under få anledning til å konsolidere 1-1,5 år. Den positive effekten denne konsolideringen har på leiras styrke er vist i teknisk notat:

- NGI, technical note “Submarine Wreck U-864. Effect of consolidation on shear strength, Document No. 20130288-02-TN, 31 January 2014.

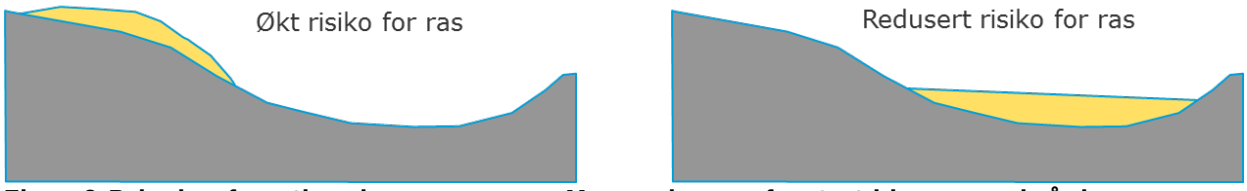
Miljøavdelingene ved NGI og DNVGL har vurdert nærmere design av tildekkingslaget og funnet at tildekkingslaget må justeres, spesielt rundt vrakdelene i forhold til det som ble lagt til grunn i analysesen utført av Geopartner i 2007. Ved vrakdelene er tildekkingslaget blitt økt og lenger vekk fra vrakdelene er tildekkingslaget blitt noe redusert. Geopartner har med bakgrunn i oppdatert styrkeprofil og oppjusterte tildekkingslag vurdert på nytt behov for samlet volum av tildekkingsmateriale for å ivareta skråningsstabiliteten. Det henvises her til notat fra Geopartner:

- Geopartner Marine as, Technical Note, Submarine Wreck U-864. Capping of wreck and contaminated seabed. Evaluation of soil consolidation and increased capping height, 2014-03-04.

Opprinnelig volum av fyllingen ble i 2007 beregnet til 236.000m^3. Nytt volum er beregnet til 235.300m^3. Det betyr at redusert volum som følge av forkonsolidering tilnærmet blir oppveid av økt volum som følge av økt tykkelse av tildekkingslag.

1.1 Prinsipp ved utlegging av masser.

Viktig prinsipp for utlegging av masser er at man alltid legger masser i bunn av skråningen og bygger seg oppover.



Figur 2 Prinsipp for utlegging av masser. Masser legges først ut i bunn av skråningen.

Geopartner har utarbeidet en detaljert beskrivelse av utlegging i deres rapport fra 2007. I neste fase av prosjektet må denne revideres basert på at man skal først legge ut en støttefylling i 1-1.5år og at tildekkingslaget er økt.

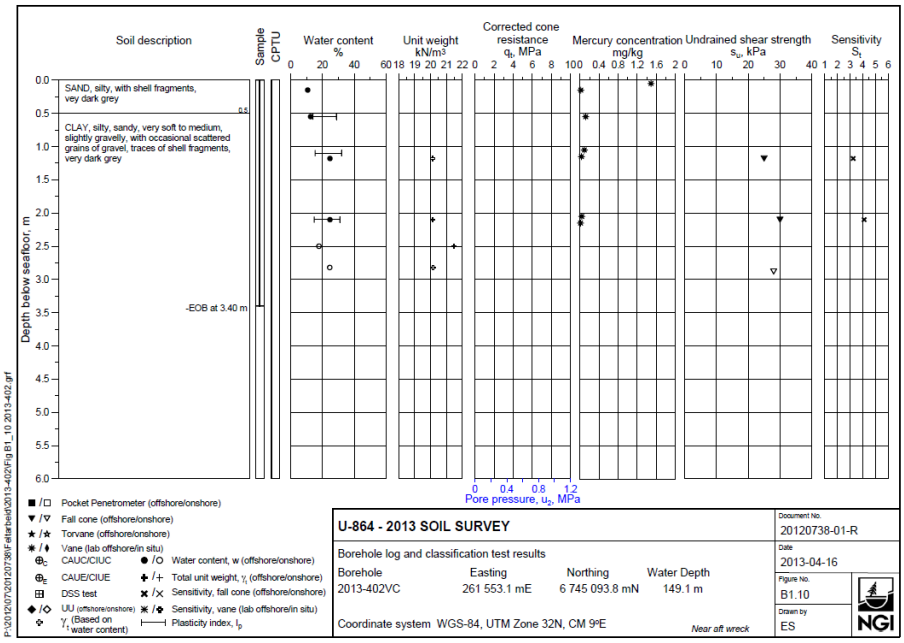
Det vil bli en egen entreprise for utlegging av støttefylling. Omtrentlige mål for støttefyllingen er 150mx75mx7m (ca. 80.000m^3). Det første laget som legges ut er et 0.5-1.0m tykt sandlag før man legger ut en steinfylling. Det er ingen spesielle krav til steinstørrelse, men det anbefales utlegging med fleksibelt fallrør, og da vil steinstørrelsen stort sett måtte være mindre enn 0.5m i diameter. Van Oord og Jan de Nul har skip som i løpet av en tur kan legge ut ca. 25.000 tonn (ca.12.500m^3) med diameter på fallrør ca. 1m. Etter at støttefyllingen er lagt ut, vil det være nødvendig å legge ut ca. 160.000m^3 med tildekkings masser.

Figur 3 Spesialskip for utlegging av sand og stein, Van Oord (ref www.vanoord.com).

1.2 Geoteknisk stabilitet ved heving av last[1]

I januar 2014 utførte Kystverket ytterligere undersøkelser av vrakdelene. I den forbindelse var det et ønske å vite mer om lagtykkelse av bløt leire over morene tett inntil vrakdelene. Grunnen til dette er usikkerhet knyttet til hvordan kjølen ligger i forhold til morenelaget, stabilitet av jorda dersom man skal rotere eller flytte vrakdelene samt muligheter for tilkomst til kjølen ved graving. DOF Subsea klarte ikke med tilgjengelig utstyr å måle dybde til morene laget som ønsket. Derimot ble det gravd med grabb og minigraver inntil akterdelen og deretter mudring. Erfaring fra toktet er at det ikke er lett å grave med maskin inntil vraket. Det var problemer med bratte arbeidsskråninger for gravemaskinen fordi leira er bløt. Man må tilstrebe slake graveskråninger. Videre ble det observert mye oppvirvling av masser i vannet ved graving med tilhørende redusert sikt. Når det gjelder de faktiske forhold, så vil DNV GL forholde seg til vibro core målinger utført 2013 inntil vrakdelene. Ved akterdelen er det påvist løsmasser fra 1.45m til 3.4m.

[1] Gjelder kun Alternativ 3 «Heving av last»



Figur 4 Typisk resultat fra vibro core boring like ved aktervraket, NGI.

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Rapport / Report

U-864 2013 Soil survey

Geotechnical Report

20120738-01-R
17 April 2013
Revision: 0

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Project

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Client

Client:	DOF Subsea
Client's contact person:	Agnete Strømme
Contract reference:	PO 3121221

For NGI

Project manager:	Egil Solhjell
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Reviewed by:	Tom Lunne

Executive Summary

The report presents the geotechnical data from the 2013 soil investigation performed near the wreck parts from the submarine U-864 located about 2 nautical miles west of the island Fedje in Hordaland, Norway. Data from a soil investigation performed in 2006 is also included where applicable.

The soil investigation was carried out in January 2013 using the dynamically positioned vessel Skandi Skolten. The soil investigation consisted of 50 locations with CPTUs or soil sampling to depths ranging up to 6.1 m. Two of the locations consisted of both CPTU and gravity core sampling. The water depth at the wreck parts is around 150 m.

In the 2013 soil investigation 2 soil units was encountered, Unit I consist of sandy, clayey SILT or clayey, silty SAND. Unit II is interpreted as a soft to medium CLAY.

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Part A - Soil Parameters for Design

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Part A1 - Summary of Soil Conditions

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A1.1 General

The German submarine U-864 was sunk by the British submarine Venturer on 9th February 1945, whilst being on its way from Germany via Norway to Japan with a cargo of war material. According to historical documents, U-864 was carrying about 65 tonnes of metallic (liquid) mercury, stored in steel containers. The wreck of the U-864 was found by the Royal Norwegian Navy in March 2003 on 150 meters depth. The wreck lies approx 2 nautical miles west of the island Fedje in Hordaland, Norway and was broken into two main parts as a result of the torpedo hit.

A soil investigation was performed in 2006 (NGI, 2006). In January 2013 a new soil investigation was performed as part of a larger survey using the vessel Skandi Skolten.

This report summarizes the results from the soil investigations from the offshore and onshore test results.

A detailed location plan with testing locations is shown in Figure A1.1. Herein, the classification (in Norwegian only) of measured mercury content is given using a colour for each of the samples acquired using the ROV. The mercury measurements were performed by NIVA.

The onshore laboratory testing has been performed in NGI's laboratory in Oslo.

In addition to the 35 samples acquired using the ROV, the 2013 soil investigation consisted of 2 gravity core samples, 7 vibro core samples and 8 seabed CPTUs.

A1.2 Soil stratigraphy

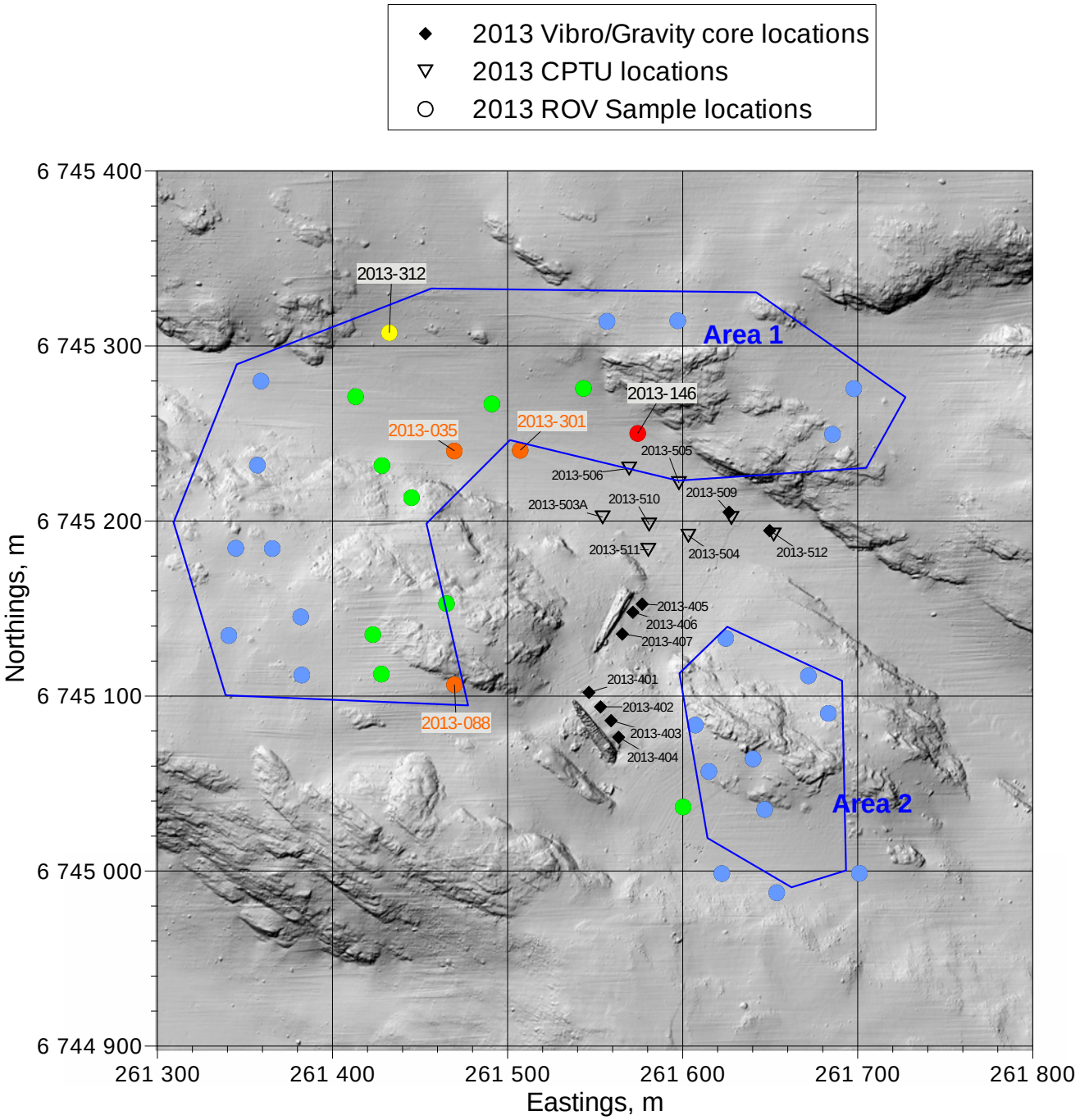
In the 2013 soil investigation following two units was encountered:

- Unit I consist of sandy, clayey SILT or clayey, silty SAND.
- Unit II is interpreted as a soft to medium CLAY.

Thicknesses of soil units are given in Part A2.

	Class I Background	Class II Good	Class III Moderately polluted	Class IV Bad	Class V Very bad
Mercury (mg/kg) dry weight	<0.15	0.15 – 0.63	0.63 – 0.86	0.86 – 1.6	>1.6

The results are classified according to the classification system of the Norwegian Climate and Pollution Agency for classification of environmental quality in fjords and coastal water



WGS-84, UTM Zone 32N, CM 9°E

U-864 - 2013 SOIL SURVEY

Location plan - 2013 soil samples/testing

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Date	2013-04-17
Figure No.	A1.1
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Part A2 - Interpretation and Evaluation of Geotechnical Data

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A2.1 General

This part contains the interpretation of the available data from boreholes with sampling and CPTUs carried out for the U-864 in 2006 and 2013. The scope of work was to provide general soil information and information about mercury in the soil.

The soil investigation builds on the 2006 soil investigation (NGI, 2006) where an evaluation of the soil conditions was performed. A vicinity map and location plan is shown in Part A1. Onshore and offshore laboratory testing has been performed on soil samples down to about 4 m below seafloor. Seabed CPTU testing has been performed to about 6 m below seafloor.

A2.2 Soil stratigraphy

The soil investigation in 2013 revealed, as the soil investigation in 2006, quite homogenous soil conditions in the area.

In the 2013 soil investigation the following two soil layers was encountered

Unit I: SILT, sandy, clayey or SAND, clayey, silty
Unit II: CLAY, soft to medium

Table A2-1 shows the thickness of the 2 soil units identified. The individual borehole logs, Part B1, should be consulted for specific details.

Table A2-1 Soil layer thickness for locations performed in 2013

Location	Unit I thickness [m]	Unit II thickness [m]
2013-503/503A	> 1.7	-
2013-504	1.2	> 4.9
2013-505	-	> 5.9
2013-506	1.5	> 4.6
2013-509	0.15	> 6.0
2013-510	0.75	> 5.35
2013-511	1.5	> 4.6
2013-512	0.95	> 5.0
2013-401	0.6	> 5.0
2013-402	0.5	> 2.9
2013-403	0.0	> 1.45
2013-404	1.0	> 0.45

Location	Unit I thickness [m]	Unit II thickness [m]
2013-405	0.6	> 2.6
2013-406	0.1	> 1.9
2013-407	>1.0	-

A2.3 Basic soil parameters

A2.3.1 Water content

The water contents were determined offshore and onshore. The individual results for each borehole are presented on the borehole logs given in Part B1.

The measured values of water content are summarised in Figure A2.1. Results from (NGI, 2006) are included.

A representative profile has been included in the figures and is based on data herein and that presented in 2006. No systematic difference between onshore and offshore measurements has been observed.

There is some scatter in the results, but in general the water content falls between 16% and 34% in the upper 4 m investigated with a representative value of 25 %.

The figure shows that the water contents measured in 2013 have a larger scatter than in measurements performed in 2006. This is reasonable since the measurements in 20013 are performed on samples from a larger area with larger variations in water depth.

A2.3.2 Total unit weight of soil

Total unit weight of the soil, γ, was determined onshore on a limited number of advanced laboratory testing. Total unit weight values based on water content measurements and unit weight of solid particles, $\gamma_s = 27.3$ kN/m^3, assuming full saturation, were also determined. The individual results for each borehole are presented on the borehole logs in Part B1.

The total unit weight values are summarised in Figure A2.2 with the results from (NGI, 2006) included.

Since the values to a large extent are based water content measurements the comments given to the water content above is also applicable for the unit weight. A representative unit weight, taken close to the average value of 20.1 kN/m^3, has been included.

A2.3.3 Plasticity data

The liquid (w_L) and plastic (w_p) limits and the corresponding plasticity indices (I_p) have been determined on a number of clay samples.

The plasticity index $I_p = w_L - w_p$, is summarised and plotted versus depth in Figure A2.3 with the results from (NGI, 2006) included. The plasticity index varies between 10 % and 25 %. A representative profile close to the average value of I_p =15 % has been included.

The plasticity index is plotted versus the liquid limit, w_L, on the plasticity chart in Figure A2.4. For all samples tested the results plot above the A-line.

According to "The Unified Soil Classification System" (ASTM, 2004) the soils classify as "inorganic clay of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays".

A2.3.4 Unit weight of solid particles

The unit weight of solid particles, γ_s, was determined on a total of 6 samples. The results are presented in Figure A2.5. An average value of 27.3 kN/m^3 is considered to be a representative value.

A2.3.5 Grain size distribution

The grain size characteristics have been determined on a total of 28 samples. The individual grain size curves are presented in Part B2.

Figure A2.6 presents the clay and fines contents for the samples tested with the results from (NGI, 2006) included.

There is a large scatter within the upper 1 m below seafloor. However, no distinct trend was found. Trend lines of typical values (close to average values) of clay content and fines content are shown. One curve represents the clay fraction (i.e. particles less than 0.002 mm) with depth. The other curve represents the fines content (i.e. particles less than 0.063 mm).

A2.3.6 Remoulded shear strength

Remoulded shear strength measurements have been carried out using index shear strength tests on a number of remoulded clay samples. Whereas the sensitivity of a clay sample is influenced by sample disturbance, the remoulded strength is not, provided that the water content is unchanged. Standard practice at NGI is to use the fall cone test to obtain remoulded strength values.

All direct measurements of remoulded strength have been plotted versus depth, as presented in Figure A2.7.

NGI suggests computing the remoulded undrained shear strength corresponding to the direct simple shear, s_u^{DSS}, divided by the sensitivity (S_t). With the strength anisotropy as discussed later of s_u^{DSS}/s_u^{C} = 0.7 the remoulded strength (s_{ur}) is simply:

$$s_{ur} = 0.7 \cdot s_u^{C} / S_t$$

The high and low representative shear strength profiles from Figure A2.14 have been transformed using a general sensitivity value of 3. The resulting curves of representative s_{ur} - values for are included in Figure A2.7 and represent the suggested high and low representative s_{ur} profiles. High or low values are to be chosen depending on what is appropriate for the analysis in question.

A2.3.7 Sensitivity

Sensitivity has been determined from index shear strength tests on intact and remoulded clay samples. The sensitivity is calculated as $S_t = s_u/s_{ur}$, where s_u and s_{ur} are the shear strengths for the intact and the remoulded samples, respectively. All measurements have been presented on the borehole logs in Part B1 for each individual boring.

A summary plot of sensitivity values is presented in Figure A2.8. Results from (NGI, 2006) are included.

In the 2006 investigation 4 fall cone tests were performed with a recommended S_t=2.5. In the 2013 soil investigation 17 fall cone tests were performed. While there is scatter in the results, the sensitivity typically varies between 2 and 4. A representative value of S_t=3 is suggested.

A2.3.8 Mercury sampling locations

Mercury content measurements are performed by NIVA, both in the soil samples obtained using the ROV and the vibro core samples taken close to the 2 wreck parts. All measurements have been presented on the borehole logs in Part B1 for each individual boring. Figure A2.9 shows the sample locations together with a colour code referring to the mercury level.

A2.4 In situ stresses and stress history

A2.4.1 In situ effective vertical stress, p_0'

The representative profile of effective vertical stress, p_0', can be calculated as:

$$0 < z < 4 \text{ m:} \qquad p_0' = 10.1 \cdot z \quad [\text{kPa}]$$

where z is depth below seafloor.

A2.4.2 Preconsolidation stress (p_c') and overconsolidation ratio (OCR)

Interpretation of preconsolidation stress, p_c', is based on results from oedometer tests on undisturbed clay samples using the interpretation methods recommended by Casagrande (1936), Becker et al. (1987) and Janbu (1970). The overconsolidation ratio, OCR (= p_c'/p_0'), can be calculated directly using the estimates of p_c', and the in situ effective stress using measured unit weights.

In this project, when estimating p_c' and OCR for a clay material empirical correlations between s_u^C/σ'_v, OCR and I_p (Andresen et al., 1979), as presented in Lunne et al. (1997) have been used.

Figure A2.10 presents the overconsolidation (OCR) and include an assessment of OCR from the CPTUs using the correlations from Andresen et al. (1979), as described above. First, s_u^C is computed as described in A2.5.2 below, then s_u^C/p_0' and Ip is used to estimated OCR.

It is also possible to obtain OCR from the following formula:

$$OCR = k \cdot [(q_t - \sigma_{v0})/\sigma_{v0}'] \qquad \text{see also (Lunne et al. (1997):}$$

The profile shows a significant range in OCR in the upper 2 m below seafloor. From 2 to 6 m below seafloor, the OCR decreases from around 2 to about 1.

A2.5 Static soil strength parameters

A2.5.1 General

The undrained shear strength has been measured by various laboratory test methods including index tests in the offshore and onshore laboratories, consolidated undrained triaxial tests and consolidated constant volume DSS tests in the onshore laboratory. The methods applied and results obtained are described in Part B. In addition, CPTUs have been performed and interpreted in terms of s_u^C by a cone factor N_{kt} as discussed below.

All measured values of undrained shear strength have been summarised on the borehole logs as presented in Part B1.

A2.5.2 Interpretation of undrained shear strength, total stresses

The conventional way of calibrating the N_{kt} factors is to compare the undrained shear strength value from a triaxial compression test, s_u^C, with the corrected cone resistance, q_t, from nearby CPTUs at the same depth. Figure A2.11 presents corrected cone resistance, q_t, versus depth.

Both in 2006 and in 2013 some triaxial compression tests were performed. In 2006 an N_{kt}-factor of 15 was recommended. The CPTU results have been correlated to the undrained shear strength found from the static triaxial compression tests, s_u^C, using the following formula:

$$s_u^C = q_{net}/N_{kt}$$

where $q_{net} = (q_t - \sigma_{v0})$
q_t = corrected cone resistance
σ_{v0} = total vertical stress ($=p_0$)

The resulting plot of N_{kt} values with depth is presented in Figure A2.12. A representative N_{kt}-value of 12 is judged representative based on data from both soil investigations. Figure A2.13 shows the results from the triaxial tests (CAUC) and the direct simple shear tests (DSS) presented together with relevant CPTU data interpreted using an $N_{kt} = 12$.

All the CPTUs performed in 2006 and 2013 are shown in Figure A2.14 were they have been interpreted using an $N_{kt} = 12$. Representative high and low profile have been included based on all CPTU results.

Undrained shear strength anisotropy in terms of s_u^{DSS}/s_u^C has been evaluated based on the DSS and the CAUC tests performed in 2013. The representative anisotropy ratio based on the average for these tests is $s_u^{DSS}/s_u^C = 0.7$.

A2.5.3 Interpretation of static triaxial tests, effective stresses

Figure A2.15 presents the effective stress paths from the 3 triaxial tests performed in 2013.

The compression tests demonstrate contractive behaviour, typical for modest overconsolidated clays. The failure envelope defined by the effective stress paths can be represented by two parameters, the effective stress friction angle ϕ' and the attraction intercept, a. The intercept, a, is related to the internationally used cohesion, c, as:

$$c = a \cdot \tan \phi'$$

One common failure line was defined as presented in Figure A2.15.The following effective stress strength parameters is considered representative:

$\varphi_u' = 33.4^o$, a = 5 kPa (in compression)

For comparison, the effective stress strength parameters recommended in 2006 (NGI, 2006) were:

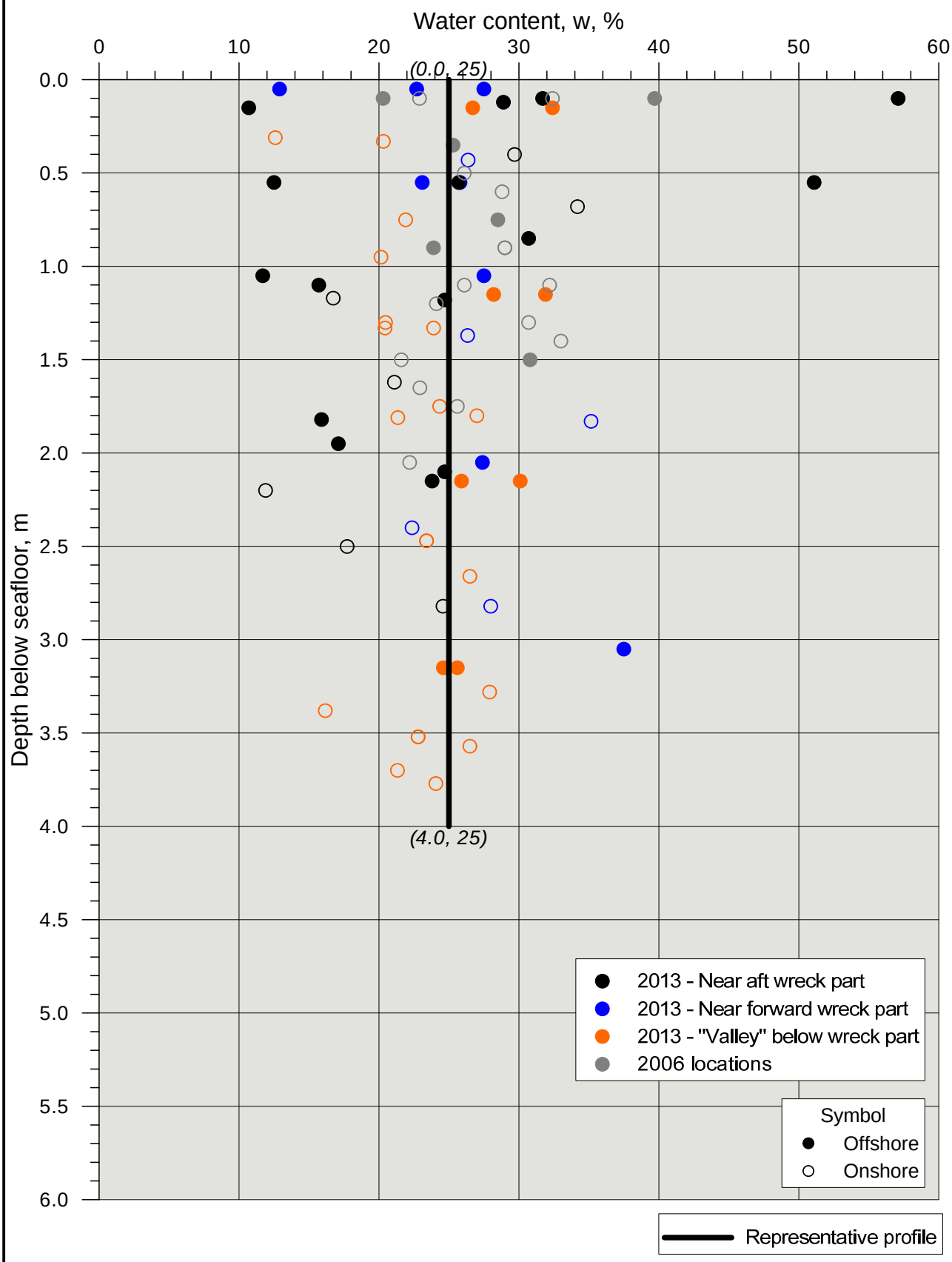
$\varphi_u' = 31.0^o$, a = 3.3 kPa (in compression)

The difference is believed to be a result of different testing depths between the tests done in 2006 compared to the tests done in 2013.

A2.6 Comments on quality of samples

Based on results of oedometer and triaxial tests carried out at NGI's laboratory 4 samples have been evaluated to be of "good to fair" quality and one sample is evaluated to be of "poor" quality. The evaluation is based on the measured volume change when consolidating the samples back to the best estimate of in situ stresses as discussed in Part B.

The poorer sample quality comprises an uncertainty, which is considered in the evaluation of the test results, i.e. the results may be given less weight as they are believed to be more influenced by sample disturbance.



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U-864 - 2013 SOIL SURVEY

Water content versus depth.

All locations (performed in 2006 and in 2013).

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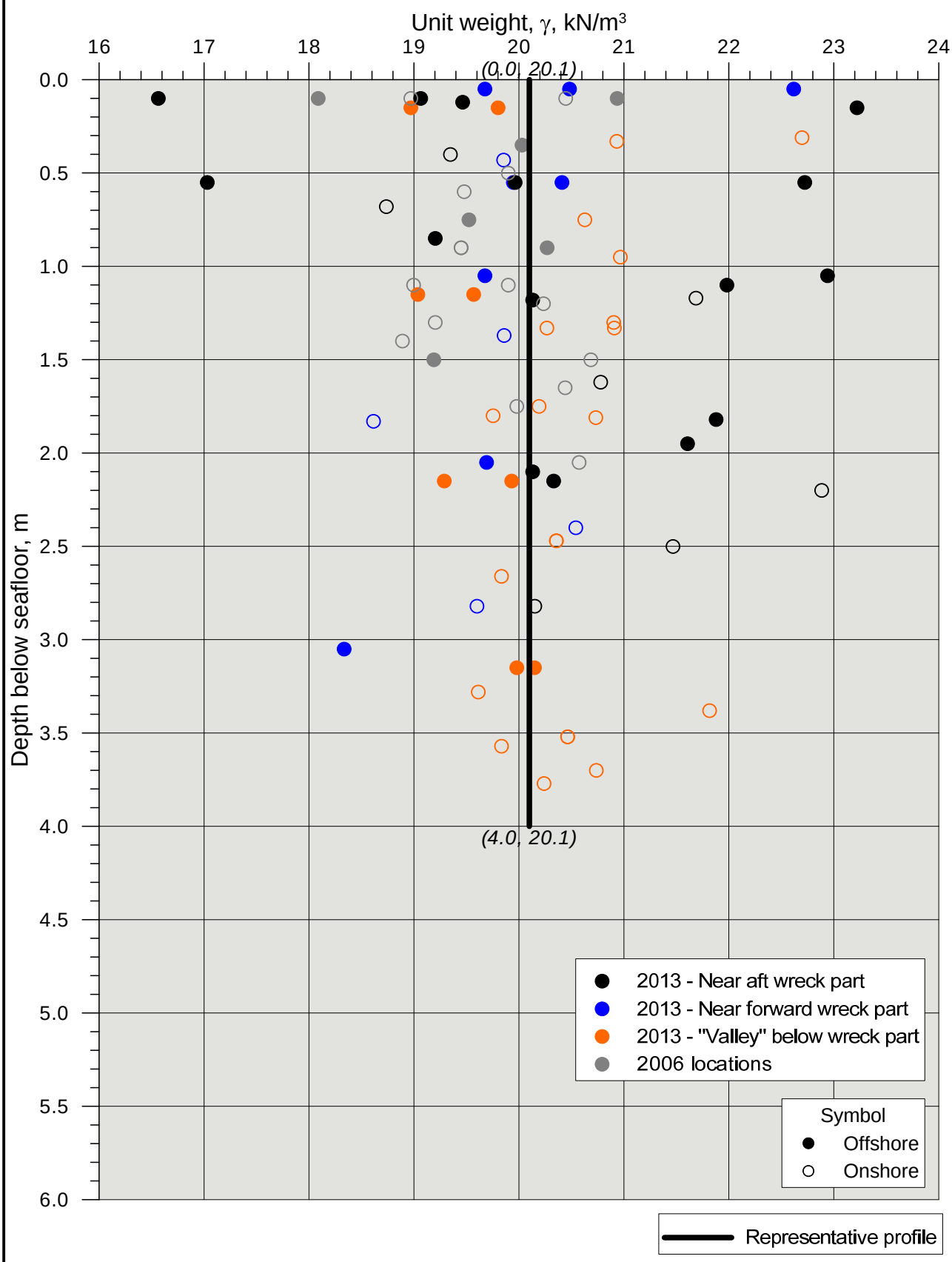

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U-864 - 2013 SOIL SURVEY

Unit weight versus depth (based on water content).

All locations (performed in 2006 and in 2013).

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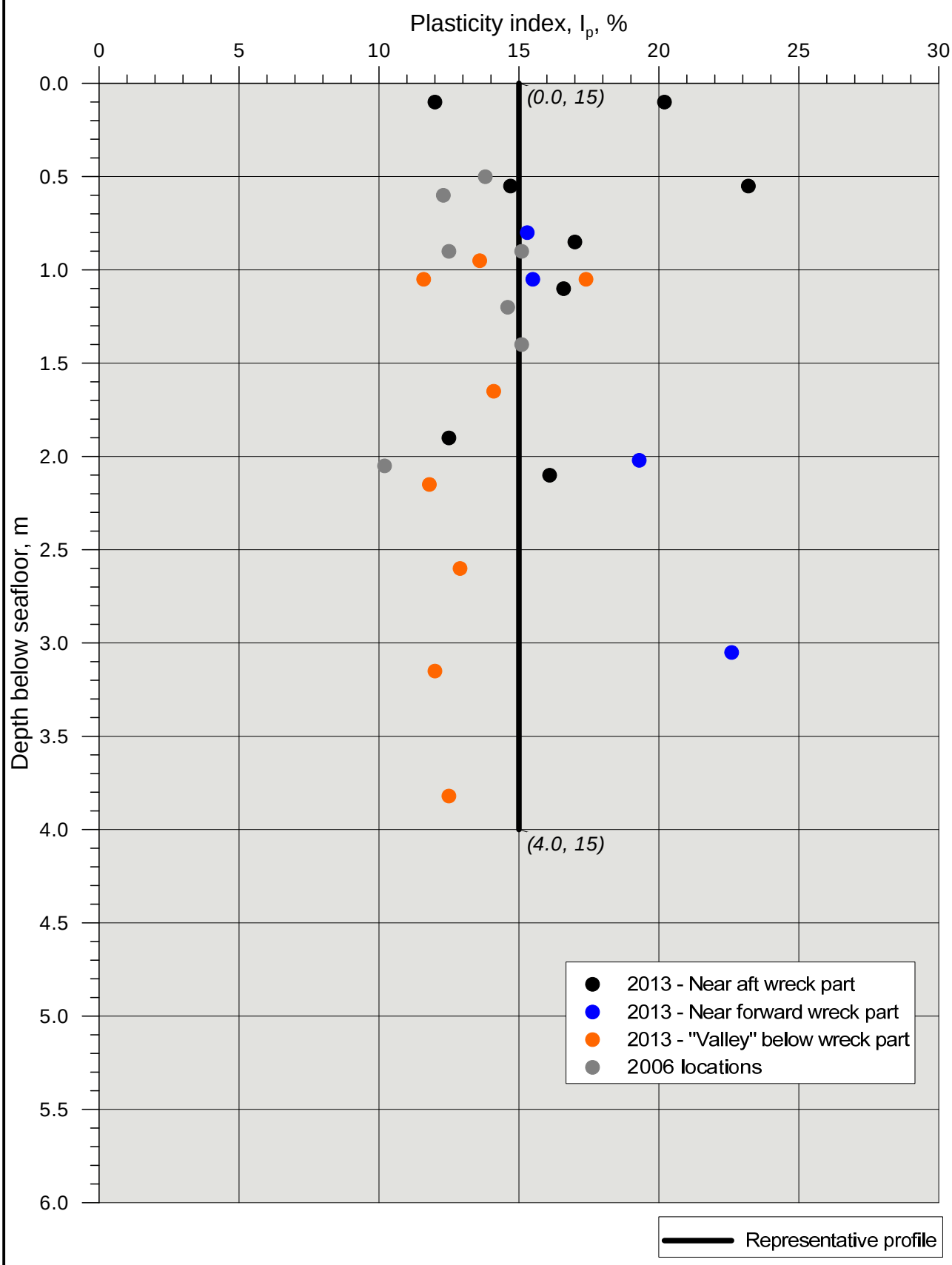

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Date 2013-03-20

Plasticity index versus depth.

All locations (performed in 2006 and in 2013).

Figure No. A2.3

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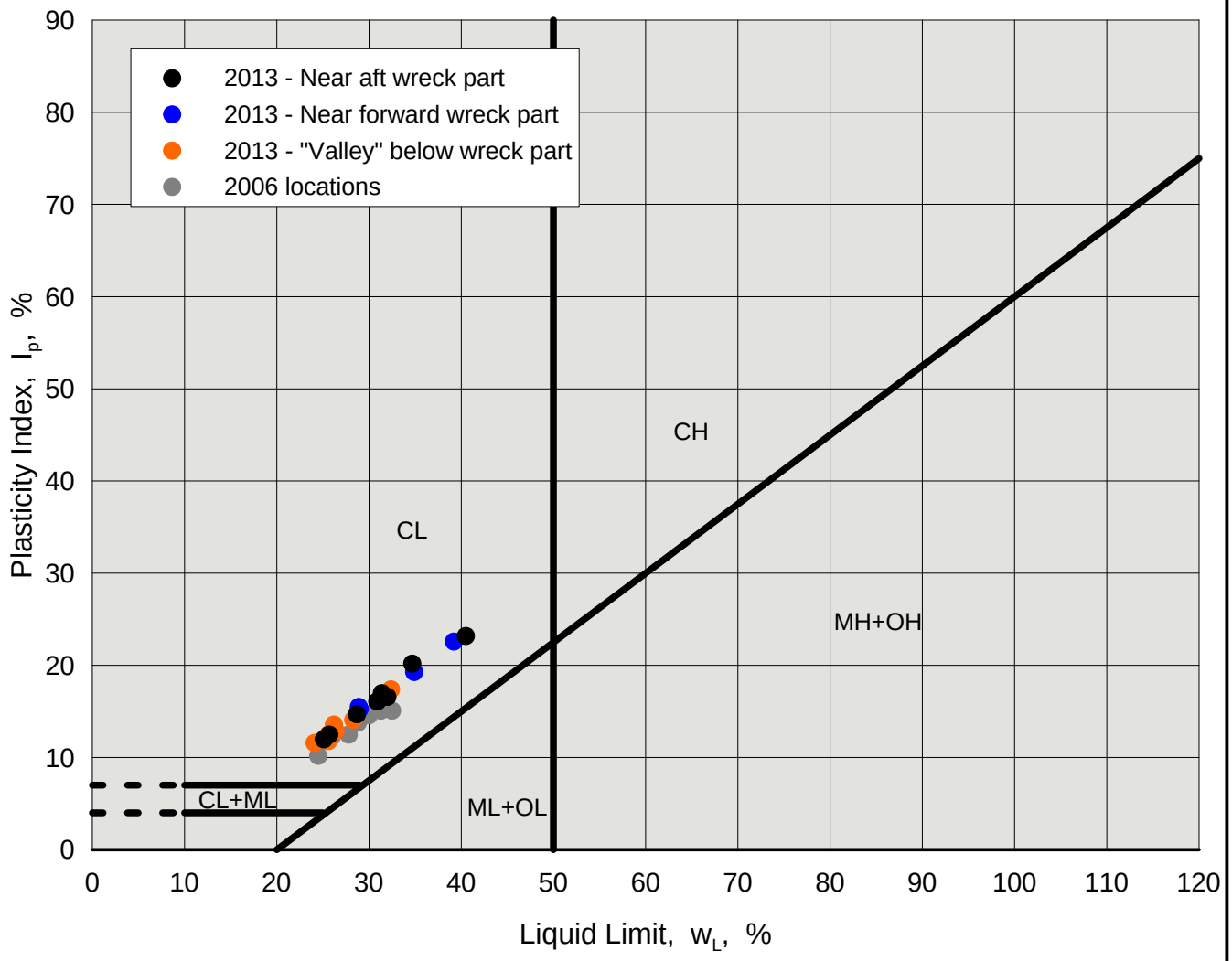

UNIFIED SOIL CLASSIFICATION

ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands
MH	Inorganic silts, micaceous fine sands or silts, elastic silts
CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
CH	Inorganic clays of high plasticity, fat clays
OL	Organic silts and organic silty clays of low plasticity
OH	Organic clays of medium to high plasticity
PT	Peat, muck and other highly organic soils

U-864 - 2013 SOIL SURVEY

Plasticity chart

Unified soil classfication (from ASTM D2487)

All locations (performed in 2006 and in 2013).

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Date 2013-03-20

Figure No. A2.4

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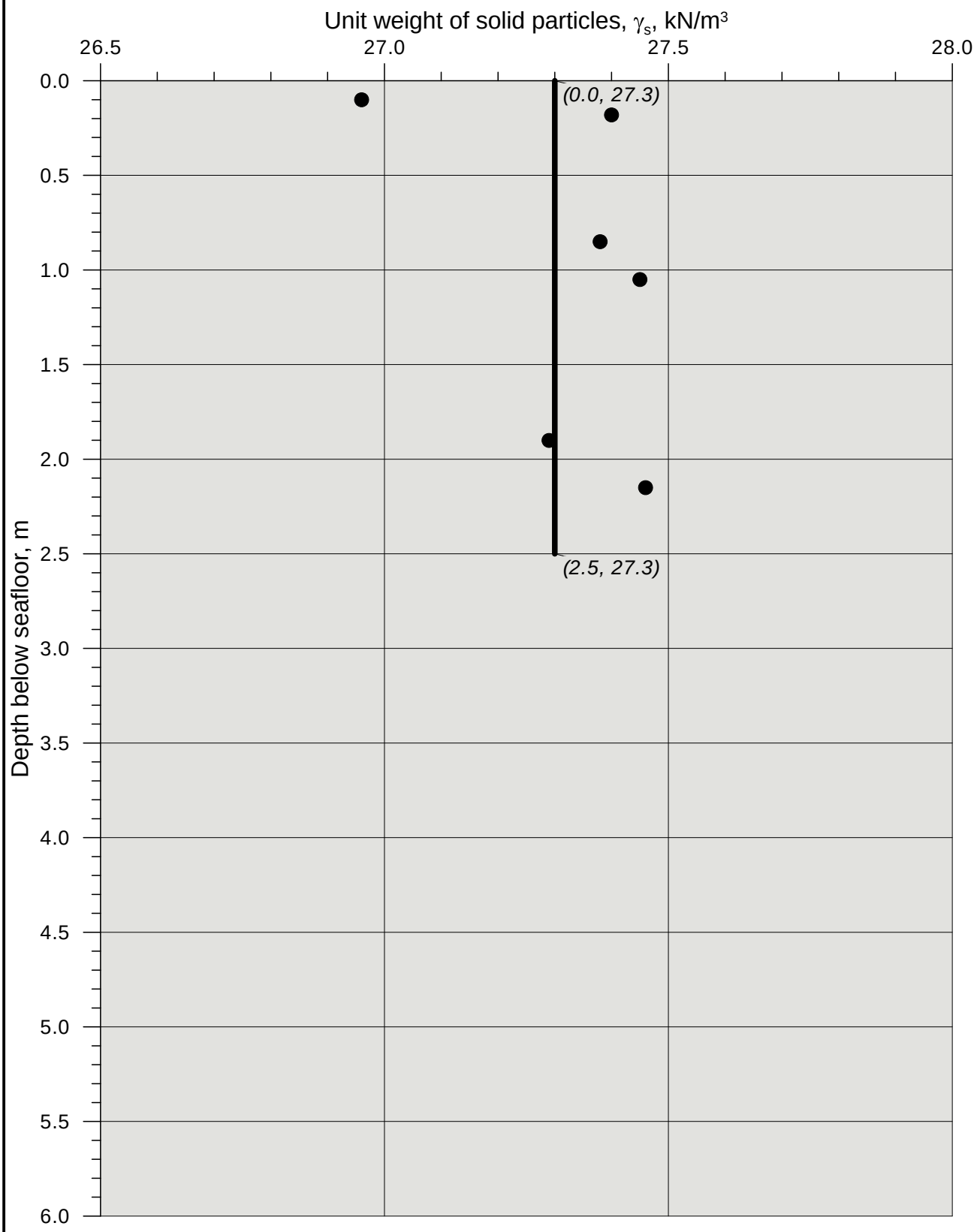

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Unit weight of solid particles versus depth.

All locations (performed in 2013).

Figure No. A2.5

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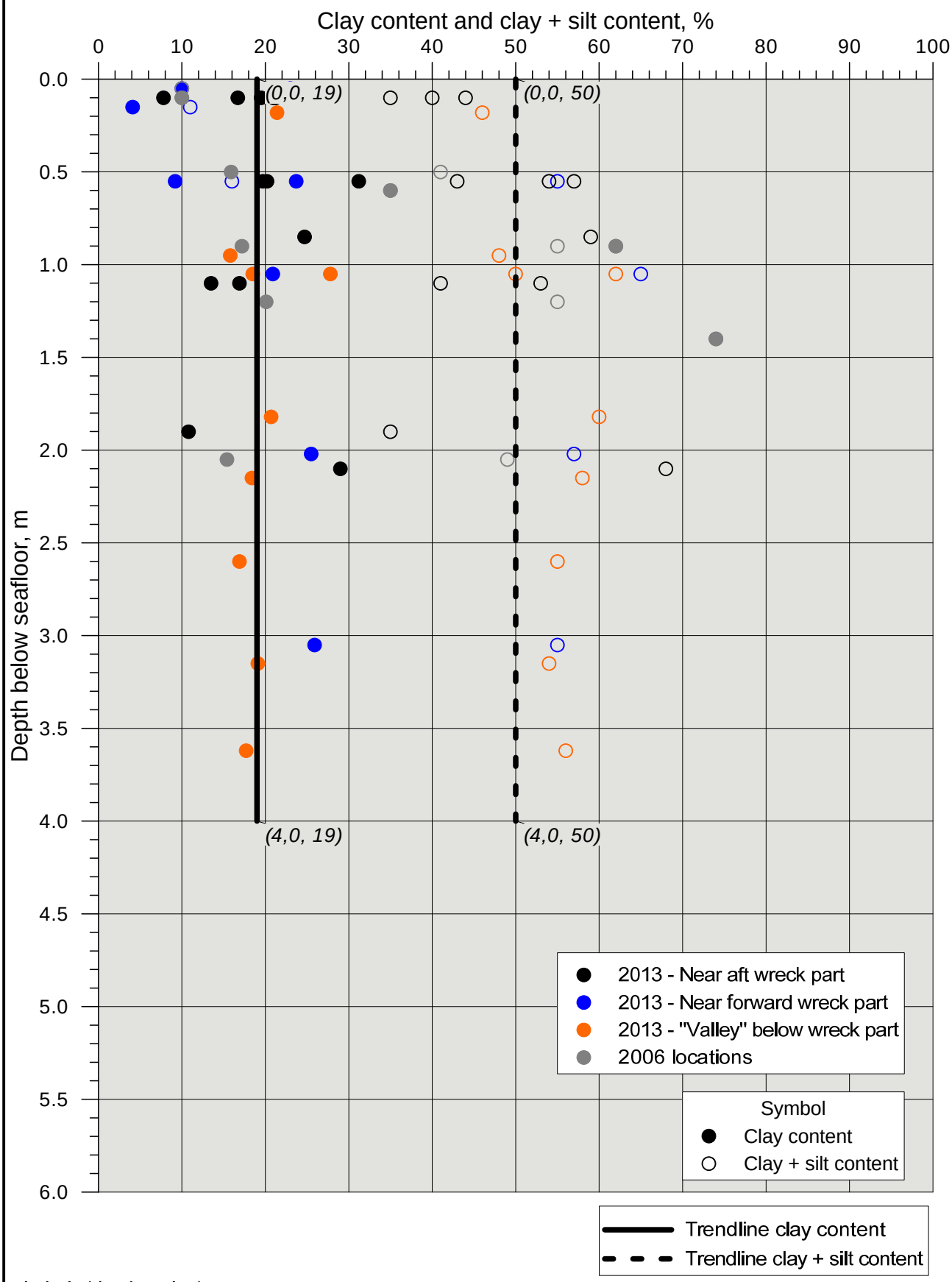

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Date 2013-03-20

Clay content and clay + silt content versus depth.

All locations (performed in 2006 and in 2013).

Figure No. A2.6

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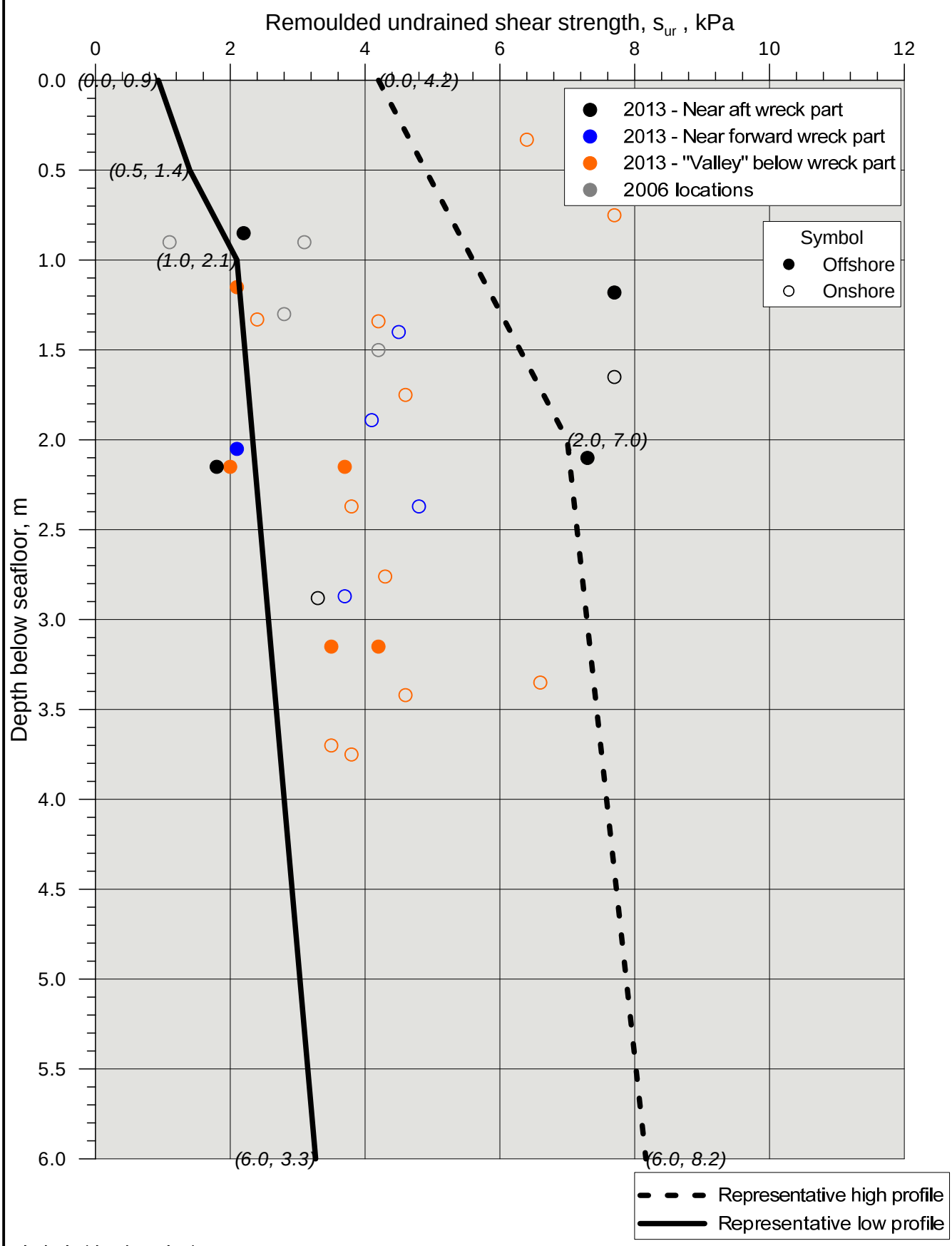

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U-864 - 2013 SOIL SURVEY

Remoulded undrained shear strength versus depth.

All locations (performed in 2006 and in 2013).

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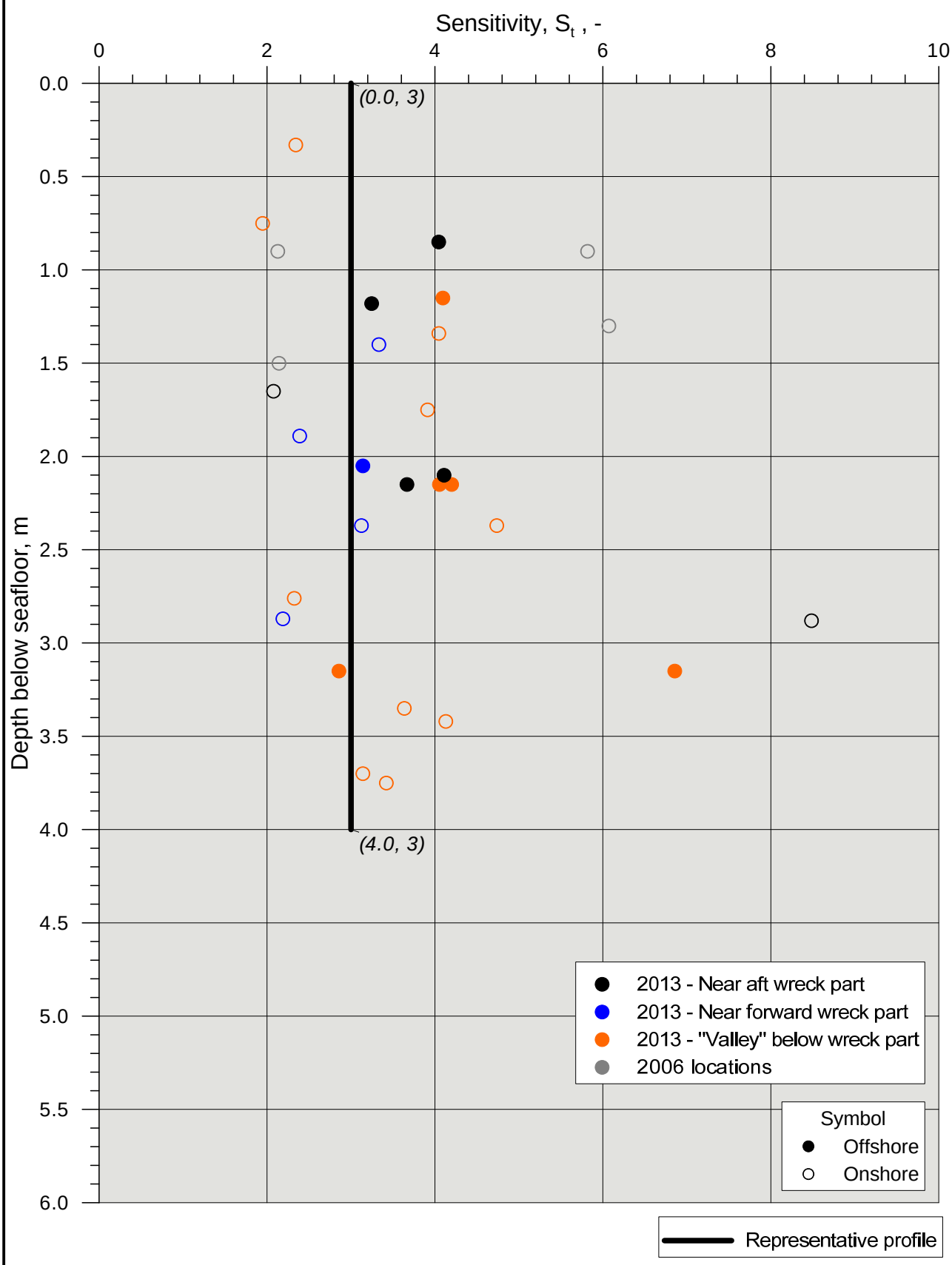

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Document No. 20120738-01-R

Date 2013-03-20

Sensitivity versus depth.

All locations (performed in 2006 and in 2013).

Figure No. A2.8

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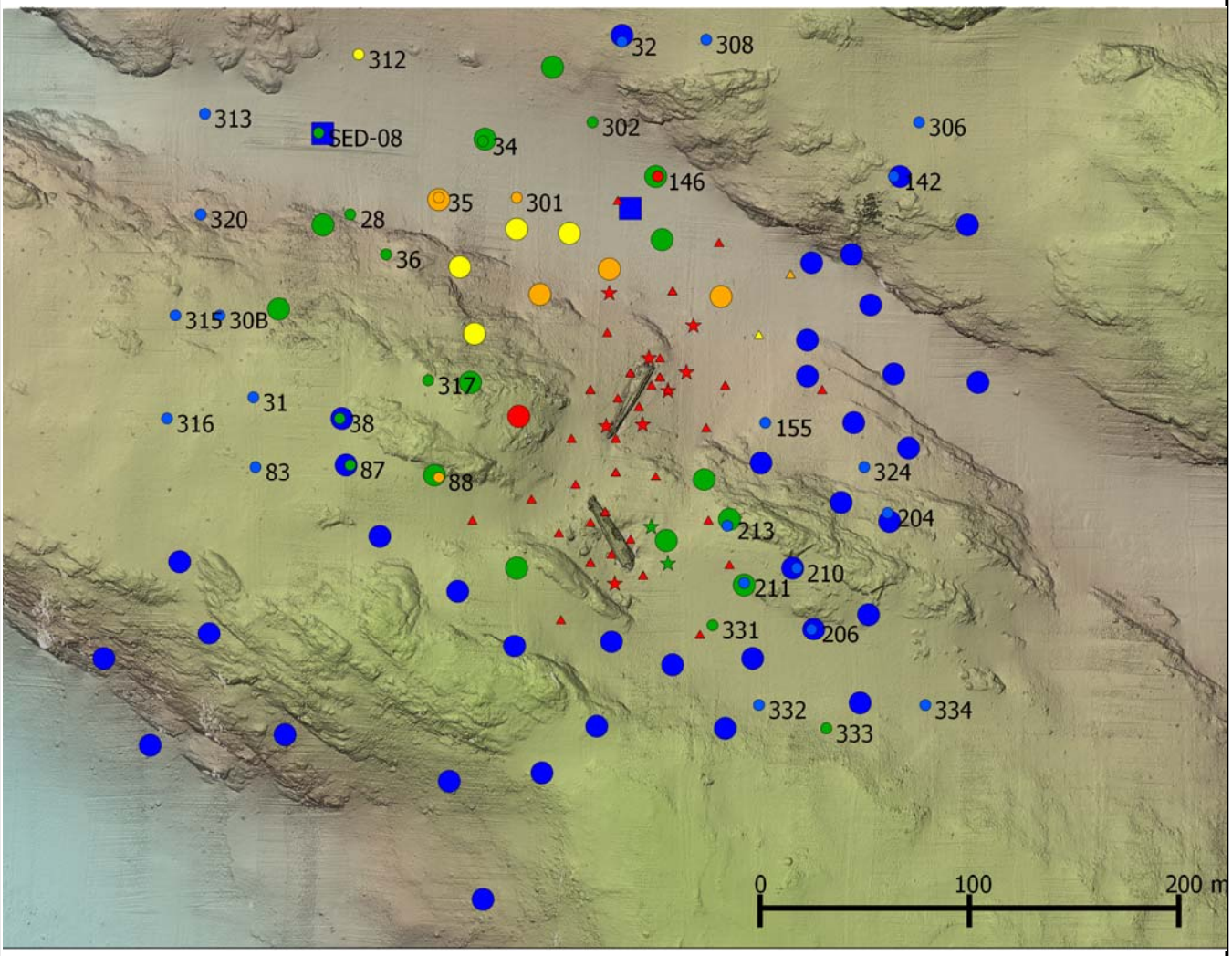
	Class I Background	Class II Good	Class III Moderately polluted	Class IV Bad	Class V Very bad
Mercury (mg/kg) dry weight	<0.15	0.15 – 0.63	0.63 – 0.86	0.86 – 1.6	>1.6

The results are classified according to the classification system of the Norwegian Climate and Pollution Agency for classification of environmental quality in fjords and coastal water

NOTE: This figure is made by NIVA



Hg Classification (mg/kg dw)

- <0.15
- 0.15-0.629
- 0.63-0.86
- 0.86-1.59
- >1.6

Sample year

- 2013
- 2006
- 2005 October
- 2005 April
- 2003

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NIVA: Mercury sample locations
(performed in 2003, 2005, 2006 and in 2013).

Document No. 20120738-01-R

Date 2013-04-17

Figure No. A2.9

Drawn by ES

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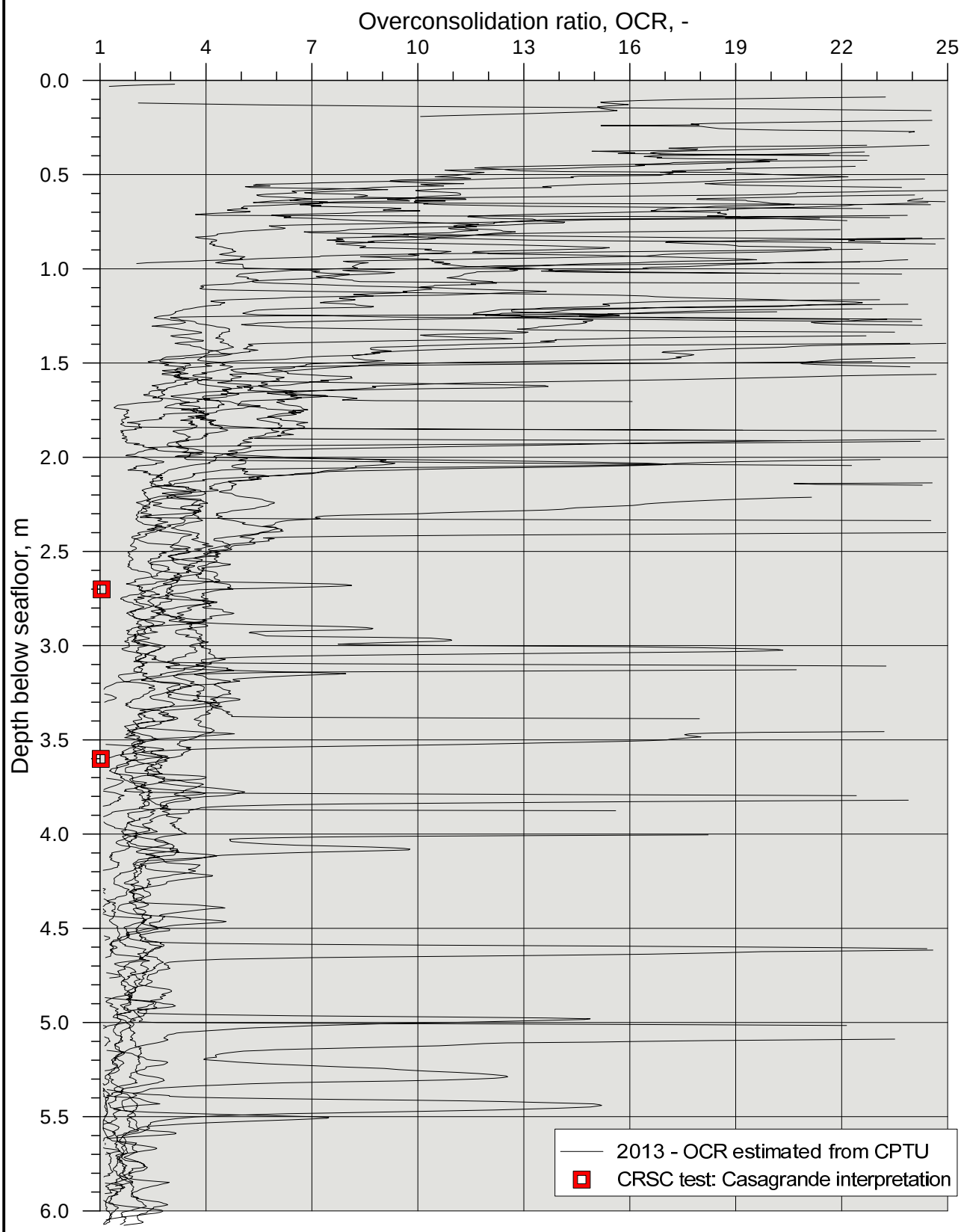

NOTE:
q_t is used for interpretation of CPTU using
γ=20 kN/m3, N_{kt} = 12 and I_p = 15%.
OCR in clay from CPTU using Andresen et al. (1979).

Label: *(depth, value)*

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Remoulded undrained shear strength versus depth.

All locations (performed in 2013).

Document No.	20120738-01-R
Date	2013-03-21
Figure No.	A2.10
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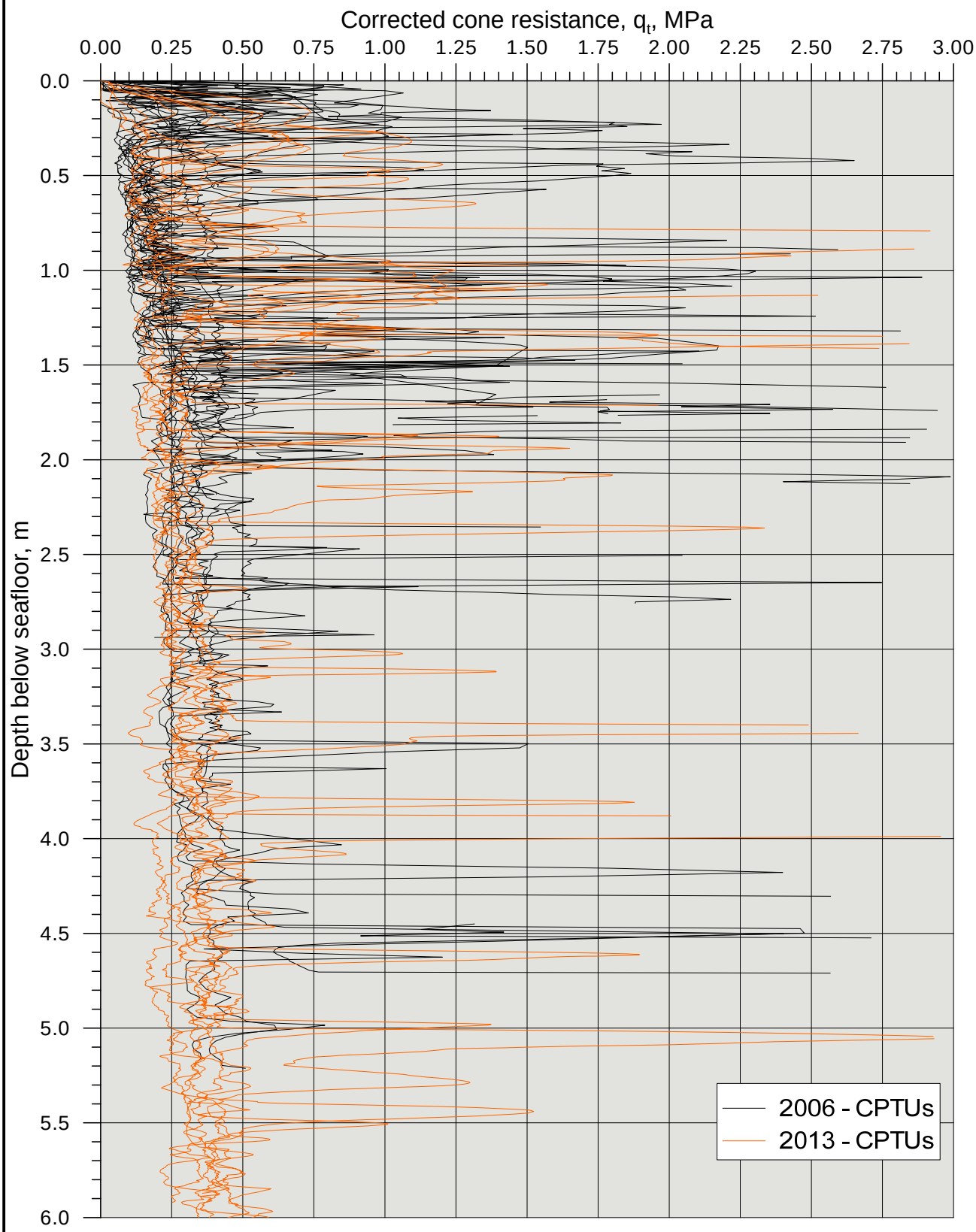

U-864 - 2013 SOIL SURVEY

Corrected cone resistance versus depth.

All locations (performed in 2006 and in 2013).

Document No.	20120738-01-R
Date	2013-03-20
Figure No.	A2.11
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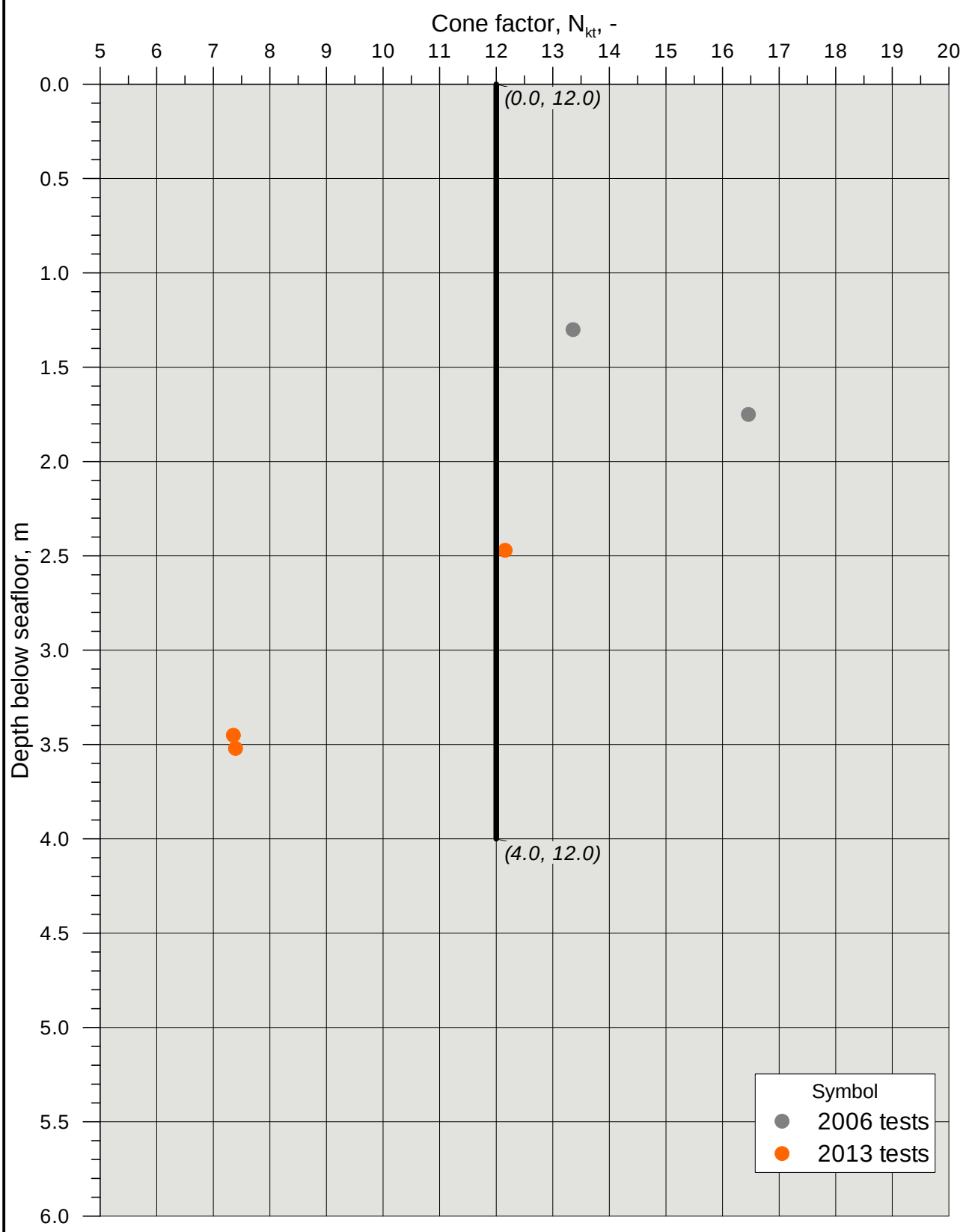

Label: *(depth, value)*

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N_{kt} versus depth.

All CAUC tests and relevant CPTU locations (performed in 2006 and in 2013).

Document No.	20120738-01-R
Date	2013-03-20
Figure No.	A2.12
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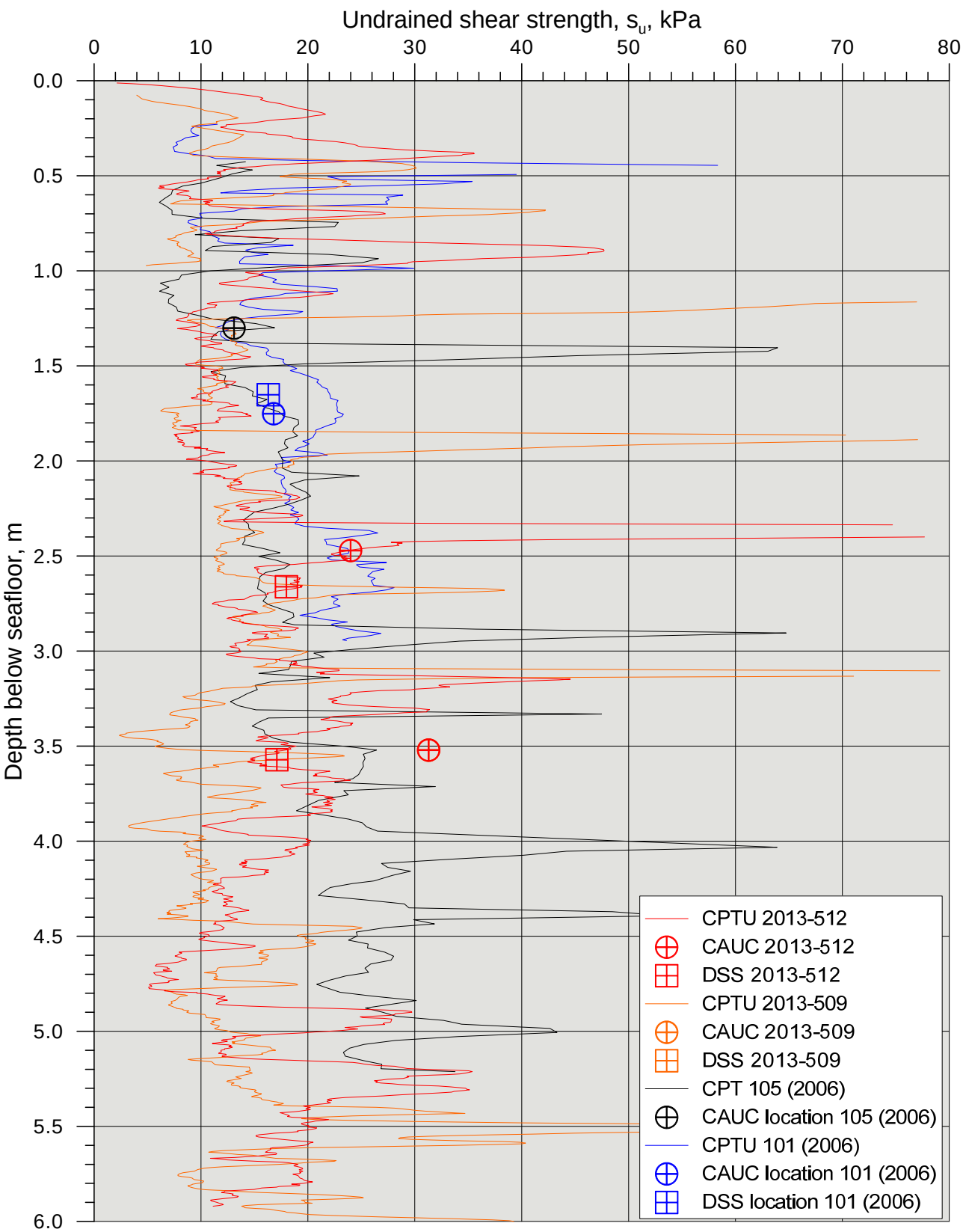

NOTE:
q_t is used for interpretation of CPTU using γ=20 kN/m³ and N_{kt}=12

Label: *(depth, value)*

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Document No.
20120738-01-R

Date
2013-04-16

Figure No.
A2.13

Drawn by
ES

Undrained shear strength versus depth.

All locations were advanced testing and CPTU are performed (in 2006 and in 2013).

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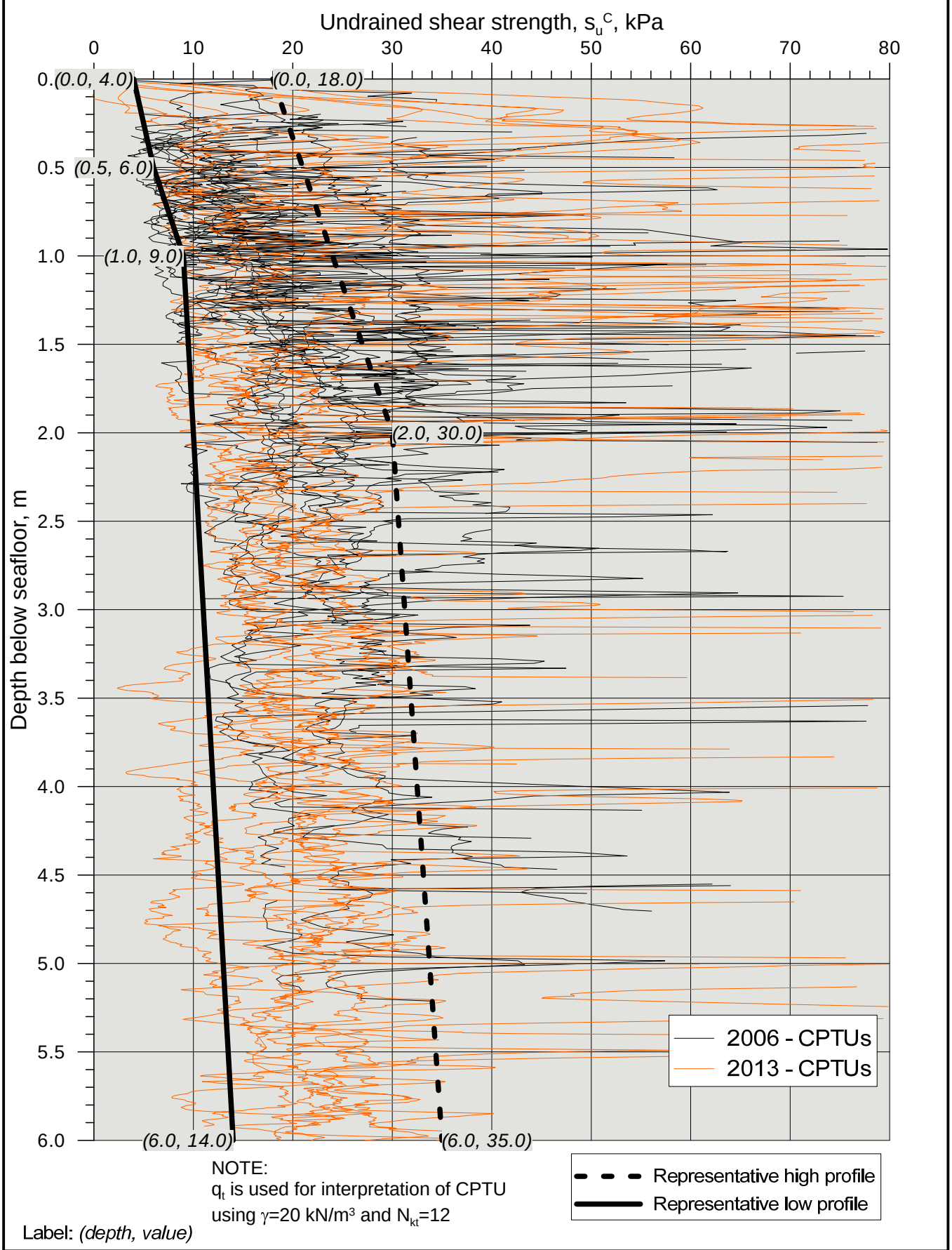

NOTE:
q_t is used for interpretation of CPTU using γ=20 kN/m³ and N_{kt}=12

Label: *(depth, value)*

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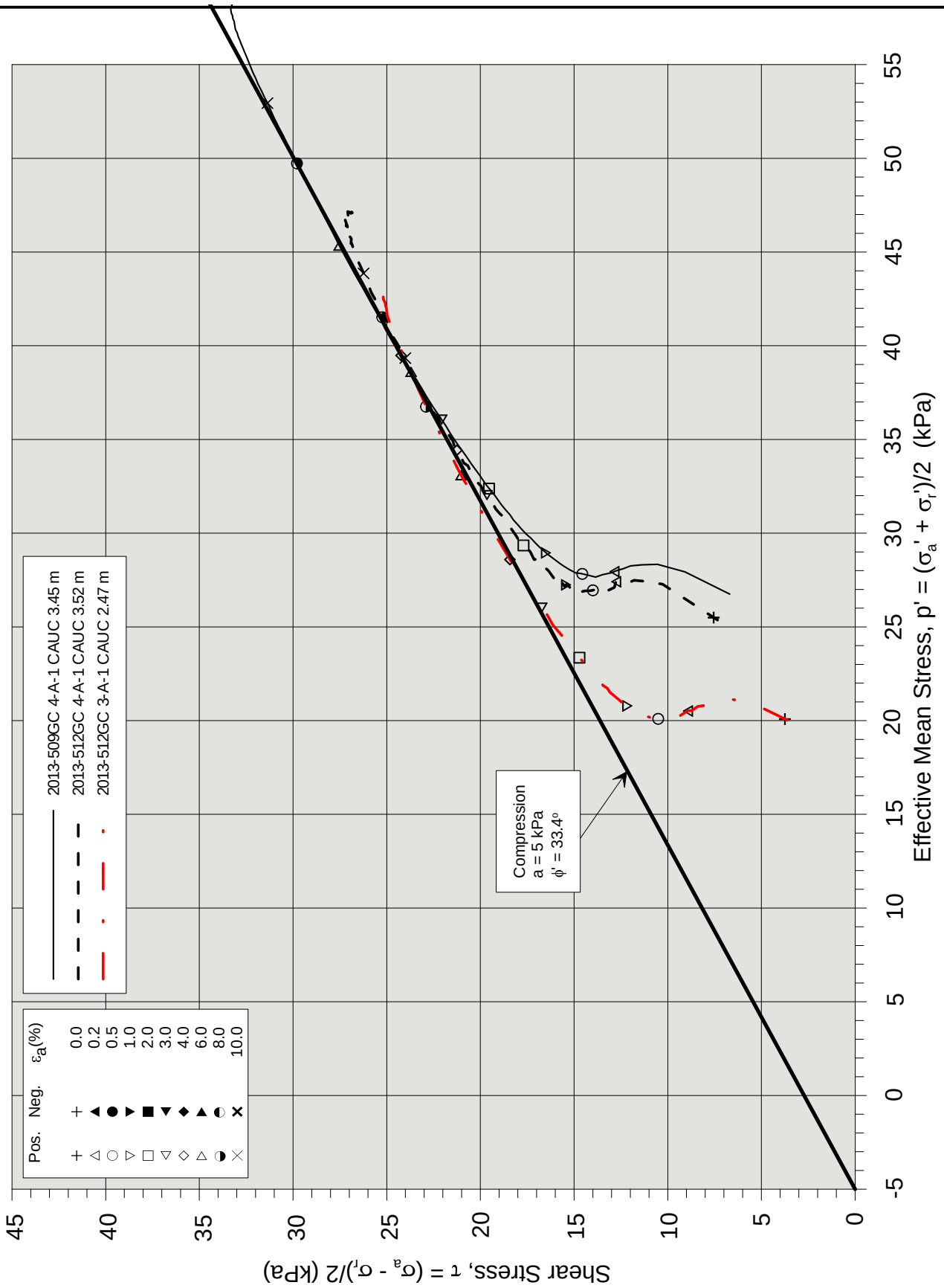
U-864 - 2013 SOIL SURVEY	Document No. 20120738-01-R
Corrected cone resistance versus depth. All locations (performed in 2006 and in 2013).	Date 2013-03-21
	Figure No. A2.14
	Drawn by ES
	NGI



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U-864 - 2013 SOIL SURVEY	Document No. 20120738-01-R
CAU triaxial stress paths	Date 2013-03-20
	Figure No. A2.15
	Drawn by ES
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Part A3 - List of Symbols and Classification System used

Contents

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A3.1 List of symbols

ENGLISH

a	=	attraction (= c' cot ϕ', in terms of effective stress)
A	=	pore pressure parameter
A	=	area
A_b	=	skirt base area
A_c	=	cross-sectional area of cone.
A_w	=	skirt wall area
B	=	Skempton's pore pressure parameter
B_q	=	pore pressure parameter
c'	=	cohesion (in terms of effective stress)
c	=	cohesion (in terms of total stress)
c_a	=	rate of secondary compression
c_h	=	horizontal coefficient of consolidation
c_v	=	vertical coefficient of consolidation
c_u=s_u	=	undrained shear strength
D	=	diameter
D	=	damping ratio
D	=	dilatancy parameter
D_r	=	relative density ($D_r = \frac{e_{max} - e}{e_{max} - e_{min}} \cdot 100\%$)
D_{10}	=	the size such that 10, 50, 60 or 90 % (by weight)
D_{50}		of the sample consists of particles having a smaller
D_{60}		nominal diameter
D_{90}		
e	=	void ratio
e_{max}	=	maximum void ratio
e_{min}	=	minimum void ratio
E	=	Young's modulus
E_u	=	undrained Young's modulus
f	=	unit skin friction resistance
f	=	degree of mobilization
f_s	=	unit sleeve friction resistance
F	=	pile penetration factor
F	=	factor of safety
F_p	=	factor calculating friction resistance to driving
F_L	=	pile penetration factor
FR	=	friction ratio (= $f_s/q_c \cdot 100$ %)
g	=	acceleration due to gravity
G	=	shear modulus
G	=	specific weight
G_{max}	=	maximum shear modulus, shear stiffness
i	=	water pressure gradient
I_p	=	plasticity index
J	=	factor to estimate reduced strength zone
K_d	=	horizontal stress index from dilatometer

k	=	coefficient of permeability
k	=	correction factor; ratio of the pore pressure measured immediately behind the cone neck and the measured pore pressure at the tip
K_{rac}'	=	coefficient of earth pressure at rest (effective), remoulded and reconsolidated soil
K_c'	=	$\sigma_{hc}'/\sigma_{vc}'$, ratio between horizontal and vertical consolidation stress after pile installation
K_o	=	coefficient of earth pressure at rest (effective)
L	=	length
L/D	=	pile length/pile diameter
LI	=	liquidity index = $(w-w_p)/(w_L-w_p)$
m	=	dimensionless deformation modulus number
m_v	=	coefficient of volume change
M	=	constrained deformation modulus
M_{av}	=	average constrained deformation modulus
M_o	=	reference constrained modulus from CPT results
n	=	porosity
n_{max}	=	maximum porosity
n_{min}	=	minimum porosity
N	=	No. of blows on the SPT
N	=	number of cycles
$N_{\Delta u}$	=	pore pressure factor
N_c	=	bearing capacity factors
N_f, N_q, N_q^*, N_{fq}, N_p, N_k, N_{ke}, N_{kt}	=	cone factors
N_m	=	cone resistance number
N_u	=	pore pressure factor
p_o'	=	effective overburden pressure
p_o	=	total overburden pressure
p_c'	=	effective preconsolidation pressure
Δp	=	increase in effective vertical stress
p_r'	=	reference pressure for modulus number concept
p-y	=	curves representing lateral soil reaction versus relative displacement between pile and soil
q_c	=	measured point resistance
$q_c(z)$	=	cone resistance at depth z
q_E	=	effective cone resistance
q_f	=	unit skirt wall friction
q_t	=	corrected point resistance
q_n	=	net point resistance (= $q_t - p_o$)
q_o	=	unit end bearing
q_T	=	total cone resistance
q_{tip}	=	unit skirt tip resistance

q_w	=	unit wall friction
Q	=	estimated pile bearing capacity
Q_s	=	shaft friction capacity
Q_e	=	end bearing capacity
Q_{eo}	=	end bearing capacity. Total cross-section
Q_{ew}	=	end bearing capacity. Wall cross-section
Q_{si}	=	shaft friction capacity between soil and internal pipe wall
r_o	=	radius of cavity
r_s	=	resistance number
R_f	=	FR= friction ratio (= $f_s/q_c \cdot 100$ %)
R_i	=	initial radius of spherical cavity
R_p	=	radius of plastic zone around spherical cavity
R_u	=	ultimate radius of spherical cavity
s_u	=	undrained shear strength
SL	=	shear stress level
Sl_{cy}	=	cyclic shear stress level
S_r	=	degree of saturation
s_{uA}	=	s_u active
s_{uD}	=	s_u direct
s_{uP}	=	s_u passive
s_u^C	=	s_u from triaxial compression test
s_u^{DSS}	=	s_u from direct simple shear test
s_u^E	=	s_u from triaxial extension test
s_{ur}	=	Remoulded shear strength
S_t	=	sensitivity
SRD	=	static resistance during driving
t	=	time
t	=	pile/soil shear transfer
t-z	=	curves representing mobilization of friction with relative displacement between pile and soil
T	=	time factor
T	=	reference time
T	=	load period
UW	=	unit weight
u	=	pore water pressure
u_B	=	excess pore water pressure
Δu	=	excess pore water pressure
v	=	rate of flow
WC	=	water content
w	=	water content
w_i	=	initial water content
w_f	=	final water content
w_p	=	plastic limit
w_L	=	liquid limit
z	=	depth
z	=	vertical displacement of pile element

GREEK

α	=	angle
α	=	"constant"
α	=	coefficient converting undrained shear strength to wall friction q_w or unit skin friction f
α	=	area ratio (CPT)
α_m	=	factor converting undrained shear strength to E_u
ß	=	angle
ß	=	"constant"
ß	=	correction factor
γ'	=	effective unit weight
γ_d	=	dry unit weight
γ_s	=	unit weight of solid particles
γ_w	=	unit weight of water
γ	=	shear strain
γ_a	=	average shear strain
γ_{cy}	=	cyclic shear strain
γ_f	=	shear strain at failure
γ_h	=	horizontal shear strain
γ_N	=	cyclic shear strain after N cycles
δ	=	settlement
δ	=	displacement
δ	=	rate of settlement
Δ	=	change, e.g. $\Delta\sigma$
ε	=	normal strain
ε_a	=	axial strain
ε_{ac}	=	axial consolidation strain
ε_{acy}	=	axial cyclic strain
ε_{df}	=	axial strain at failure
ε_{ap}	=	permanent axial strain
ε_{cy}	=	cyclic strain
ε_h	=	horizontal strain
ε_N	=	axial strain after N cycles
ε_v	=	vertical strain
ε_{vol}	=	volumetric strain
λ	=	rate factor
λ	=	skin friction factor
υ	=	Poisson's ratio
υ	=	coefficient of variation
ρ	=	specific resistivity
ρ	=	density
ρ	=	mobilized total friction angle
ρ'	=	mobilized effective friction angle
ρ_s	=	density of solid particles
Σ	=	sum
σ,σ'	=	normal stress (total, effective)
σ_1,σ_1'	=	major principal stress

σ_2,σ_2'	=	intermediate principal stress
σ_3,σ_3'	=	minor principal stress
σ_a	=	reference stress (atmospheric pressure) = 100 kPa
σ_a,σ_a'	=	axial stress (total, effective)
σ_{ac},σ_{ac}'	=	axial consolidation stress
$\sigma_{acy},\sigma_{acy}'$	=	axial cyclic stress
σ_c,σ_c'	=	consolidation stress
σ_h,σ_h'	=	horizontal stress
$\sigma_{oct},\sigma_{oct}'$	=	octahedral stress
σ_r,σ_r'	=	radial stress
σ_{rc},σ_{rc}'	=	radial consolidation stress
σ_v,σ_v'	=	vertical stress
τ	=	shear stress
τ_a	=	average shear stress
τ_{cy}	=	cyclic shear stress
τ_f	=	undrained shear strength
τ_h	=	horizontal shear stress
τ_{ha}	=	average cyclic horizontal shear stress
τ_{hcy}	=	cyclic horizontal shear stress
τ_{hf}	=	horizontal shear stress at failure
τ_{hfcy}	=	horizontal shear stress at failure after cycling
Φ	=	total friction angle
Φ'	=	effective friction angle
Φ_{mob}'	=	mobilized effective friction angle
Φ_d	=	drained friction angle
Φ_u	=	undrained friction angle

A3.2 Abbreviations

ADP	=	Active, direct and passive
ASTM	=	American Standard for Testing and Materials
CAD	=	Consolidated Anisotropic Drained
CAU	=	Consolidated Anisotropic Undrained
CCV	=	Consolidated Constant Volume
CID	=	Consolidated Isotropic Drained
CIU	=	Consolidated Isotropic Undrained
CPT	=	Cone Penetration Test
CPTU	=	Cone Penetration Test
PCPT	=	Cone Penetration Test
CRSC	=	Constant Rate of Strain Consolidation
DSS	=	Direct Simple Shear
ECSMFE	=	European Conference on Soil Mechanics and Foundation Engineering
ESOPT	=	European Symposium on Penetration Testing
GWT	=	Ground Water Table
INCR	=	Incremental Loading
ICSMFE	=	International Conference of Soil Mechanics and Foundation Engineering
JGED	=	Journal of the Geotechnical Engineering Division
NC	=	Normally Consolidated
NPD	=	Norwegian Petroleum Directorate
OC	=	Overconsolidated
OCR	=	Overconsolidation Ratio
OED	=	Consolidation Test
SPT	=	Standard Penetration Test
UCT	=	Unconfined Compression Test
UU	=	Unconsolidated Undrained

A3.3 Classification systems (NGIs standard practice)

A3.3.1 Shear strength of cohesive soils

The terms used to describe specific shear strength ranges are:

Term	s_u (kPa)
Very soft	< 12.5
Soft	12.5 – 25
Medium	25 – 50
Stiff	50 – 100
Very stiff	100 – 200
Hard	200 – 400
Very hard	> 400

A3.3.2 Density of sand

The density of sand is described to be

Term	D_r (%)
Very loose	< 15
Loose	15 – 35
Medium dense	35 – 65
Dense	65 – 85
Very dense	> 85

A3.3.3 Terms characterizing soil structure

Term	Description
PARTING	horizontal inclusion of different soil type less than 3mm thick
SEAM(S)	horizontal inclusion of different soil type 3mm to 75 mm thick
LAYER	horizontal inclusion of different soil type greater than 75mm thick
POCKET(S)	inclusion of different soil type that is smaller than the diameter of the soil sample
BLOCKY	containing discrete blocks of soil set in a non-structured matrix
PSEUDO-BLOCKY	block structures formed by intersecting fissures
PLATY	containing discrete platelets with one dimension (the vertical) limited and less than the other two
SLICKENSIDED	having inclined planes of weakness that are slick and glossy in appearance
FISSURED	containing small scale discontinuities in soil fabric
LAMINATED	composed of thin seams or partings of varying colour and texture
FOLIATED	containing small scale laminar structure with no colour or textural variations
INTERLAYERED	composed of alternate layers of different soil types
WELL-GRADED	having wide range in grain sizes and substantial amounts of all intermediate particle sizes
POORLY-GRADED	predominantly of one grain size, or having a range of sizes with some intermediate size missing

A3.3.4 Grain size distribution

The grain size distribution is presented as percentages of the various grain sizes present in the soil as determined by sieving and sedimentation. The terms used to describe grain sizes are:

Cobbles	60 - 200 mm
Gravel	2 - 60 mm
Coarse gravel	20 - 60 mm
Medium gravel	6 - 20 mm
Fine gravel	2 - 6 mm
Sand	0.06 - 2 mm
Coarse sand	0.6 - 2 mm
Medium sand	0.2 - 0.6 mm
Fine sand	0.06 - 0.2 mm
Silt	0.002 - 0.06 mm
Coarse silt	0 02 - 0.06 mm
Medium silt	0.006 - 0.02 mm
Fine silt	0.002 - 0.006 mm
Clay	< 0.002 mm

A3.3.5 Plasticity

The soil classification system used is the soil classification NS 8002 and NS 8003.

Part A4 - References

Contents

A4.1 References 2

A4.1 References

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Part B - Geotechnical Data

Contents

Part B1 Soil Description and Boring Profiles
Part B2 Classification Tests
Part B3 Piezocone Penetration Tests
Part B4 Oedometer Tests
Part B5 Triaxial Tests
Part B6 Direct Simple Shear Tests
Part B7 Description of Laboratory Test Procedures
Part B8 References

Part B1 - Soil Description and Boring Profiles

Contents

B1.1 General 2
B1.2 Borehole logs 2

Figures

B1.1 - B1.8 Borehole logs and classification results. CPTU and Gravity core locations
B1.9 - B1.15 Borehole logs and classification results. Vibro core locations
B1.16 – B1.50 Borehole logs and classification results. ROV sample locations

B1.1 General

This part presents the borehole logs based on in situ and offshore laboratory test results from the field work and the results from the onshore laboratory tests performed at NGI's laboratory in Oslo.

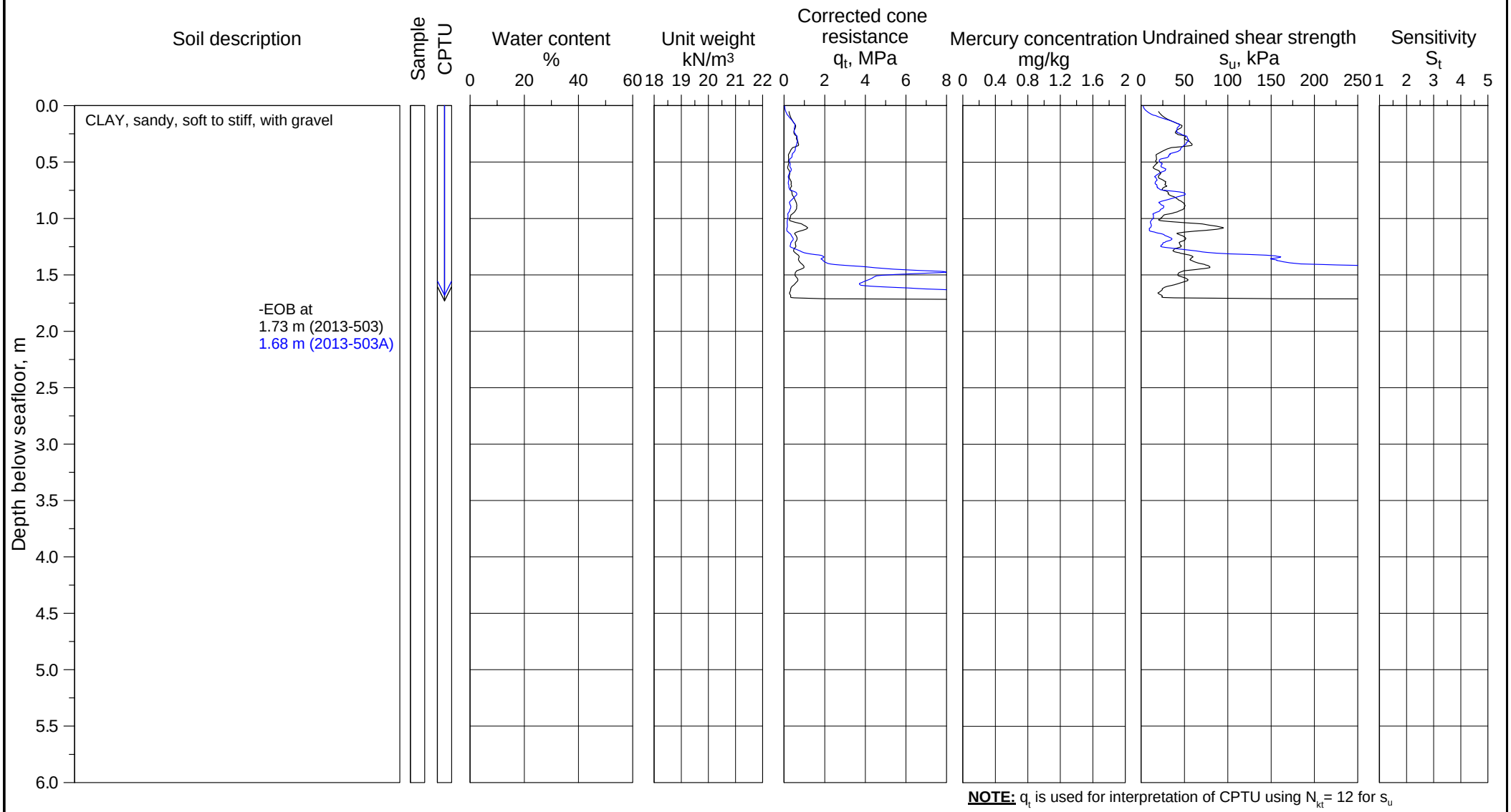
Note that the laboratory testing of the mercury concentration was performed by NIVA. The borehole locations are shown in Part A1.

B1.2 Borehole logs

The borehole logs are presented in Figures B1.1 to B1.50 for the performed sample locations near the submarine U-864. The borehole logs are based on
- offshore and onshore laboratory test results on gravity and vibro core samples
- offshore laboratory tests on samples obtained using the ROV tool
- cone penetration test results, as presented in Part B3.

The classification system used is the NGIs standard practice as described in Part A3. The water depth was submitted to NGI by DOF Subsea during the offshore campaign.

An average total unit weight of 20 kN/m^3 has been used to establish the corrected cone resistance. For interpretation of s_u^C from the CPTU data in the borehole logs an N_{kt} factor of 12. This is based on a combined evaluation of measurements performed in 2006 and in 2013 and is also further evaluated in Part A.



■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ / ♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✥ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✥ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

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Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-503CPT	261 554.8 mE	6 745 200.3 mN	174.7 m
2013-503A CPT	261 554.4 mE	6 745 202.1 mN	174.7 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

"Valley"

Document No. 20120738-01-R

Date 2013-04-16

Figure No. B1.1

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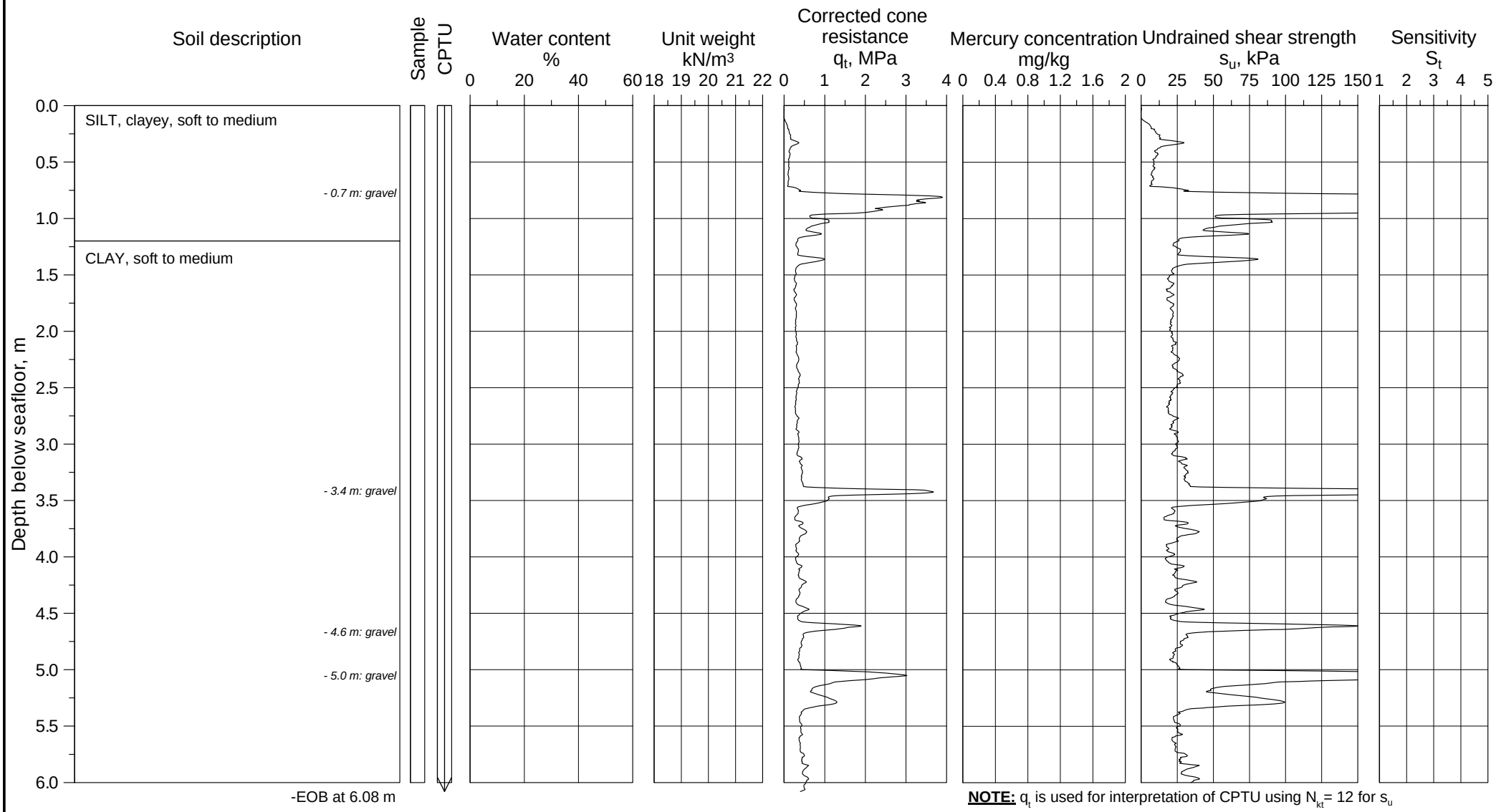

NOTE: q_t is used for interpretation of CPTU using N_{kt}= 12 for s_u

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /♦ Vane (lab offshore/in situ)
$\oplus_C$ CAUC/CIUC
$\oplus_E$ CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✤ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-504CPT	261 603.3 mE	6 745 191.7 mN	174.7 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

"Valley"

Document No. 20120738-01-R

Date 2013-04-16

Figure No. B1.2

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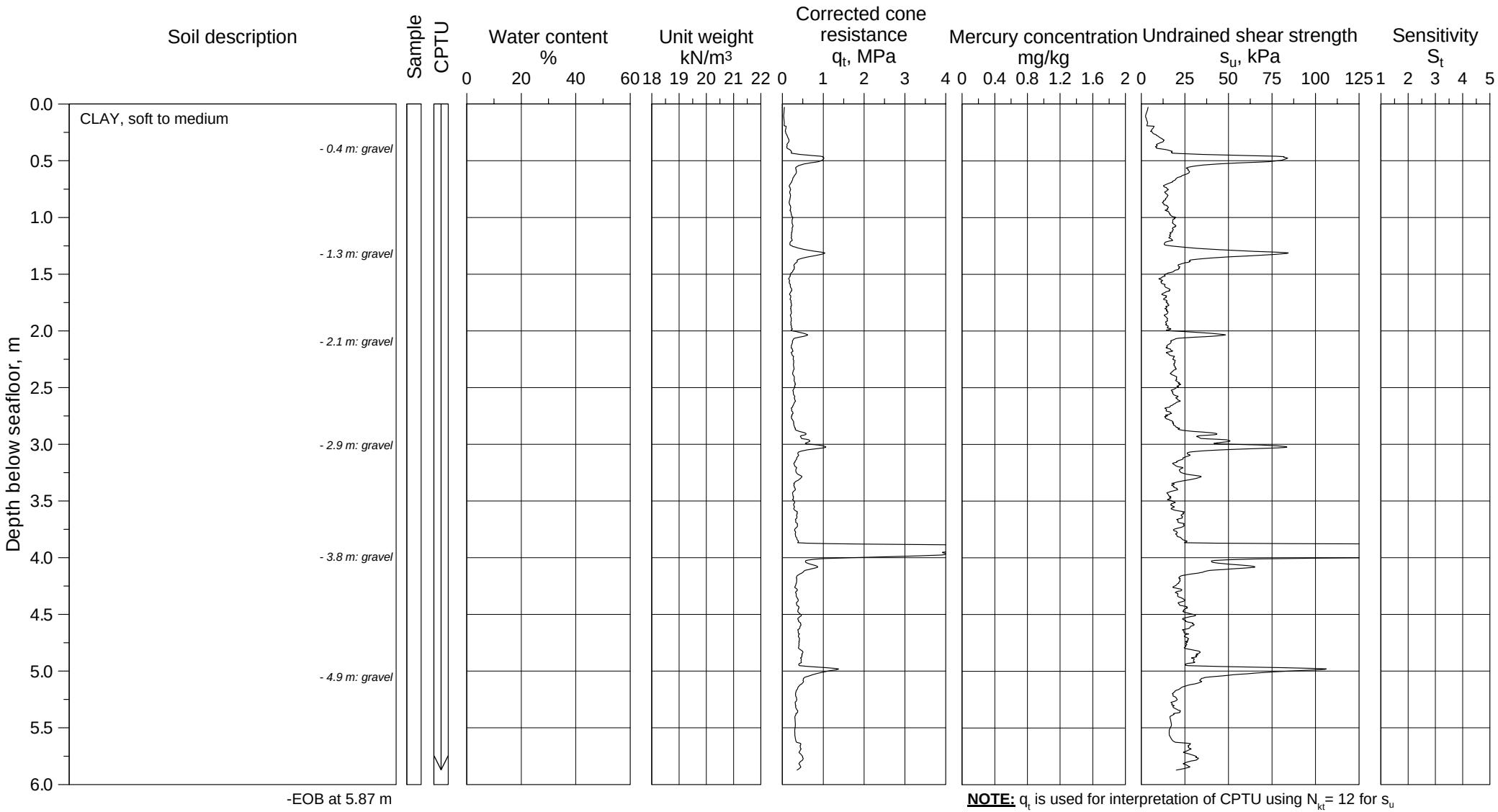

NOTE: q_t is used for interpretation of CPTU using N_{kt} = 12 for s_u

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /♦ Vane (lab offshore/in situ)
$\oplus_C$ CAUC/CIUC
$\oplus_E$ CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✤ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-505CPT	261 597.9 mE	6 745 221.7 mN	176.9 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

"Valley"

Document No. 20120738-01-R

Date 2013-04-16

Figure No. B1.3

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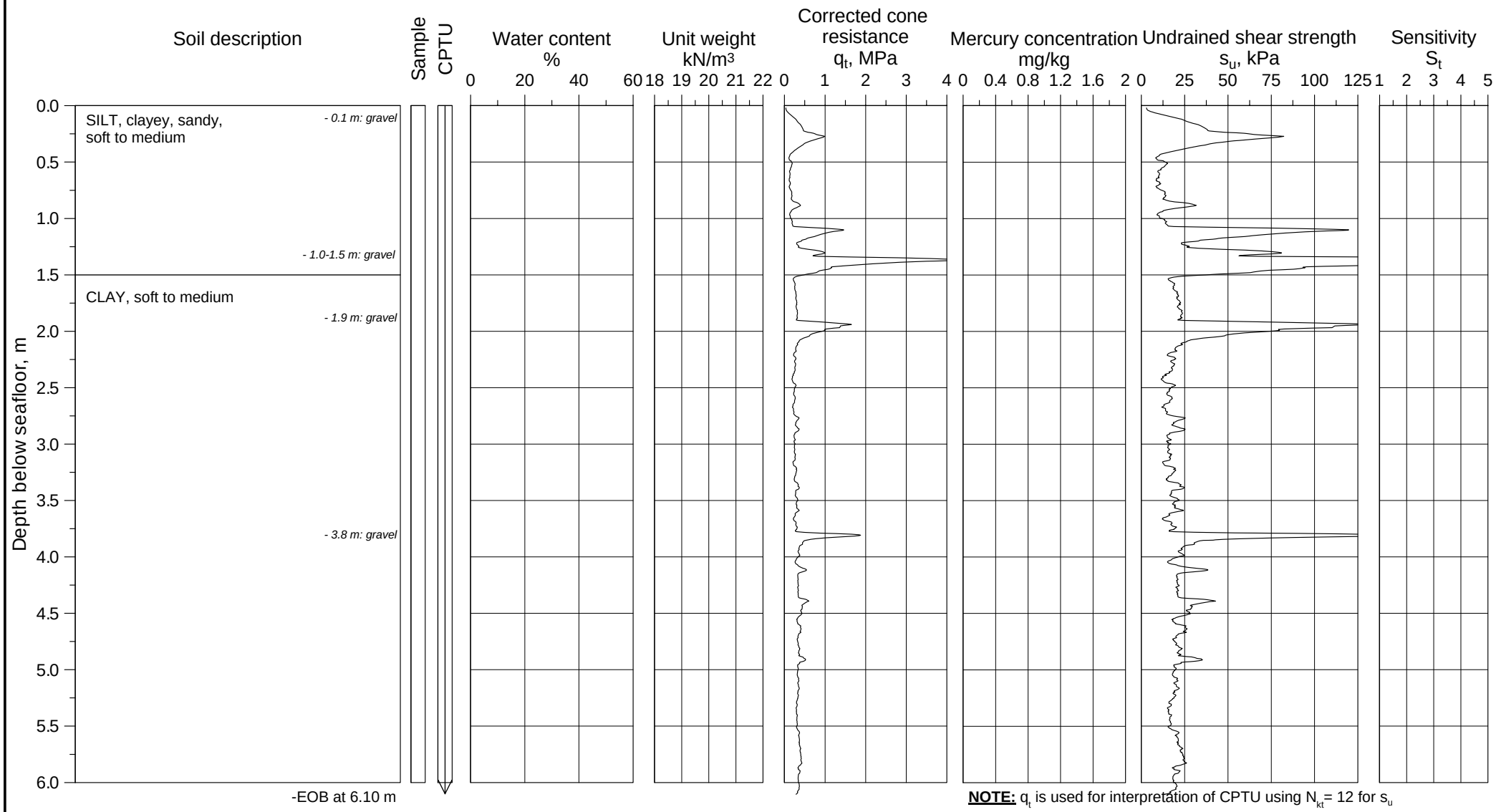


■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ / ♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✤ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-506CPT	261 569.5 mE	6 745 230.0 mN	178.1 m

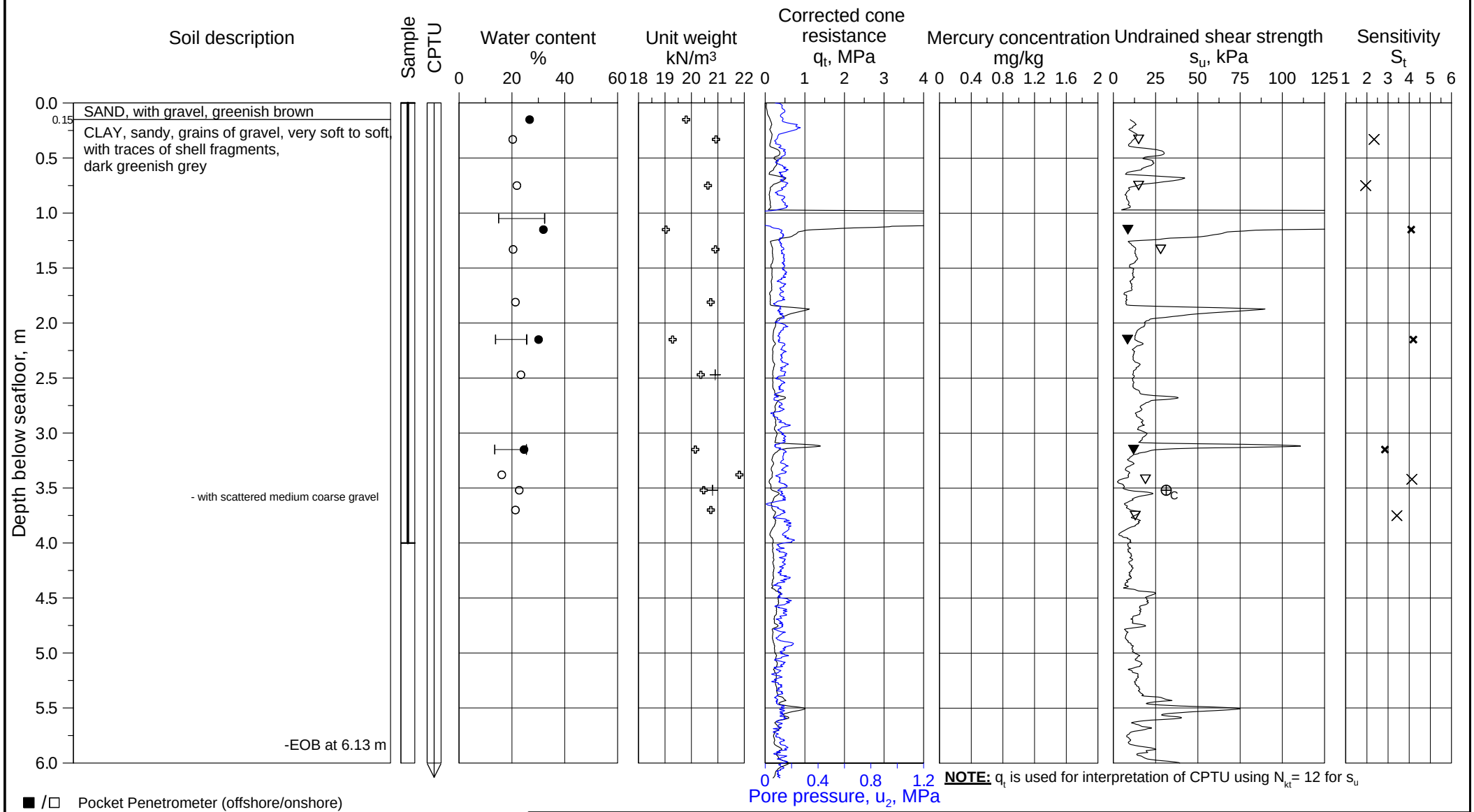
Coordinate system WGS-84, UTM Zone 32N, CM 9°E

"Valley"

Document No. 20120738-01-R
Date 2013-04-16
Figure No. B1.4
Drawn by ES

NGI

P:\2012\07\20120738\Feltarbeid\2013-506\Fig B1_04 2013-506.grf



NOTE: q_t is used for interpretation of CPTU using N_{kt} = 12 for s_u

■ / □ Pocket Penetrometer (offshore/onshore)
▼ / ▽ Fall cone (offshore/onshore)
★ / ☆ Torvane (offshore/onshore)
✳ / ♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ / ◇ UU (offshore/onshore)
✤ γ_t (Based on water content)
● / ○ Water content, w (offshore/onshore)
✚ / + Total unit weight, γ_t (offshore/onshore)
✖ / × Sensitivity, fall cone (offshore/onshore)
✳ / ✤ Sensitivity, vane (lab offshore/in situ)
Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-509GC	261 626.5 mE	6 745 205.0 mN	176.0 m
2013-509CPT	261 627.9 mE	6 745 201.8 mN	176.0 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

"Valley"

Document No. 20120738-01-R

Date 2013-04-16

Figure No. B1.5

Drawn by ES

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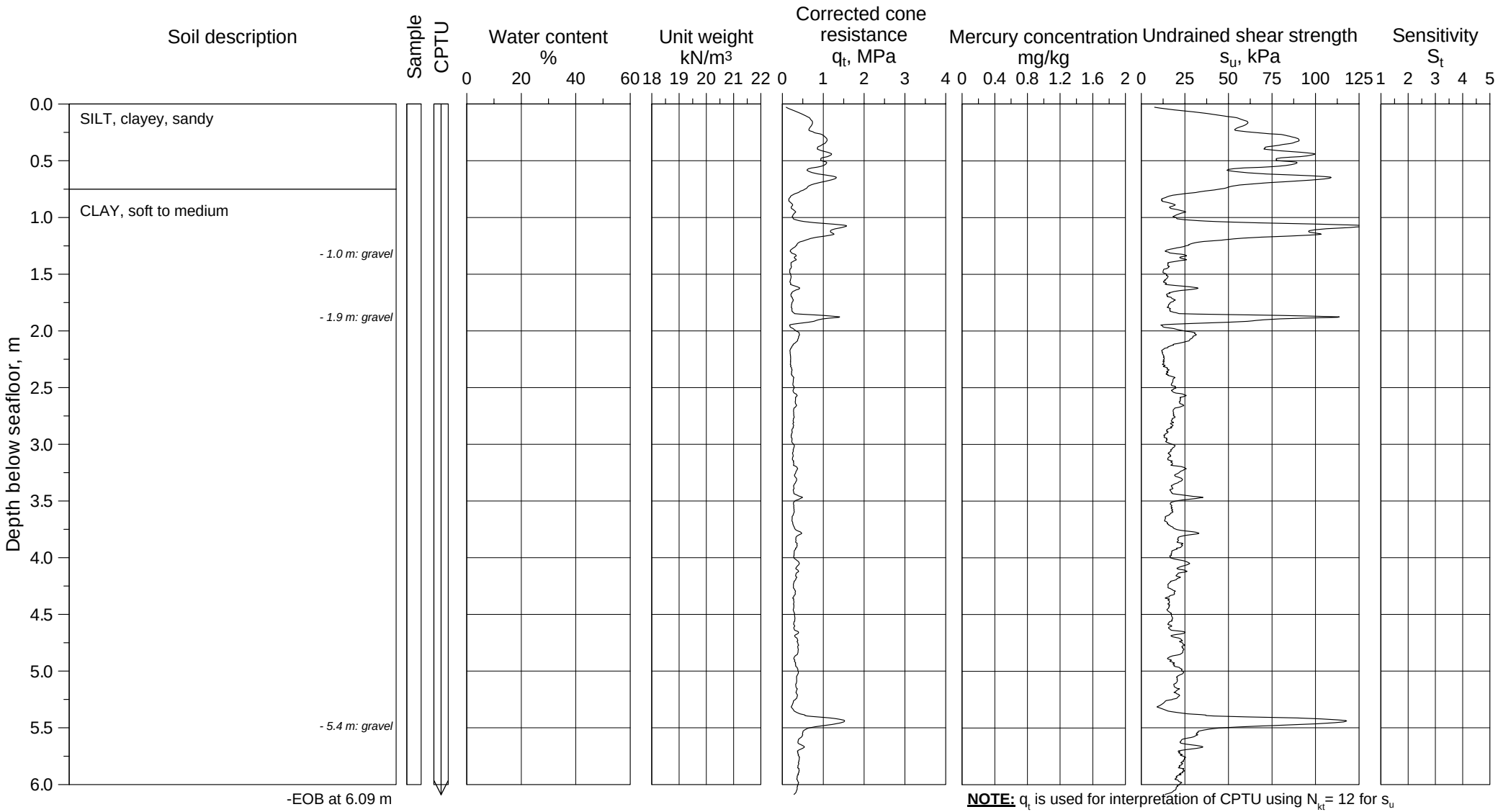

NOTE: q_t is used for interpretation of CPTU using N_{kt} = 12 for s_u

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /♦ Vane (lab offshore/in situ)
$\oplus_C$ CAUC/CIUC
$\oplus_E$ CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✤ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-510CPT	261 580.9 mE	6 745 198.0 mN	175.5 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

"Valley"

Document No. 20120738-01-R
Date 2013-04-16
Figure No. B1.6
Drawn by ES

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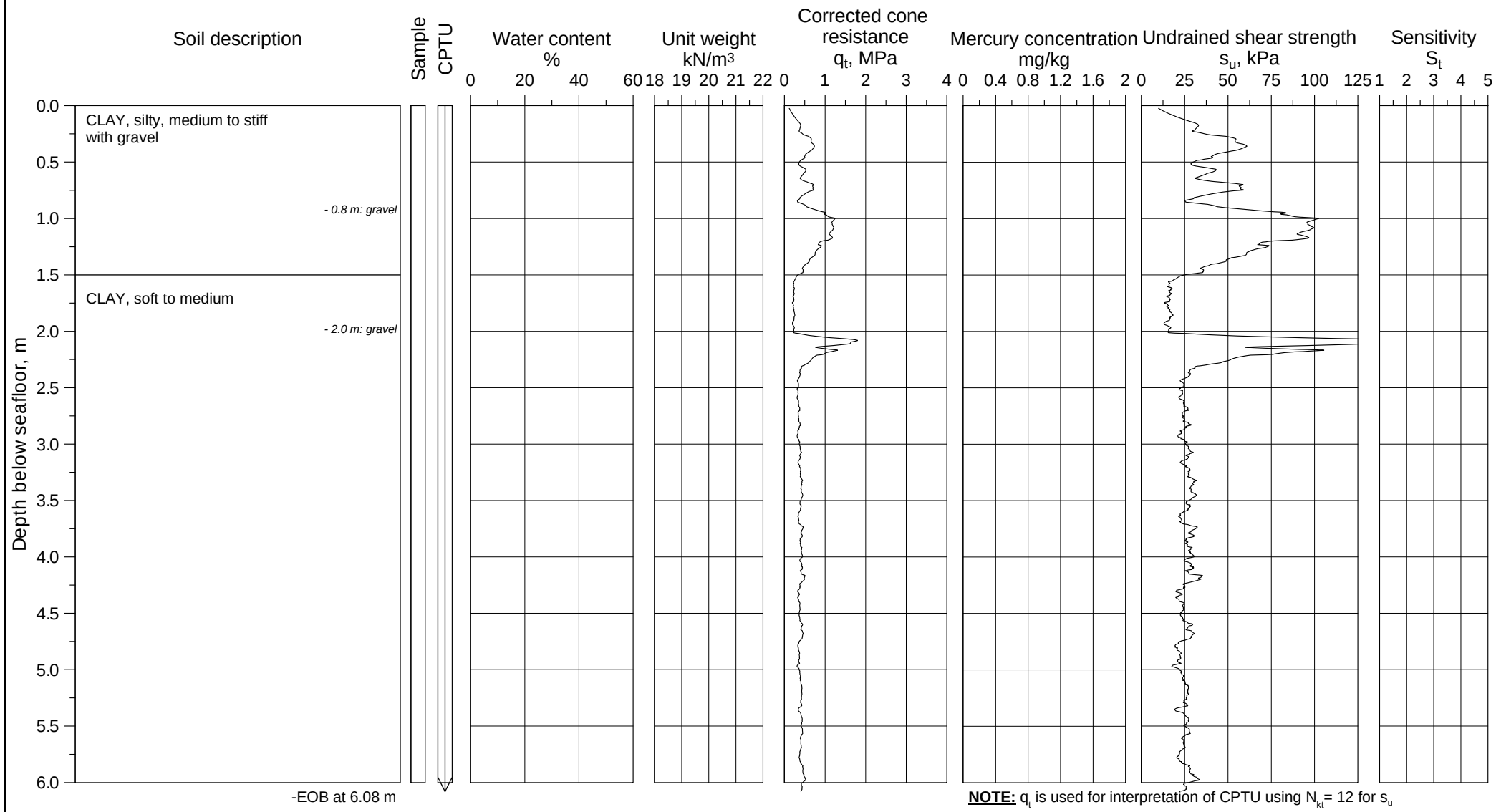
P:\2012\07\20120738\Feltarbeid\2013-510\Fig B1_06 2013-510.grf



NOTE: q_t is used for interpretation of CPTU using N_{kt} = 12 for s_u

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✤ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-511CPT	261 580.5 mE	6 745 183.5 mN	172.7 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

"Valley"

Document No. 20120738-01-R

Date 2013-04-16

Figure No. B1.7

Drawn by ES

NGI

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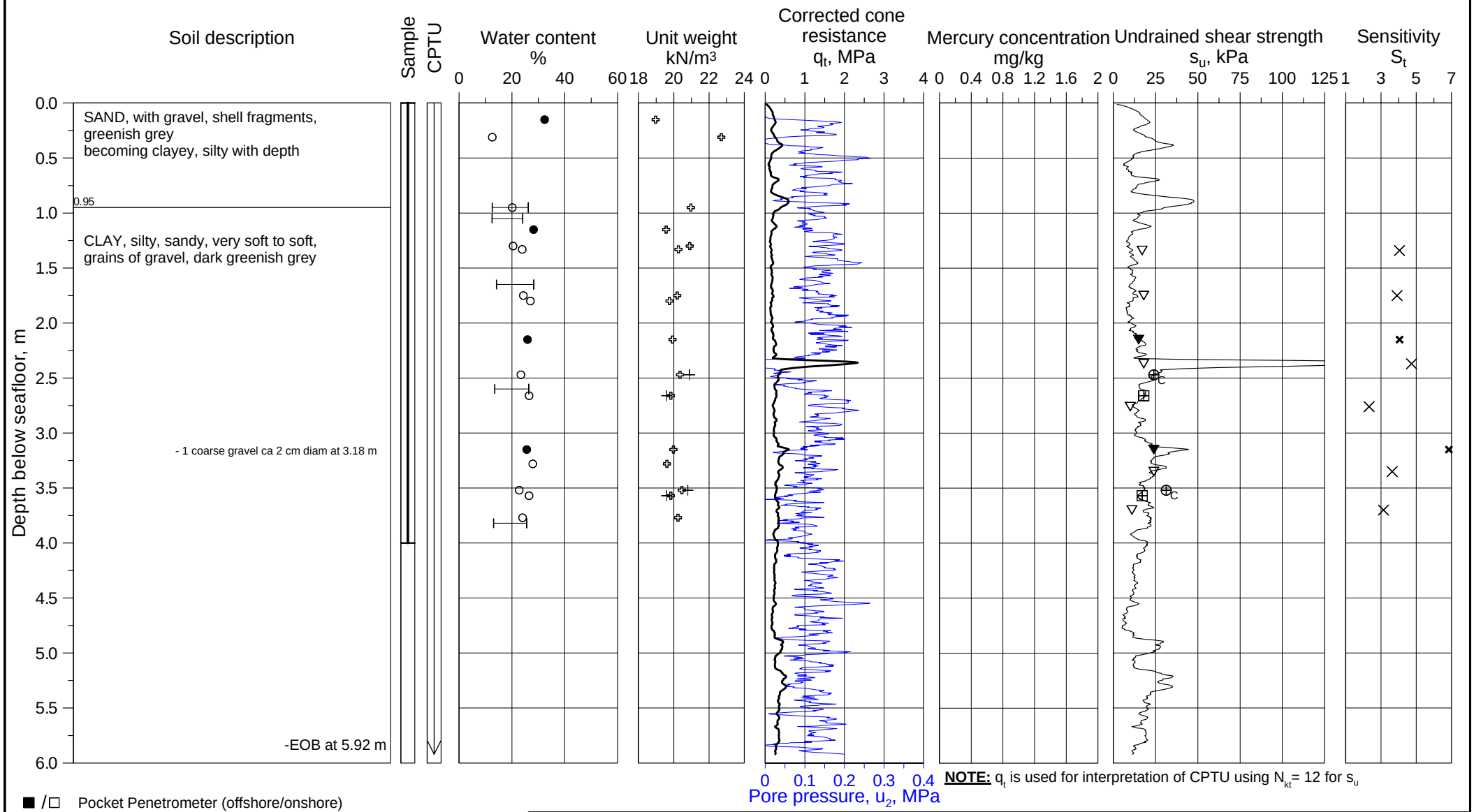

NOTE: q_t is used for interpretation of CPTU using N_{kt} = 12 for s_u

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ / ♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✤ Sensitivity, vane (lab offshore/in situ)
Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-512GC	261 652.0 mE	6 745 194.6 mN	175.6 m
2013-512CPT	261 649.7 mE	6 745 192.3 mN	175.6 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

"Valley"

Document No. 20120738-01-R

Date 2013-04-16

Figure No. B1.8

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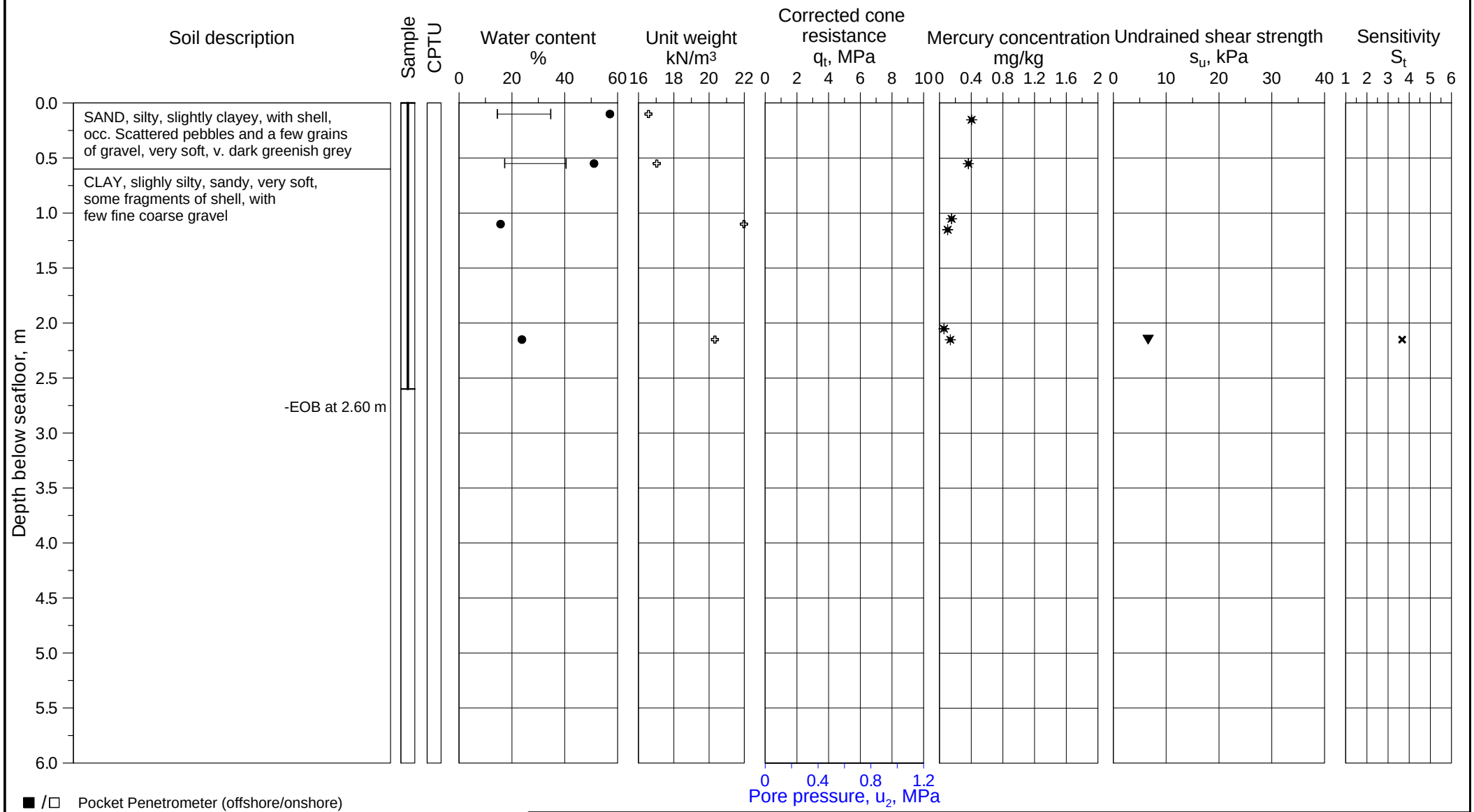

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✣ γt (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γt (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✣ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, Ip

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-401VC	261 546.5 mE	6 745 102.1 mN	150.9 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

Near aft wreck

Document No. 20120738-01-R

Date 2013-04-16

Figure No. B1.9

Drawn by ES

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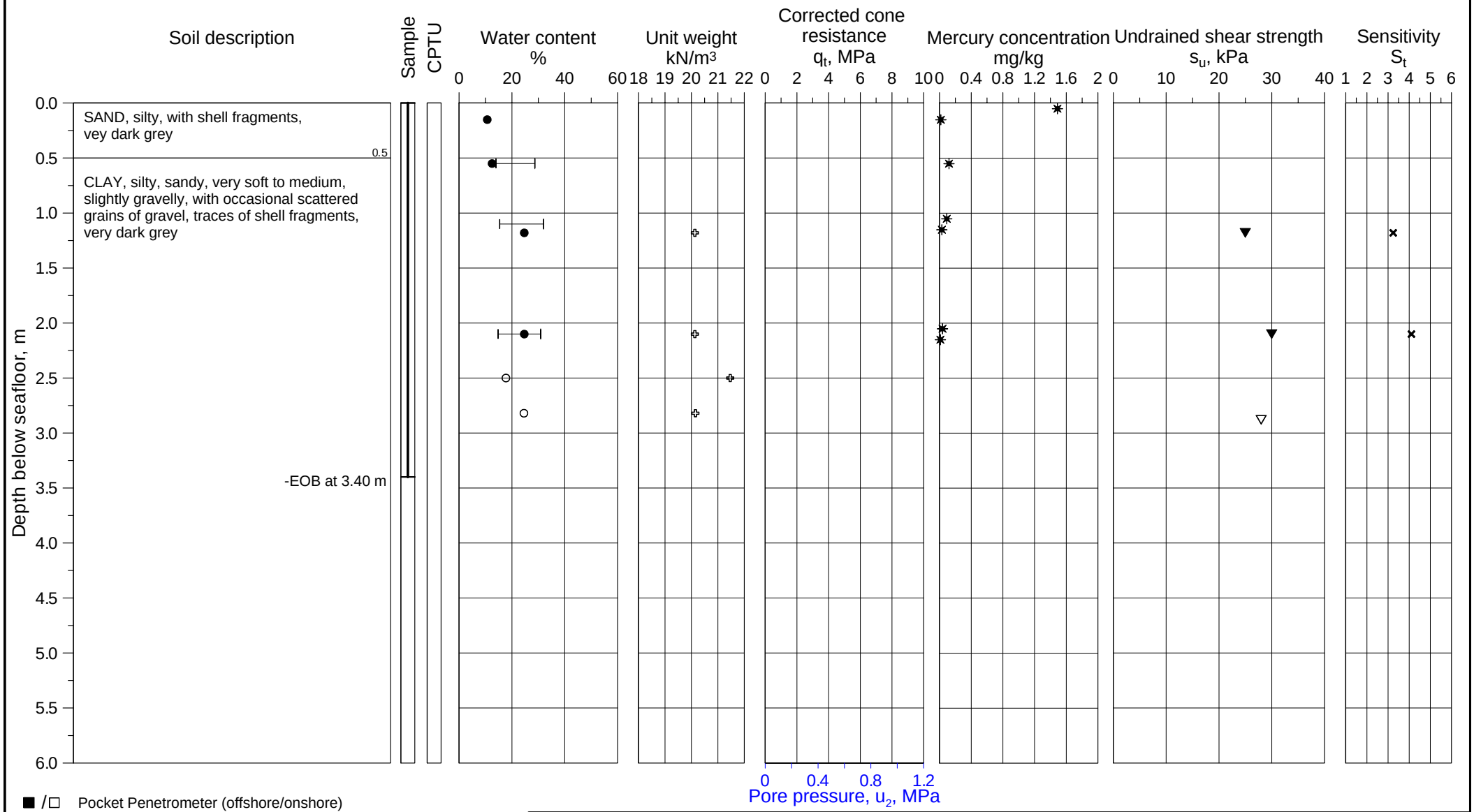

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ / ♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✣ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✣ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-402VC	261 553.1 mE	6 745 093.8 mN	149.1 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

Near aft wreck

Document No. 20120738-01-R

Date 2013-04-16

Figure No. B1.10

Drawn by ES

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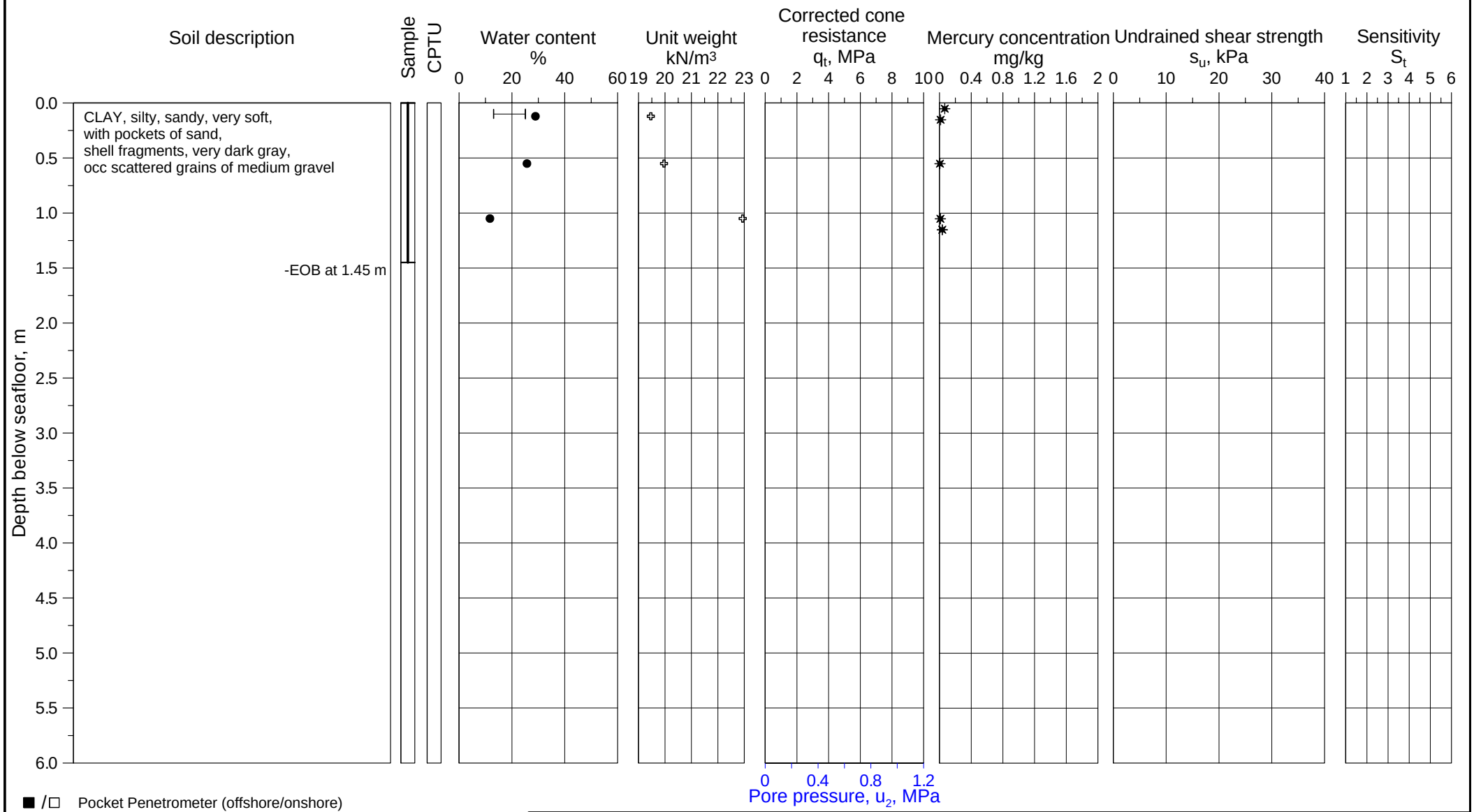

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✣ γt (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γt (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✣ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, Ip

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-403VC	261 559.1 mE	6 745 086.0 mN	149.2 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

Near aft wreck

Document No. 20120738-01-R

Date 2013-04-16

Figure No. B1.11

Drawn by ES

NGI

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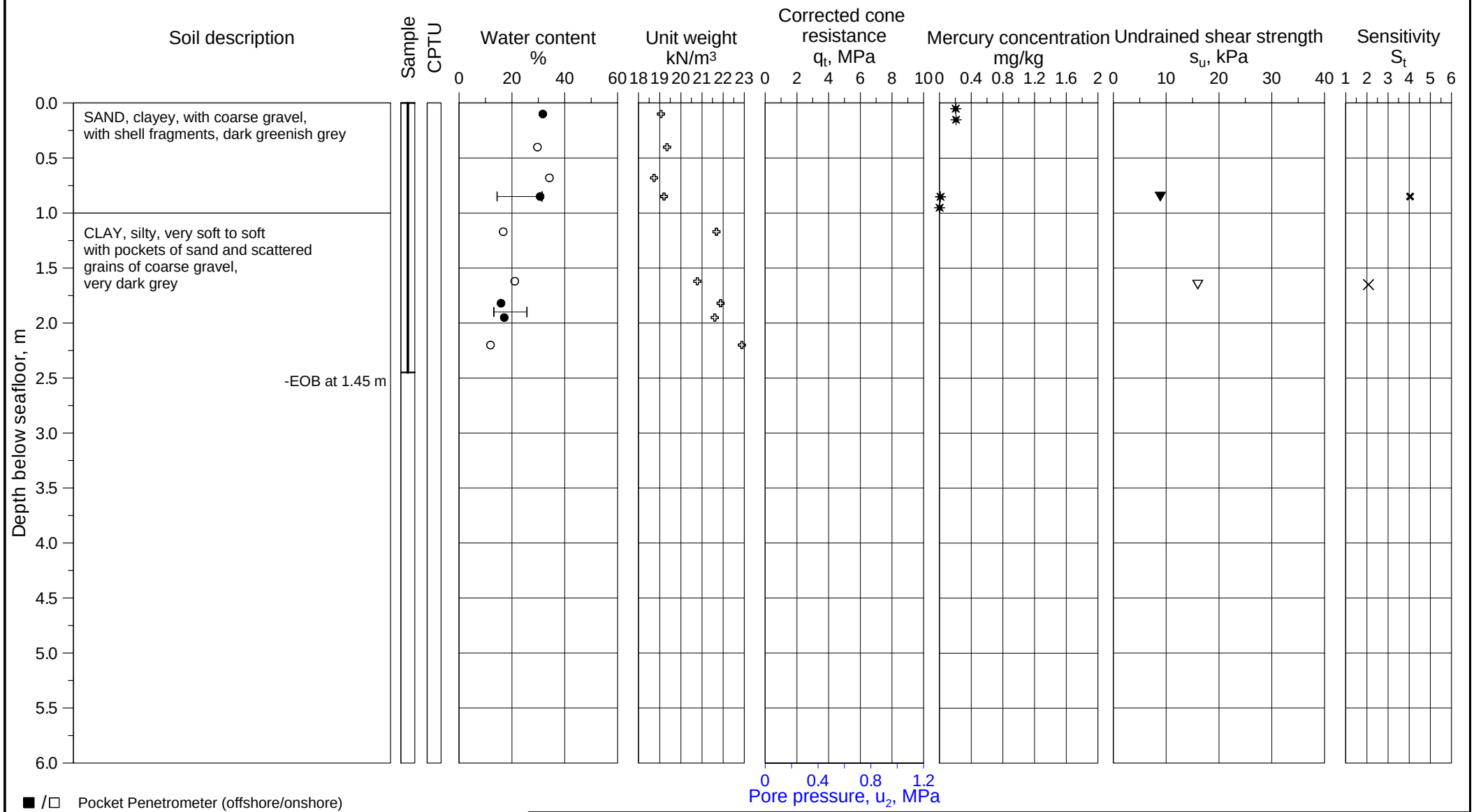

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✜ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✜ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-404VC	261 563.5 mE	6 745 076.5 mN	148.9 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

Near aft wreck

Document No. 20120738-01-R

Date 2013-04-16

Figure No. B1.12

Drawn by ES

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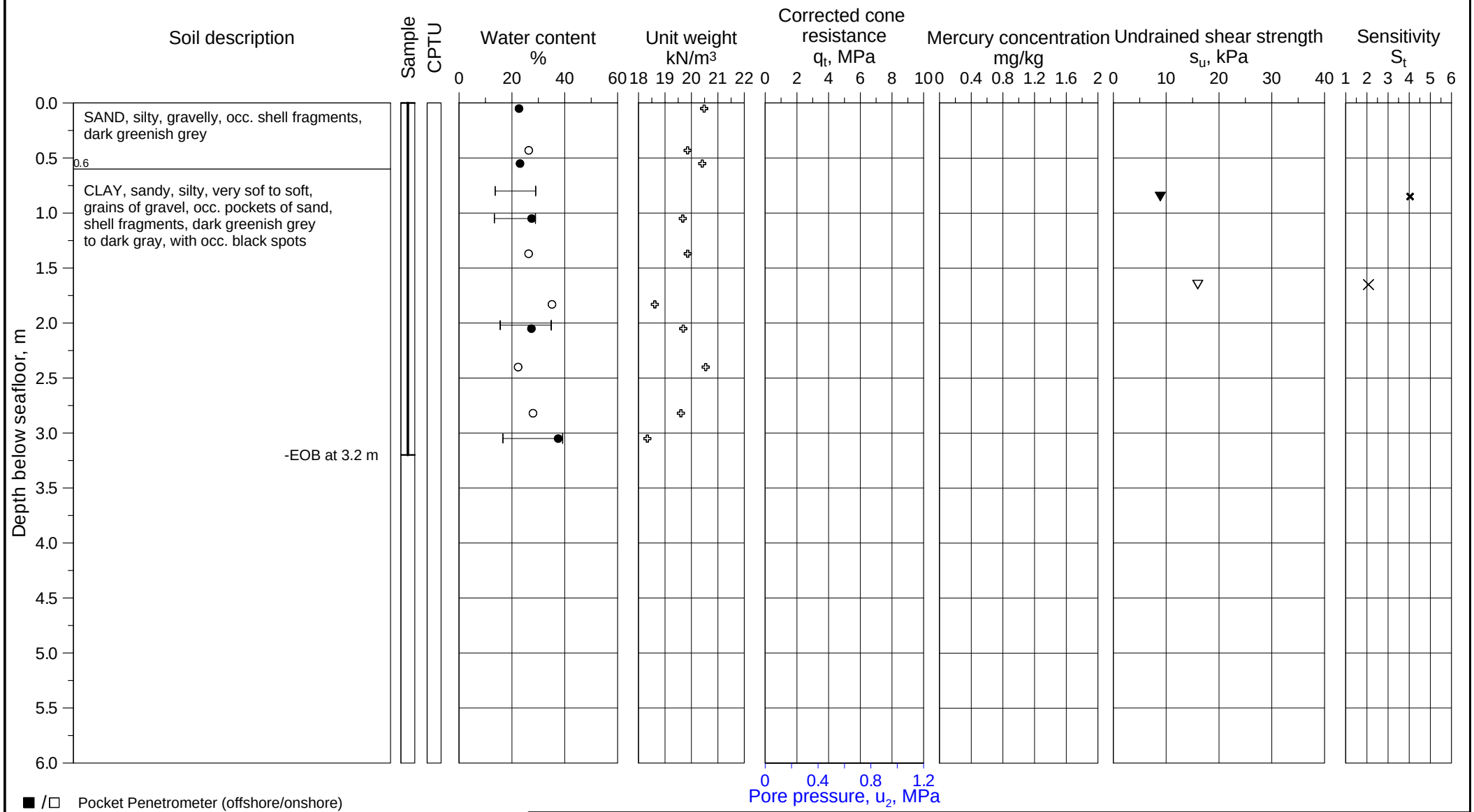

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✤ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-405VC	261 576.9 mE	6 745 152.6 mN	166.2 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

Near fwd wreck part

Document No. 20120738-01-R
Date 2013-04-16
Figure No. B1.13
Drawn by ES

NGI

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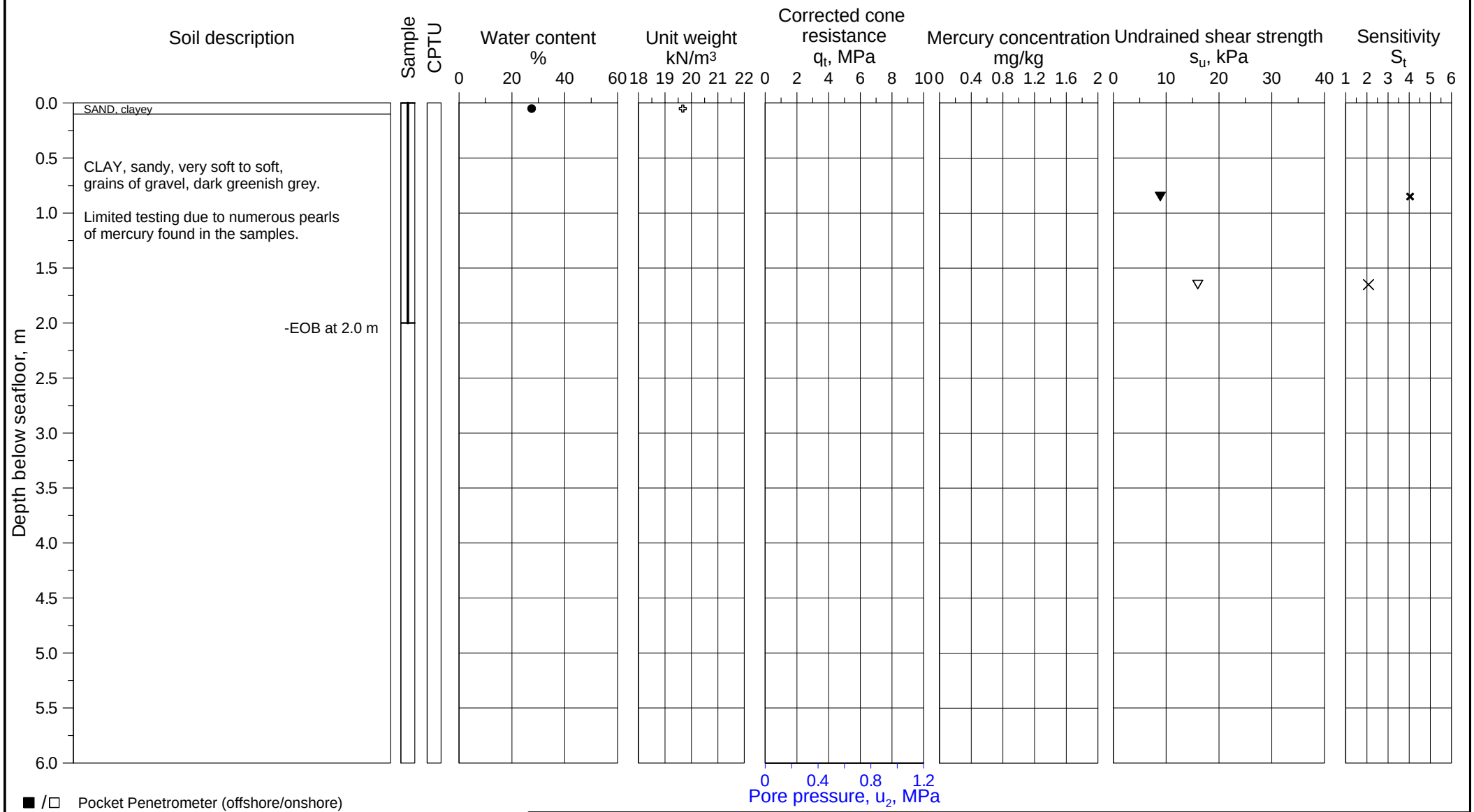

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ / ♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ γt (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γt (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✤ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, Ip

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-406VC	261 571.6 mE	6 745 147.9 mN	163.2 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

Near fwd wreck part

Document No. 20120738-01-R

Date 2013-04-16

Figure No. B1.14

Drawn by ES

NGI

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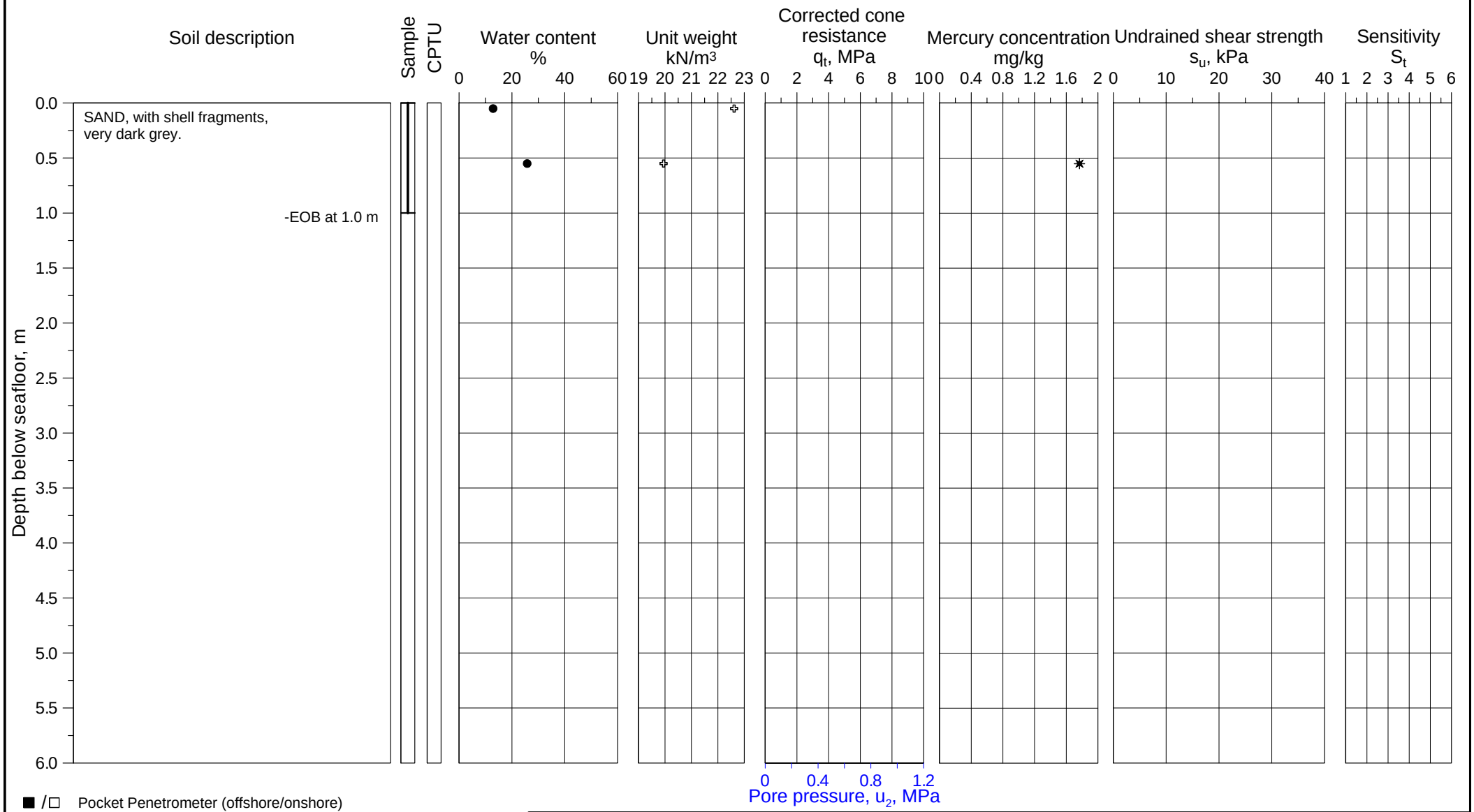

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ / ♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✣ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✣ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-407VC	261 565.6 mE	6 745 135.5 mN	160.4 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

Near fwd wreck part

Document No. 20120738-01-R
Date 2013-04-16
Figure No. B1.15
Drawn by ES

NGI

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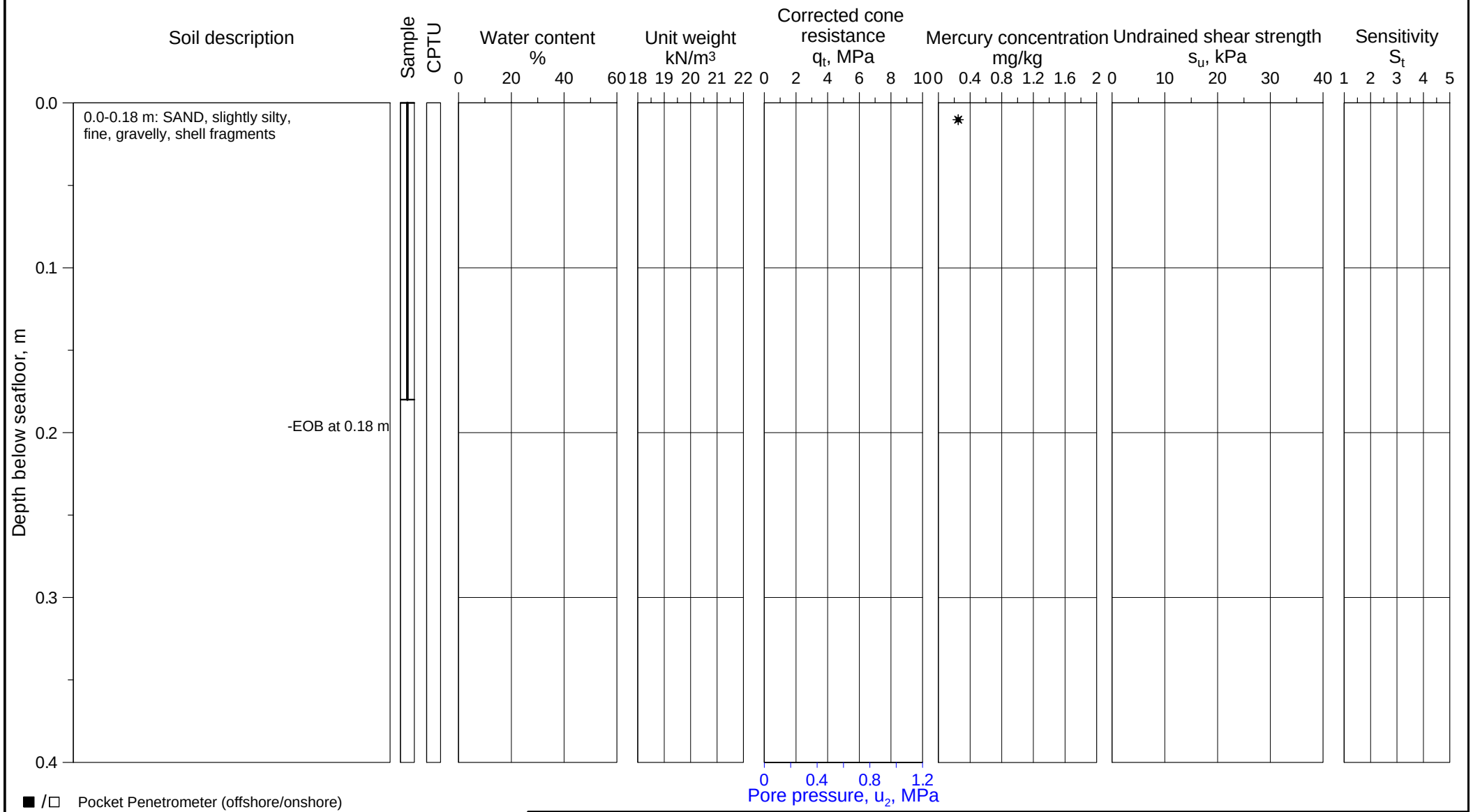

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✤ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-08	261 413.2 mE	6 745 271.1 mN	178.1 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.16

Drawn by ES

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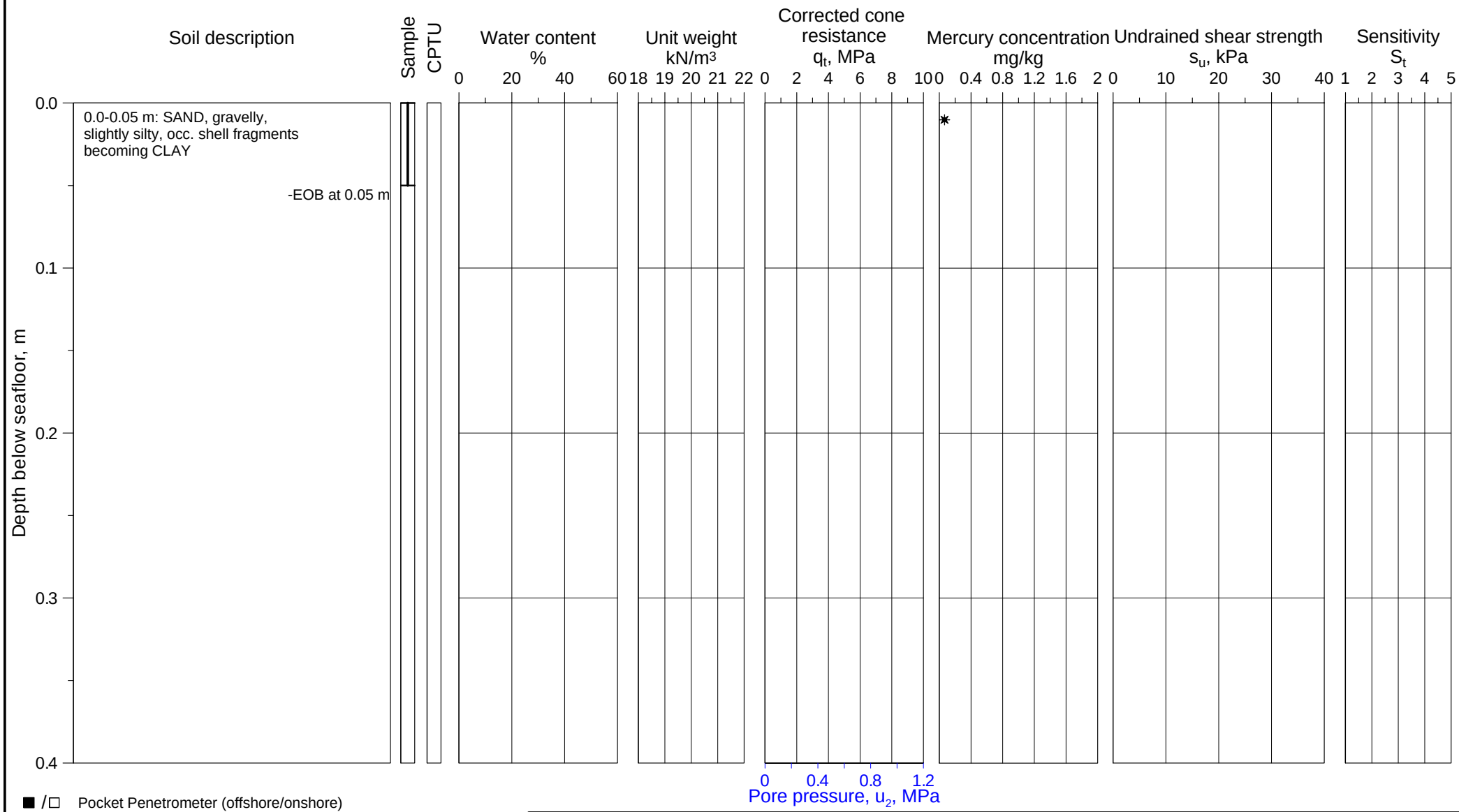

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✥ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✥ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-28	261 428.3 mE	6745 231.8 mN	168.9 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.17

Drawn by ES

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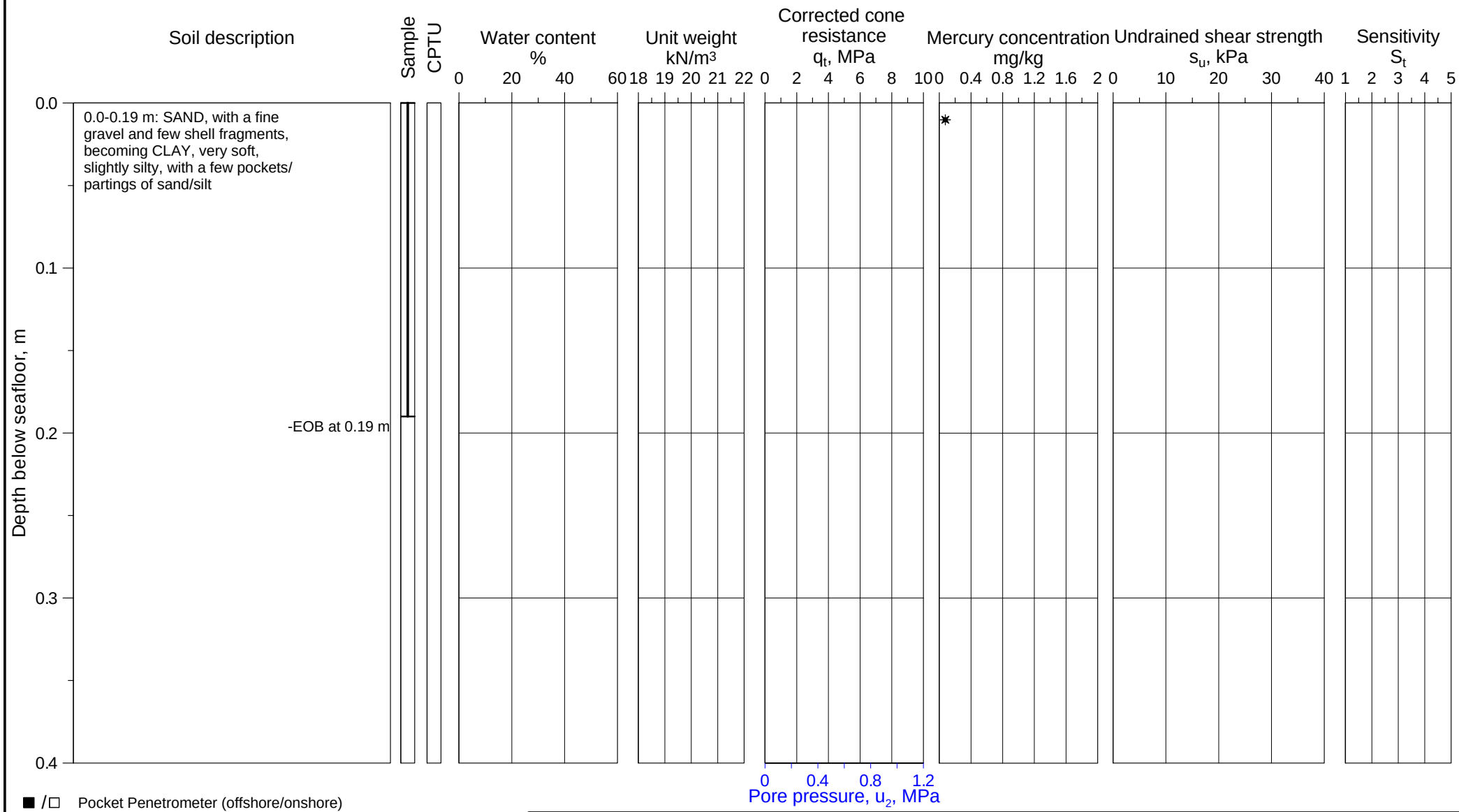

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ / ♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✤ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-30 B	261 365.6 mE	6 745 184.4 mN	153.7 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.18

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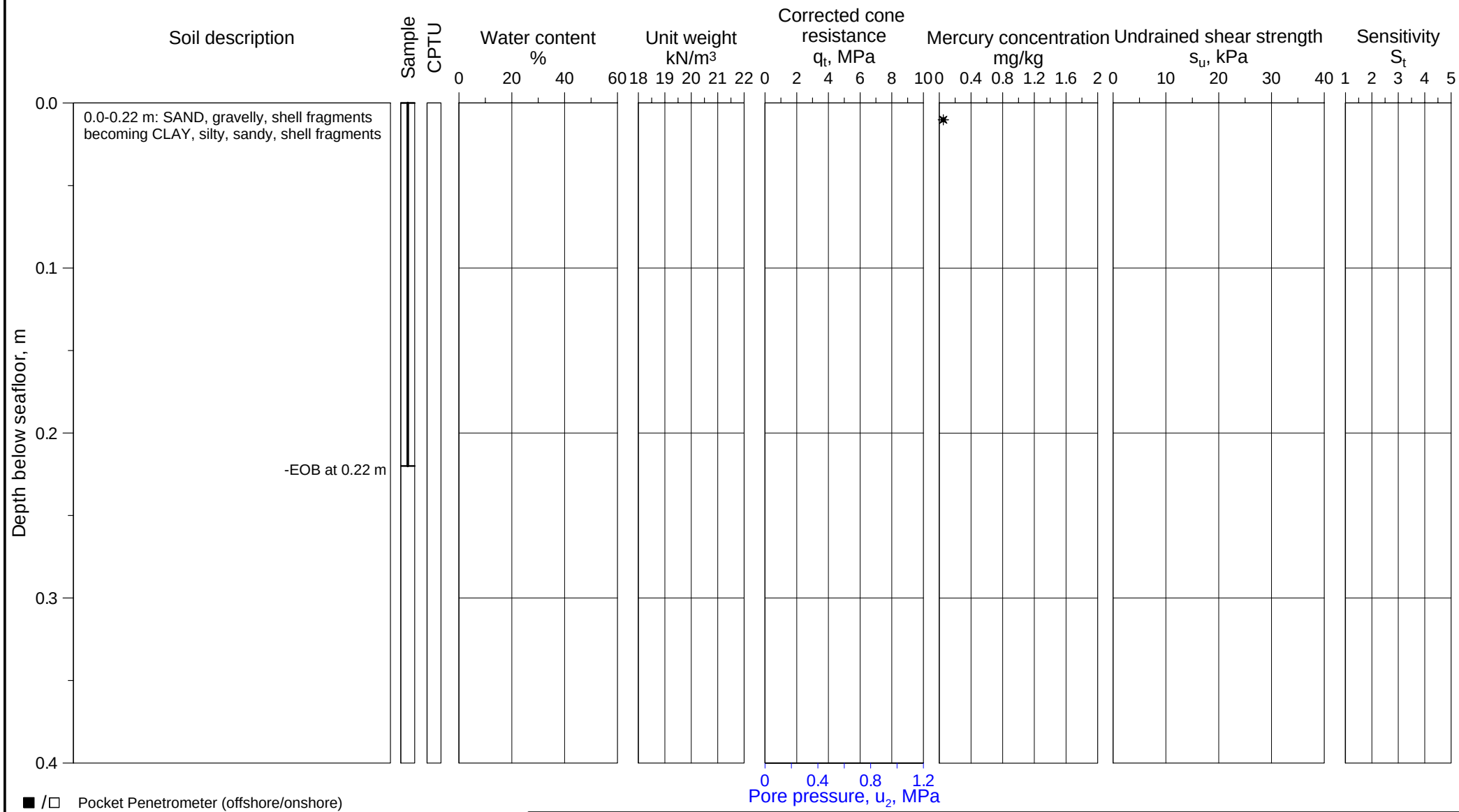

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ / ♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✥ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✥ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-31	261 381.9 mE	6 745 145.3 mN	144.9 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.19

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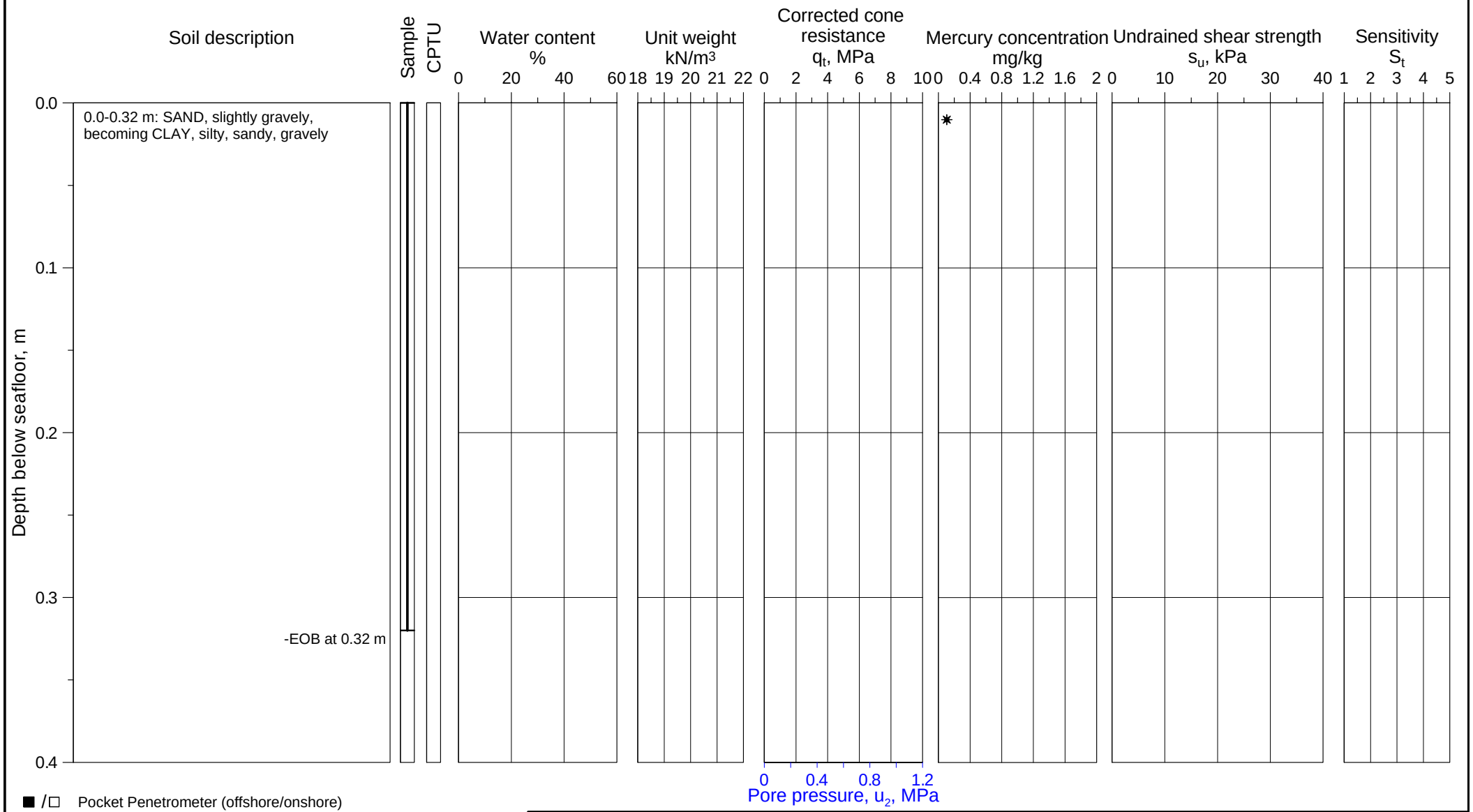

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ / ♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✜ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✜ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-32	261 556.8 mE	6 745 314.2 mN	161.0 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.20

Drawn by ES

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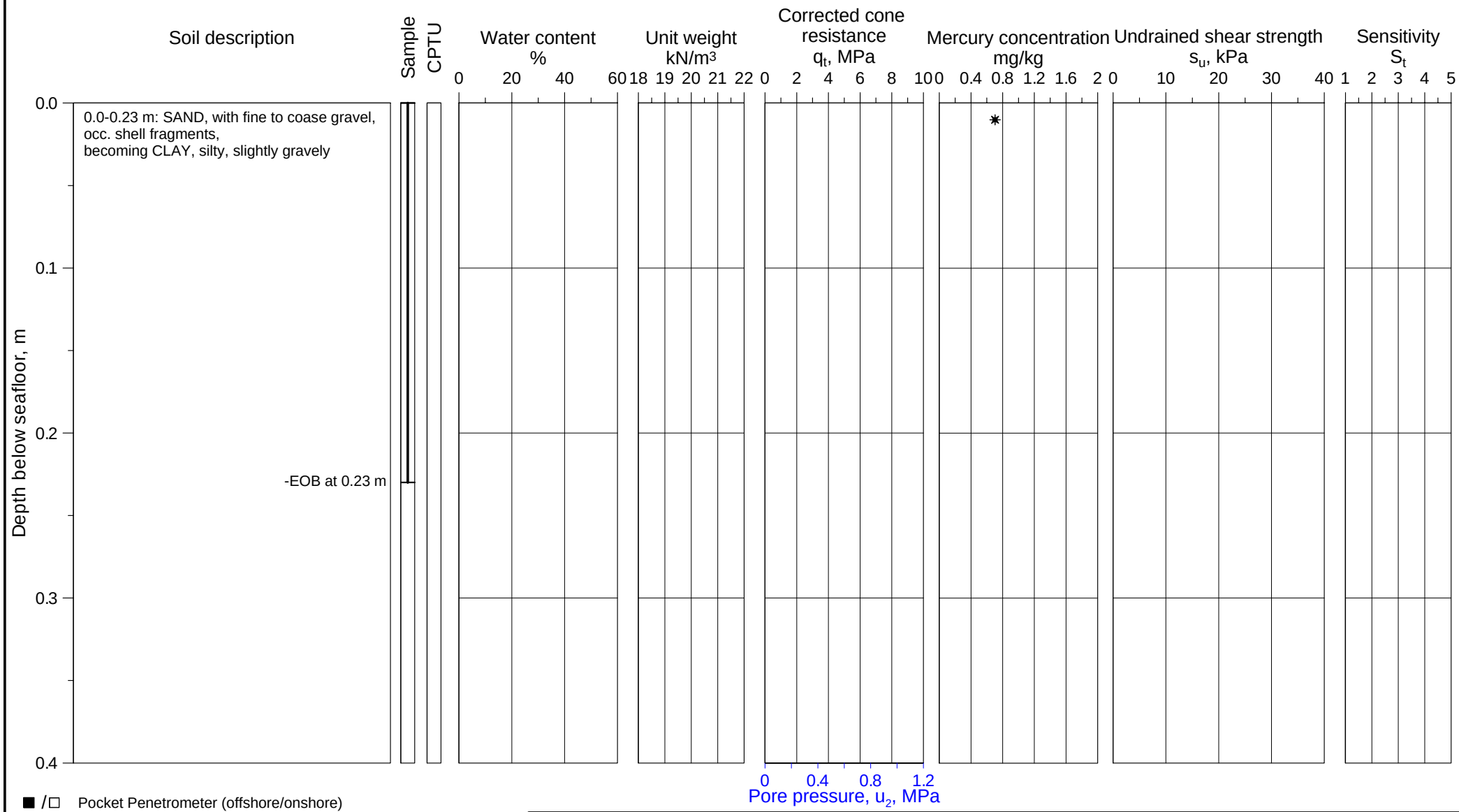

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✤ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-34	261 491.0 mE	6 745 267.0 mN	177.9 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.21

Drawn by ES

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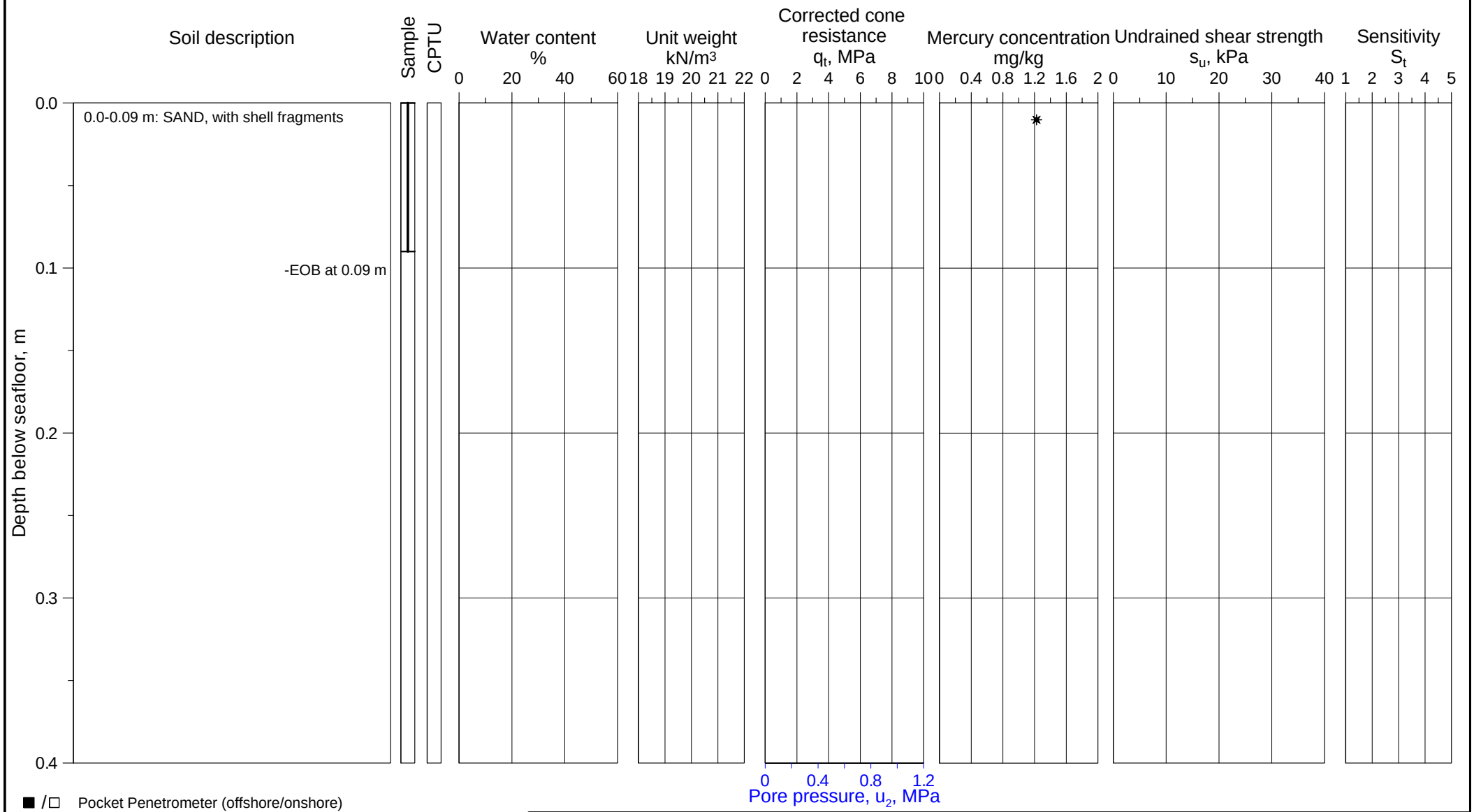

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ / ♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✥ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✥ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-35	261 469.6 mE	6 745 240.1 mN	177.6 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.22

Drawn by ES

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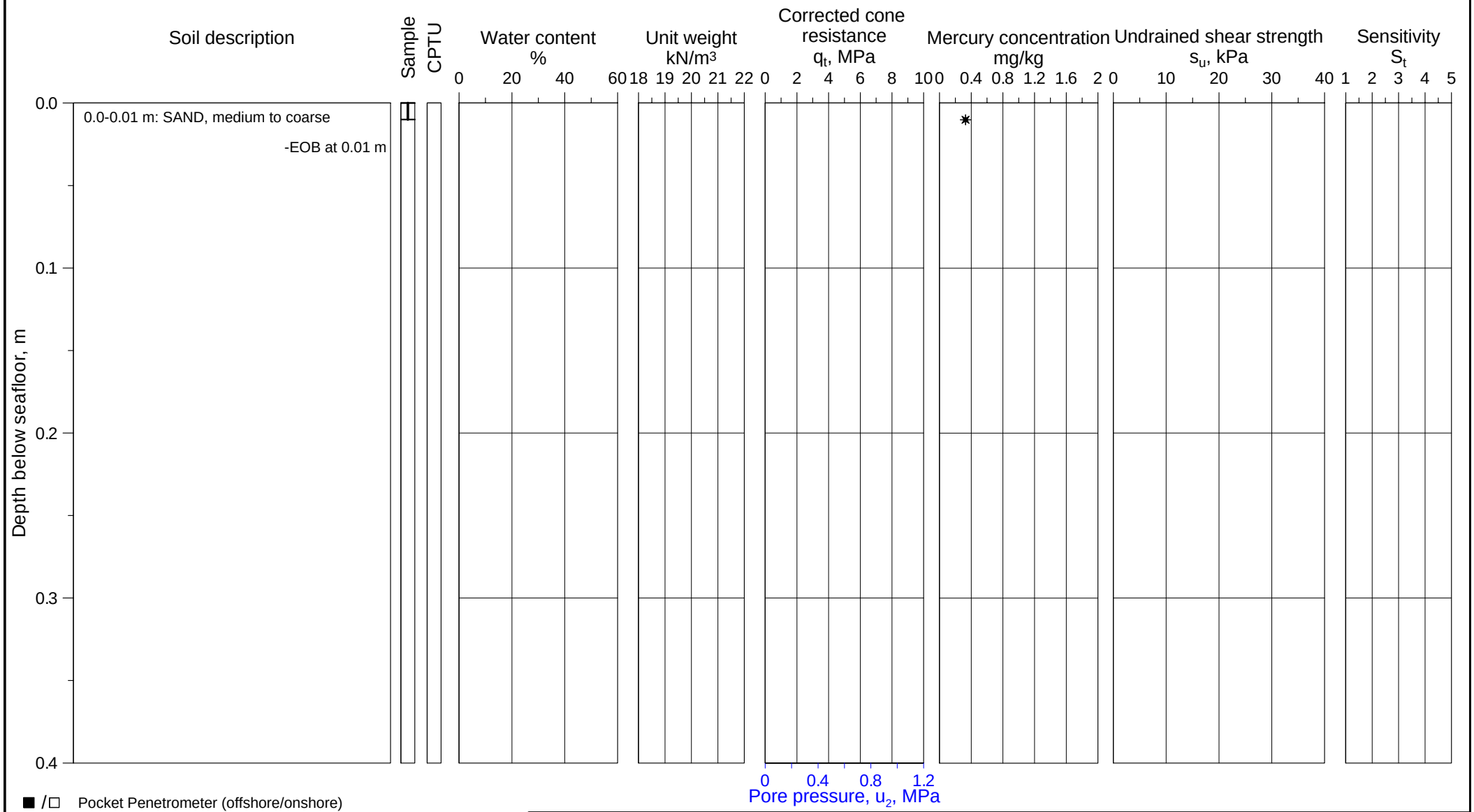

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ / ♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✥ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✥ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-36	261 445.2 mE	6 745 213.4 mN	164.6 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.23

Drawn by ES

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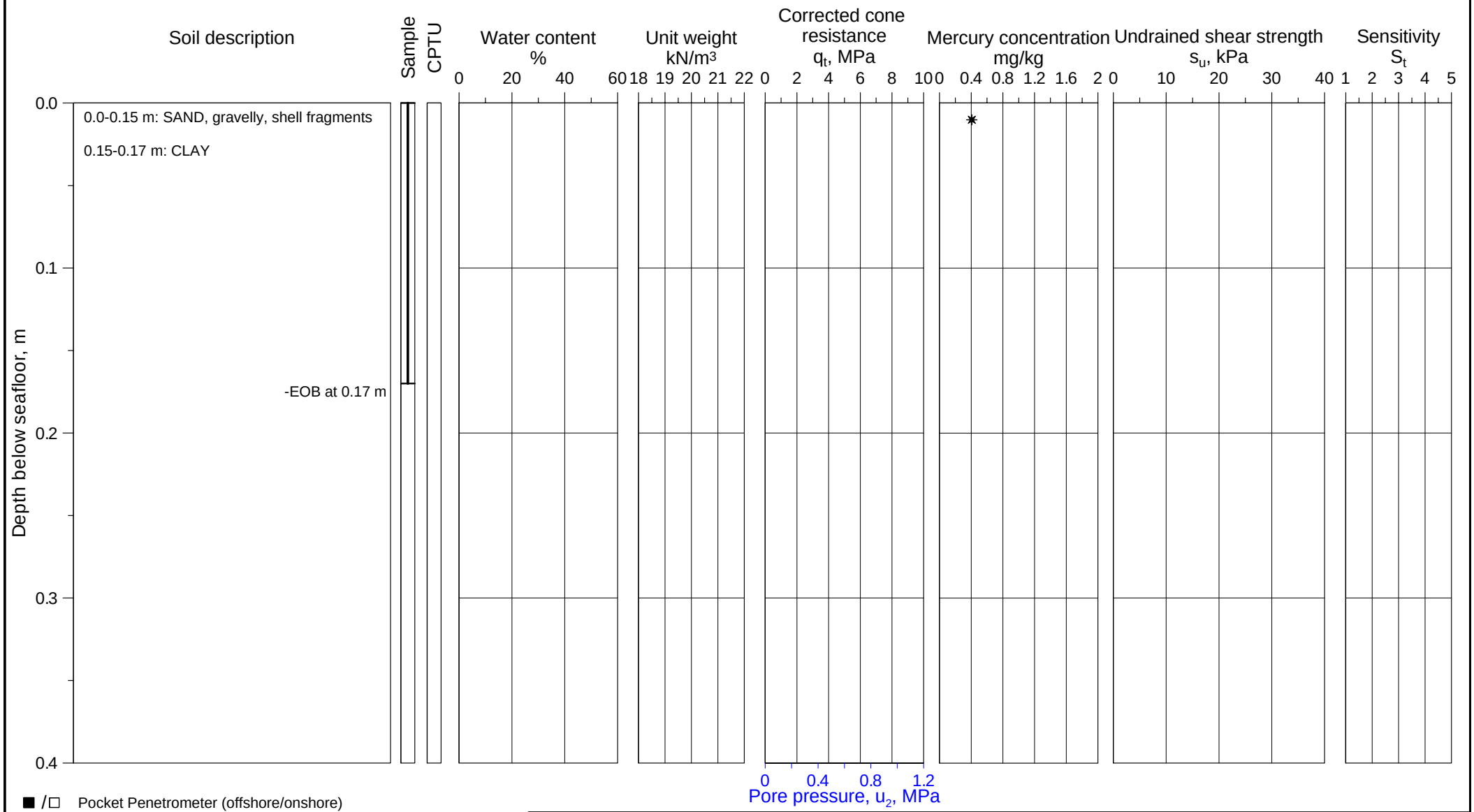

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✜ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✜ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-38	261 423.2 mE	6 745 135.1 mN	142.0 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.24

Drawn by ES

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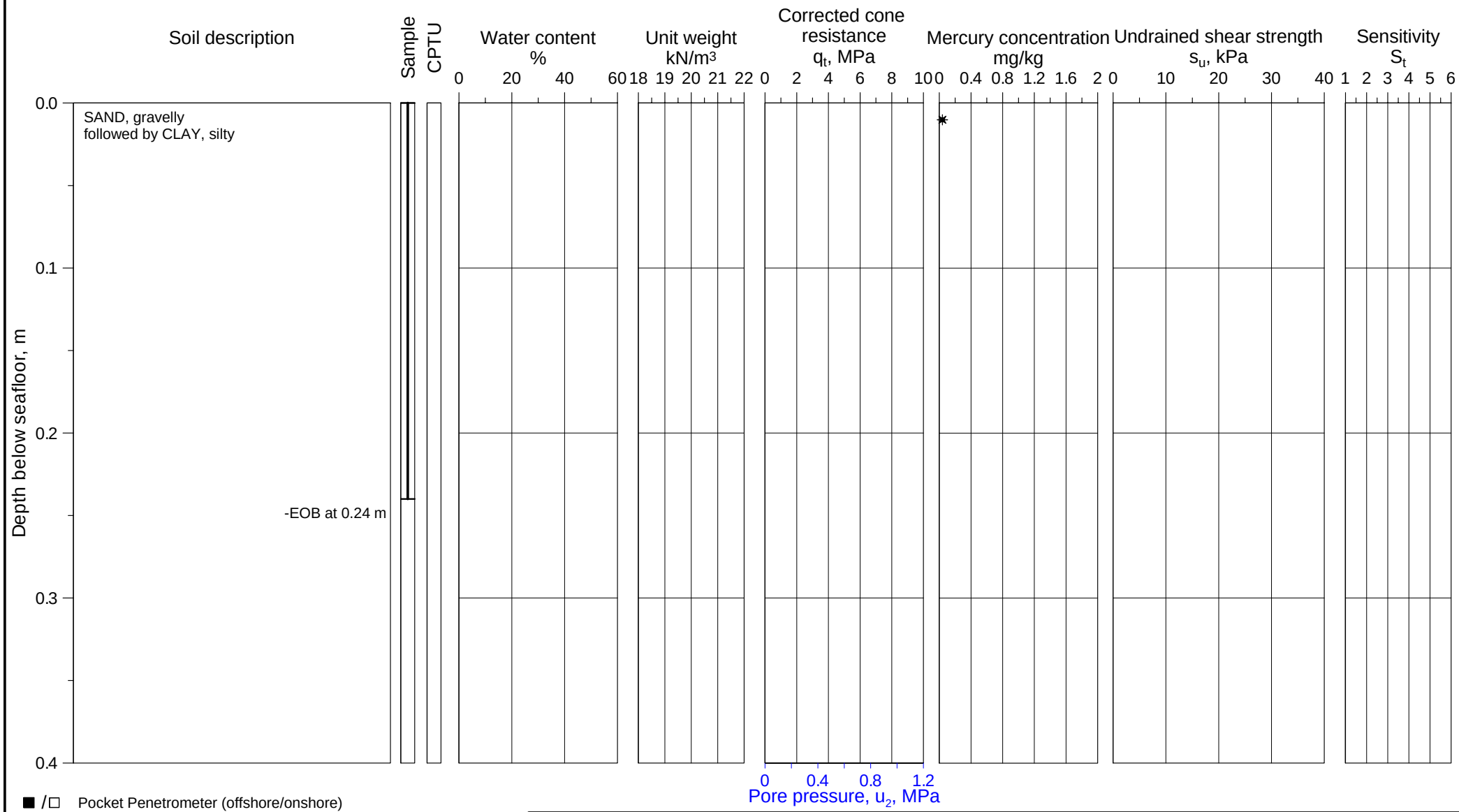

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ / ♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✤ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-83	261 382.5 mE	6 745 112.1 mN	142.7 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.25

Drawn by ES

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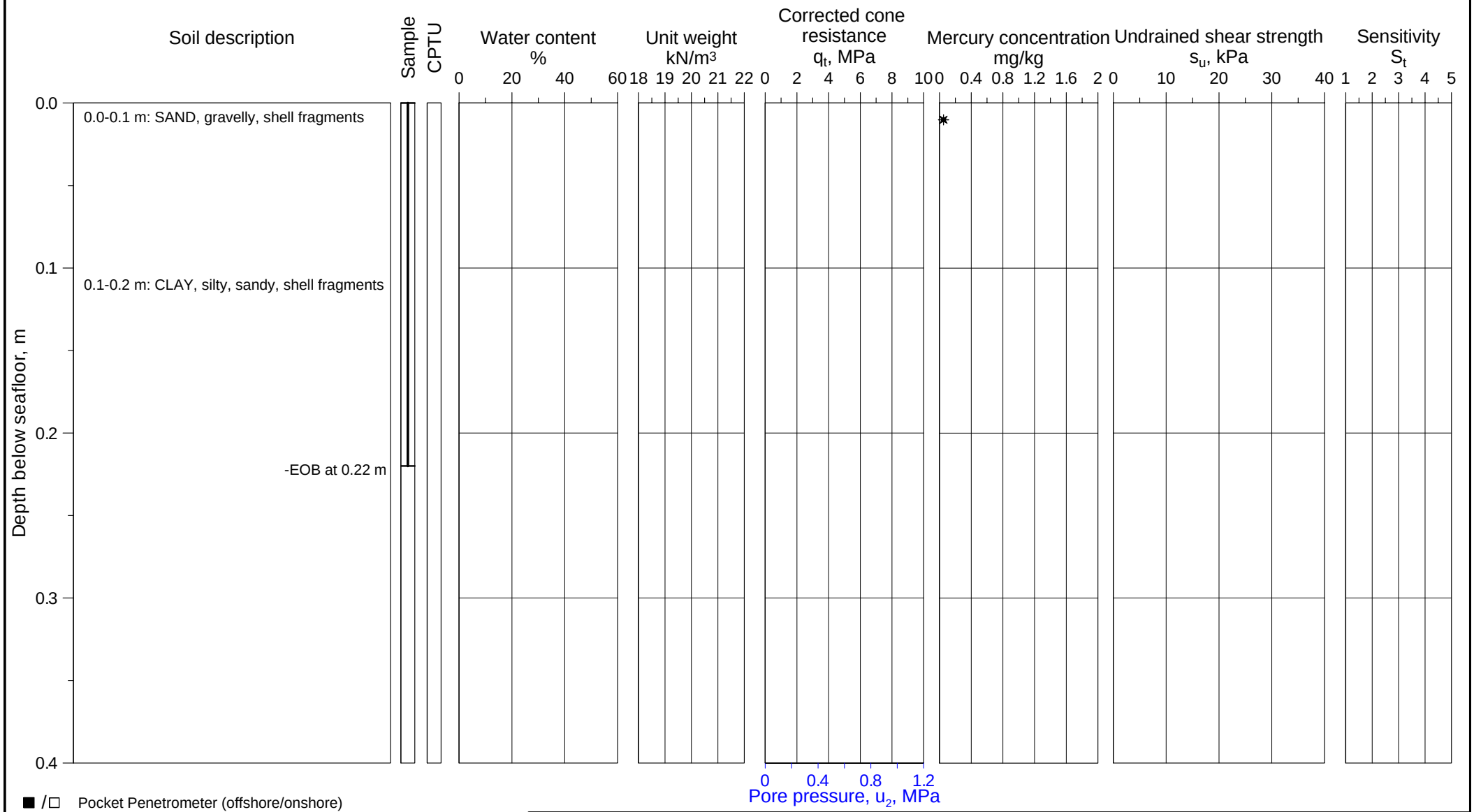

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✤ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-31	261 381.9 mE	6 745 145.3 mN	144.9 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.26

Drawn by ES

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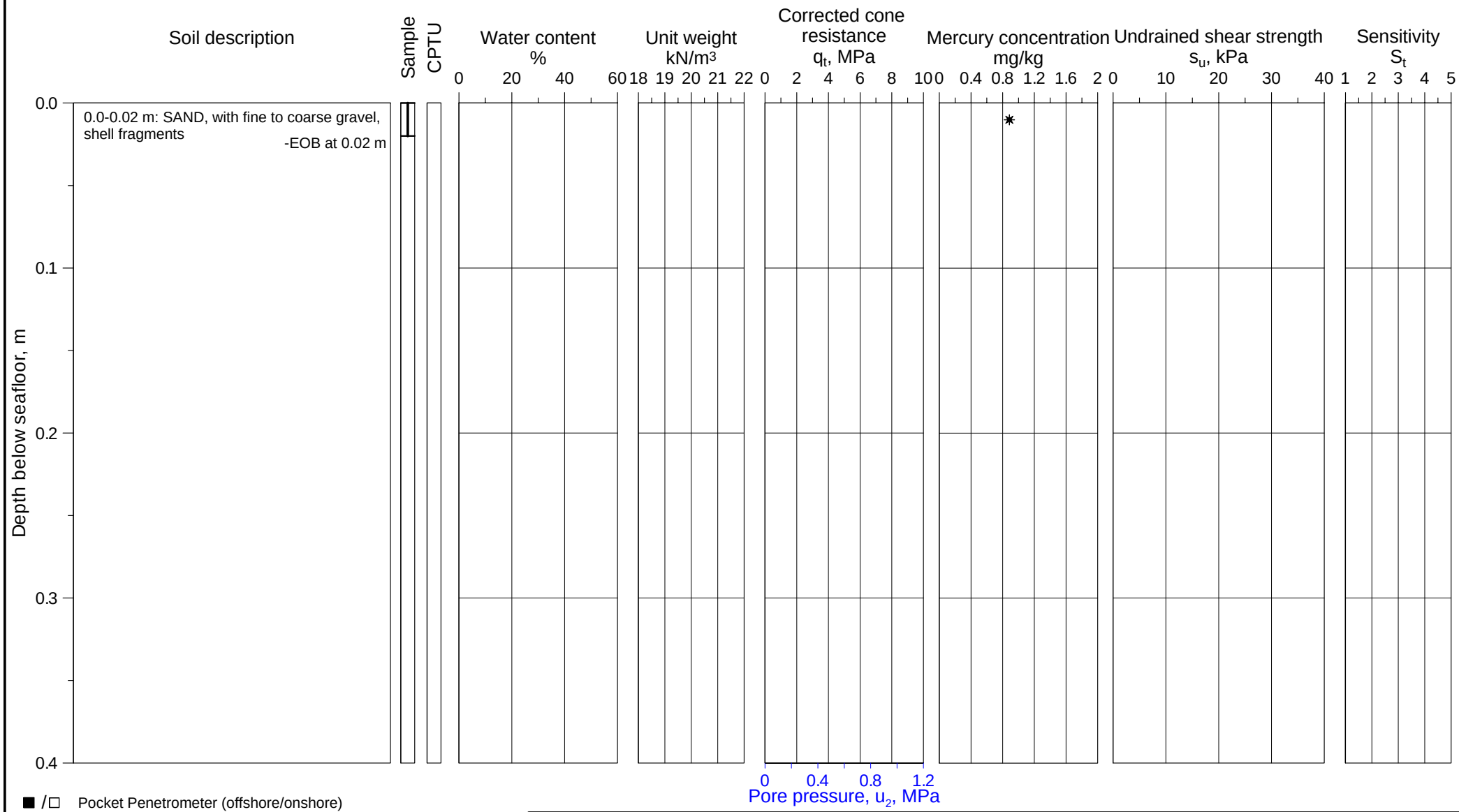

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ / ♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✤ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-88	261 469.7 mE	6 745 106.5 mN	138.8 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.27

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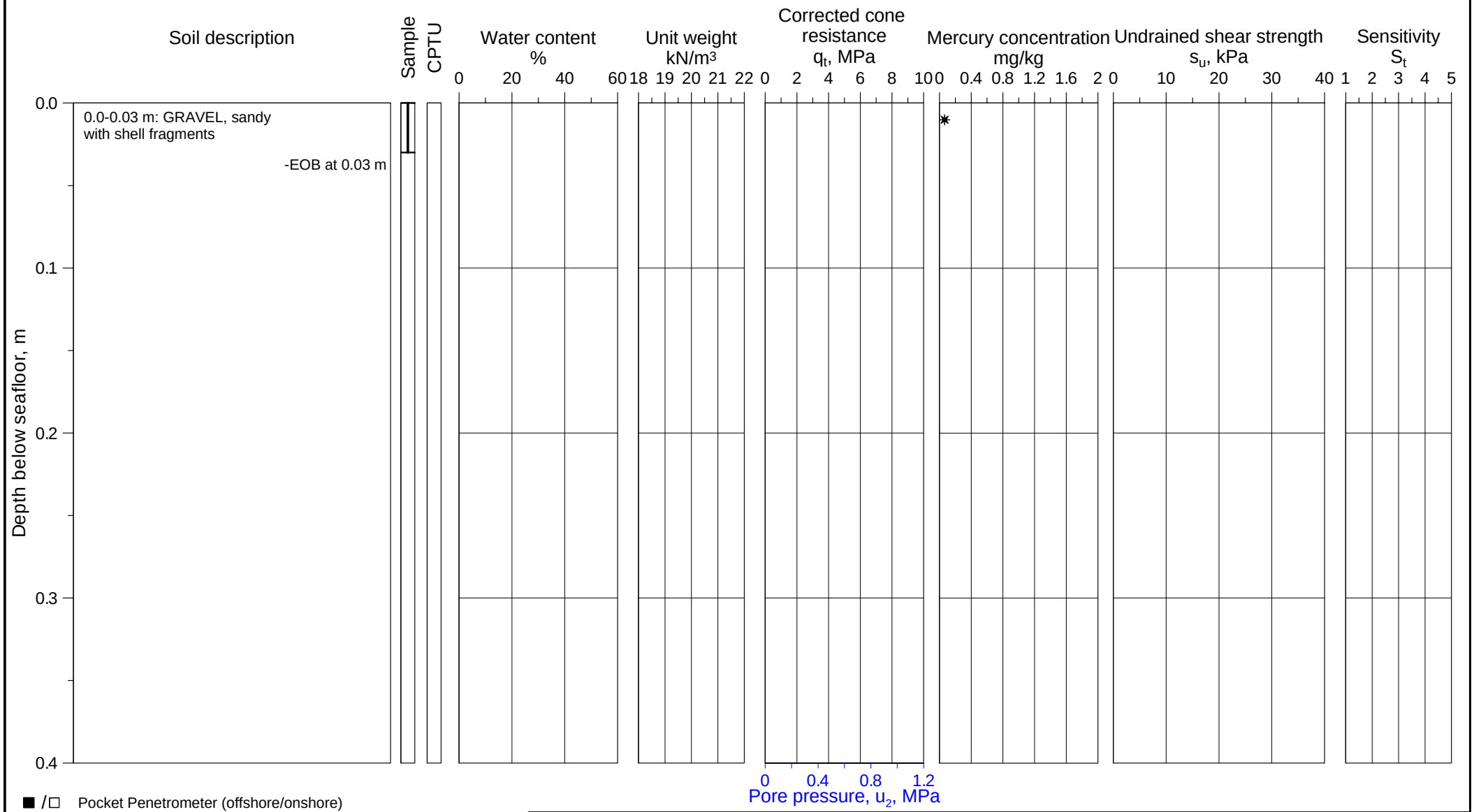

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ / ♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✤ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-142	261 685.6 mE	6 745 249.6 mN	152.8 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.28

Drawn by ES

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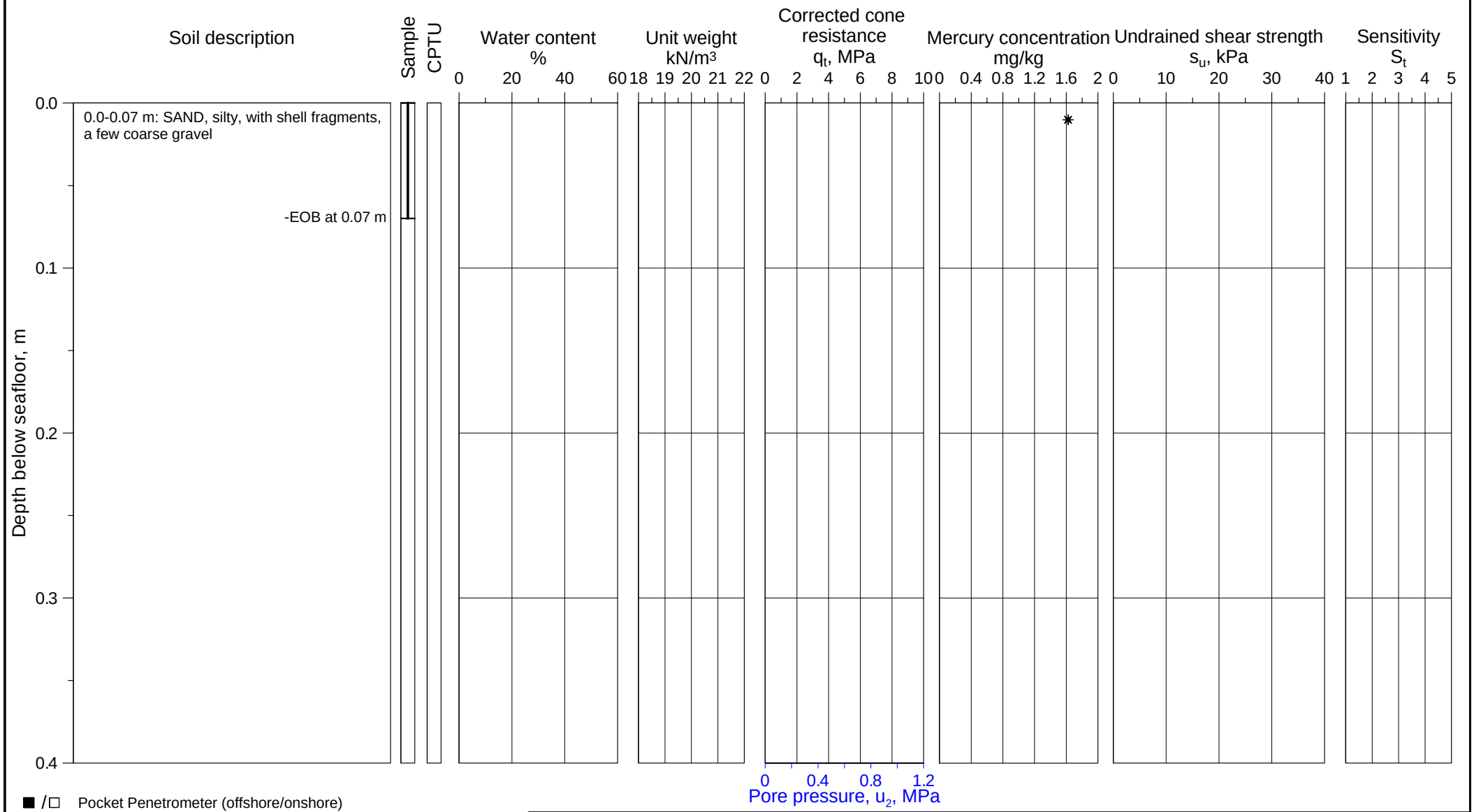

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /♦ Vane (lab offshore/in situ)
$\oplus_C$ CAUC/CIUC
$\oplus_E$ CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✥ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✥ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-146	261 574.4 mE	6 745 250.1 mN	177.6 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.29

Drawn by ES

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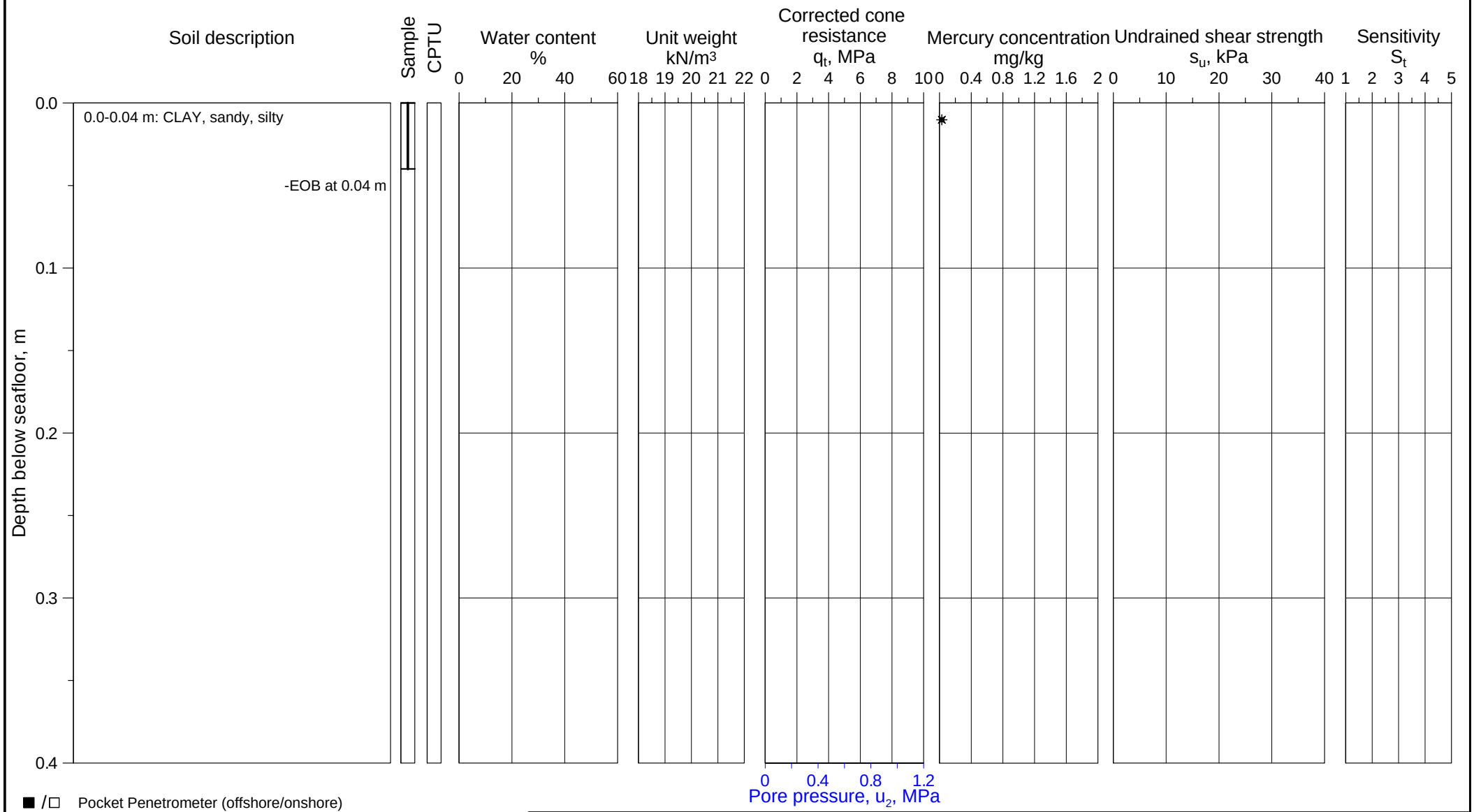

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✥ γt (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γt (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✥ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, Ip

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-155	261 624.7 mE	6 745 133.0 mN	164.8 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.30

Drawn by ES

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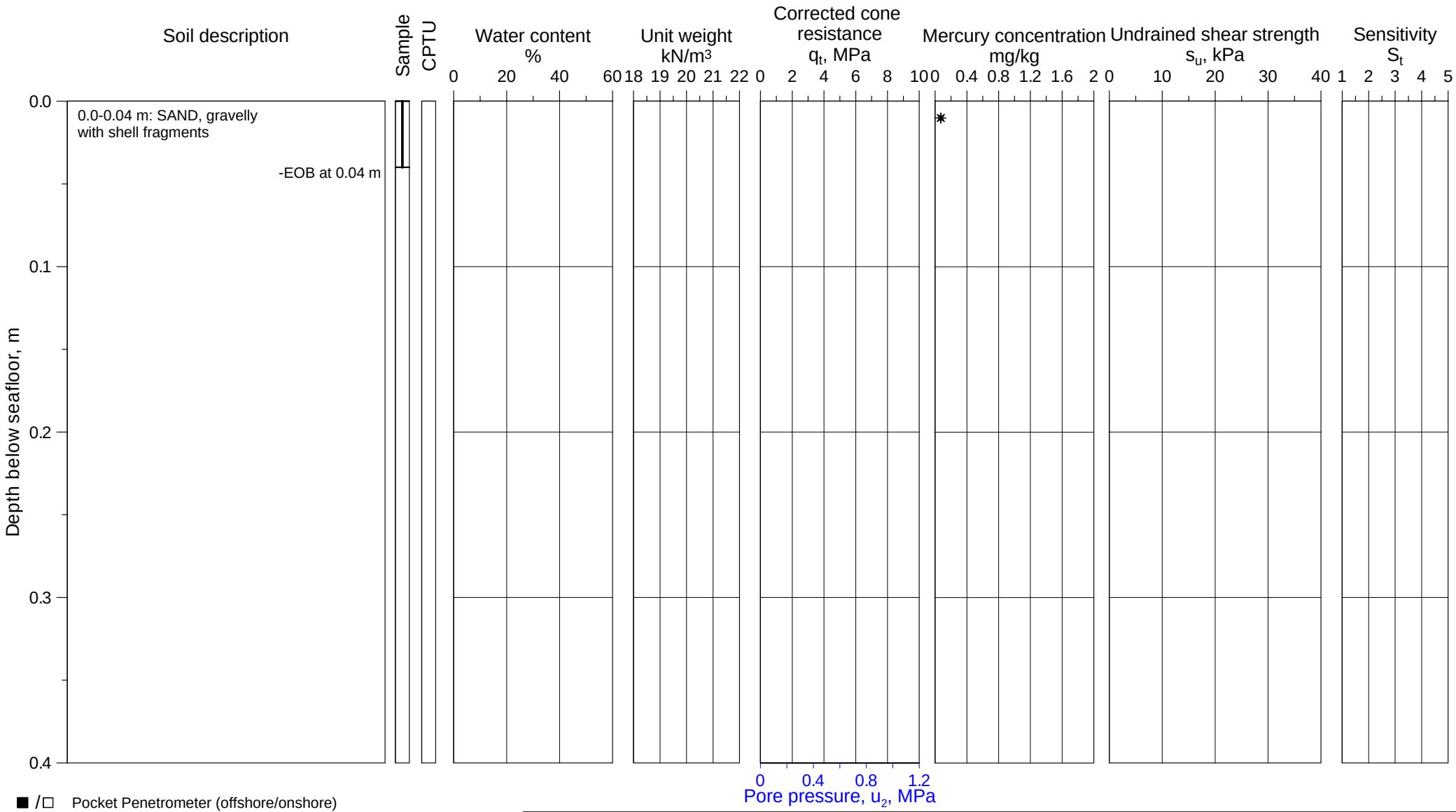

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ / ♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✤ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-204	261 683.2 mE	6 745 090.2 mN	151.1 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.31

Drawn by ES

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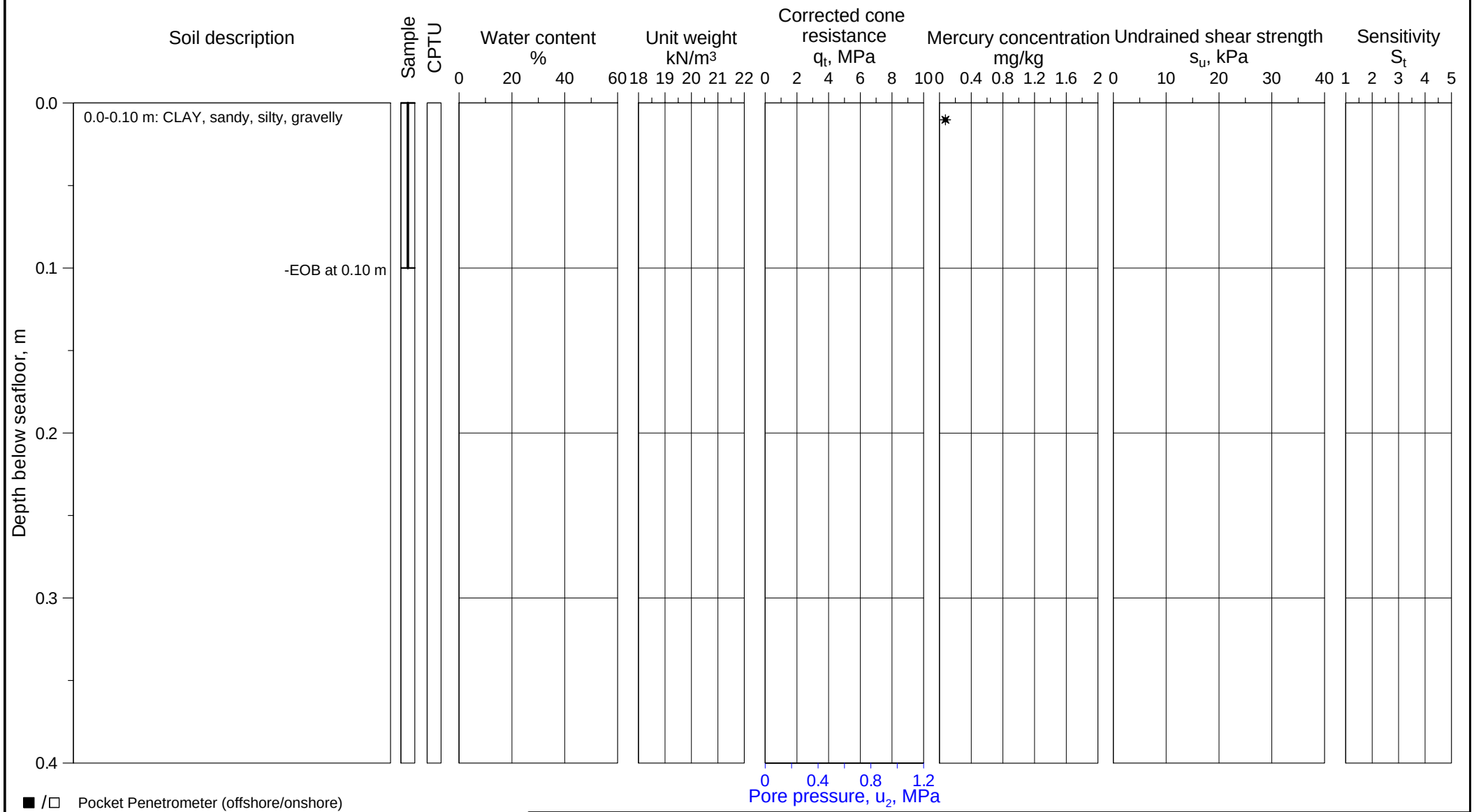

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✣ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✣ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-206	261 646.9 mE	6 745 035.2 mN	147.5 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.32

Drawn by ES

NGI

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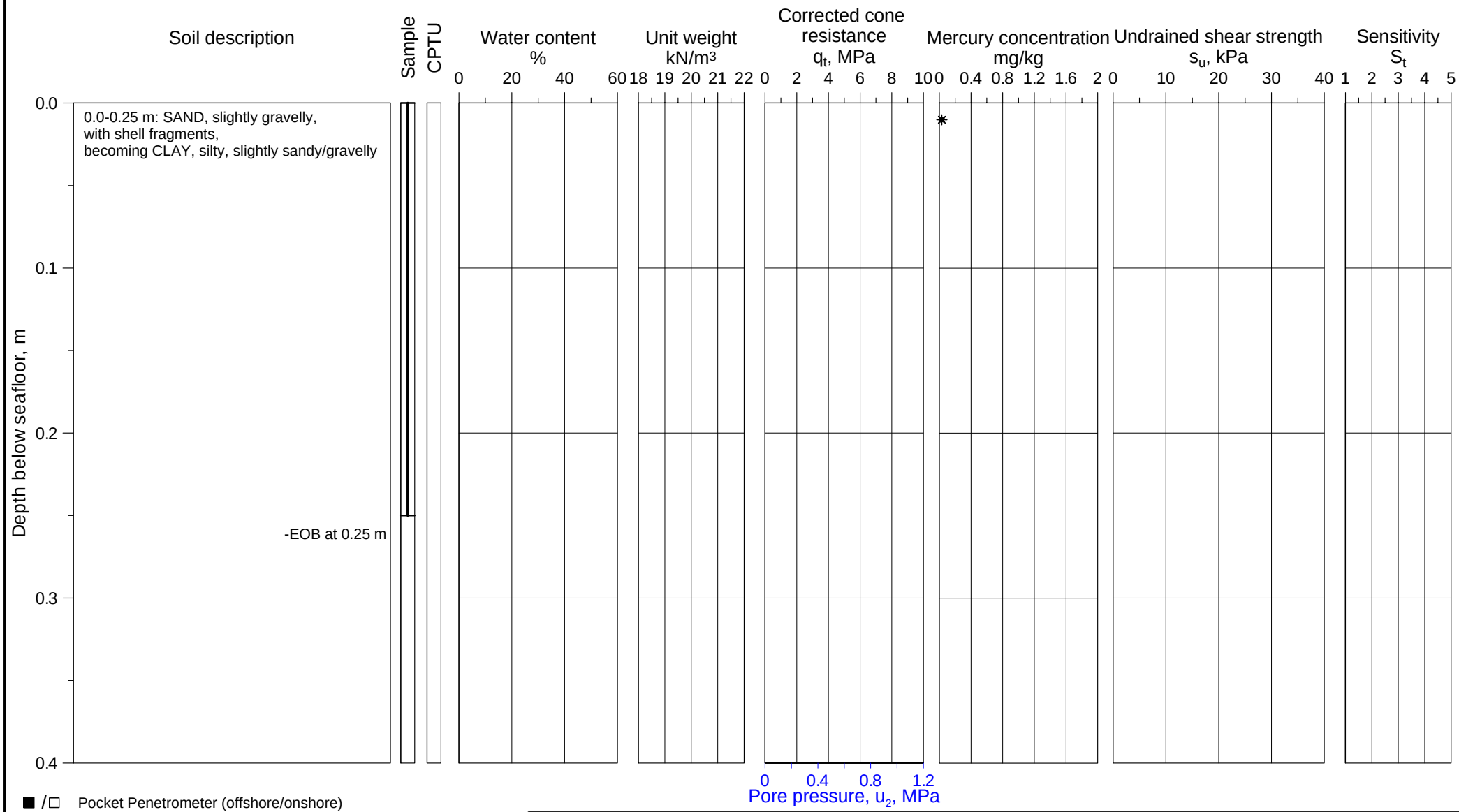


■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /♦ Vane (lab offshore/in situ)
$\oplus_C$ CAUC/CIUC
$\oplus_E$ CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✤ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-210	261 640.3 mE	6 745 133.0 mN	143.8 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

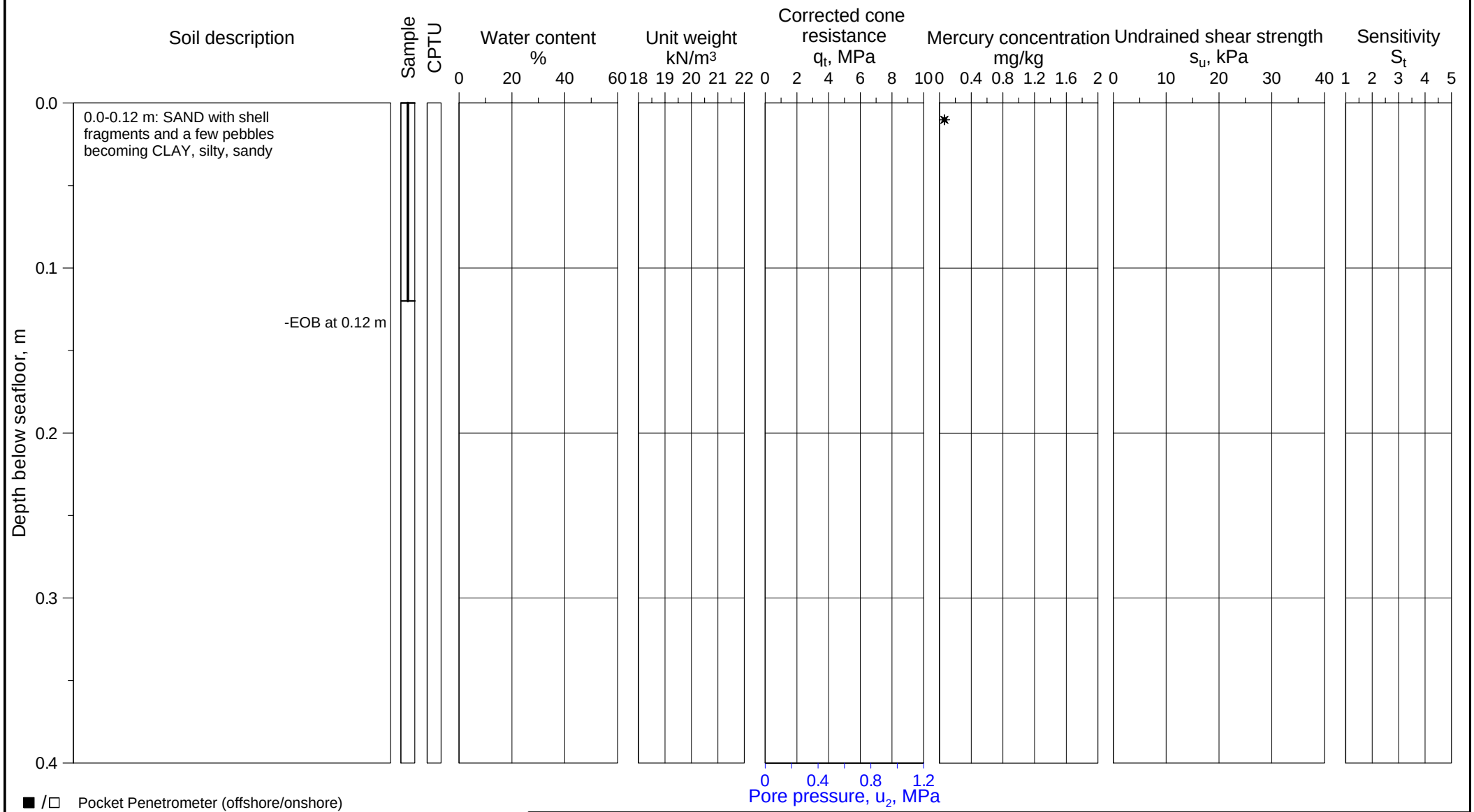
Date 2013-03-15

Figure No. B1.33

Drawn by ES

NGI

P:\2012\07\20120738\Feltarbeid\2013-210\Fig B1_33 2013-210.grf



■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✣ γt (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γt (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✣ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, Ip

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-211	261 615.0 mE	6 745 057.0 mN	146.8 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.34

Drawn by ES

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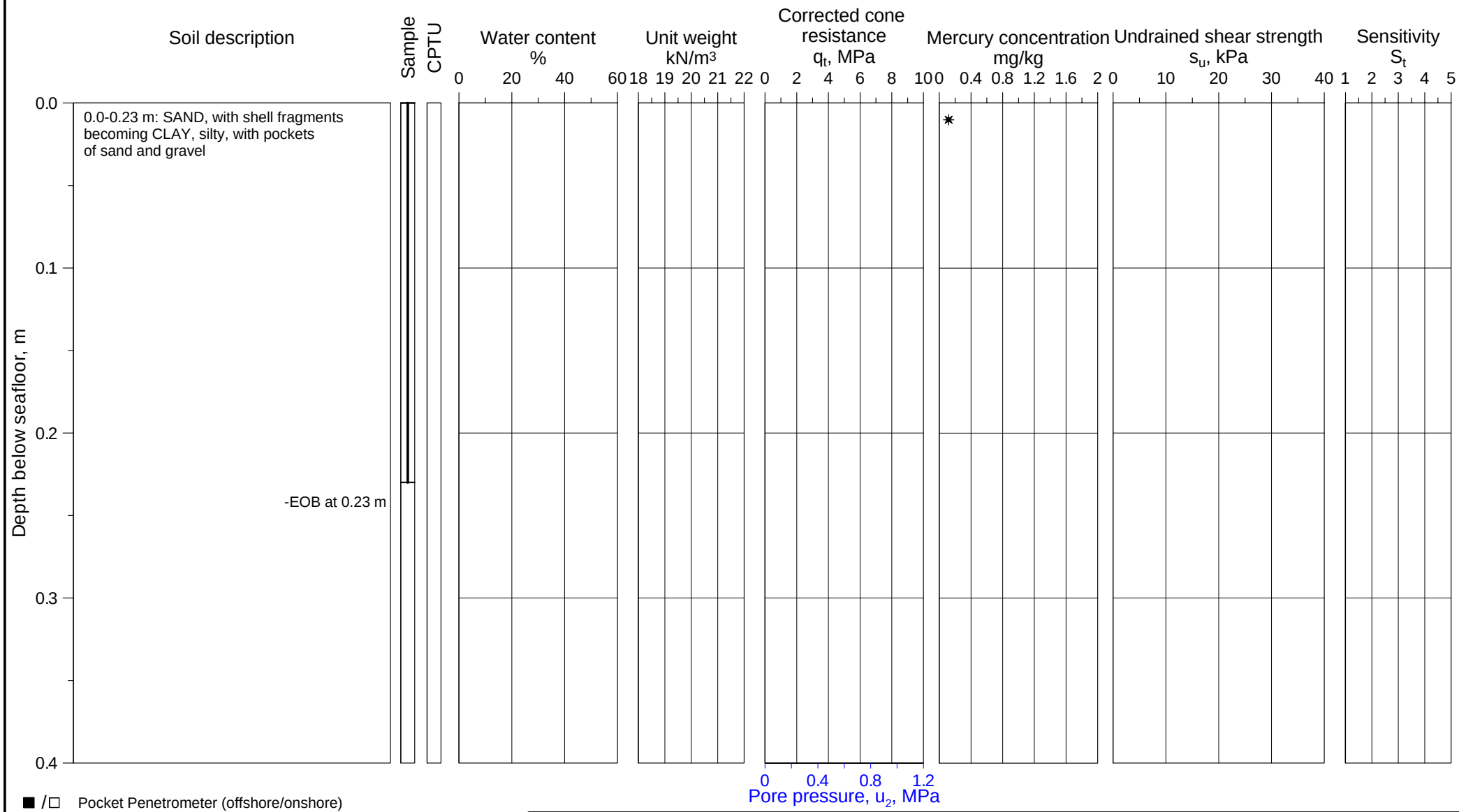
P:\2012\07\20120738\Feltarbeid\2013-211\Fig B1_34 2013-211.grf



■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✣ γt (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γt (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✣ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, Ip

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-213	261 607.3 mE	6 745 083.5 mN	147.0 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.35

Drawn by ES

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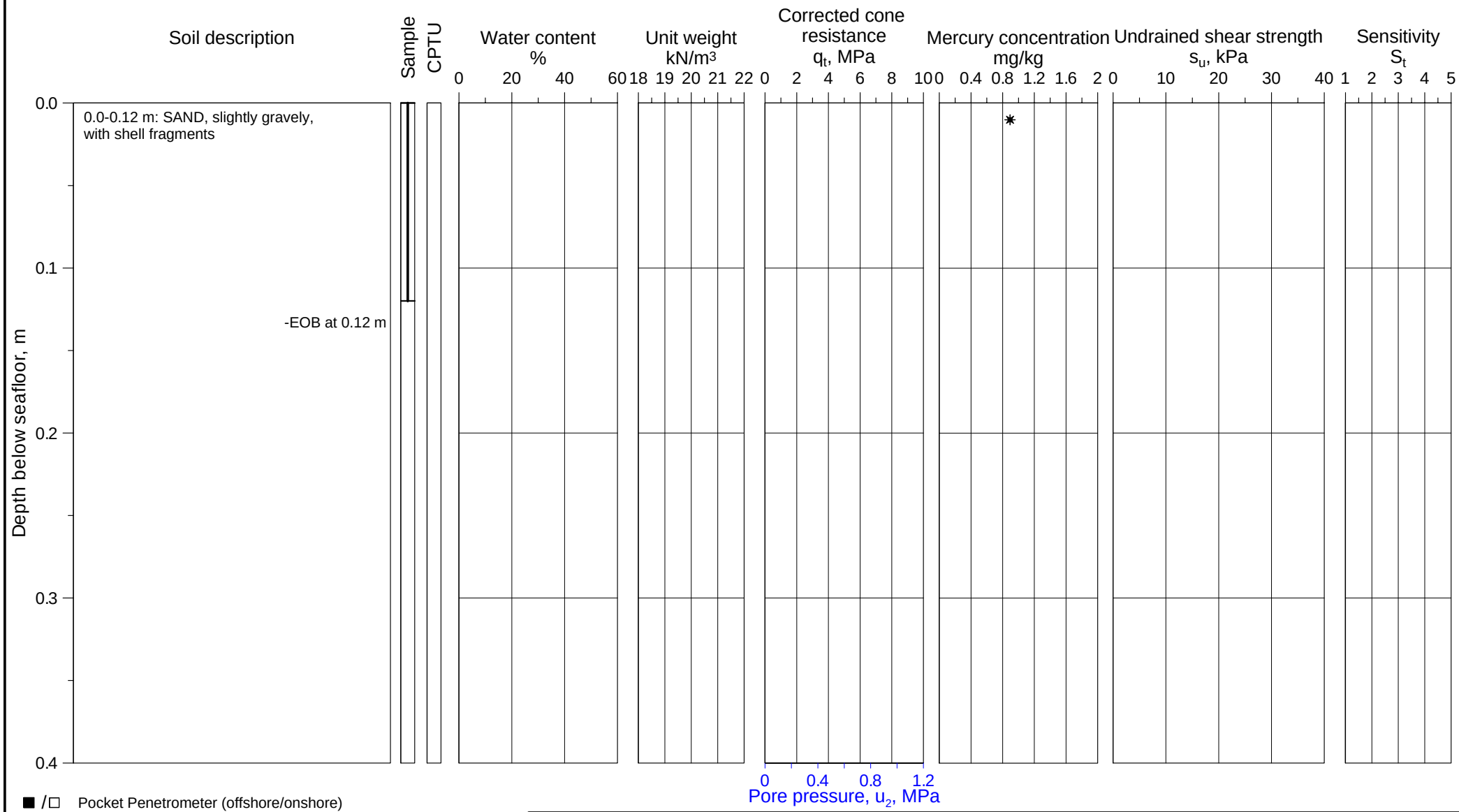
P:\2012\07\20120738\Feltarbeid\2013-213\Fig B1_35 2013-213.grf



■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ / ♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✤ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-301	261 507.3 mE	6 745 240.5 mN	177.9 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.36

Drawn by ES

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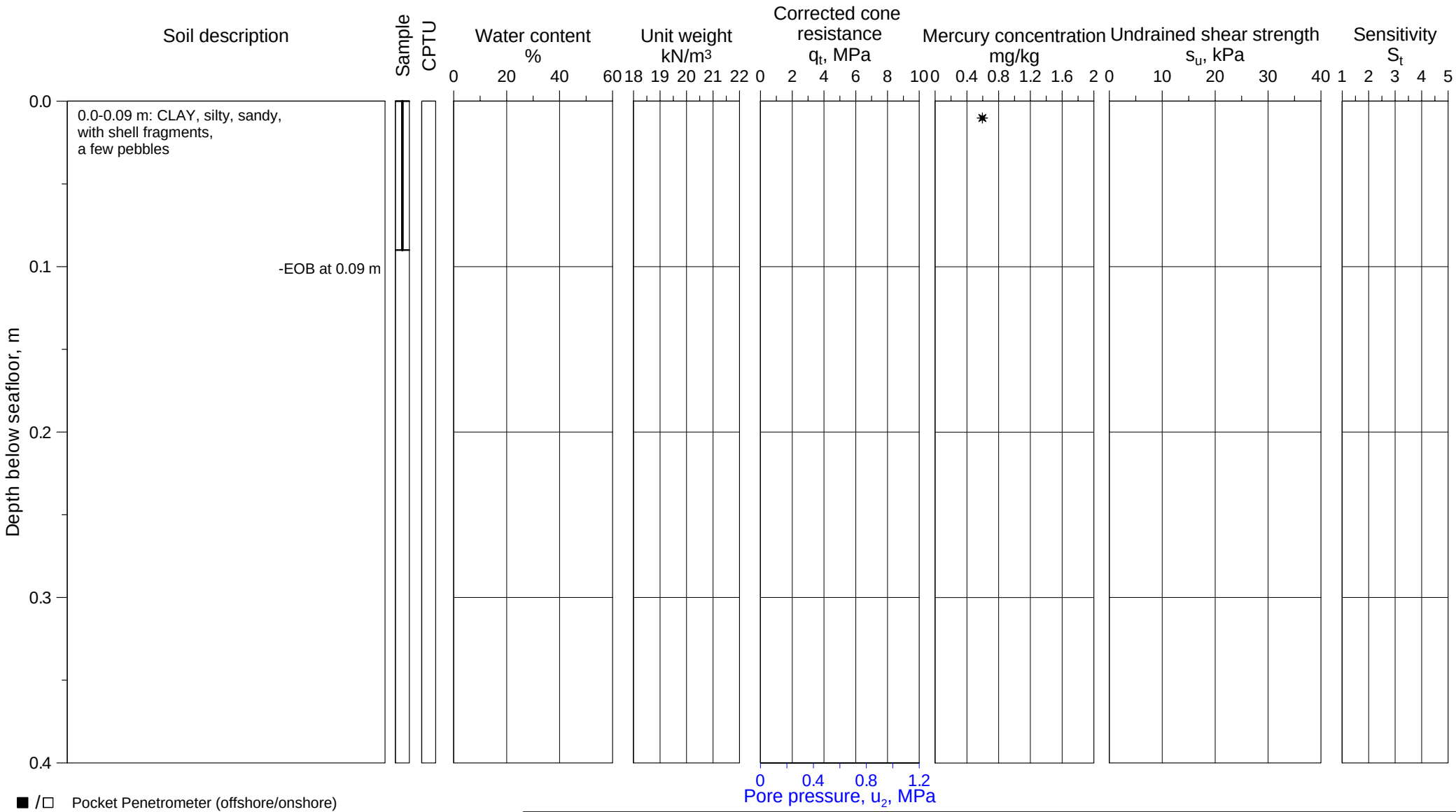
P:\2012\07\20120738\Feltarbeid\2013-301\Fig B1_36 2013-301.grf



■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✣ γt (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γt (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✣ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, Ip

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-302	261 543.4 mE	6 745 275.8 mN	174.9 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.37

Drawn by ES

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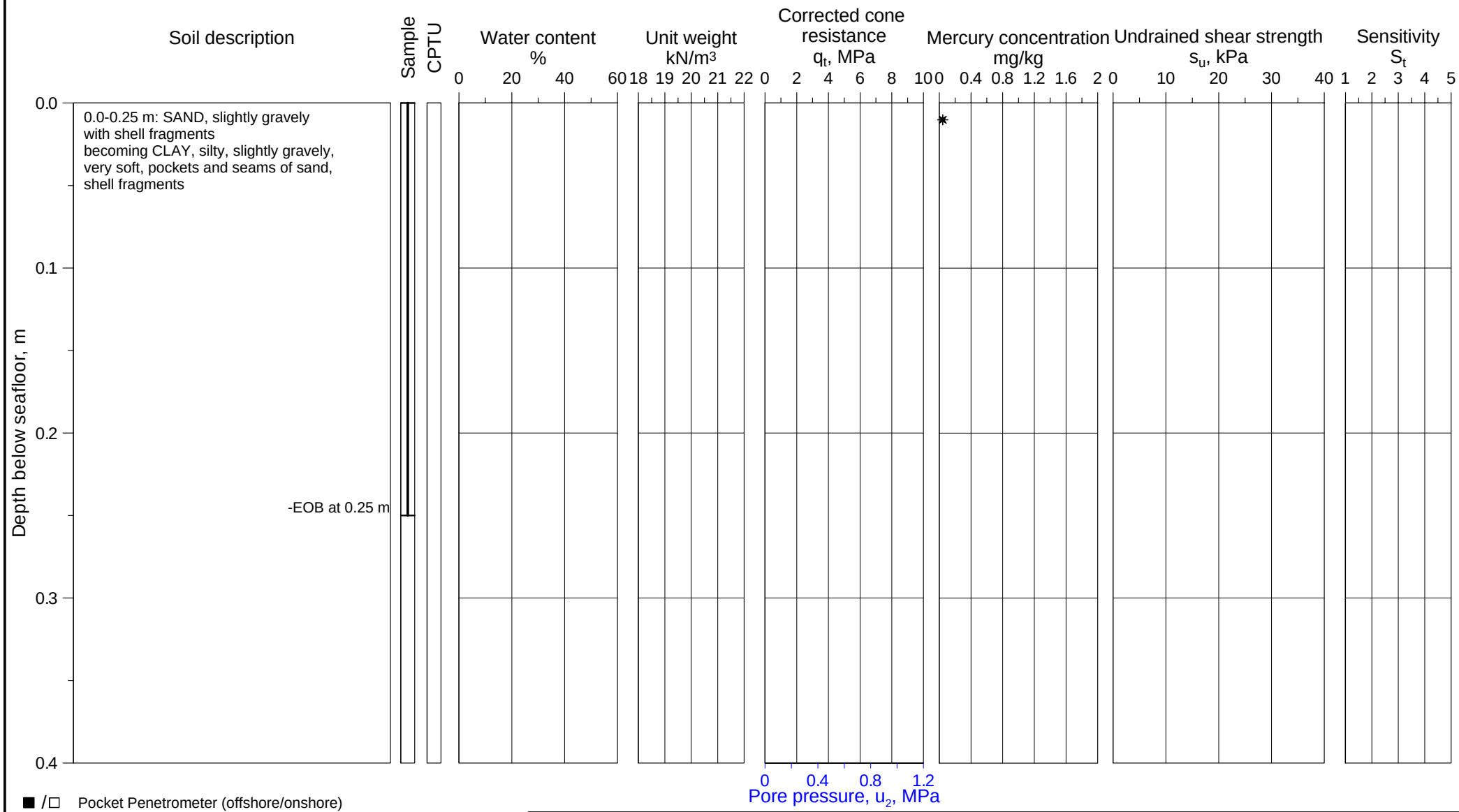
P:\2012\07\20120738\Feltarbeid\2013-302\Fig B1_37 2013-302.grf



■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ γt (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γt (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✤ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, Ip

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-306	261 697.8 mE	6 745 275.7 mN	153.2 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

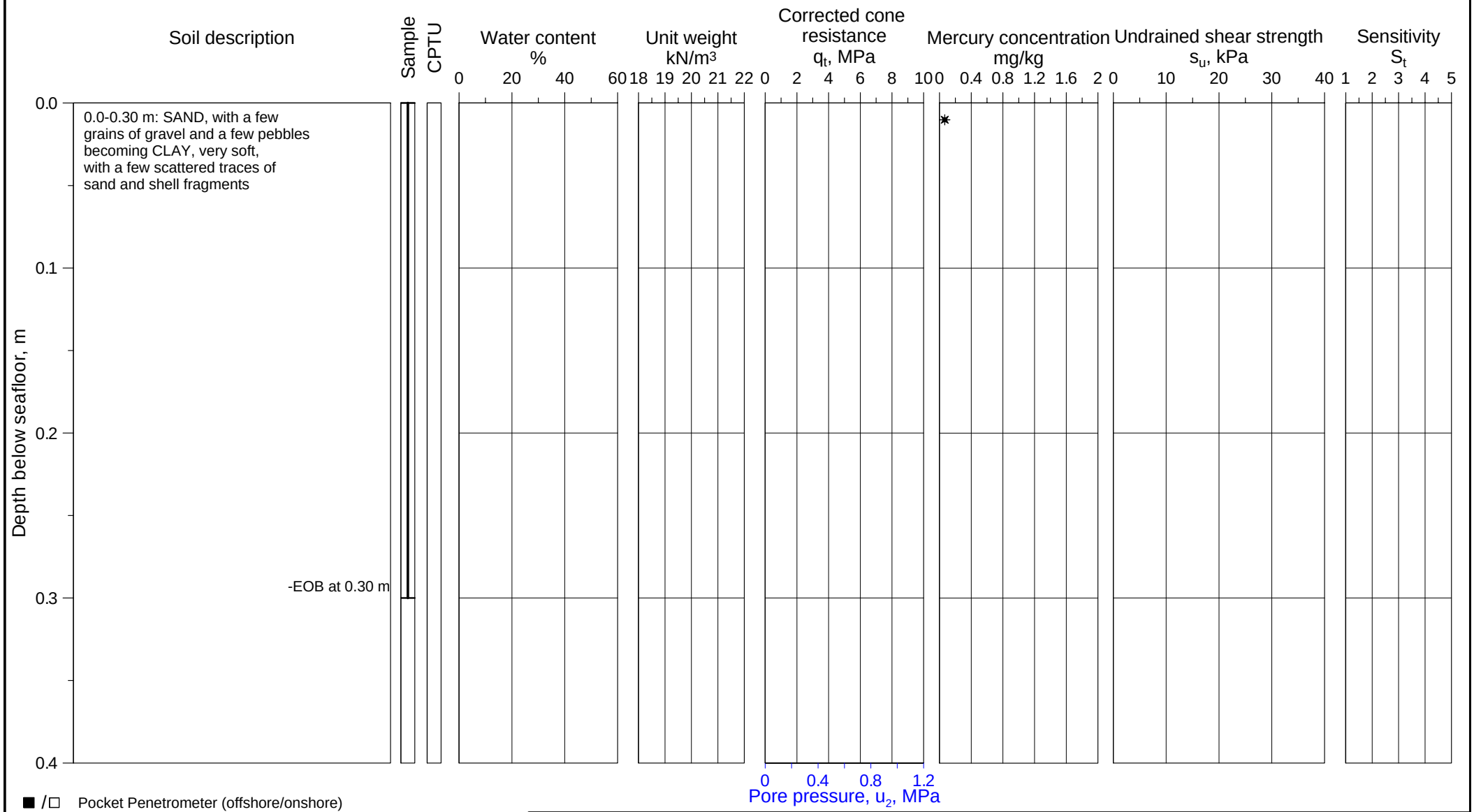
Date 2013-03-15

Figure No. B1.38

Drawn by ES

NGI

P:\2012\07\20120738\Feltarbeid\2013-306\Fig B1_38 2013-306.grf



■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✤ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-308	261 597.2 mE	6 745 314.5 mN	154.4 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.39

Drawn by ES

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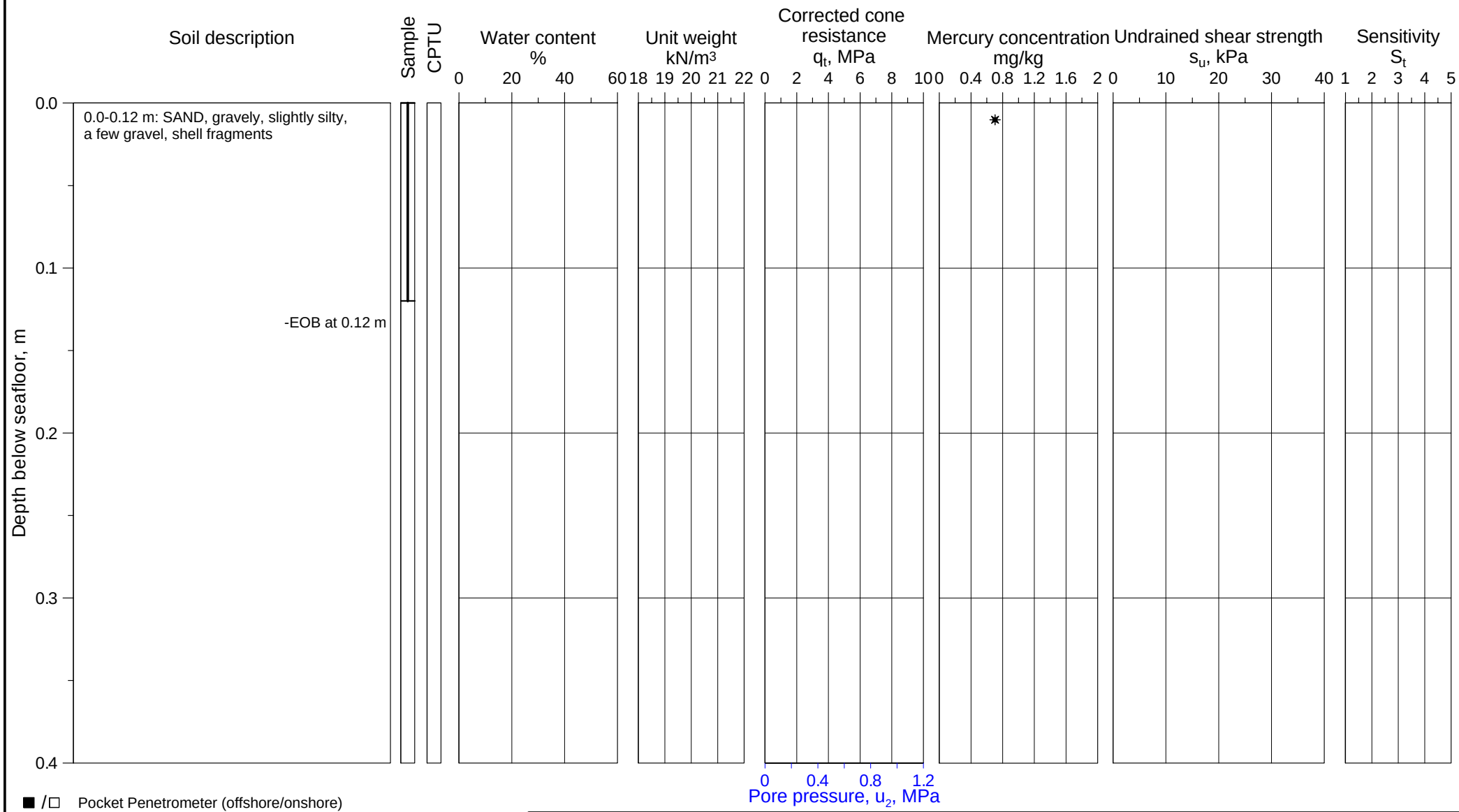
P:\2012\07\20120738\Feltarbeid\2013-308\Fig B1_39 2013-308.grf



■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ / ♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✤ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-312	261 432.5 mE	6 745 307.6 mN	176.2 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.40

Drawn by ES

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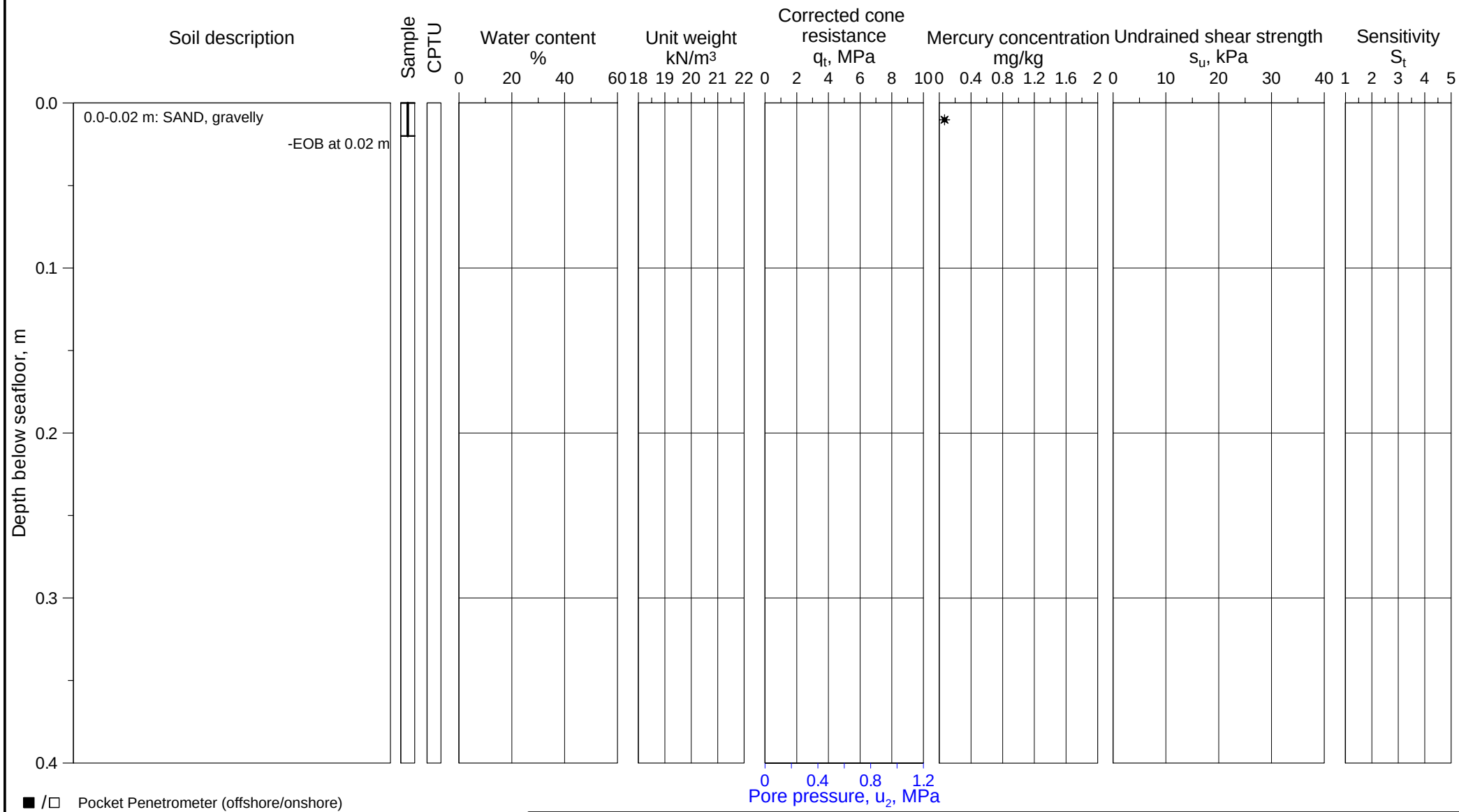
P:\2012\07\20120738\Feltarbeid\2013-312\Fig B1_40 2013-312.grf



■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✣ γt (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γt (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✣ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, Ip

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-313	261 359.2 mE	6 745 280.1 mN	180.1 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.41

Drawn by ES

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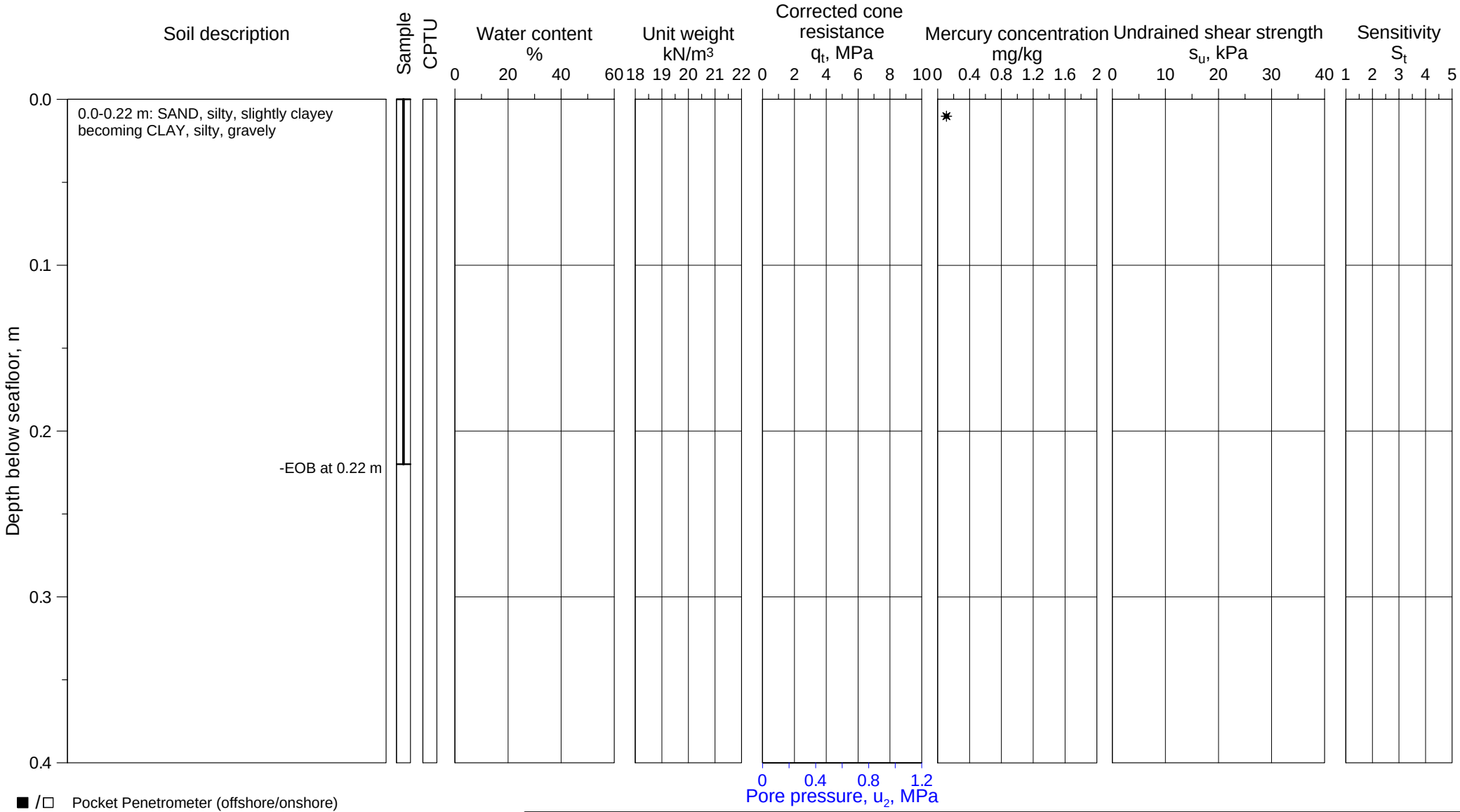


■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✤ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-315	261 344.8 mE	6 745 184.5 mN	152.3 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

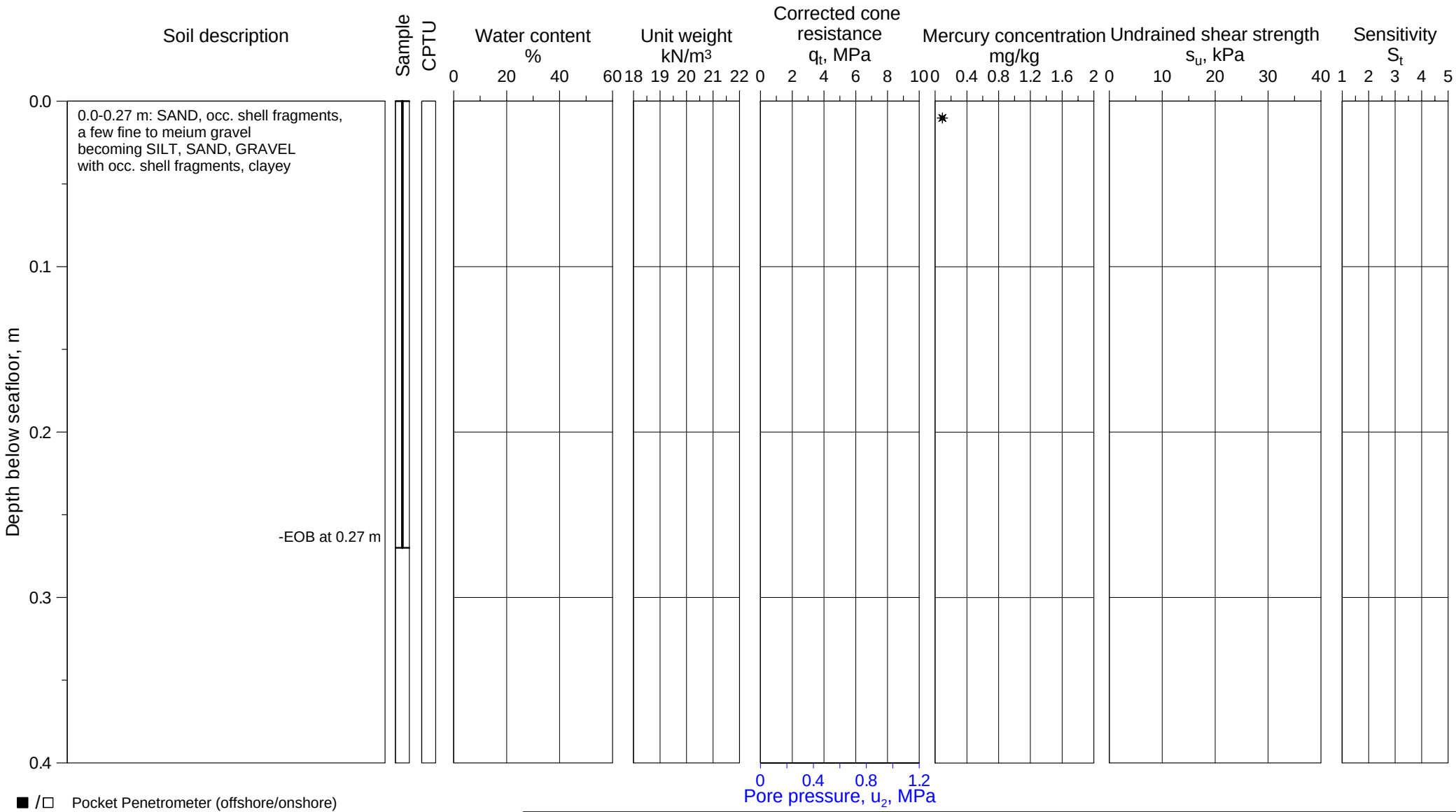
Date 2013-03-15

Figure No. B1.42

Drawn by ES

NGI

P:\2012\07\20120738\Feltarbeid\2013-315\Fig B1_42 2013-315.grf



■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✤ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-316	261 340.8 mE	6 745 134.7 mN	147.1 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.43

Drawn by ES

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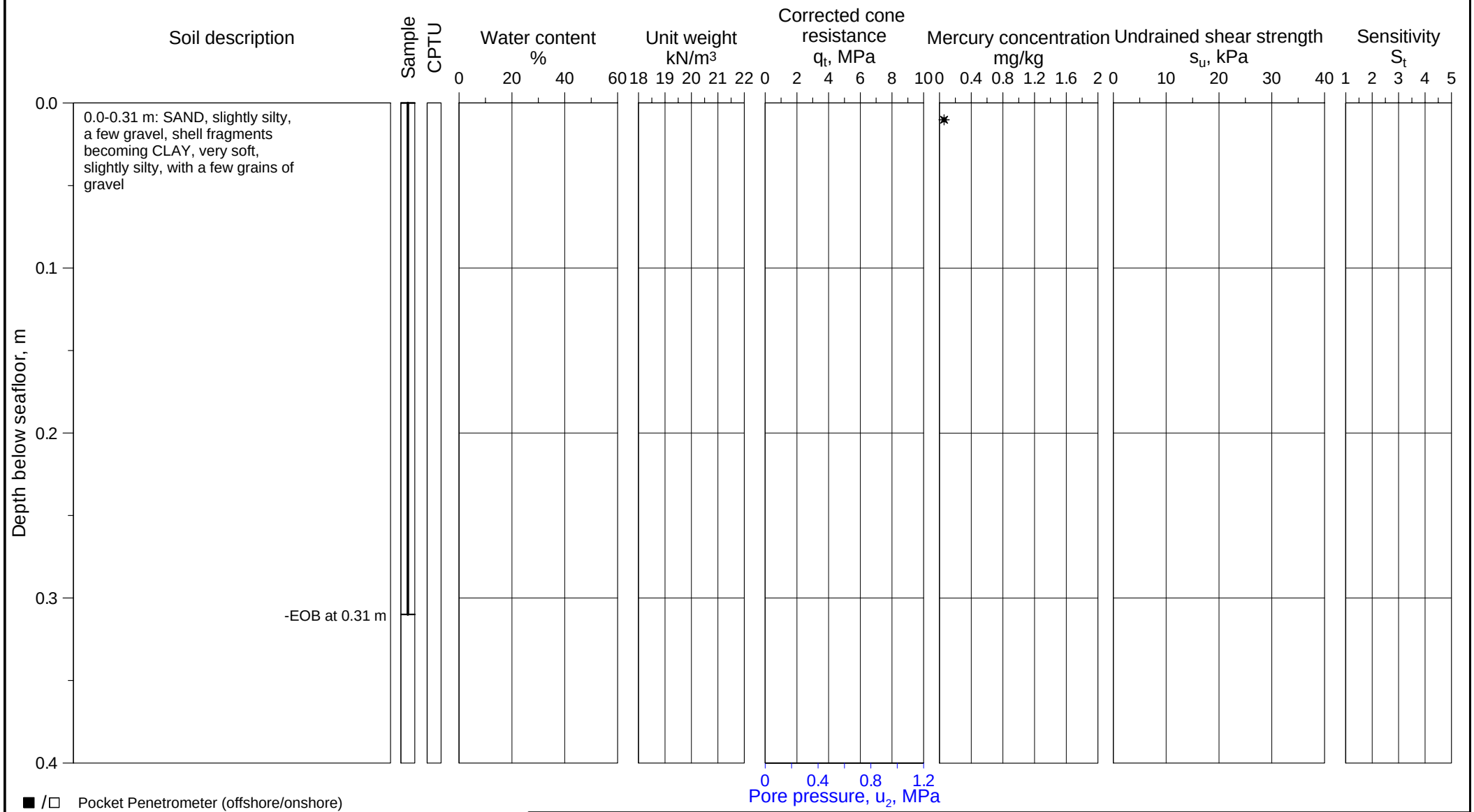
P:\2012\07\20120738\Feltarbeid\2013-316\Fig B1_43 2013-316.grf



■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✤ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-317	261 465.2 mE	6 745 152.8 mN	141.8 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

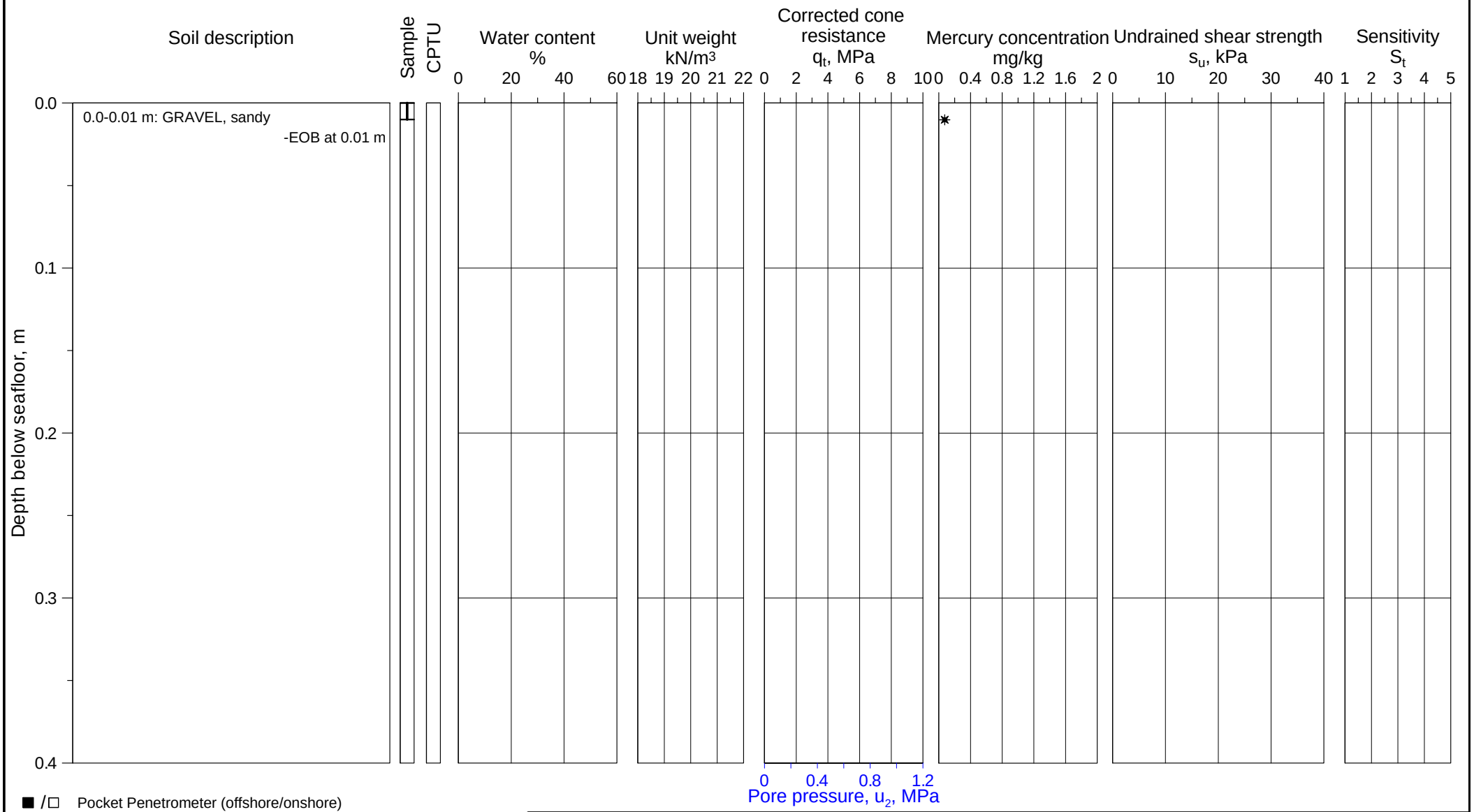
Date 2013-03-15

Figure No. B1.44

Drawn by ES

NGI

P:\2012\07\20120738\Feltarbeid\2013-317\Fig B1_44 2013-317.grf



■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ γt (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γt (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✤ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, Ip

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-320	261 357.2 mE	6 745 232.0 mN	168.7 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

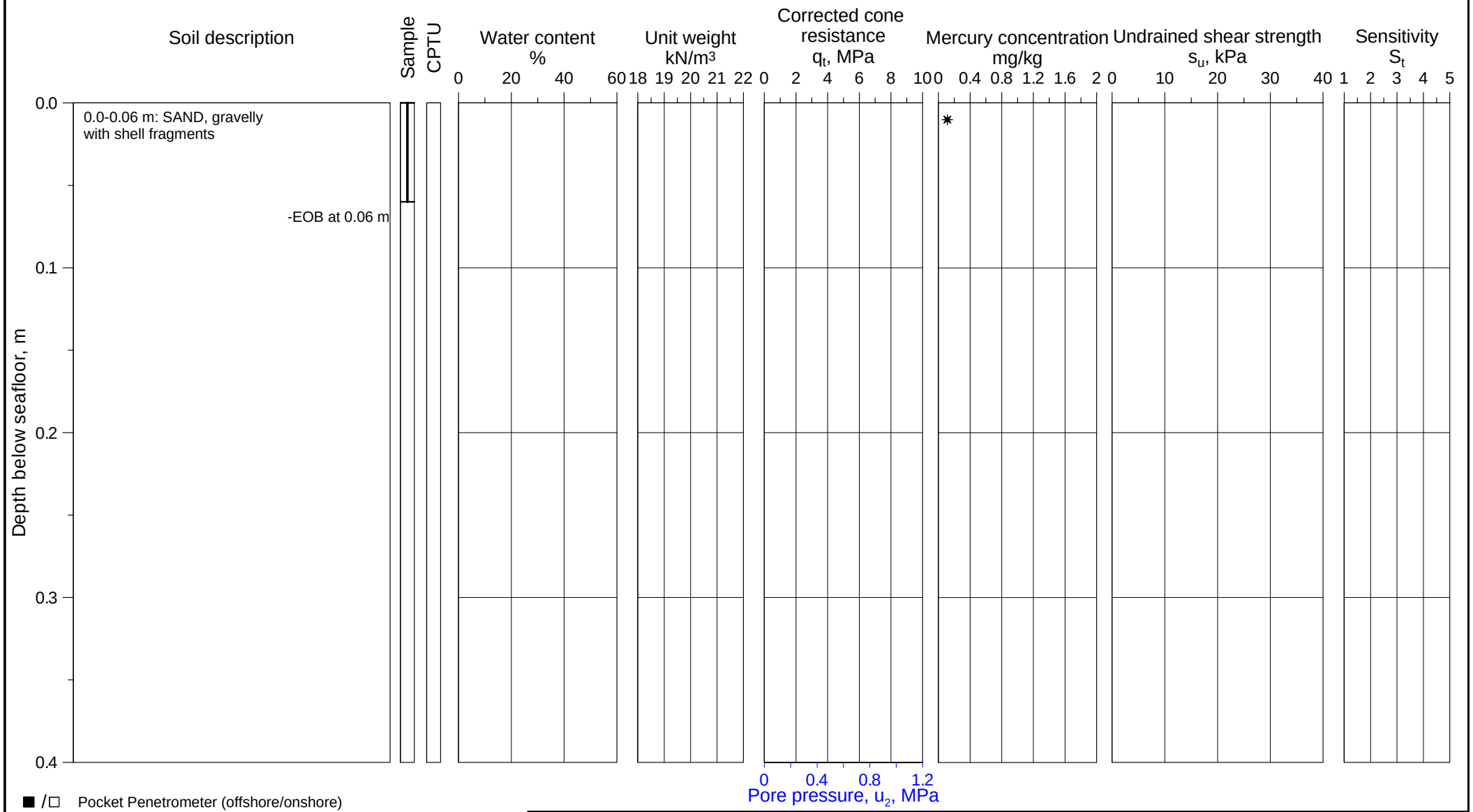
Date 2013-03-15

Figure No. B1.45

Drawn by ES

NGI

P:\2012\07\20120738\Feltarbeid\2013-320\Fig B1_45 2013-320.grf



■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ / ♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✤ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-324	261 671.8 mE	6 745 111.7 mN	160.0 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.46

Drawn by ES

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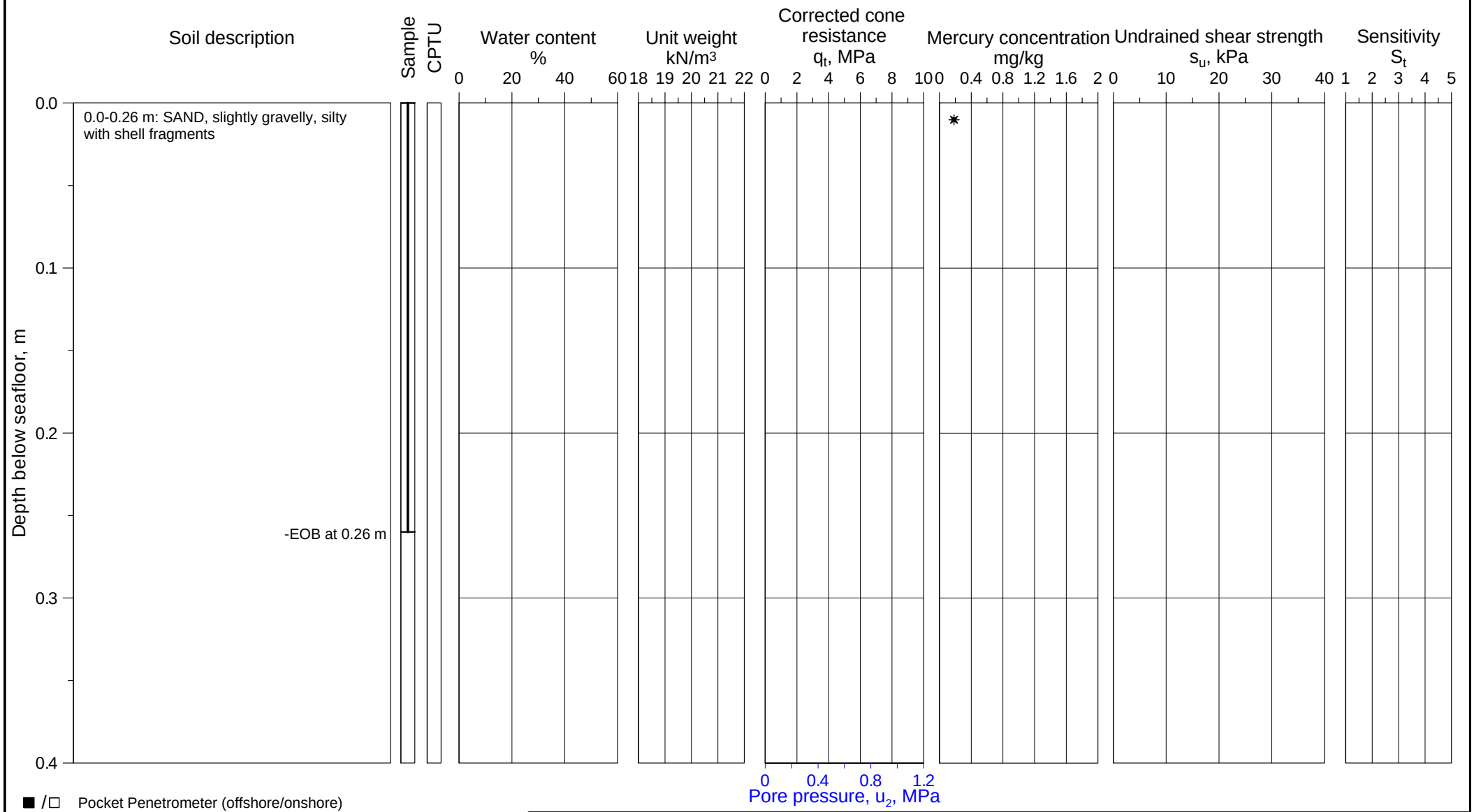
P:\2012\07\20120738\Feltarbeid\2013-324\Fig B1_46 2013-324.grf



■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ / ♦ Vane (lab offshore/in situ)
$\oplus_C$ CAUC/CIUC
$\oplus_E$ CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✤ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-331	261 600.3 mE	6 745 036.7 mN	147.6 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

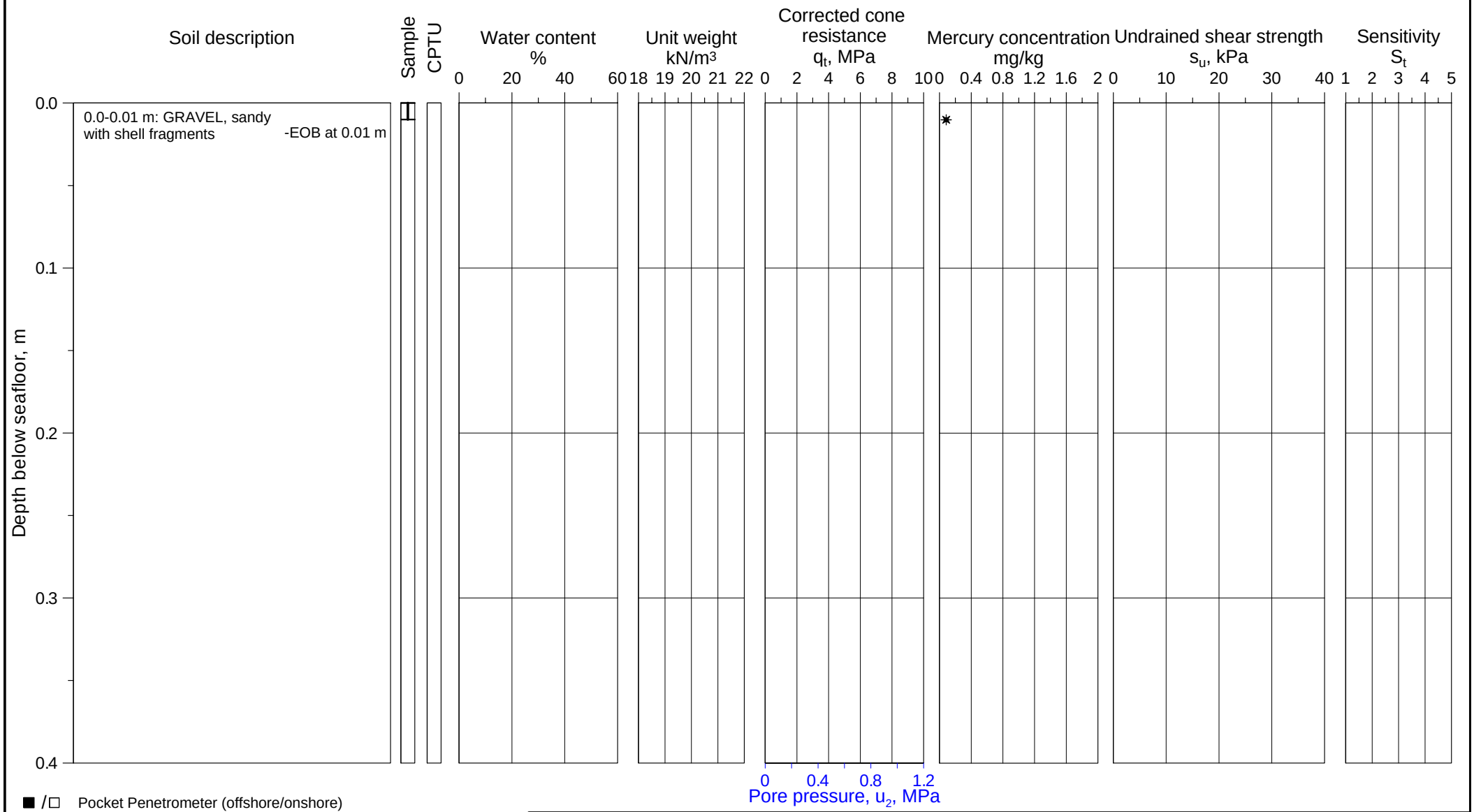
Date 2013-03-15

Figure No. B1.47

Drawn by ES

NGI

P:\2012\07\20120738\Feltarbeid\2013-331\Fig B1_47 2013-331.grf



■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ / ♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✤ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-332	261 622.4 mE	6 744 998.7 mN	144.6 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.48

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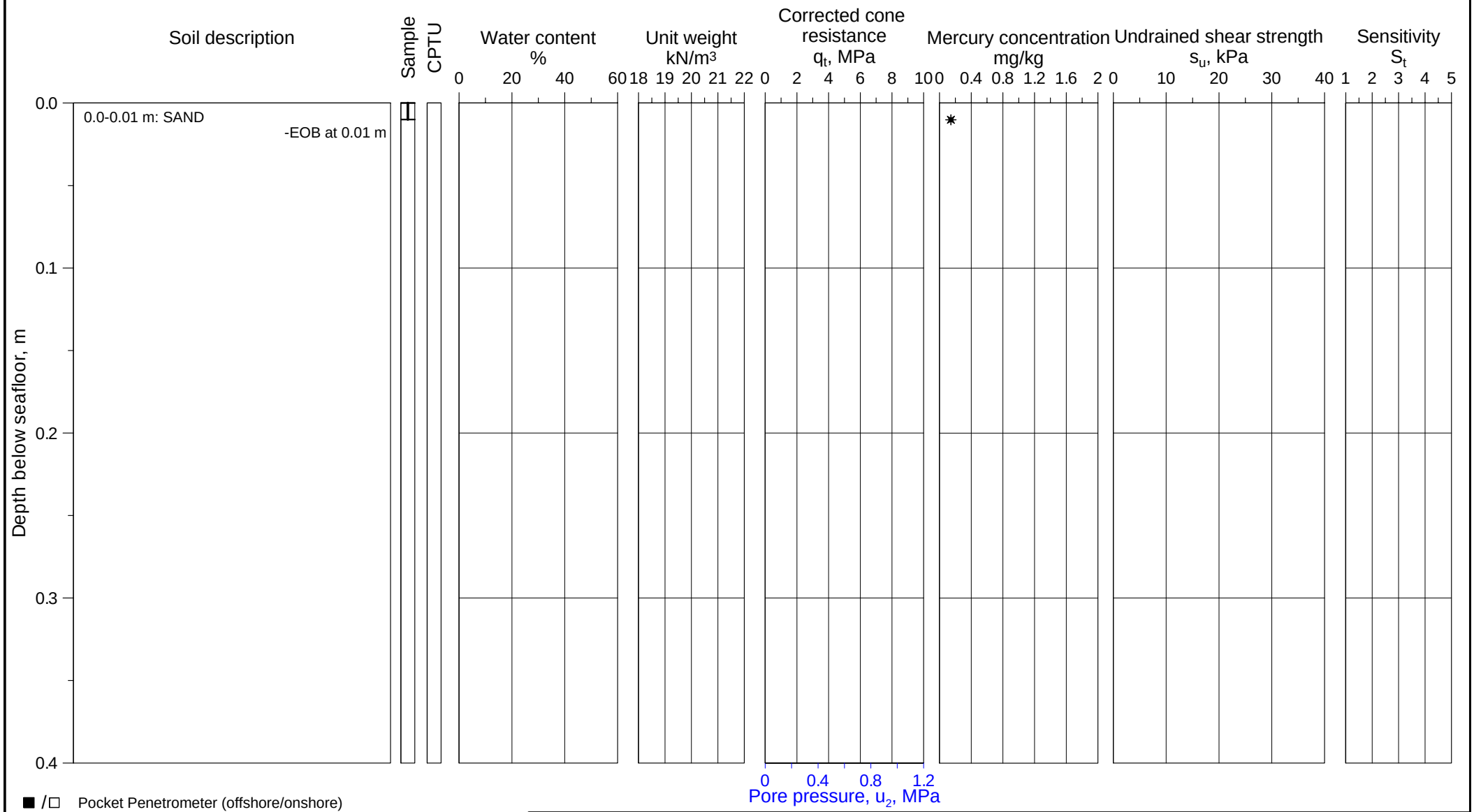

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✜ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✜ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-333	261 653.8 mE	6 744 987.7 mN	142.4 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.49

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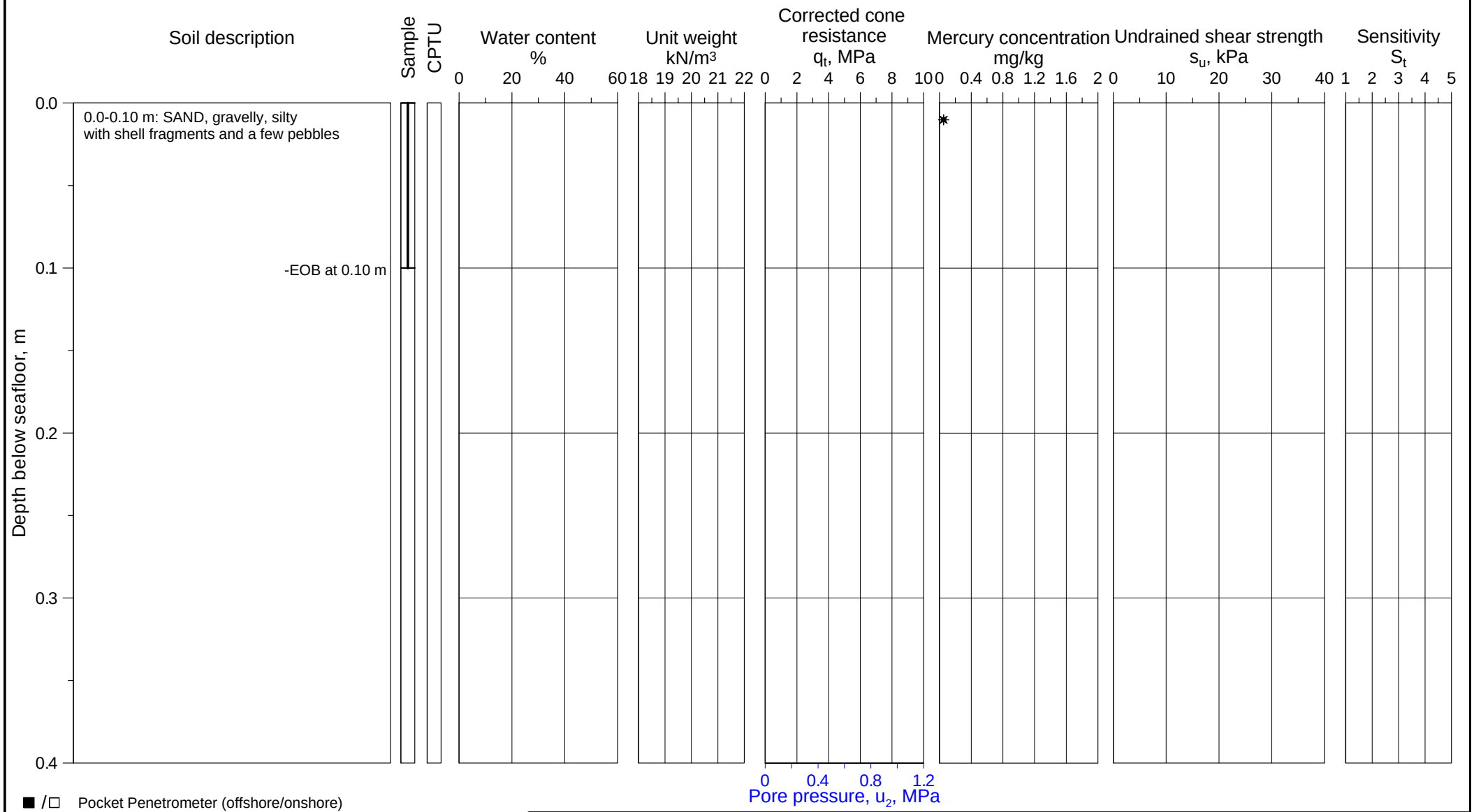

■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ / ♦ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✜ γ_t (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γ_t (offshore/onshore)
✖ /× Sensitivity, fall cone (offshore/onshore)
✳ /✜ Sensitivity, vane (lab offshore/in situ)
⊢⊣ Plasticity index, I_p

U-864 - 2013 SOIL SURVEY

Borehole log and classification test results

Borehole	Easting	Northing	Water Depth
2013-334	261 701.0 mE	6 744 998.8 mN	148.7 m

Coordinate system WGS-84, UTM Zone 32N, CM 9°E

ROV soil sample

Document No. 20120738-01-R

Date 2013-03-15

Figure No. B1.50

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Part B2 - Classification Tests

Contents

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B2.4	**Grain size distribution**	**2**
B2.5	**Liquid and plastic limits**	**2**
B2.6	**Index shear strengths and sensitivity**	**3**
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B2-1 Summary of classification tests, offshore laboratory
B2-2 Summary of classification tests, onshore laboratory

Figures

B2.1 – B2.6 Grain size distribution curves

B2.1 General

A number of classification tests have been performed in the offshore and onshore laboratories in order to obtain basic soil characteristics on samples from the locations where samples were obtained. Most individual test results are given in the borehole logs in Part B1.

Tables B2-1 and B2-2 show a summary of classification tests performed in the offshore and onshore laboratories.

The test procedures for the individual tests are presented in Part B7.

B2.2 Water content

Water contents measured on all sample tubes opened offshore and on selected specimens onshore are presented in the borehole logs in Part B1.

B2.3 Total unit weight

The measured results are presented in the borehole logs in Part B1. Total unit weight as measured on all advanced tests as well as the values based on water content measurements are presented in the borehole logs, assuming a unit weight of solid particles of 27.3 kN/m^3 and 100 % saturation.

B2.4 Grain size distribution

The grain size distribution was determined on selected samples. Grain size distributions are found using the falling drop method (Moum, 1965) for the clay and silt fractions, and by wet sieving for the coarser fractions. See Part B7 for description of test procedure. Numerical values for the clay, silt and sand fractions are listed in Table B2-2.

The detailed grain size distribution curves are presented in Figures B2.1 to B2.6.

B2.5 Liquid and plastic limits

The liquid limit, w_L, and the plastic limit, w_p, have been determined on selected samples. The measured w_L and w_p together with the plasticity index $I_p = w_L - w_p$, are presented in the borehole logs in Part B1 and in Table B2-2.

The liquidity index, $I_L=(w-w_p)/I_p$, where the in situ water content (w) is taken as the measured water content (offshore or onshore) closest to the corresponding depth of the measured plastic limit are presented in Table B2-2.

B2.6 Index shear strengths and sensitivity

Index strength tests were carried out offshore and onshore using fall cone, motor vane, lab vane and torvane.

The sensitivity is taken as $S_t = s_u/s_{ur}$ where s_u and s_{ur} are the shear strengths found for the intact and the remoulded samples, respectively. The results are presented in Tables B2-1 and B2-2 as well as in the borehole logs in Part B1.

B2.7 Unit weight of solid particles

The unit weight of solid particles, γ_s, was determined on selected samples. The individual results are presented in Table B2-2.

Table B2-1 SUMMARY OF CLASSIFICATION TESTS, OFFSHORE LABORATORY

Boring No.	Depth	Water content	Mercury content	Unit weight	INDEX STRENGTH			COMMENTS
					Fall cone		Sensitivity	
		w		γ (wc)	s_u	s_{ur}	$S_t^{Fall\ cone}$	
	m	%	mg/kg	kN/m^3	kPa	kPa	-	
2013-401	0.05		3.563					
2013-401	0.10	57.1		16.6				
2013-401	0.15		0.406					
2013-401	0.55	51.1	0.365	17.0				
2013-401	1.05		0.153					
2013-401	1.10	15.7		22.0				
2013-401	1.15		0.103					
2013-401	2.05		0.057					
2013-401	2.15	23.8	0.137	20.3	6.6	1.8	3.7	
2013-402	0.05		1.490					
2013-402	0.15	10.7	0.018	23.2				
2013-402	0.55	12.5	0.120	22.7				
2013-402	1.05		0.092					
2013-402	1.15		0.030					
2013-402	1.18	24.7		20.1	25.0	7.7	3.2	
2013-402	2.05		0.039					
2013-402	2.10	24.7		20.1	30.0	7.3	4.1	
2013-402	2.15		0.012					
2013-403	0.05		0.067					
2013-403	0.12	28.9		19.5				
2013-403	0.15		0.014					
2013-403	0.55	25.7	0.006	20.0				
2013-403	1.05	11.7	0.012	22.9				
2013-403	1.15		0.036					
2013-404	0.05		0.205					
2013-404	0.10	31.7		19.1				
2013-404	0.15		0.209					
2013-404	0.85	30.7	0.013	19.2	8.9	2.2	4.0	
2013-404	0.95		0.002					
2013-404	1.82	15.9		21.9				
2013-404	1.95	17.1		21.6				
2013-405	0.05	22.7	87.600	20.5				
2013-405	0.55	23.1	0.837	20.4				
2013-405	1.05	27.5	0.128	19.7				
2013-405	1.15		0.132					
2013-405	2.05	27.4	0.075	19.7	6.6	2.1	3.1	
2013-405	2.15		0.131					
2013-405	3.05	37.5		18.3				
2013-405	3.05		0.060					
2013-405	3.15		8.220					
2013-406	0.05	27.5	3.030	19.7				
2013-406	0.15		34.000					
2013-406	2.15		23.800					
2013-407	0.05	12.9	37.400	22.6				
2013-407	0.15		18.400					
2013-407	0.55	25.8	1.768	19.9				
2013-509	0.15	26.7		19.8				
2013-509	1.15	31.9		19.0	8.6	2.1	4.1	
2013-509	2.15	30.1		19.3	8.4	2.0	4.2	
2013-509	3.15	24.6		20.1	12.0	4.2	2.9	
2013-512	0.15	32.4		19.0				
2013-512	1.15	28.2		19.6				
2013-512	2.15	25.9		19.9	15.0	3.7	4.1	
2013-512	3.15	25.6		20.0	24.0	3.5	6.9	

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TABLE B2-2 SUMMARY OF CLASSIFICATION TESTS, ONSHORE LABORATORY

Boring No.	Depth	Water content	Soil unit weight	Unit weight of solid part.	INDEX STRENGTH			PLASTICITY DATA			GRAIN SIZE DISTRIBUTION			COMMENTS
					Fall cone		Sensitivity	Plastic limit	Liquid limit	Plast.Index	clay	clay+silt	clay+silt +sand	
	m	w %	γ kN/m^3	γ_s kN/m^3	s_u kPa	s_{ur} kPa	S_t Fall Cone -	w_P %	w_L %	I_p %	< 2 µm %	< 0.063 mm %	< 2 mm %	
2013-401	0.10							14.5	34.7	20.2	21	40	96	
2013-401	0.55							17.3	40.5	23.2	31	57	95	
2013-402	0.10										8	21	79	
2013-402	0.55							14.0	28.7	14.7	20	43	94	
2013-402	1.10							15.4	32.0	16.6	17	53	97	
2013-402	2.10							14.8	30.9	16.1	29	68	100	
2013-402	2.50	17.7	21.47											
2013-402	2.82	24.6	20.15											
2013-402	2.88				28.0	3.3	8.5							
2013-403	0.10							13.1	25.1	12.0	17	44	81	
2013-403	0.55										20	54	97	
2013-403	1.10										14	41	92	
2013-404	0.10			26.96							20	35	72	
2013-404	0.40	29.7	19.35											
2013-404	0.68	34.2	18.74											
2013-404	0.85			27.38				14.4	31.4	17.0	25	59	100	
2013-404	1.17	16.7	21.69											
2013-404	1.62	21.1	20.78											
2013-404	1.65				16.0	7.7	2.1							
2013-404	1.90			27.29				13.2	25.7	12.5	11	35	85	
2013-404	2.20	11.9	22.89											
2013-405	0.05										10	23	73	
2013-405	0.43	26.4	19.86											
2013-405	0.55										9	16	81	
2013-405	0.80							13.7	29.0	15.3				
2013-405	1.05							13.4	28.9	15.5	21	65	94	
2013-405	1.37	26.3	19.86											
2013-405	1.40				15.0	4.5	3.3							
2013-405	1.83	35.2	18.62											
2013-405	1.89				9.8	4.1	2.4							
2013-405	2.02							15.6	34.9	19.3	26	57	100	
2013-405	2.37				15.0	4.8	3.1							
2013-405	2.40	22.4	20.54											
2013-405	2.82	28.0	19.60											
2013-405	2.87				8.1	3.7	2.2							
2013-405	3.05							16.6	39.2	22.6	26	55	92	
2013-407	0.15										4	11	87	
2013-407	0.55										24	55	94	
2013-509	0.18			27.40							21	46	91	
2013-509	0.33	20.3	20.93		15.0	6.4	2.3							
2013-509	0.75	21.9	20.63		15.0	7.7	1.9							
2013-509	1.05			27.45				15.0	32.4	17.4	28	62	91	
2013-509	1.33	20.4	20.91		28.0	2.4	11.7							
2013-509	1.81	21.4	20.73											
2013-509	2.15			27.46				13.8	25.6	11.8	18	58	100	
2013-509	2.47	23.4	20.36											
2013-509	3.15							13.5	25.5	12.0	19	54	100	
2013-509	3.38	16.2	21.82											
2013-509	3.42				19.0	4.6	4.1							
2013-509	3.70	21.3	20.74											
2013-509	3.75				13.0	3.8	3.4							
2013-512	0.31	12.6	22.70											
2013-512	0.95	20.2	20.97					12.6	26.2	13.6	16	48	93	
2013-512	1.05							12.5	24.1	11.6	19	50	100	
2013-512	1.30	20.5	20.90											
2013-512	1.33	23.9	20.27											
2013-512	1.34				17.0	4.2	4.0							
2013-512	1.65							14.2	28.3	14.1				
2013-512	1.75	24.3	20.19		18.0	4.6	3.9							
2013-512	1.80	27.0	19.75											
2013-512	1.82										21	60	100	
2013-512	2.37				18.0	3.8	4.7							
2013-512	2.60							13.5	26.4	12.9	17	55	99	
2013-512	2.66	26.5	19.83											
2013-512	2.76				10.0	4.3	2.3							
2013-512	3.28	27.9	19.61											
2013-512	3.35				24.0	6.6	3.6							
2013-512	3.45	24.5	20.17											
2013-512	3.52	22.8	20.46											
2013-512	3.57	26.5	19.83											
2013-512	3.62										18	56	100	
2013-512	3.70				11.0	3.5	3.1							
2013-512	3.77	24.1	20.24											
2013-512	3.82							13.1	25.6	12.5				

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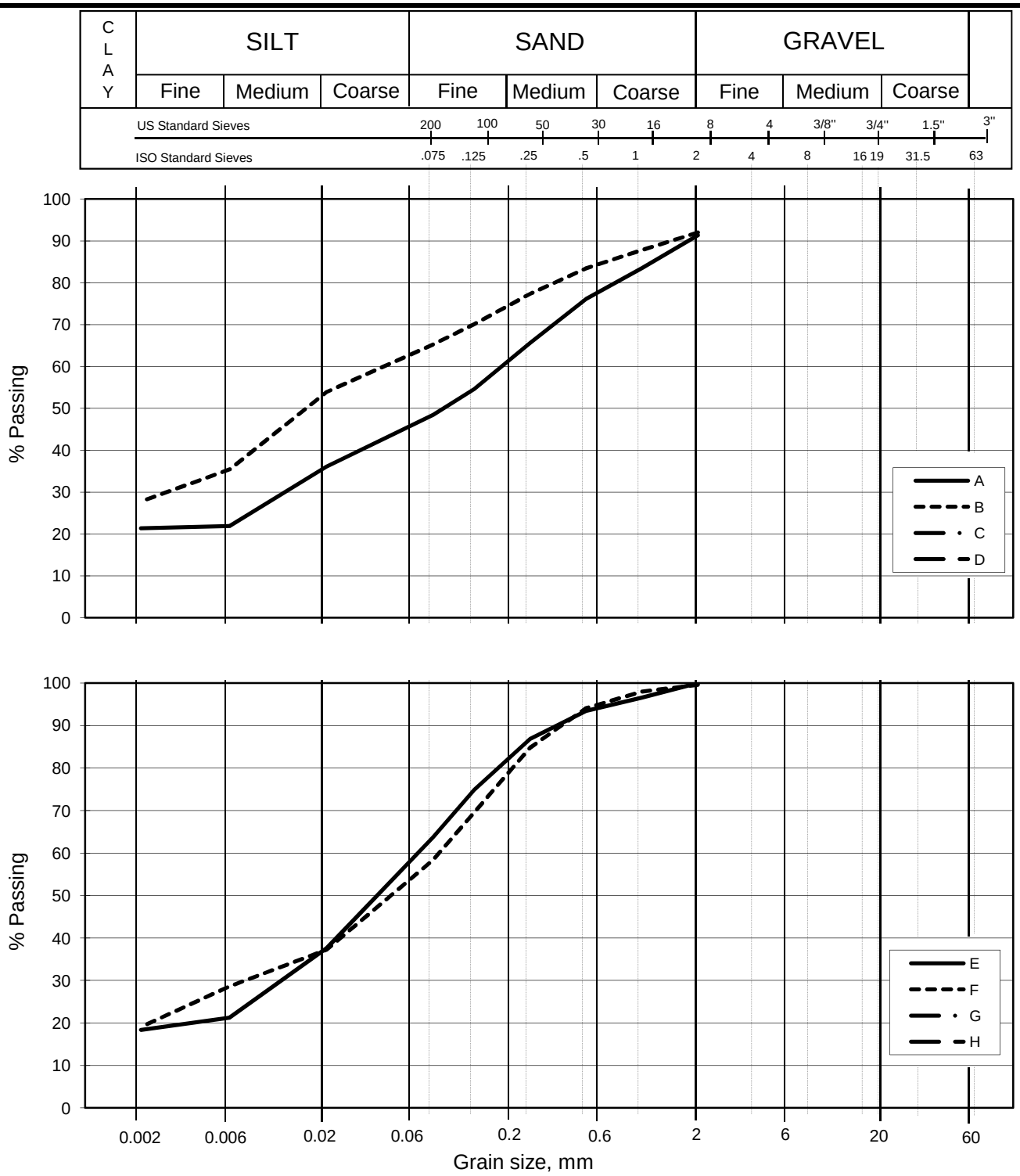

Curve	Boring No.	Sample No.	Depth m	D_{10} mm	D_{60} mm	Clay cont. %	Soil Description	Method dry/wet-sieving
A	2013-509GC	1	0.17		0.175	21.4	CLAY, sandy, silty	Fall
B	2013-509GC	2	1.05		0.041	27.8	CLAY, silty, sandy	Fall
C								
D								
E	2013-509GC	3	2.15		0.062	18.4	CLAY, silty, sandy	Fall
F	2013-509GC	4	3.15		0.081	19.1	CLAY, sandy, silty	Fall
G								
H								

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U-864 2013 Soil survey

Grain size distribution curves.

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Date 2013-03-06

Figure No. B2.1

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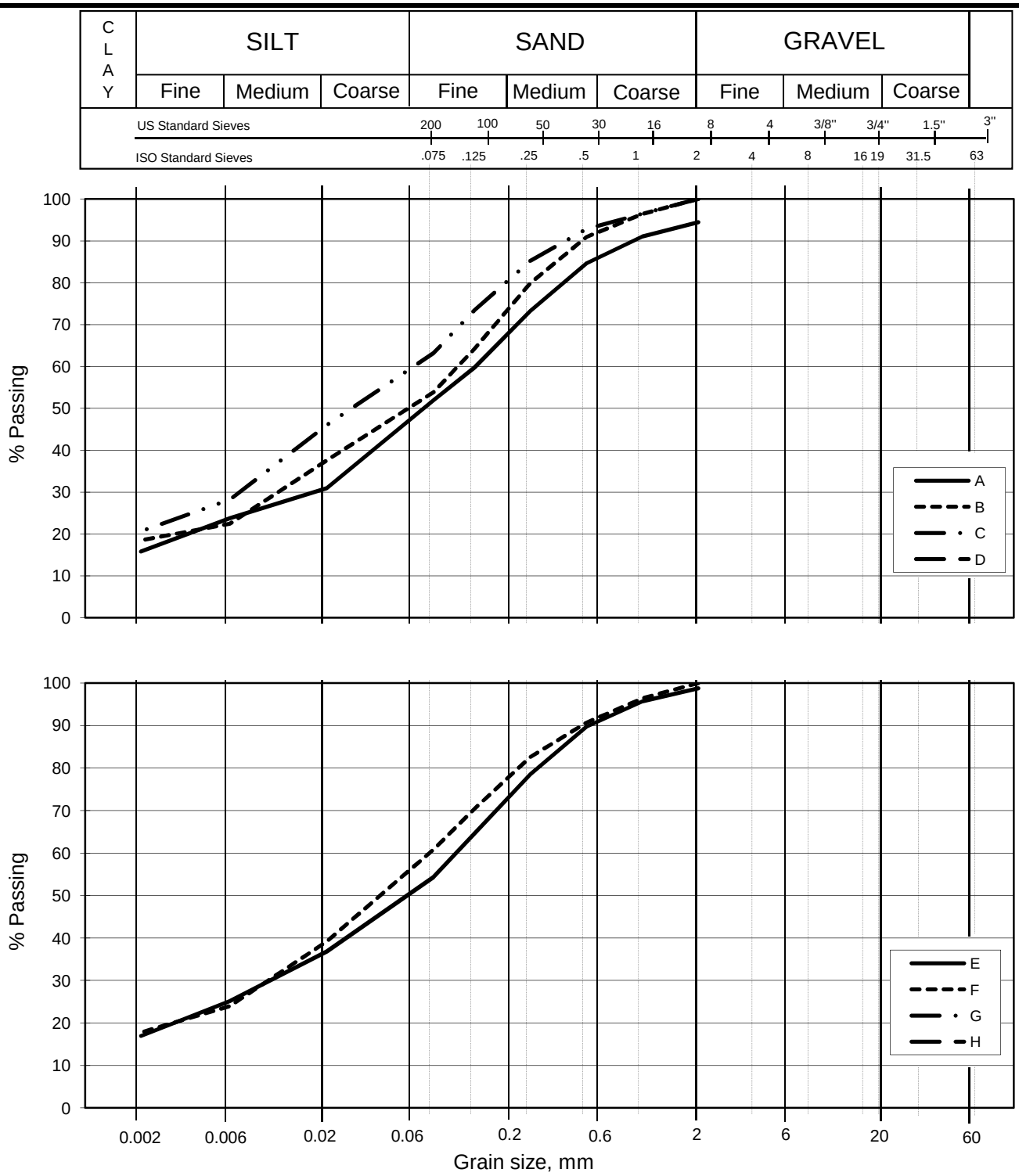

Curve	Boring No.	Sample No.	Depth m	D_{10} mm	D_{60} mm	Clay cont. %	Soil Description	Method dry/wet-sieving
A	2013-512GC	1	0.95		0.126	15.8	CLAY, sandy, silty	Fall
B	2013-512GC	2	1.05		0.101	18.5	CLAY, sandy, silty	Fall
C	2013-512GC	2	1.82		0.059	20.7	CLAY, silty, sandy	Fall
D								
E	2013-512GC	3	2.6		0.100	16.9	CLAY, sandy, silty	Fall
F	2013-512GC	4	3.62		0.072	17.7	CLAY, silty, sandy	Fall
G								
H								

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Grain size distribution curves.

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Date 2013-03-06

Figure No. B2.2

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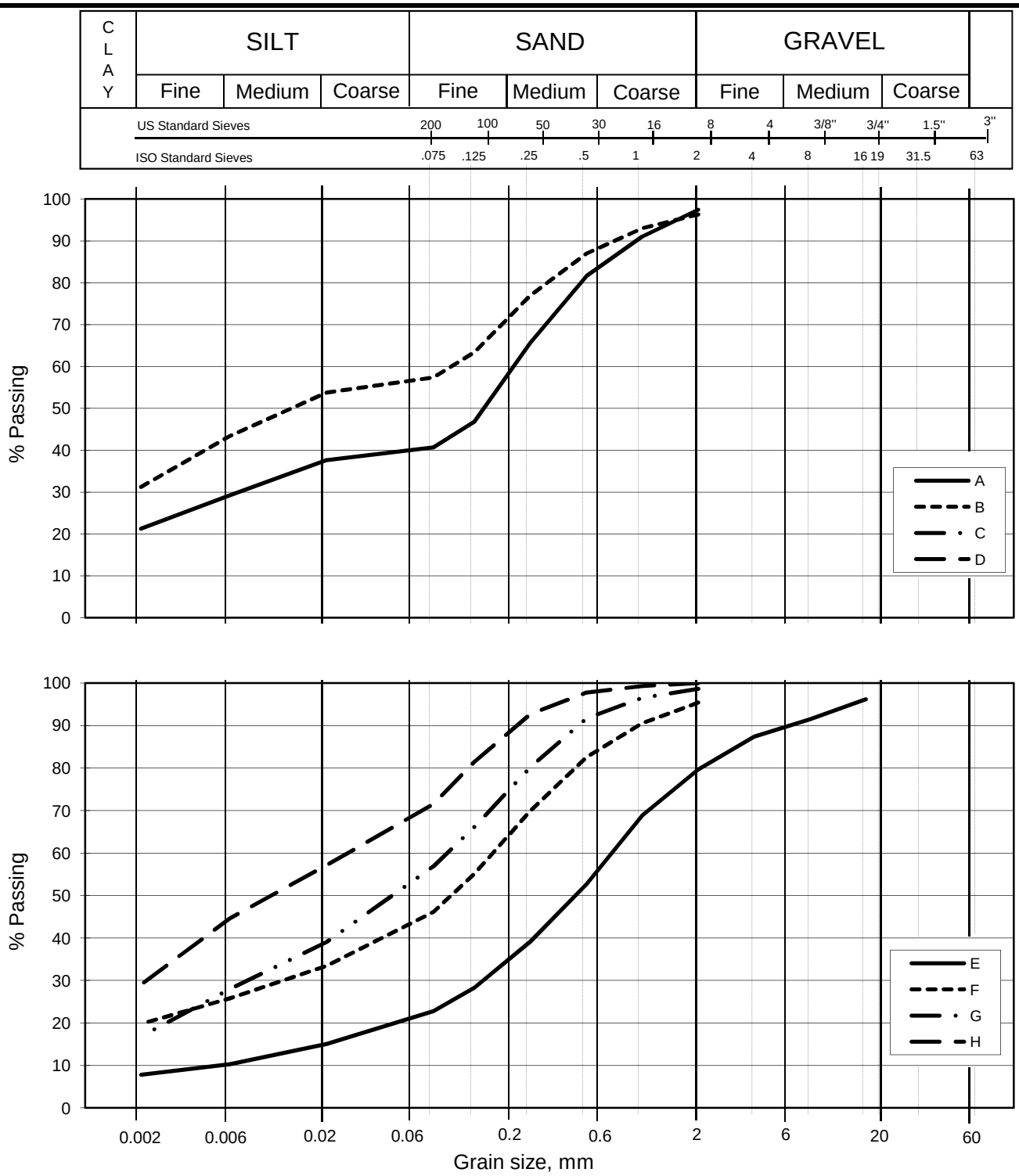

Curve	Boring No.	Sample No.	Depth m	D_{10} mm	D_{60} mm	Clay cont. %	Soil Description	Method dry/wet-sieving
A	2013-401VC	1	0.1		0.203	21.2	CLAY, sandy, silty	Fall
B	2013-401VC	1	0.55		0.094	31.2	CLAY	Fall
C								
D								
E	2013-402VC	1	0.1	0.005	0.685	7.8	Sandy, gravelly, silty, clayey	Wet/Fall
F	2013-402VC	1	0.55		0.157	19.7	CLAY, sandy, silty	Fall
G	2013-402VC	2	1.1		0.089	16.9	CLAY, sandy, silty	Fall
H	2013-402VC	3	2.1		0.026	29.0	CLAY, silty, sandy	Fall

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Grain size distribution curves.

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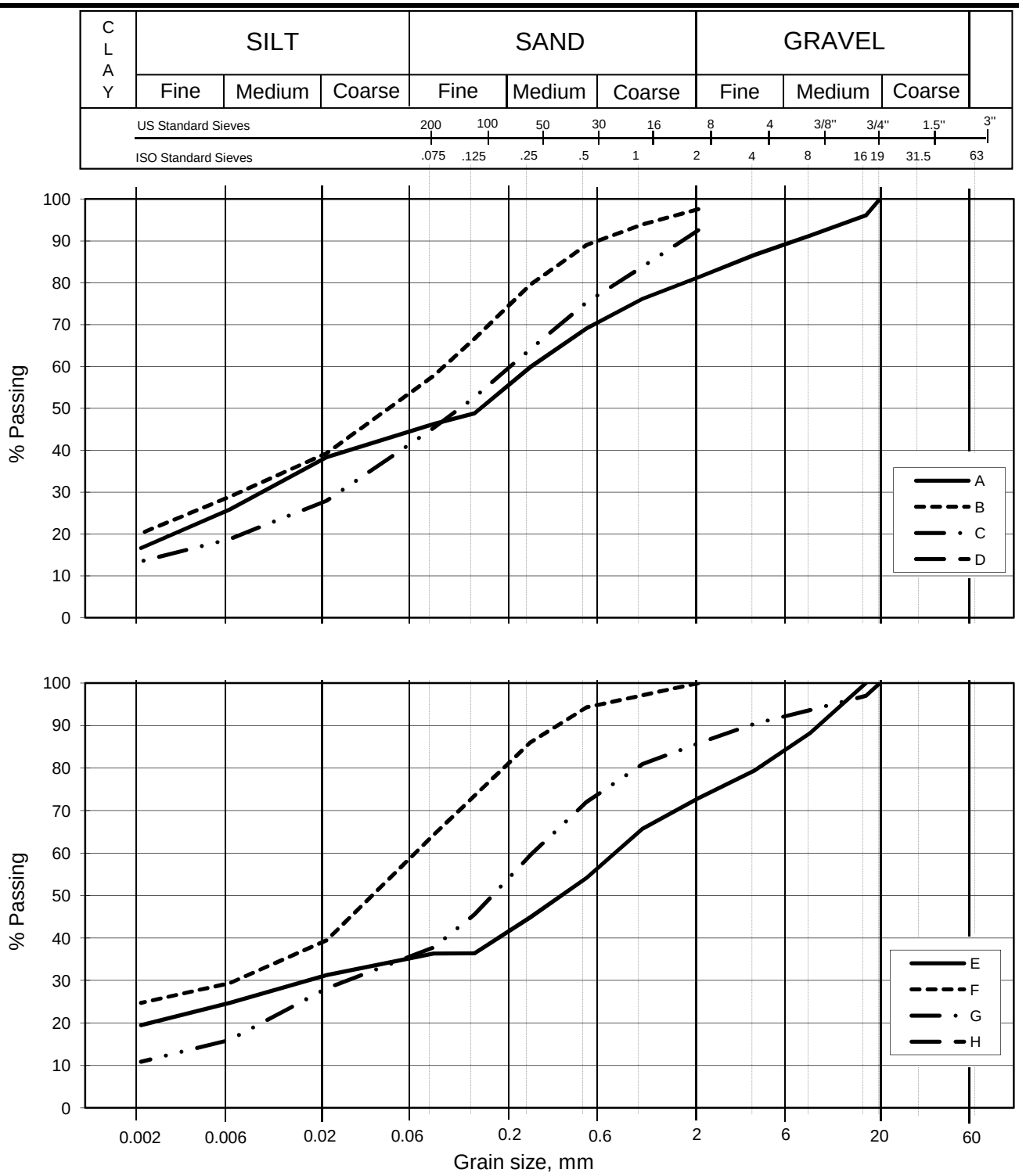

Curve	Boring No.	Sample No.	Depth m	D_{10} mm	D_{60} mm	Clay cont. %	Soil Description	Method dry/wet-sieving
A	2013-403VC	1	0.1		0.252	16.7	CLAY, sandy, silty	Wet/Fall
B	2013-403VC	1	0.55		0.085	20.2	CLAY, sandy, silty	Fall
C	2013-403VC	2	1.1		0.195	13.5	Sandy, silty, clayey	Fall
D								
E	2013-404VC	1	0.1		0.710	19.5	CLAY, gravelly, sandy, silty	Wet/Fall
F	2013-404VC	1	0.85		0.060	24.7	CLAY, silty, sandy	Fall
G	2013-404VC	2	1.9		0.257	10.8	Sandy, silty, clayey	Wet/Fall
H								

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Curve E: >19mm =61.27g = 20.90% is removed from sample

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Figure No. B2.4

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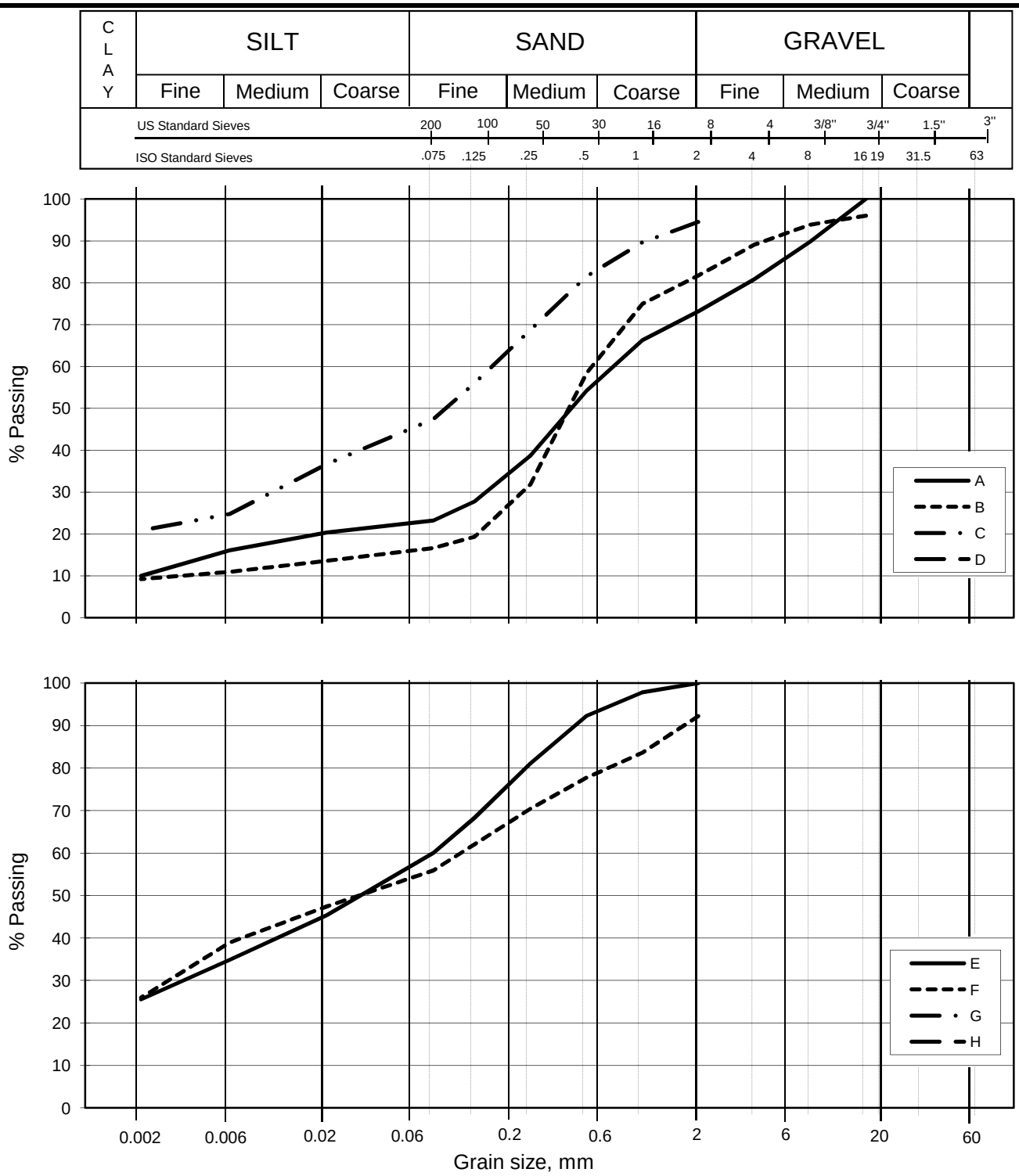

Curve	Boring No.	Sample No.	Depth m	D_{10} mm	D_{60} mm	Clay cont. %	Soil Description	Method dry/wet-sieving
A	2013-405VC	1	0.05		0.696	10.0	Sandy, gravelly, clayey	Wet/Fall
B	2013-405VC	1	0.55	0.003	0.535	9.2	SAND, coarse to fine, gravelly, clayey	Wet/Fall
C	2013-405VC	2	1.05		0.155	20.9	CLAY, sandy, silty	Fall
D								
E	2013-405VC	3	2		0.075	25.5	CLAY, sandy, silty	Fall
F	2013-405VC	4	3.05		0.106	25.9	CLAY, sandy, silty	Fall
G								
H								

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Curve A: >19mm = 15.19g = 8.18% is removed from sample

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Figure No. B2.5

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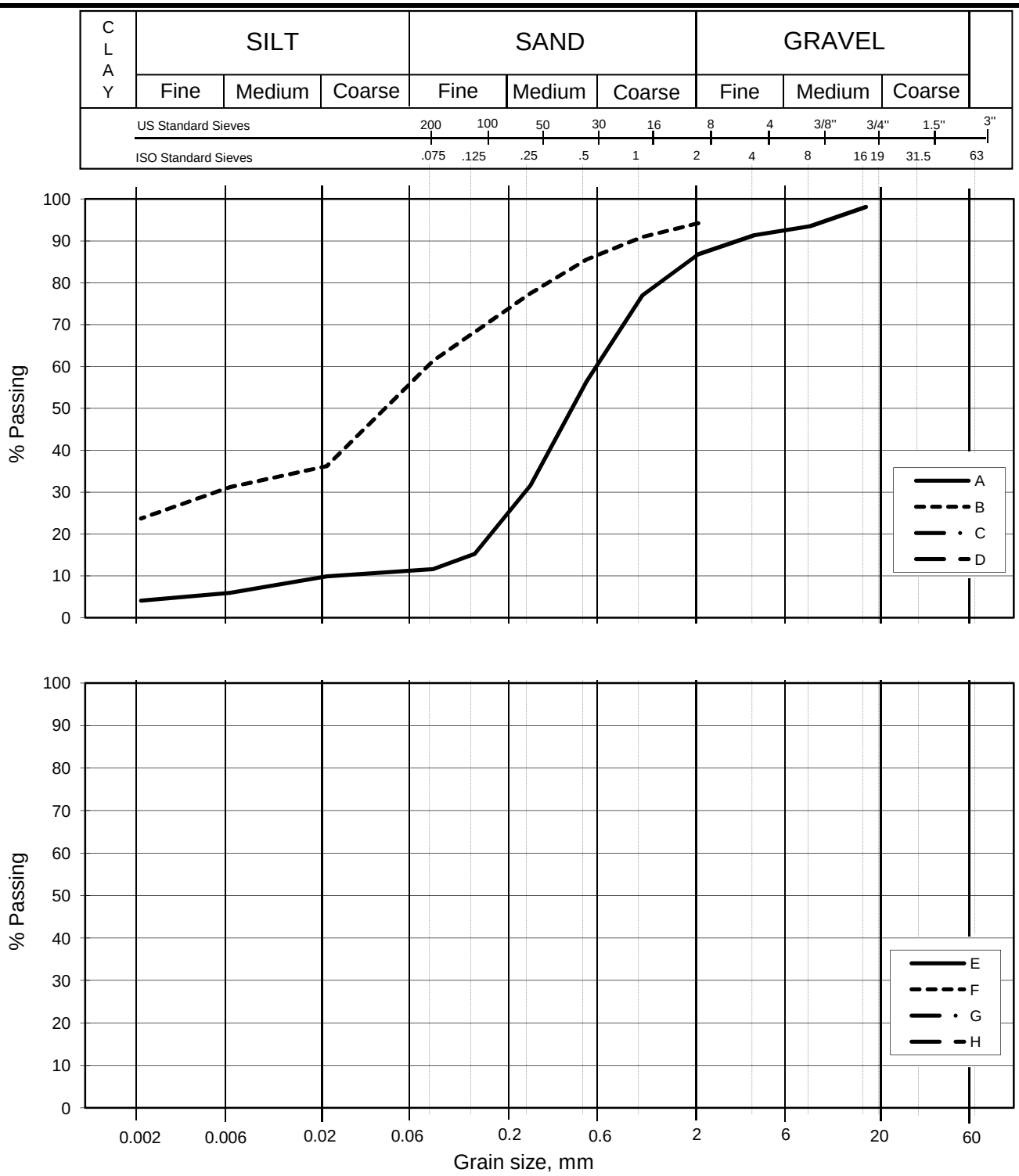

Curve	Boring No.	Sample No.	Depth m	D_{10} mm	D_{60} mm	Clay cont. %	Soil Description	Method dry/wet-sieving
A	2013-407VC	1	0.15	0.022	0.564	4.1	SAND, coarse to fine	Wet/Fall
B	2013-407VC	1	0.55		0.070	23.7	CLAY, sandy, silty	Fall
C								
D								
E								
F								
G								
H								

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Grain size distribution curves.

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Figure No.
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Part B3 - Piezocone Penetration Tests

Contents

B3.1 Summary 2

Figures

B3.1 Location 2013-503. Plot of q_c, f_s and u_2 versus depth.
B3.2 Location 2013-503. Plot of q_t, R_f and B_q versus depth.
B3.3 Location 2013-503A. Plot of q_c, f_s and u_2 versus depth.
B3.4 Location 2013-503A. Plot of q_t, R_f and B_q versus depth.
B3.5 Location 2013-504. Plot of q_c, f_s and u_2 versus depth.
B3.6 Location 2013-504. Plot of q_t, R_f and B_q versus depth.
B3.7 Location 2013-505. Plot of q_c, f_s and u_2 versus depth.
B3.8 Location 2013-505. Plot of q_t, R_f and B_q versus depth.
B3.9 Location 2013-506. Plot of q_c, f_s and u_2 versus depth.
B3.10 Location 2013-506. Plot of q_t, R_f and B_q versus depth.
B3.11 Location 2013-509. Plot of q_c, f_s and u_2 versus depth.
B3.12 Location 2013-509. Plot of q_t, R_f and B_q versus depth.
B3.13 Location 2013-510. Plot of q_c, f_s and u_2 versus depth.
B3.14 Location 2013-510. Plot of q_t, R_f and B_q versus depth.
B3.15 Location 2013-511. Plot of q_c, f_s and u_2 versus depth.
B3.16 Location 2013-511. Plot of q_t, R_f and B_q versus depth.
B3.17 Location 2013-512. Plot of q_c, f_s and u_2 versus depth.
B3.18 Location 2013-513. Plot of q_t, R_f and B_q versus depth.

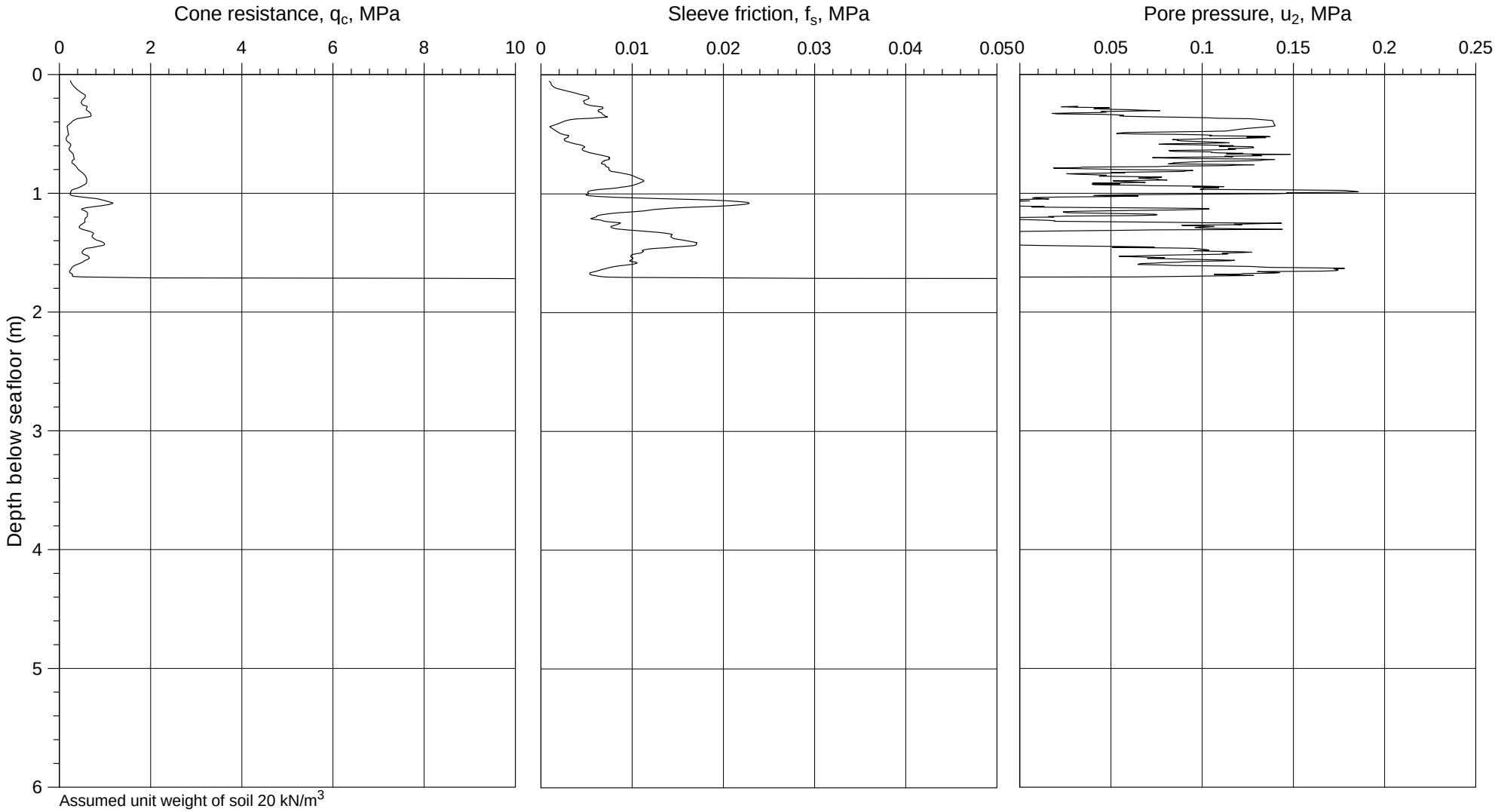
B3.1 Summary

For each location the following data are presented:

- Cone resistance (q_c)
- Sleeve friction (f_s)
- Pore water pressure (u_2)
- Total cone resistance (q_t)
- Friction ratio (R_f)
- Pore water pressure ratio (B_q)

The CPTU were performed Geo-Engineering, see field report in Part C3. It would have been useful if the zero readings before and after each test were presented. This not issued by Geo-Engineering.

There are some uncertainties with the pore pressure data, especially in the upper metre below seafloor. It is therefore recommended to put most emphasis on the cone resistance data.



U-864 - 2013 SOIL SURVEY

Cone resistance (q_c), sleeve ratio (f_s), and pore pressure (u_2)

Borehole	Easting	Northing	Water Depth
2013-503 CPT	261 554.8 mE	6 745 200.3 mN	174.7 m

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Figure No. B3.1

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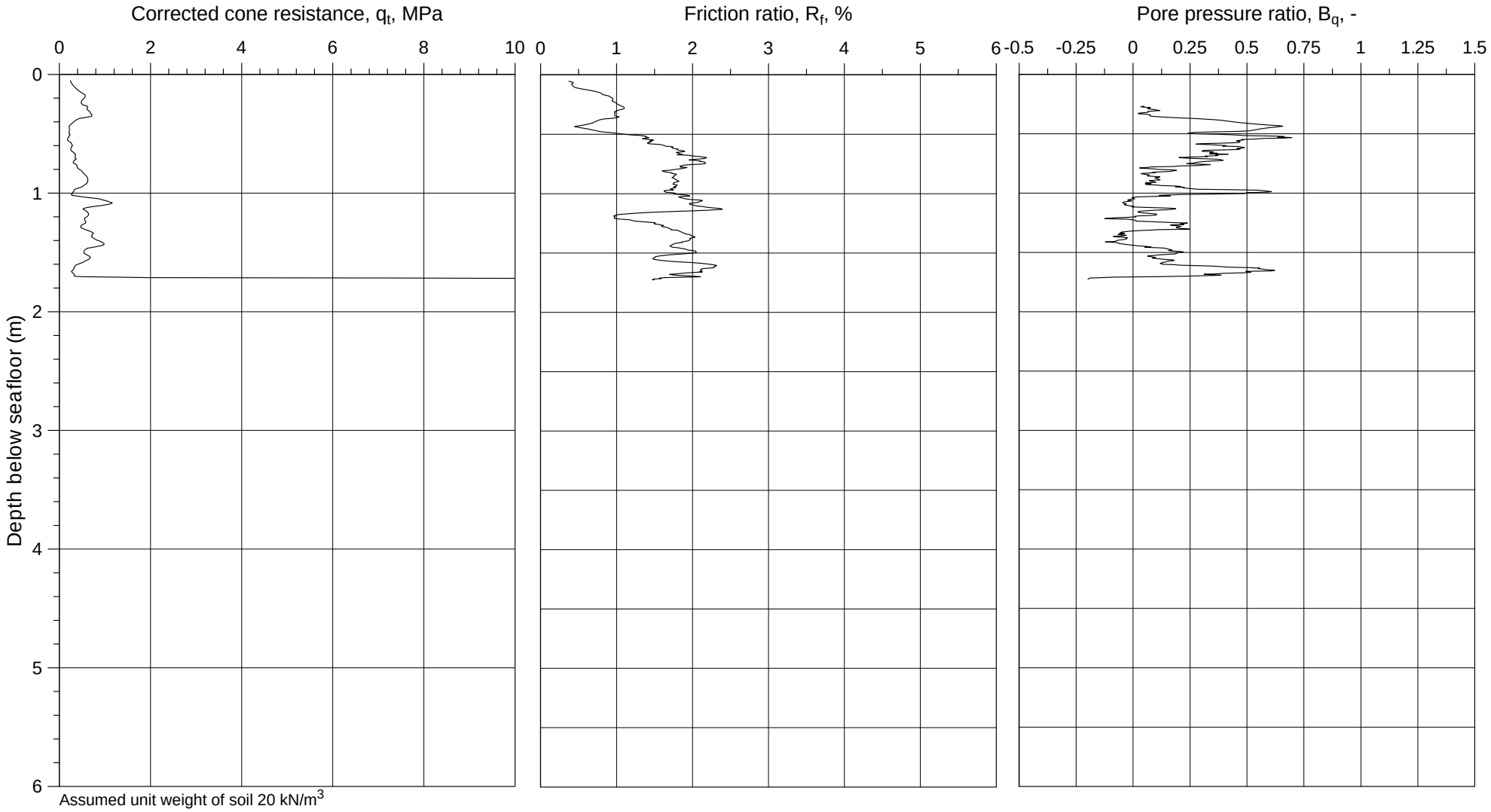

U-864 - 2013 SOIL SURVEY

Corrected cone resistance (q_t), friction ratio (R_f), and pore pressure ratio (B_q)

Borehole	Easting	Northing	Water Depth
2013-503 CPT	261 554.8 mE	6 745 200.3 mN	174.7 m

WGS-84, UTM Zone 32N, CM 9°E

Document No. 20120738-01-R

Date 2013-03-06

Figure No. B3.2

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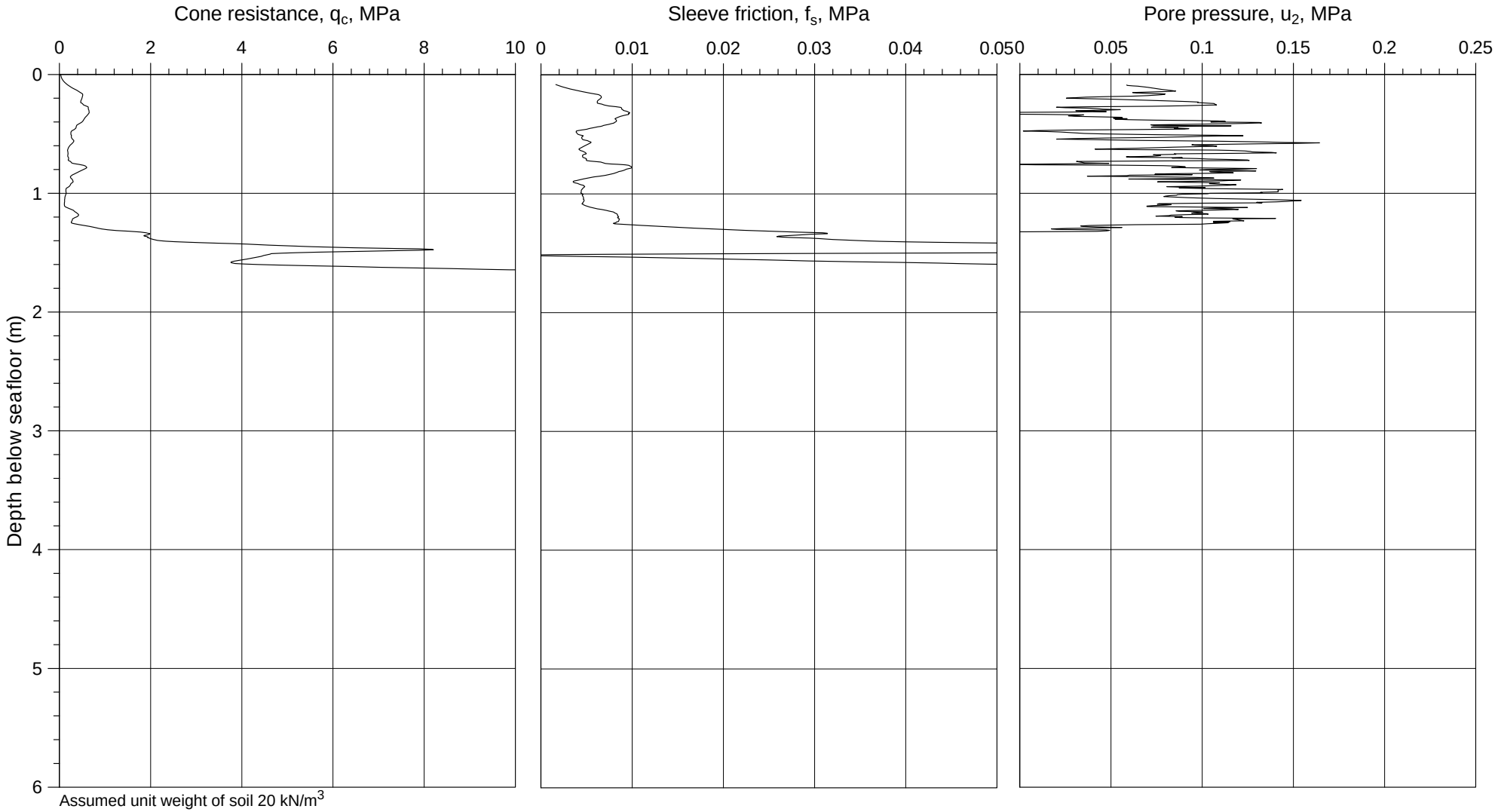

U-864 - 2013 SOIL SURVEY

Cone resistance (q_c), sleeve ratio (f_s), and pore pressure (u_2)

Borehole	Easting	Northing	Water Depth
2013-503A CPT	261 554.4 mE	6 745 202.1 mN	174.7 m

WGS-84, UTM Zone 32N, CM 9°E

Document No. 20120738-01-R

Date 2013-03-06

Figure No. B3.3

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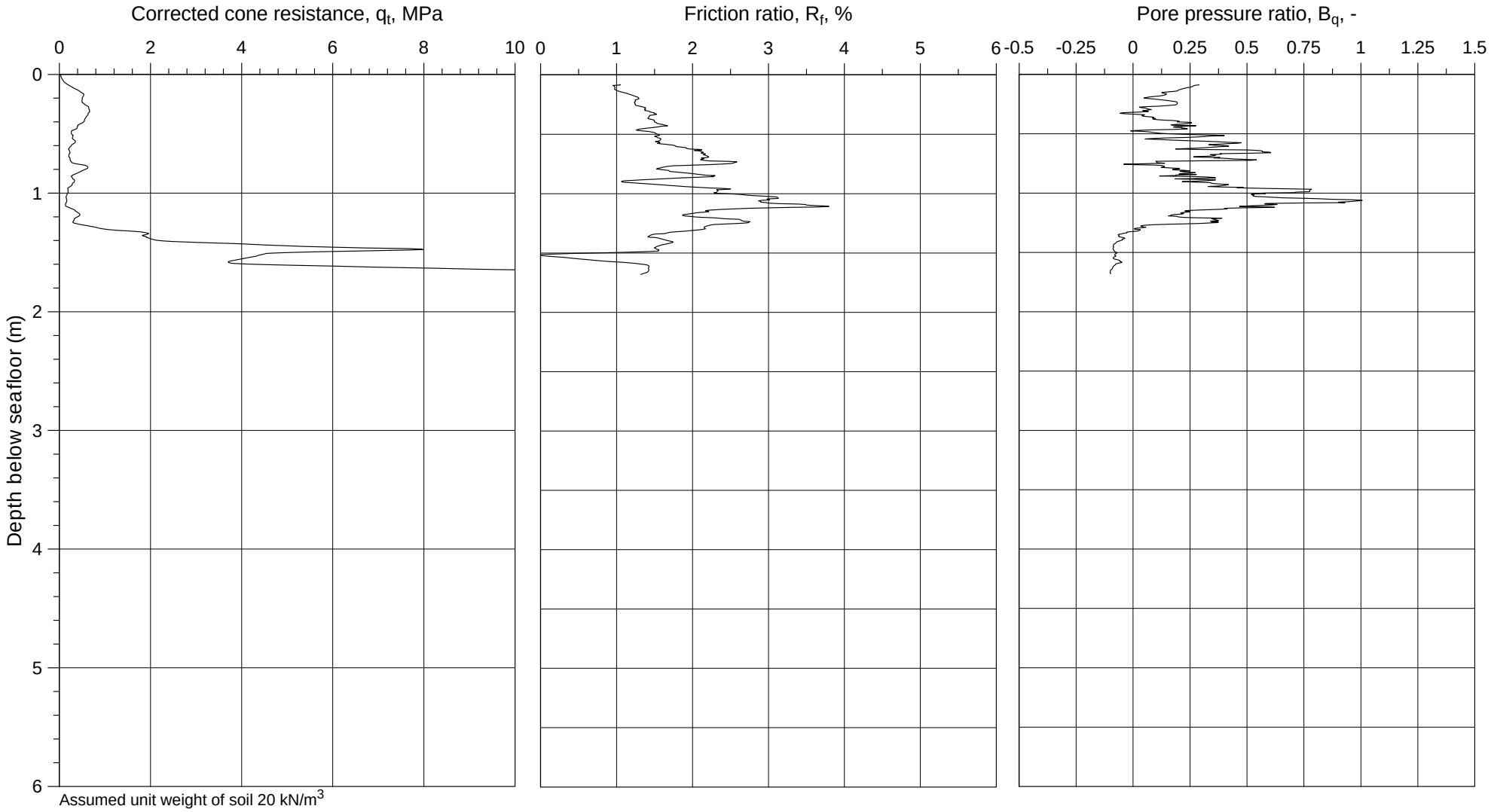

U-864 - 2013 SOIL SURVEY

Corrected cone resistance (q_t), friction ratio (R_f), and pore pressure ratio (B_q)

Borehole	Easting	Northing	Water Depth
2013-503A CPT	261 554.4 mE	6 745 202.1 mN	174.7 m

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Document No. 20120738-01-R

Date 2013-03-06

Figure No. B3.4

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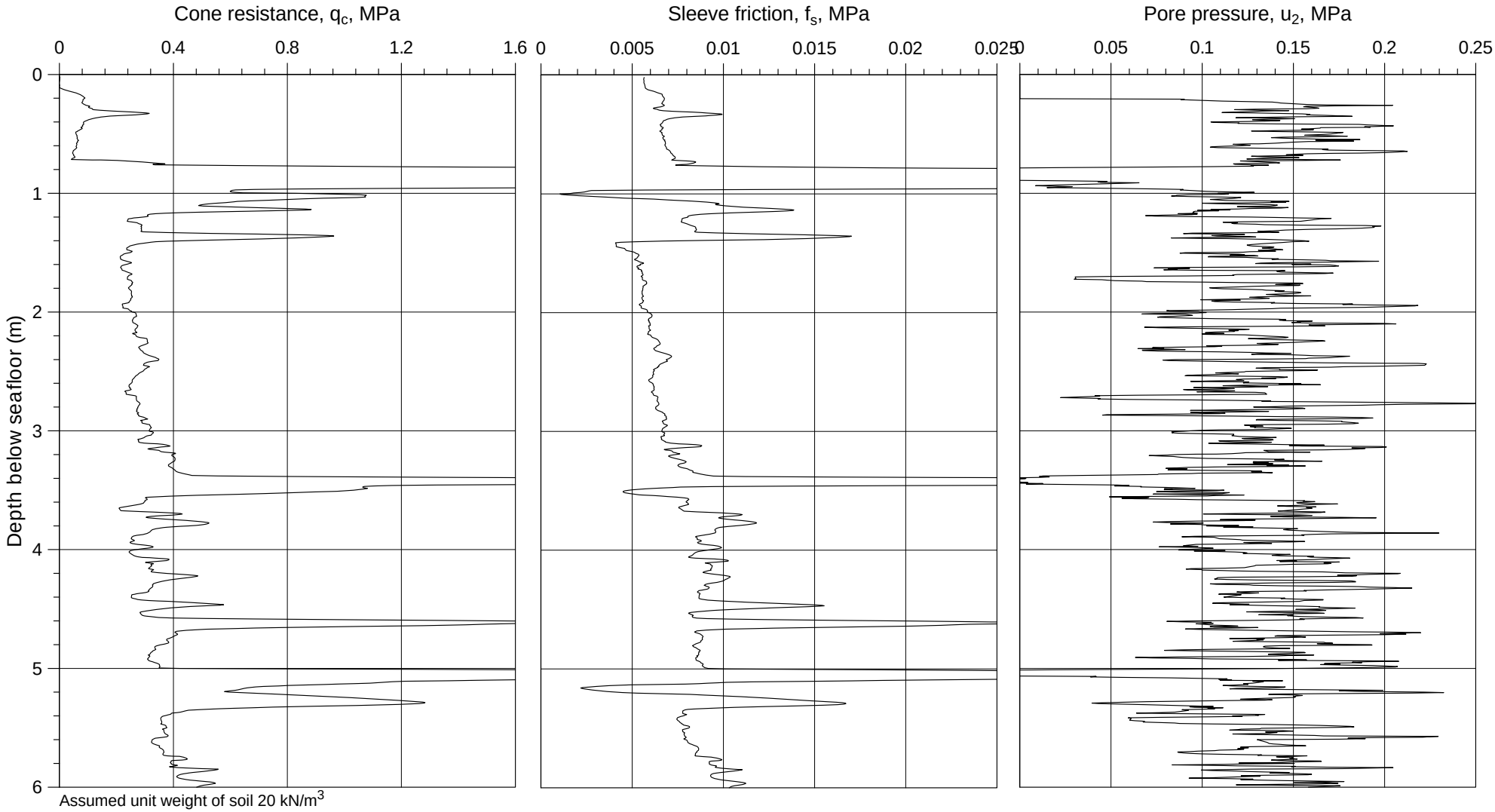

U-864 - 2013 SOIL SURVEY

Cone resistance (q_c), sleeve ratio (f_s), and pore pressure (u_2)

Borehole	Easting	Northing	Water Depth
2013-504CPT	261 603.3 mE	6 745 191.7 mN	174.7 m

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Document No. 20120738-01-R

Date 2013-03-06

Figure No. B3.5

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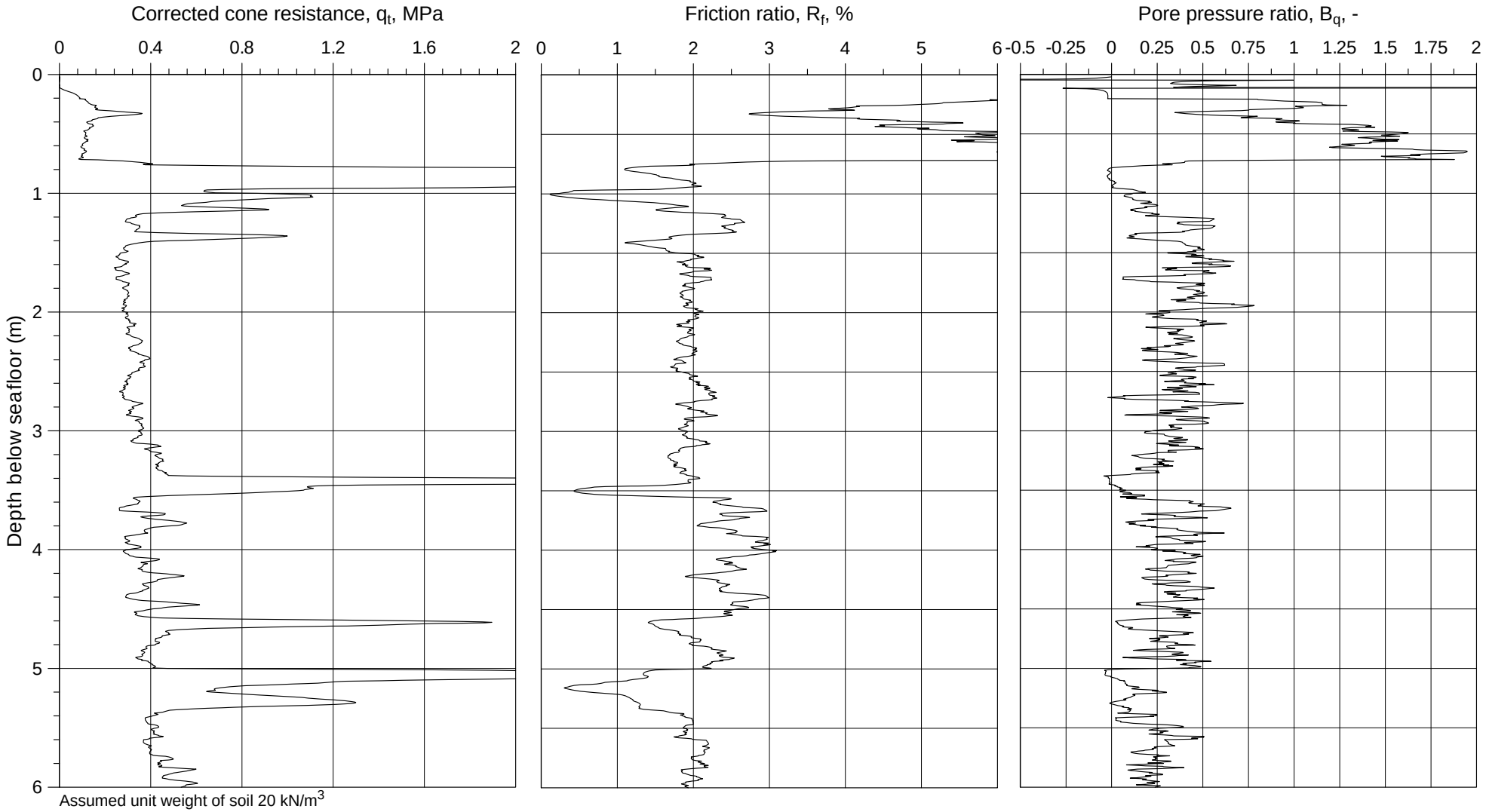

U-864 - 2013 SOIL SURVEY

Corrected cone resistance (q_t), friction ratio (R_f), and pore pressure ratio (B_q)

Borehole	Easting	Northing	Water Depth
2013-504CPT	261 603.3 mE	6 745 191.7 mN	174.7 m

WGS-84, UTM Zone 32N, CM 9°E

Document No. 20120738-01-R

Date 2013-03-06

Figure No. B3.6

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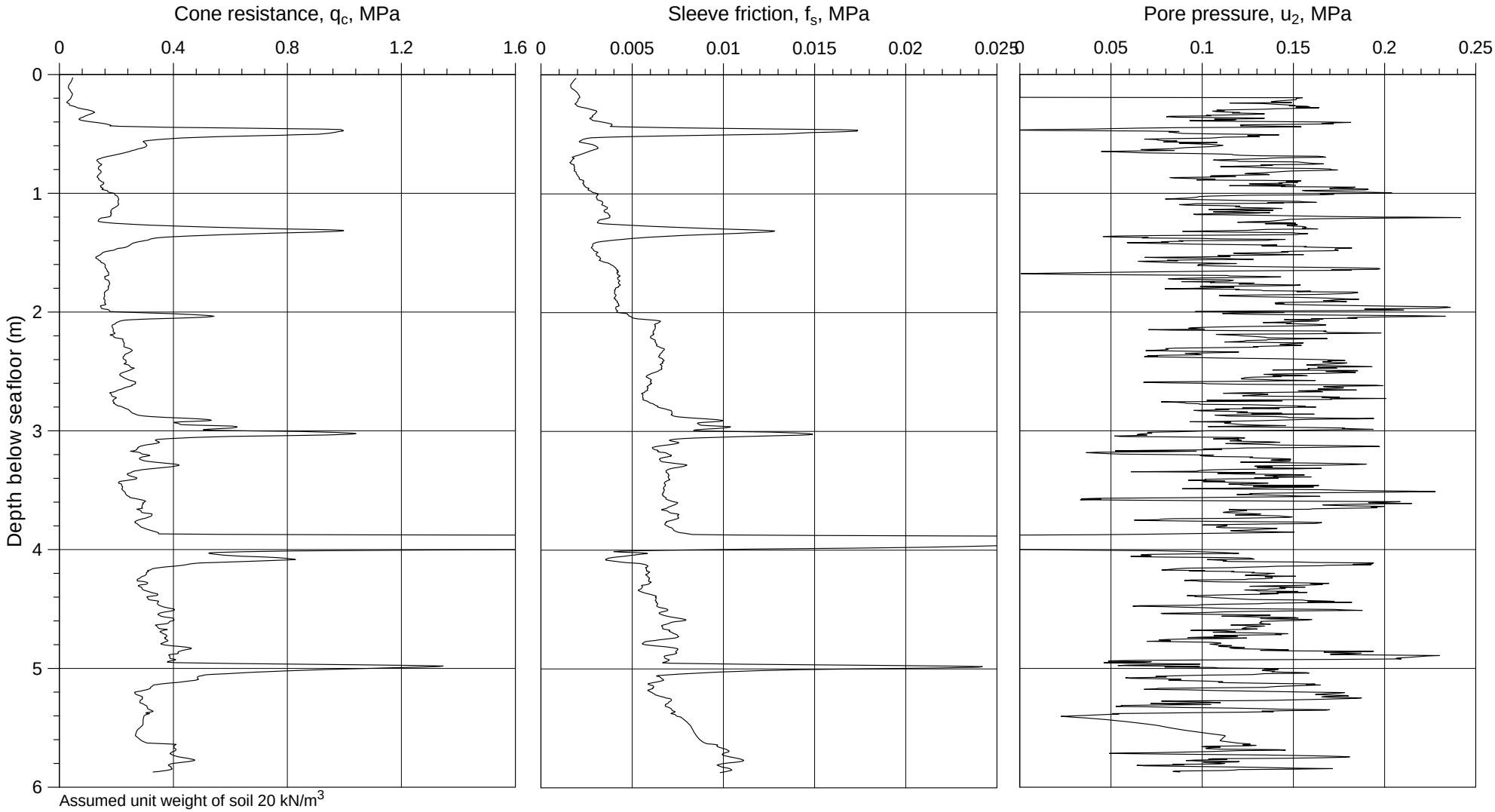

U-864 - 2013 SOIL SURVEY

Cone resistance (q_c), sleeve ratio (f_s), and pore pressure (u_2)

Borehole	Easting	Northing	Water Depth
2013-505CPT	261 597.9 mE	6 745 221.7 mN	176.9 m

WGS-84, UTM Zone 32N, CM 9°E

Document No. 20120738-01-R

Date 2013-03-06

Figure No. B3.7

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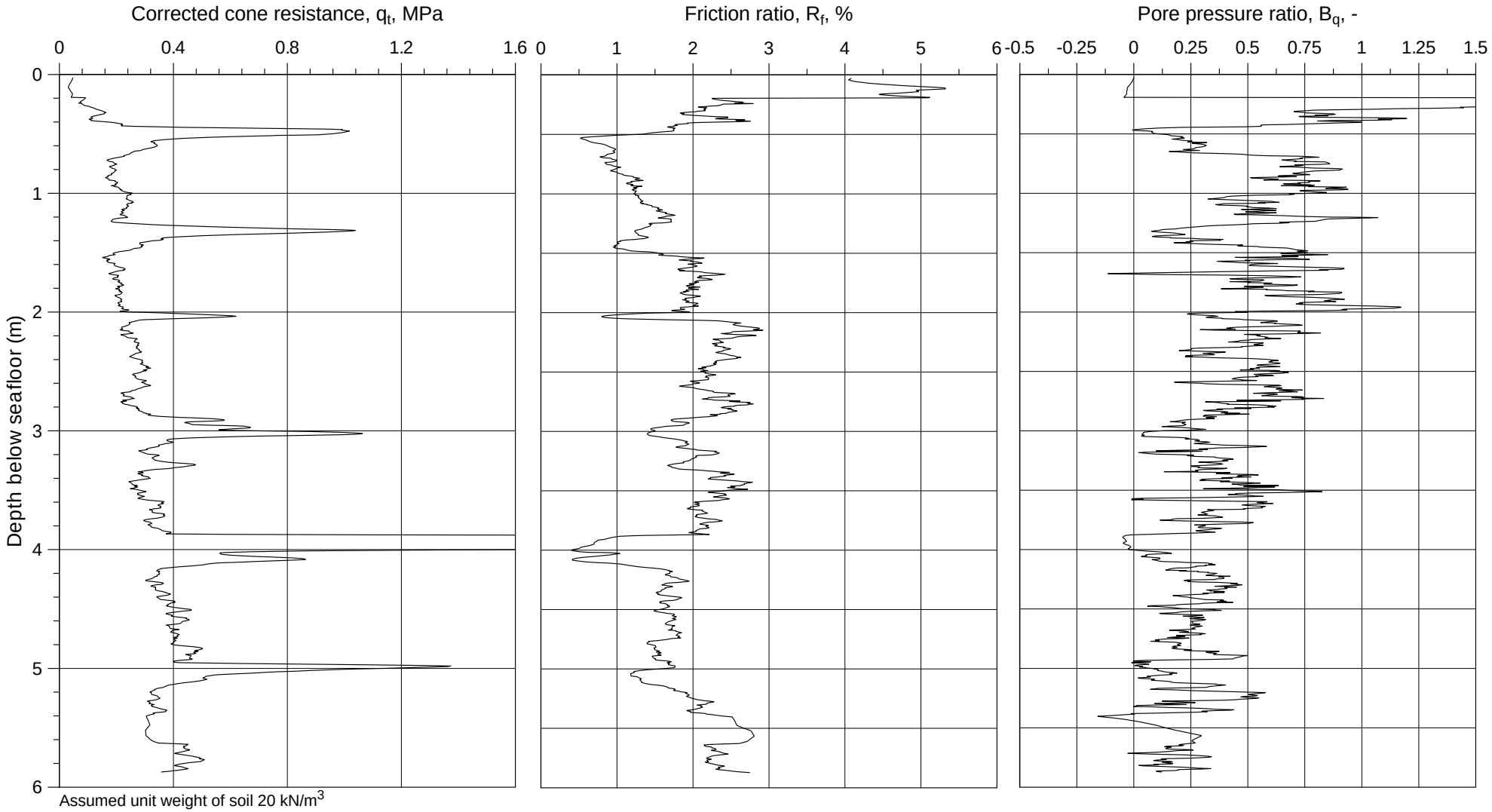

U-864 - 2013 SOIL SURVEY

Corrected cone resistance (q_t), friction ratio (R_f), and pore pressure ratio (B_q)

Borehole	Easting	Northing	Water Depth
2013-505CPT	261 597.9 mE	6 745 221.7 mN	176.9 m

WGS-84, UTM Zone 32N, CM 9°E

Document No. 20120738-01-R

Date 2013-03-06

Figure No. B3.8

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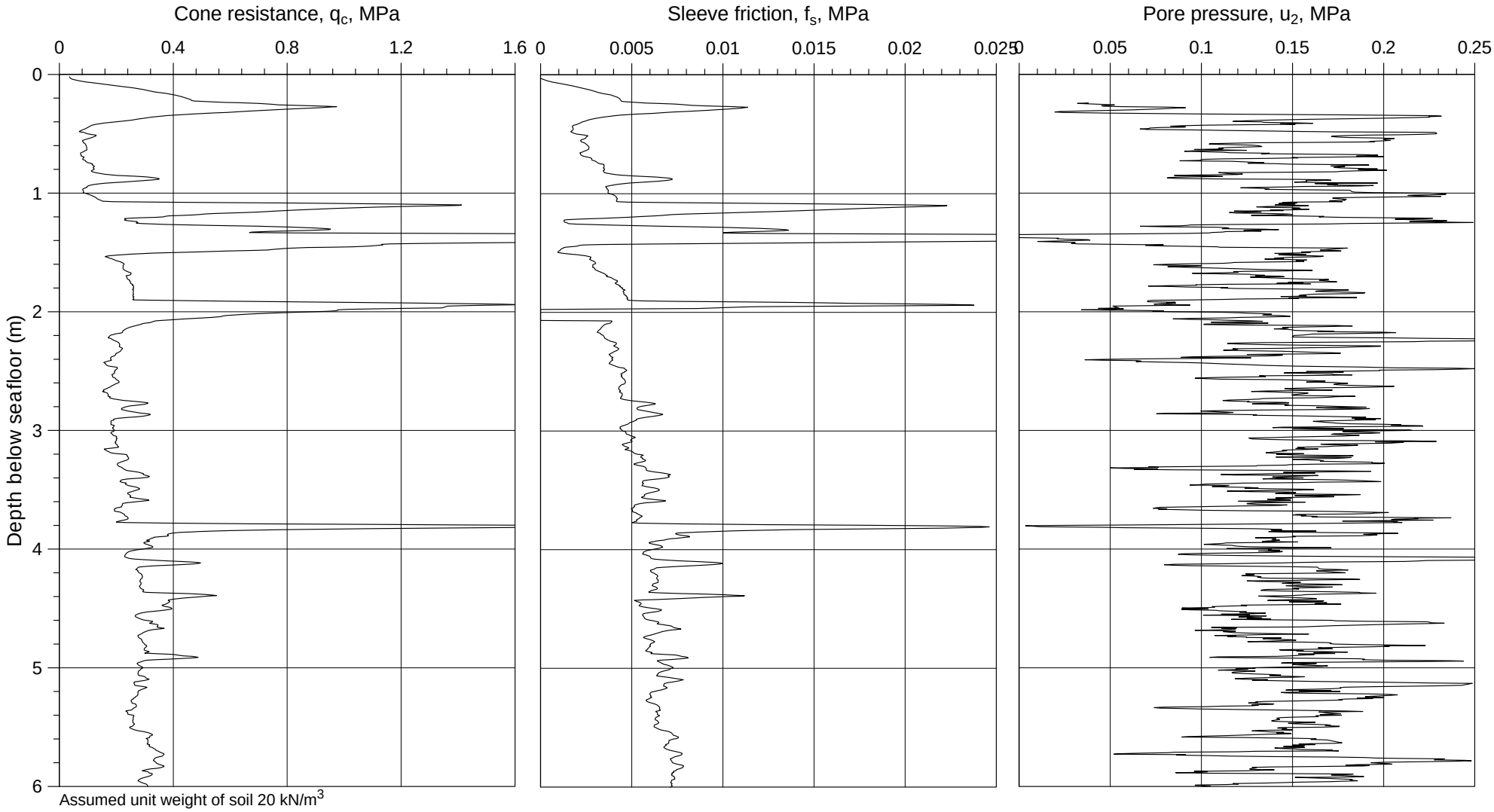

U-864 - 2013 SOIL SURVEY

Cone resistance (q_c), sleeve ratio (f_s), and pore pressure (u_2)

Borehole	Easting	Northing	Water Depth
2013-506CPT	261 569.5 mE	6 745 230.0 mN	178.1 m

WGS-84, UTM Zone 32N, CM 9°E

Document No. 20120738-01-R

Date 2013-03-06

Figure No. B3.9

Drawn by ES

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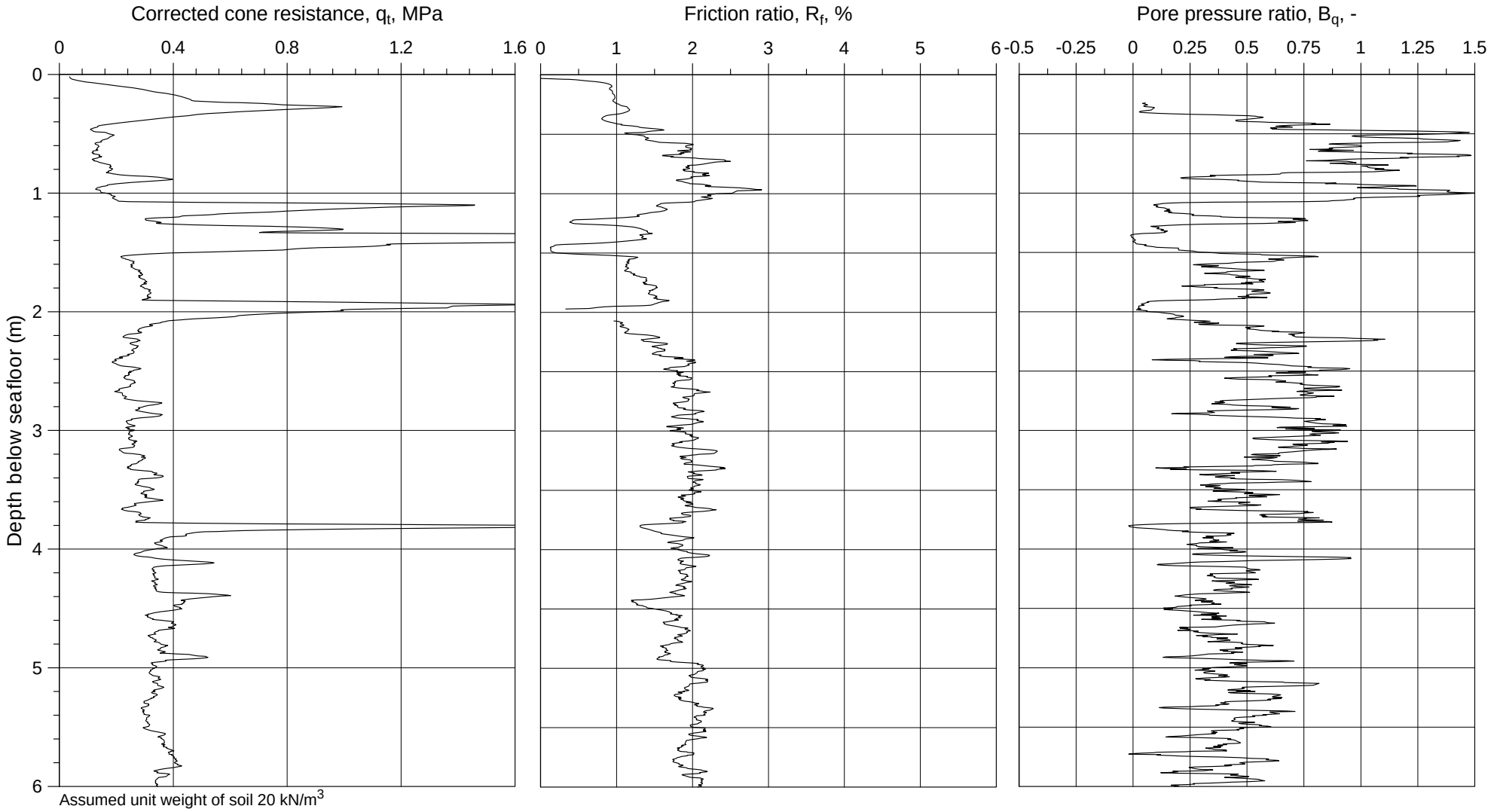

U-864 - 2013 SOIL SURVEY

Corrected cone resistance (q_t), friction ratio (R_f), and pore pressure ratio (B_q)

Borehole	Easting	Northing	Water Depth
2013-506CPT	261 569.5 mE	6 745 230.0 mN	178.1 m

WGS-84, UTM Zone 32N, CM 9°E

Document No. 20120738-01-R

Date 2013-03-06

Figure No. B3.10

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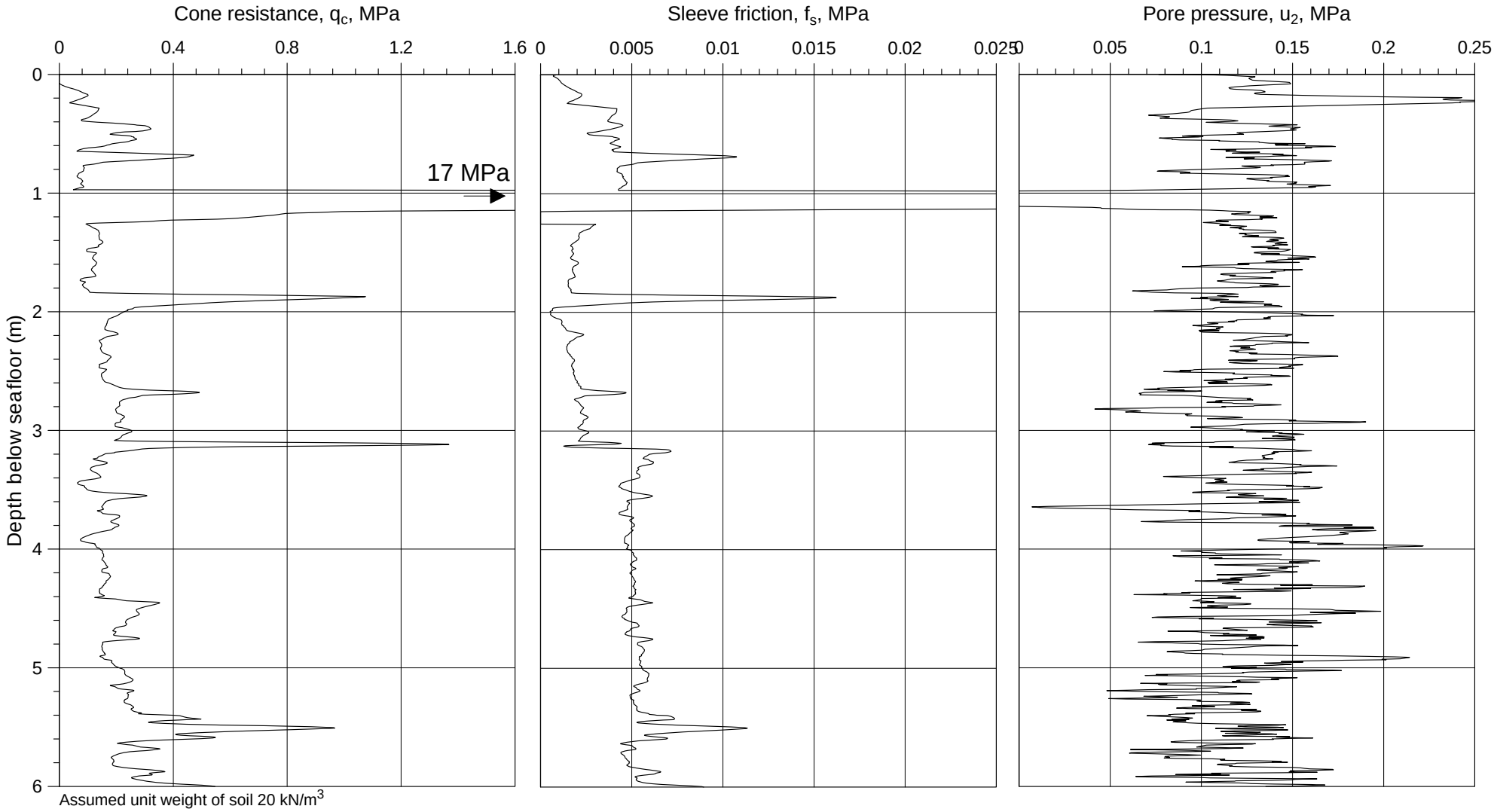

U-864 - 2013 SOIL SURVEY

Cone resistance (q_c), sleeve ratio (f_s), and pore pressure (u_2)

Borehole	Easting	Northing	Water Depth
2013-509CPT	261 627.9 mE	6 745 201.8 mN	176.0 m

WGS-84, UTM Zone 32N, CM 9°E

Document No. 20120738-01-R

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Figure No. B3.11

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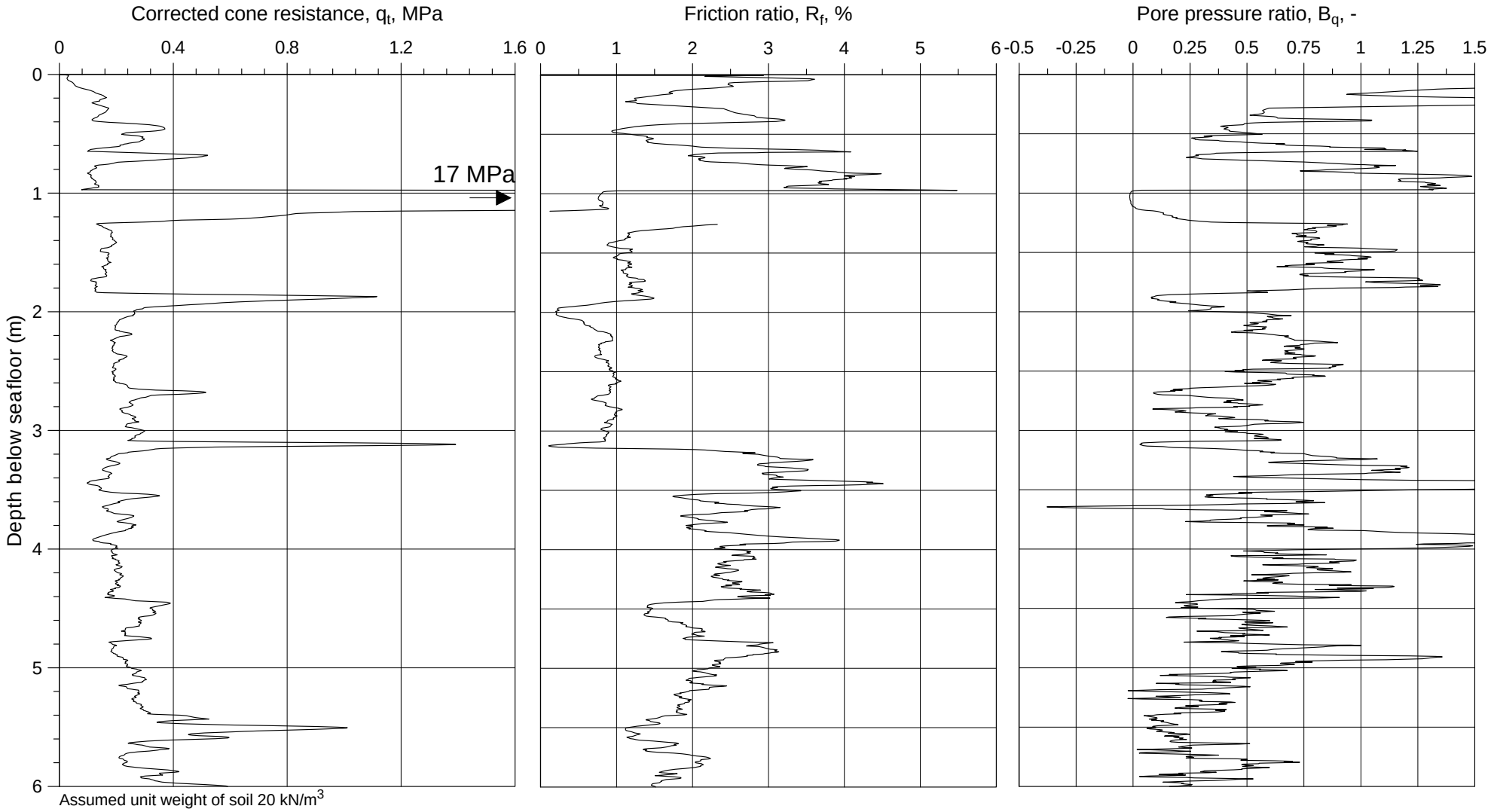

U-864 - 2013 SOIL SURVEY

Corrected cone resistance (q_t), friction ratio (R_f), and pore pressure ratio (B_q)

Borehole	Easting	Northing	Water Depth
2013-509CPT	261 627.9 mE	6 745 201.8 mN	176.0 m

WGS-84, UTM Zone 32N, CM 9°E

Document No. 20120738-01-R

Date 2013-03-06

Figure No. B3.12

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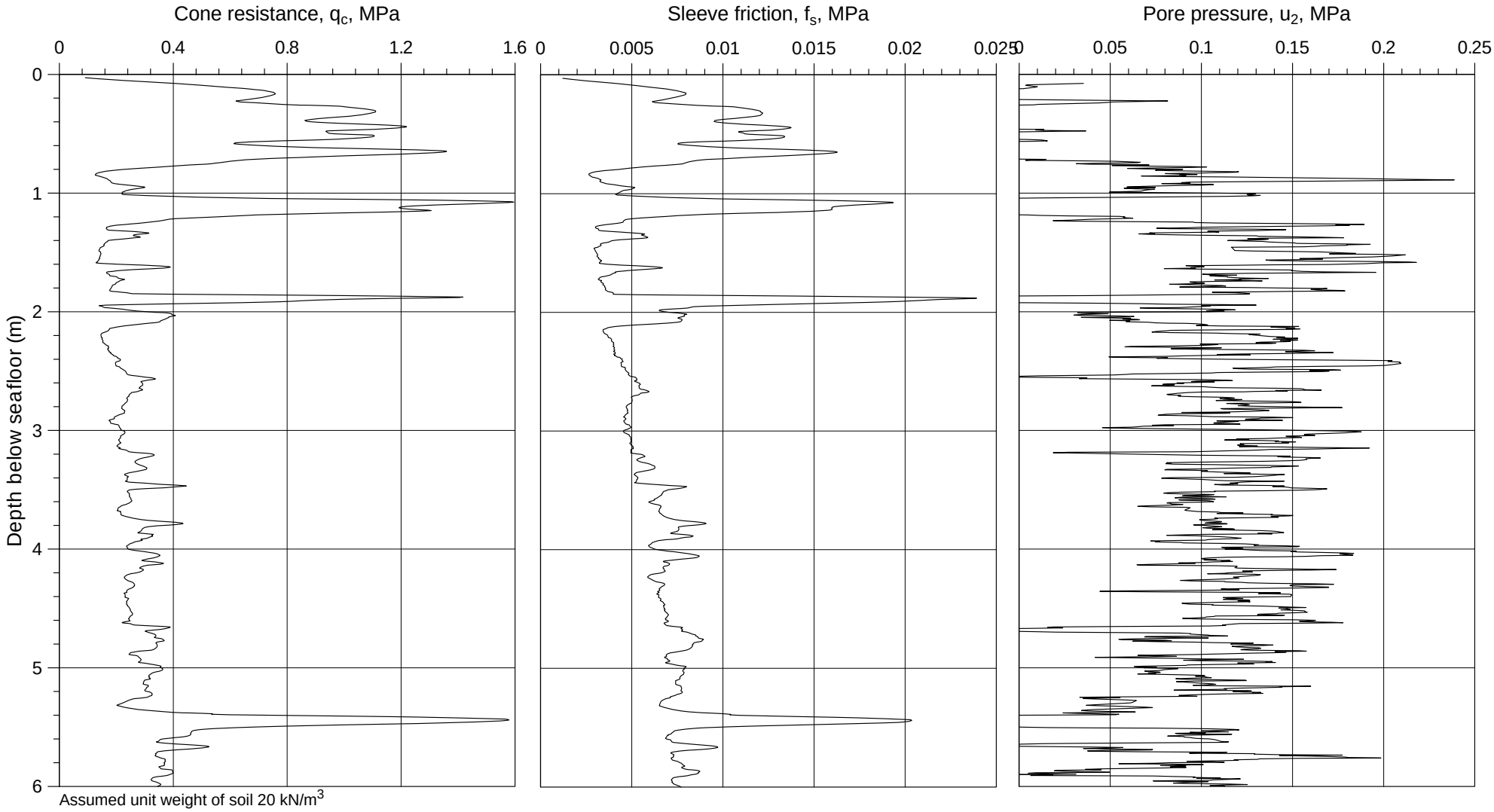

U-864 - 2013 SOIL SURVEY

Cone resistance (q_c), sleeve ratio (f_s), and pore pressure (u_2)

Borehole	Easting	Northing	Water Depth
2013-510CPT	261 580.9 mE	6 745 198.0 mN	175.5 m

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Document No. 20120738-01-R

Date 2013-03-06

Figure No. B3.13

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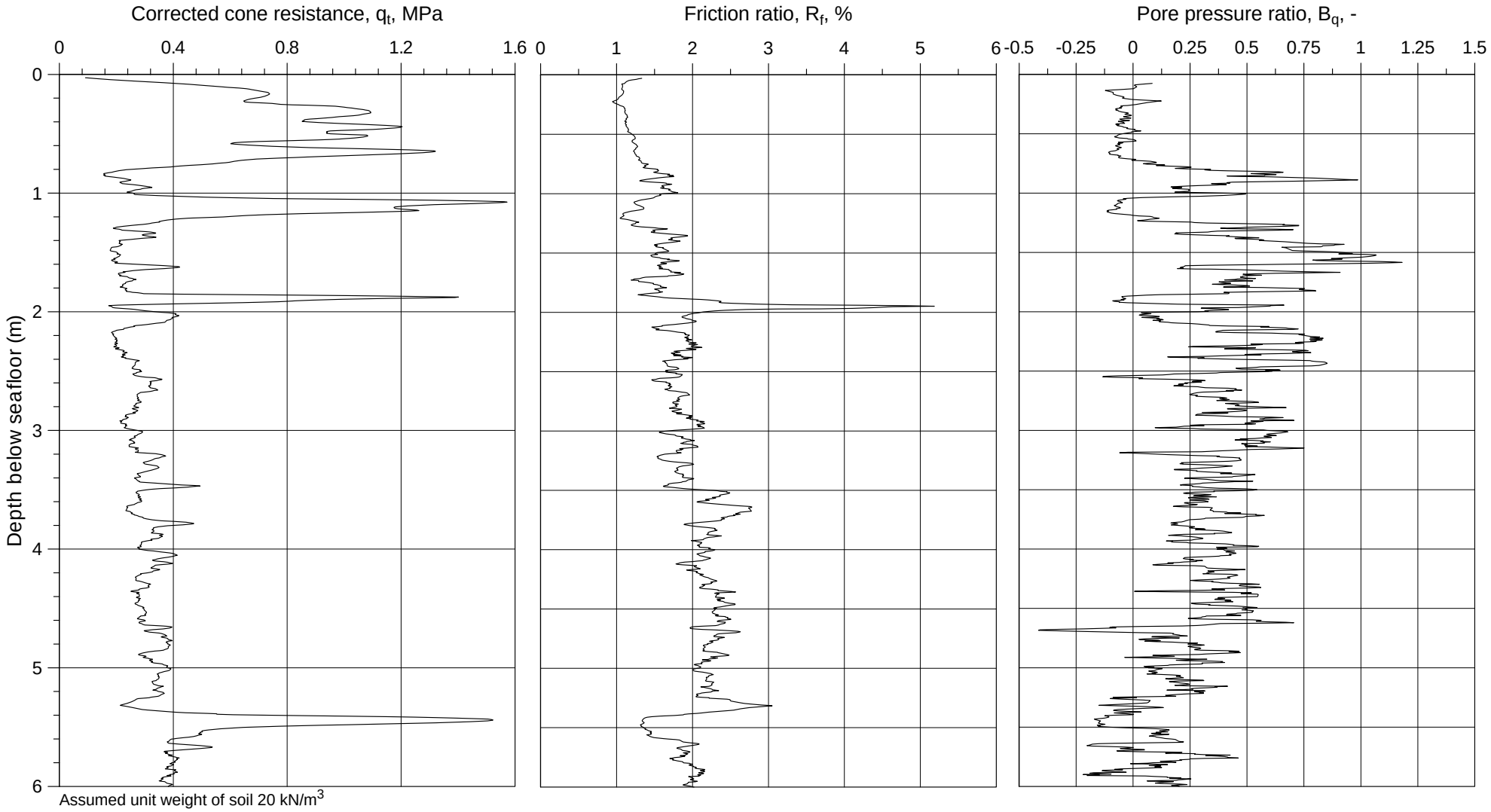

U-864 - 2013 SOIL SURVEY

Corrected cone resistance (q_t), friction ratio (R_f), and pore pressure ratio (B_q)

Borehole	Easting	Northing	Water Depth
2013-510CPT	261 580.9 mE	6 745 198.0 mN	175.5 m

WGS-84, UTM Zone 32N, CM 9°E

Document No. 20120738-01-R

Date 2013-03-06

Figure No. B3.14

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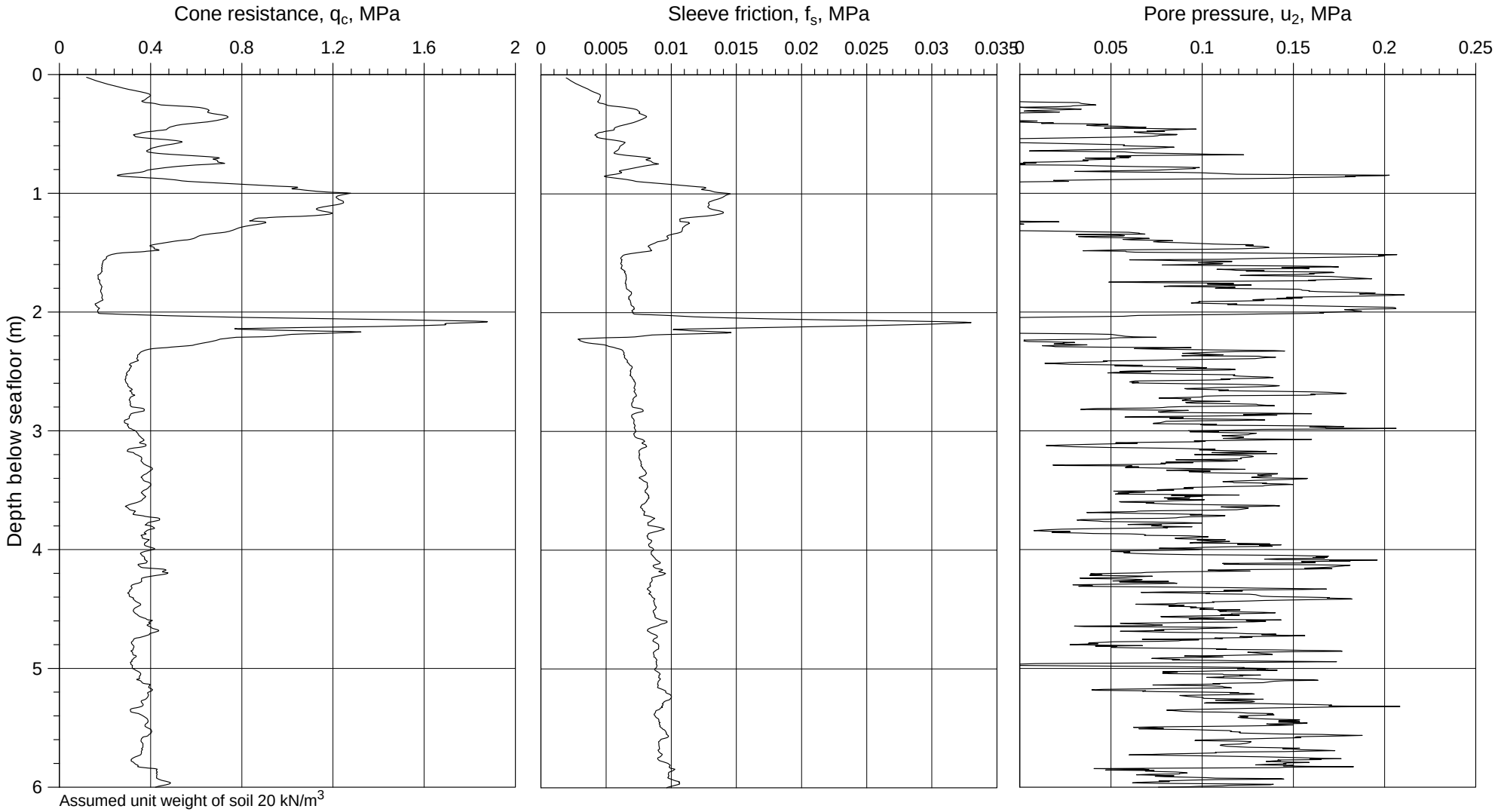

U-864 - 2013 SOIL SURVEY

Cone resistance (q_c), sleeve ratio (f_s), and pore pressure (u_2)

Borehole	Easting	Northing	Water Depth
2013-511CPT	261 580.5 mE	6 745 183.5 mN	172.7 m

WGS-84, UTM Zone 32N, CM 9°E

Document No. 20120738-01-R

Date 2013-03-06

Figure No. B3.15

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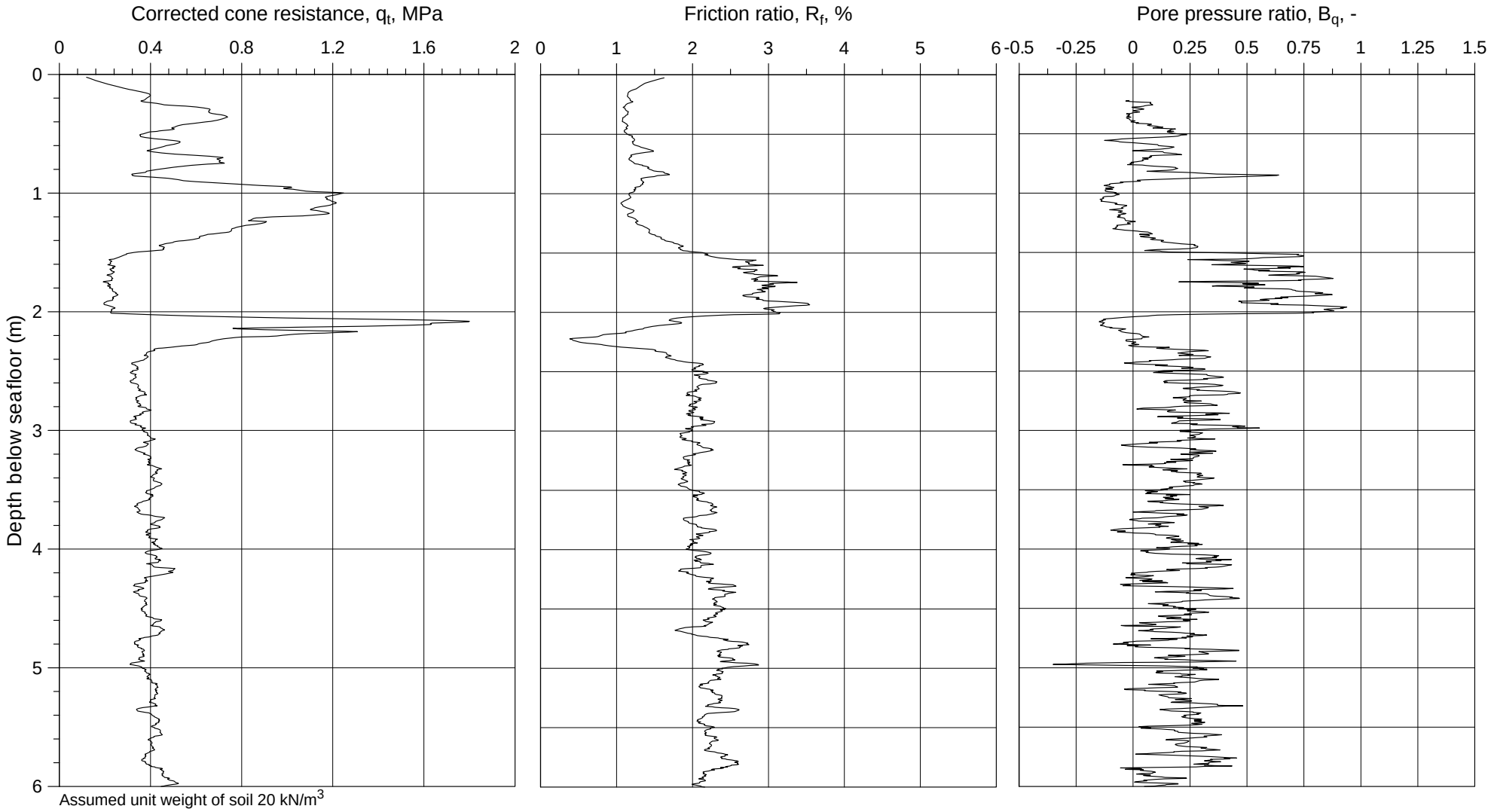

U-864 - 2013 SOIL SURVEY

Corrected cone resistance (q_t), friction ratio (R_f), and pore pressure ratio (B_q)

Borehole	Easting	Northing	Water Depth
2013-511CPT	261 580.5 mE	6 745 183.5 mN	172.7 m

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Figure No. B3.16

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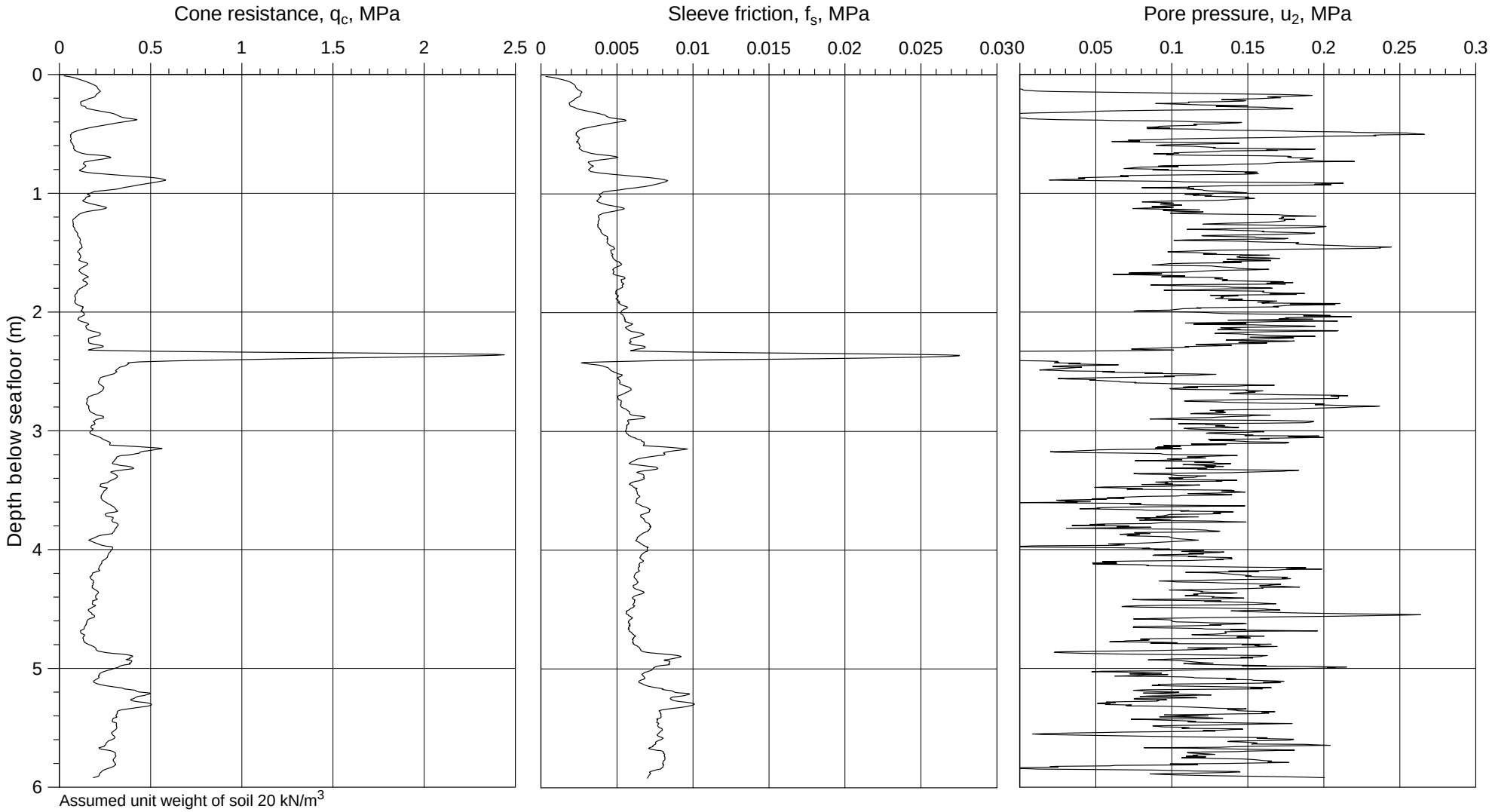

U-864 - 2013 SOIL SURVEY

Cone resistance (q_c), sleeve ratio (f_s), and pore pressure (u_2)

Borehole	Easting	Northing	Water Depth
2013-512CPT	261 649.7 mE	6 745 192.3 mN	175.6 m

WGS-84, UTM Zone 32N, CM 9°E

Document No. 20120738-01-R

Date 2013-03-06

Figure No. B3.17

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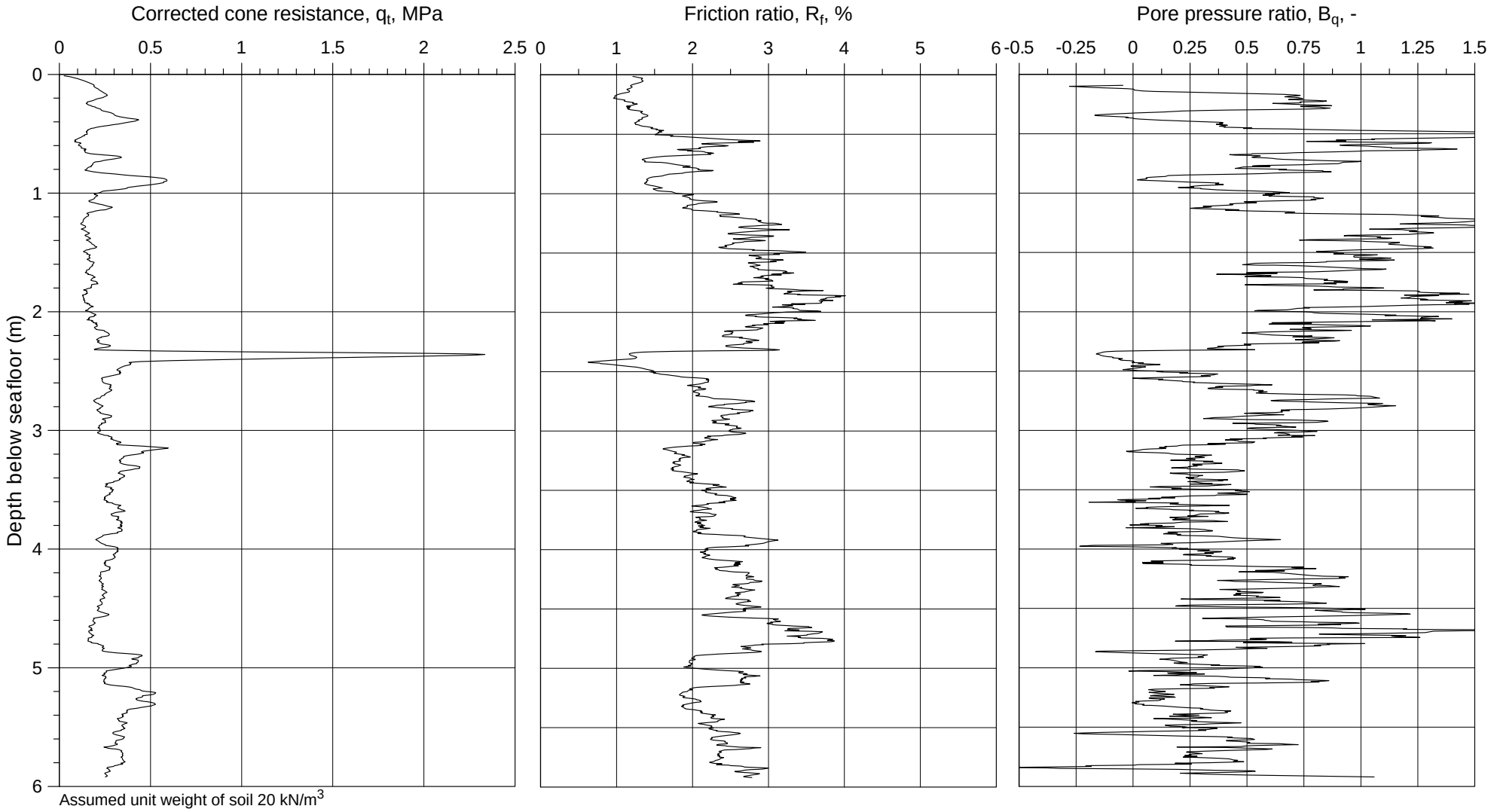

U-864 - 2013 SOIL SURVEY

Corrected cone resistance (q_t), friction ratio (R_f), and pore pressure ratio (B_q)

Borehole	Easting	Northing	Water Depth
2013-512CPT	261 649.7 mE	6 745 192.3 mN	175.6 m

WGS-84, UTM Zone 32N, CM 9°E

Document No. 20120738-01-R

Date 2013-03-06

Figure No. B3.18

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Part B4 - Oedometer Tests

Contents

B4.1 General 2
B4.2 Consolidation test results 2
B4.3 Constant rate of strain tests 2
B4.4 Evaluation of sample quality 3

Table

B4-1 Summary of CRSC oedometer tests

Figures

B4.1 – B4.6 Individual oedometer (CRSC) results

B4.1 General

The main purpose of the oedometer tests is to obtain consolidation and settlement parameters and to get an estimate of the preconsolidation stress, p_c'. Oedometer test results can also be used to assess sample quality.

Three oedometer tests have been performed as Constant Rate of Strain Consolidation (CRSC) tests.

B4.2 Consolidation test results

A total of 2 CRSC tests have been performed on undisturbed clay samples.

The key results are tabulated in Table B4-1 and the results from each individual test are presented in Figures B4.1 to B4.6 on both semi-logarithmic and linear plots. The pore pressure divided by the total applied stress is also presented for each test.

A detailed description of the laboratory test procedures is given in Part B7.

B4.3 Constant rate of strain tests

The rate of strain was between 0.4% and 0.6% per hour for the tests. The cross section area of the specimen was 35 cm^2.

The specimens were loaded directly to a high stress level or subjected to one unloading and reloading loop. One specimen was first loaded to a level of approximately 2 times the best estimated preconsolidation stress, p_c', where the stress was kept constant for 16 to 24 hours before unloading to 50 % of the stress applied before unloading. The samples were then reloaded to approximately 9 times the estimated preconsolidation stress or the maximum capacity of the test equipment.

The permeability was continuously computed based on the pore pressure measurements in the bottom of the specimen, and the rate of strain.

The variation of the deformation modulus, M, with stress is included in the linear format figures together with the coefficient of consolidation, c_v. The c_v values shown are calculated on the basis of the deformation modulus and the straight line interpretation of permeability based on the permeability computations (Sandbækken et al., 1986).

Table B4-1 presents values of constrained modulus, M, and coefficient of vertical consolidation, c_v, at various stress levels during the tests. M_0 and c_{v0} represent values at the in situ effective vertical stress, p_0', during the initial loading. M_1 and c_{v1} represent average values during the first reloading.

The modulus number, m, and the reference stress, p_r', given in Table B4-1 represent the deformation characteristics of the soil in the stress range above the preconsolidation stress, p_c', when the following relationship is used:

$$M = m \cdot (p_v' - p_r').$$

Interpretation of preconsolidation stress, p_c', is found from the procedures proposed by Casagrande (1936), by Becker (1987) and by Janbu (1963). Table B4-1 also shows p_c' values computed from empirical correlations between s_u, σ_{v0}' and I_p as given by Andresen et al. (1979). In general, the method proposed by Janbu was difficult to apply.

For use in design, reference is made to Part A.

B4.4 Evaluation of sample quality

The quality of the undisturbed clay specimens used for the CRSC tests has been evaluated based on change in void ratio (Δe), relative to initial void ratio when consolidating the specimens back to the best estimate of in situ stresses according to recommendations given by Lunne et al. (1998).

As can be observed in Table B4-1, the sample quality of these two specimens are “good to fair” and poor.

For further details on sample quality and the limitations of this method, reference is made to Part B7.

TABLE SUMMARY OF CRSC OEDOMETER TESTS

Boring No.	Tube part test	Depth m	Sample area cm^2	INDEX PROPERTIES: Water content w_i %	w_f %	I_p %	Clay cont. %	Unit weight kN/m^3	LOADING PROCEDURE: Estim. p_0' kPa	Start 1. unload, p_1' kPa	Start re-load, p_2' kPa	DEFORMATION PARAMETERS: Loading M_0 MPa	M_1 MPa	m -	p_r' kPa	COEFF. OF CONS. Loading c_{v0} $m^2/s*10^{-7}$	c_{v1} $m^2/s*10^{-7}$	PERM. k 1) $m/s * 10^{-09}$	ESTIM. PRECONS. PRESSURE p_c' 2) kPa	p_c' 3) kPa	p_c' 4) kPa	p_c' 5) kPa	$\Delta V/V$ at p_0' %	$\Delta e/e_i$ 6) -	Sample quality 7)	COMMENTS	FIGURE REFERENCE
2013-512GC	3-A-3	2.70	35	25.0	18.9	13	17	20.44	25.7	100	50	1.09	29.2	25.0	-26	0.86	12.0	1.3	-	27.0	-	30.8	3.35	0.082	3		B4.1-B4.3
2013-512GC	4-A-3	3.60	35	25.3	18.8	13	18	20.39	34.2	100	50	1.95	35.9	23.0	-33	3.00	3.3	2.1	-	35	40.0	41.0	2.58	0.063	2		B4.4-B4.6

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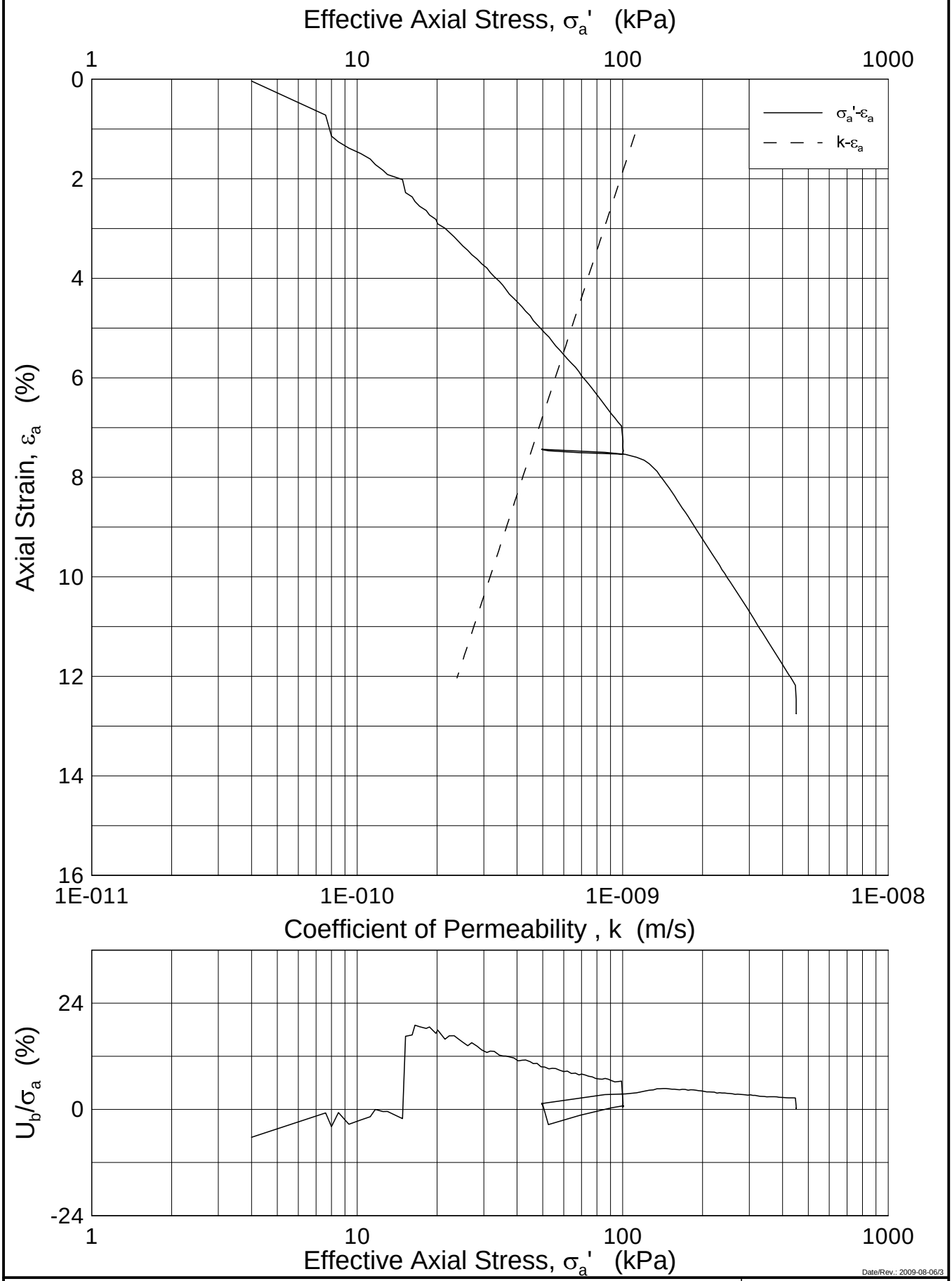
LEGEND:

NGI's criteria for sample quality				
OCR	$\Delta e/e_i$			
1-2	<0.04	0.04-0.07	0.07-0.14	>0.14
2-4	<0.03	0.03-0.05	0.05-0.10	>0.10
4-6	<0.02	0.02-0.035	0.035-0.07	>0.07
Quality	1	2	3	4

M_0, c_{v0} = at p_0' (tangent module)

M_1, c_{v1} = average from p_2' to p_1', reloading

1) k = coefficient of permeability at zero axial strain
2) Using the Casagrande interpretation
3) Using the Becker interpretation
4) Using empirical relationships between s_u, I_p, p_0' and p_c' where s_u is determined in triaxial compression tests (CAUc)
5) Using the Janbu interpretation
6) $\Delta e/e_i$, where $\Delta e = \varepsilon_{vol} (1+e_i)$ and $e_i = 2.75 * w_i$
7) 1 - very good to excellent, 2 - good to fair, 3 - poor, 4 - very poor (Ref. Lunne et al. 1998)



U-864 2013 Soil survey

Document No. 20120738-01-R

Date 2013-03-06

Oedometer test (CRSC)

Boring: 2013-512GC Tube: 3

Part: A Test: 3

Depth = 2.70 m

p_o' = 25.7 kPa

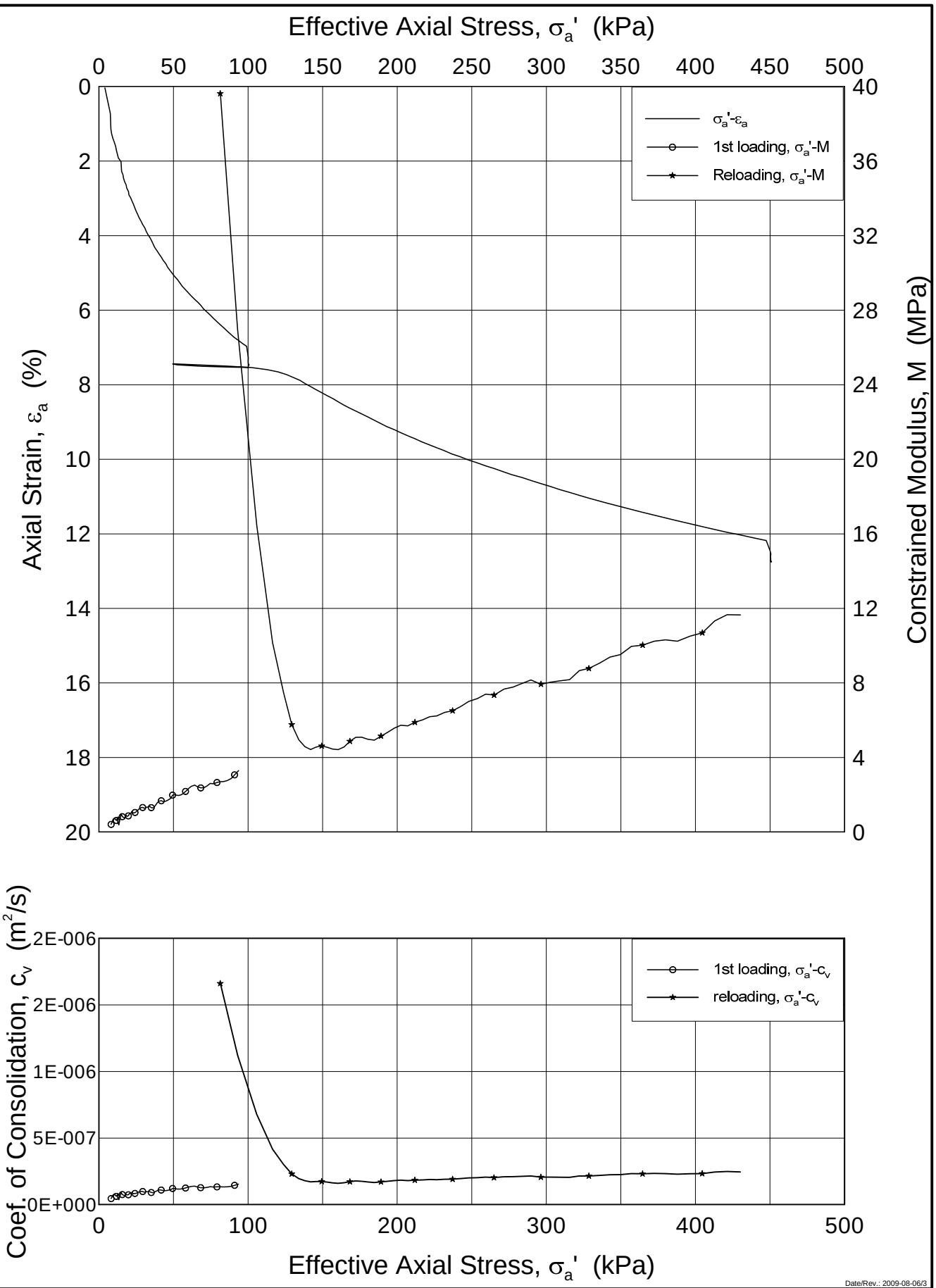
w_i = 24.99 %

Figure No. B4.1

Drawn by FP

NGI

P:\2012\07\20120738\Lab\Oedom\Fig B4_1 2013-512-GC-3-A-3 log(crs2192).grf



Date/Rev.: 2009-08-06/3

U-864 2013 Soil survey

Document No. 20120738-01-R

Oedometer test (CRSC)

Boring: 2013-512GC Tube: 3

Part: A Test: 3

Depth = 2.70 m

p_o' = 25.7 kPa

w_i = 24.99 %

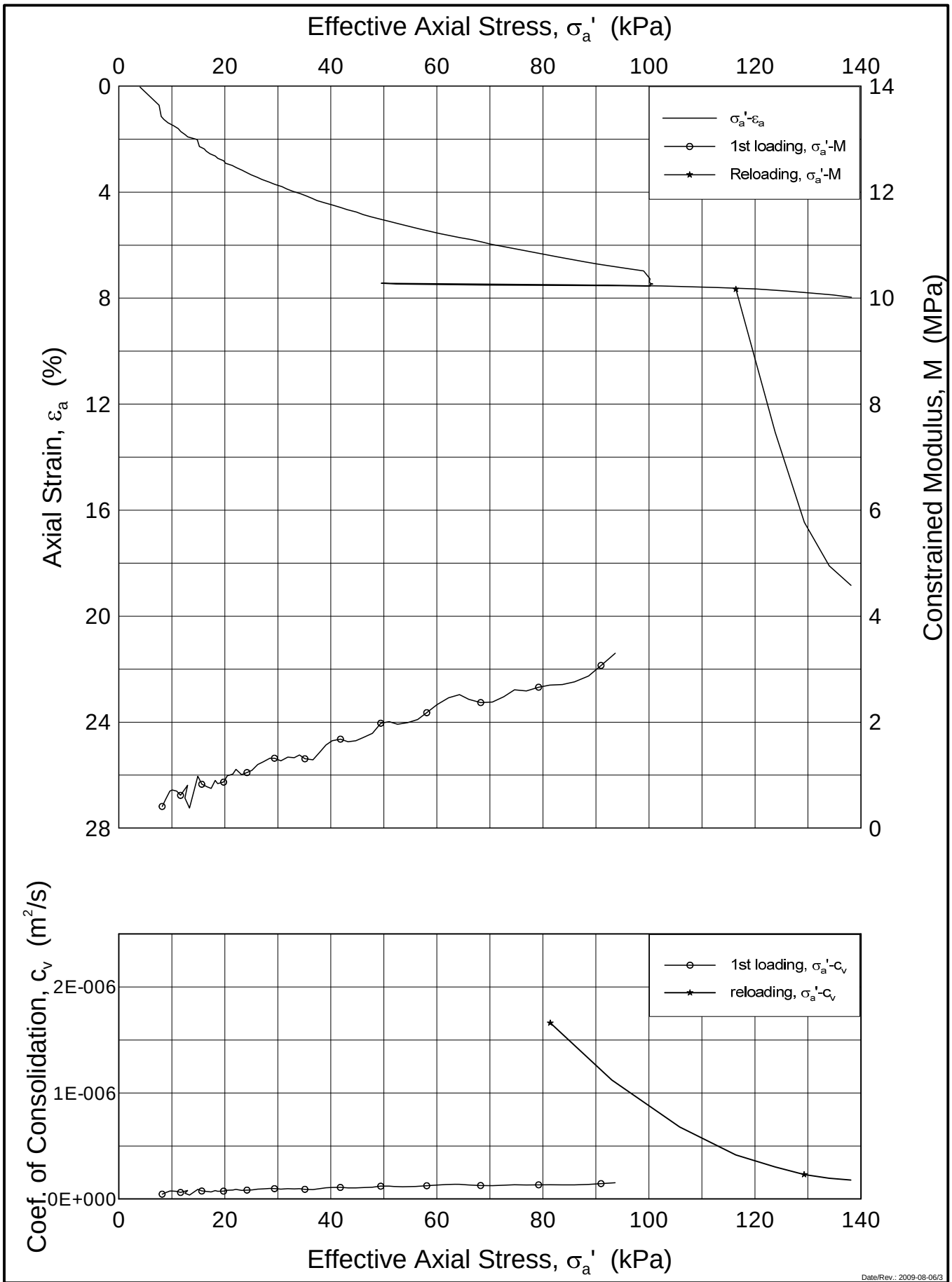
Date 2013-03-06

Figure No. B4.2

Drawn by FP/

NGI

P:\2012\07\20120738\Lab\Oedom\Fig B4_2 2013-512-GC-3-A-3 lin(crs2192).grf



Date/Rev.: 2009-08-06/3

U-864 2013 Soil survey

Document No. 20120738-01-R

Oedometer test (CRSC)

Depth = 2.70 m

Boring: 2013-512GC Tube: 3

p_o' = 25.7 kPa

Part: A Test: 3

w_i = 24.99 %

Date 2013-03-06

Figure No. B4.3

Drawn by FP/

NGI

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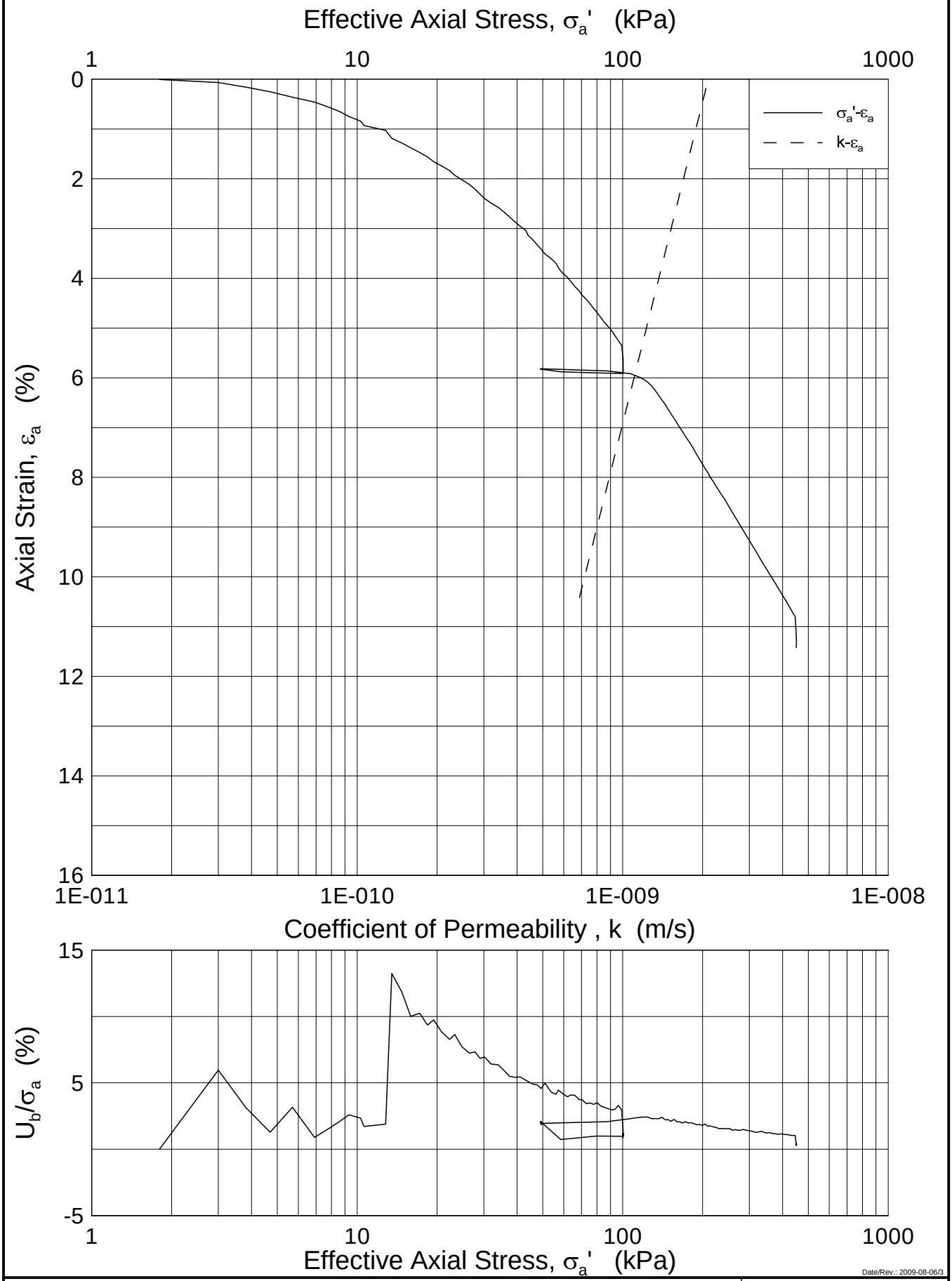

U-864 2013 Soil survey

Document No. 20120738-01-R

Date 2013-03-06

Oedometer test (CRSC)

Boring: 2013-512GC Tube: 4

Part: A Test: 3

Depth = 3.60 m

p_o' = 34.2 kPa

w_i = 25.33 %

Figure No. B4.4

Drawn by FP

NGI

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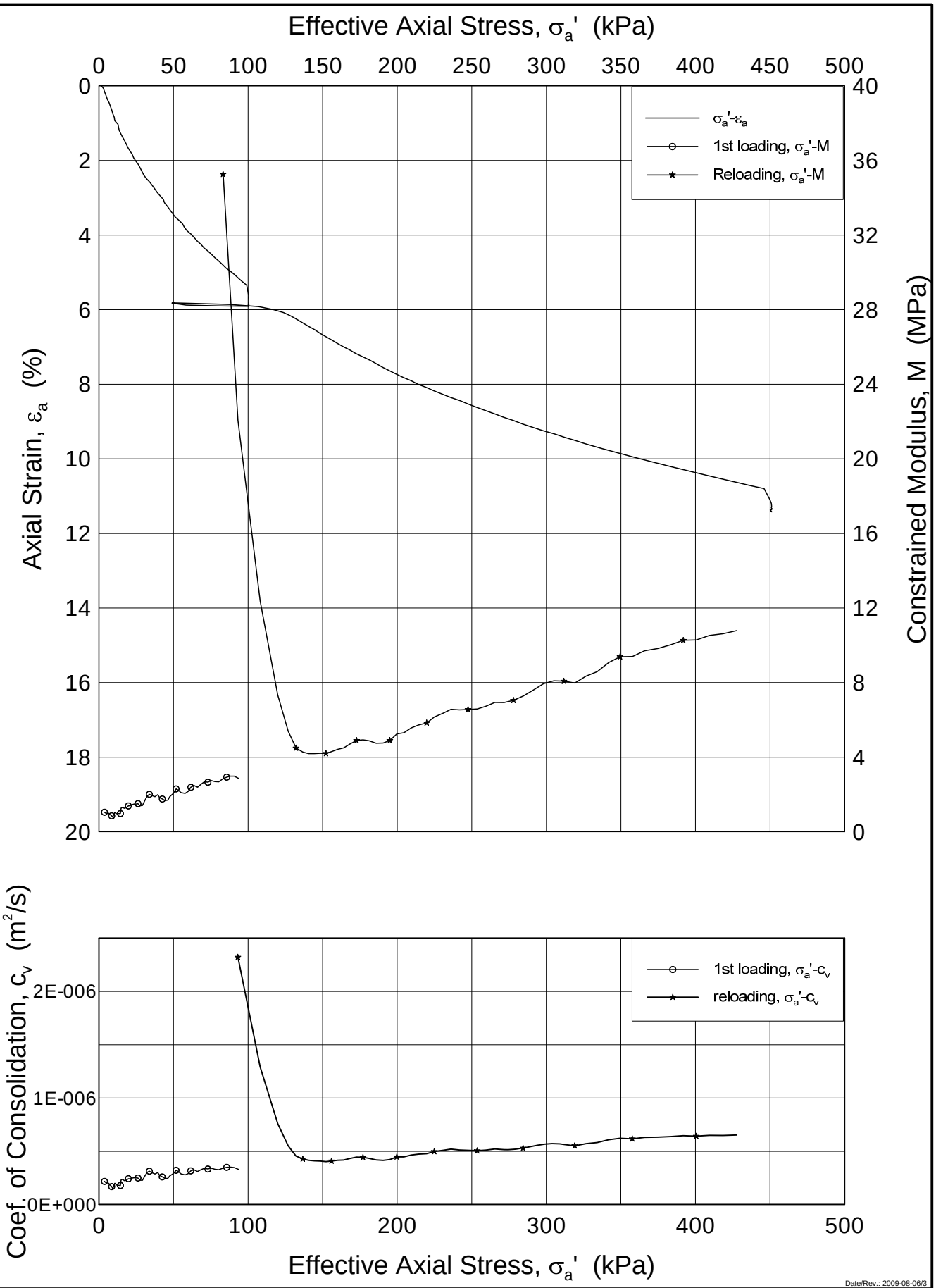

Date/Rev.: 2009-08-06/3

U-864 2013 Soil survey

Document No. 20120738-01-R

Oedometer test (CRSC)

Depth = 3.60 m

Boring: 2013-512GC Tube: 4

p_o' = 34.20 kPa

Part: A Test: 3

w_i = 25.33 %

Date 2013-03-06

Figure No. B4.5

Drawn by FP/

NGI

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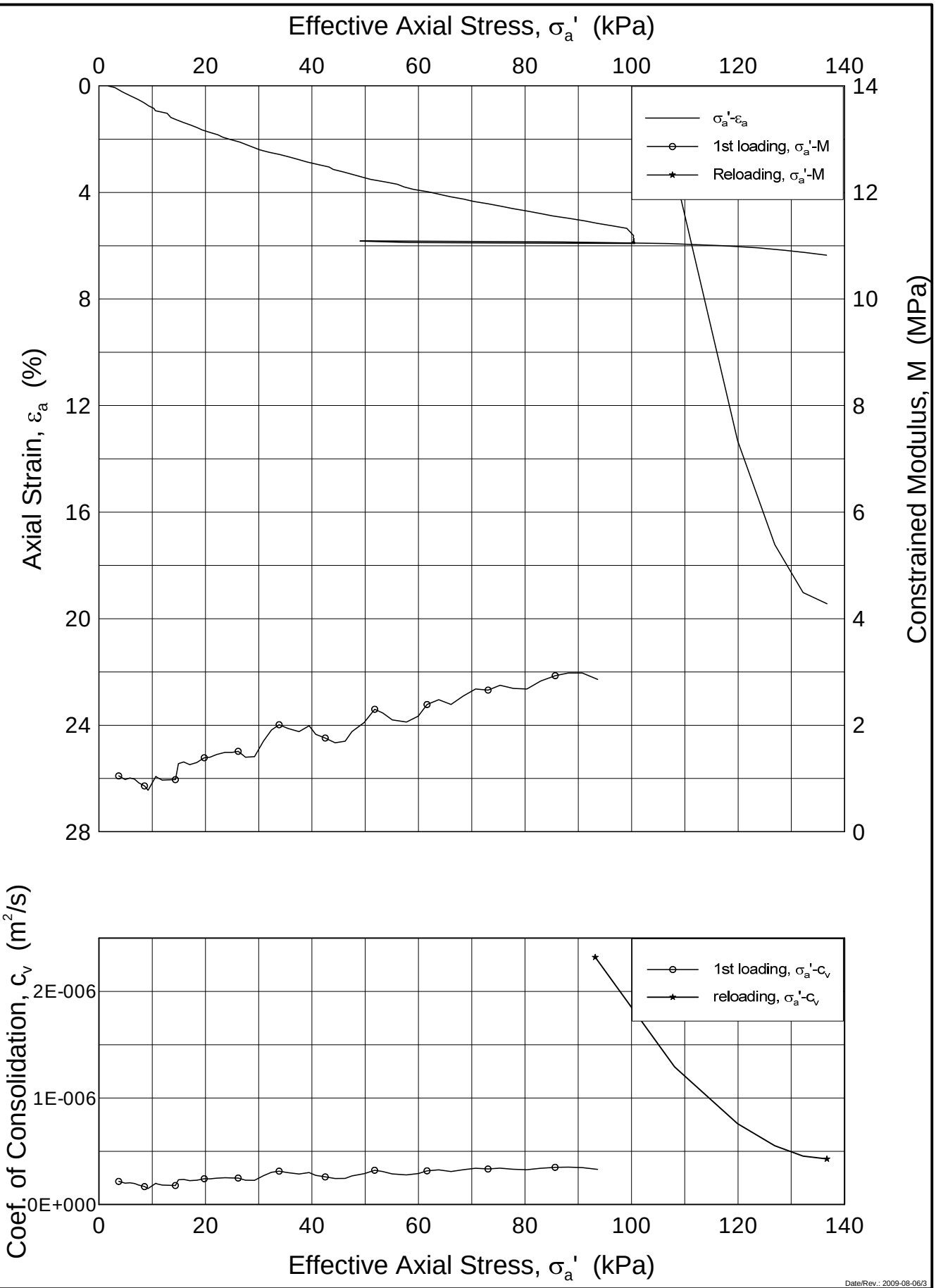

Date/Rev.: 2009-08-06/3

U-864 2013 Soil survey

Document No. 20120738-01-R

Oedometer test (CRSC)

Depth = 3.60 m

Boring: 2013-512GC Tube: 4

p_o' = 34.20 kPa

Part: A Test: 3

w_i = 25.33 %

Date 2013-03-06

Figure No. B4.6

Drawn by FP/

NGI

P:\2012\07\20120738\Lab\Oedom\Fig B4_6 2013-512-GC-4-A-3 lin-2(crs2193).grf

Part B5 - Triaxial Tests

Contents

B5.1 Summary 2
B5.2 Triaxial Test Results 2
B5.2.1 Specimen preparation and consolidation, clay material 2
B5.2.2 CAU test results 2
B5.3 Evaluation of clay sample quality 2

Table

B5-1 Summary of CAU triaxial tests on clay

Figures

B5.1 – B5.6 Individual CAU results

B5.1 Summary

The purpose of the triaxial tests is to obtain strength parameters for different foundation design aspects. This part summarises the results from the triaxial tests performed. The program consisted of 3 CAUC (Consolidated Anisotropic Undrained Compression) tests.

B5.2 Triaxial Test Results

B5.2.1 Specimen preparation and consolidation, clay material

All specimens were consolidated to a best estimate of the in situ stress conditions. The effective vertical in situ stress (p_0') was derived from the water content and total unit weight measured offshore as presented in the borehole logs in Part B1.

The horizontal consolidation stresses used were obtained using the relationship between s_u/p_0', I_p, OCR and K_0 presented by Andresen et al. (1979) and Brooker and Ireland (1965). By using s_u from CPTs and index tests and knowledge about the geological history a K_0- profile was established and used to define the consolidation stresses for each triaxial test.

Details of the consolidation of the specimens are given in Table B5-1. Detailed test procedures are given in Part B7.

B5.2.2 CAU test results

Plots of the static undrained triaxial test results are given in Figures B5.1 to B5.6 showing shear stress and pore pressure versus axial strain and stress paths in shear stress versus effective mean stress.

Key parameters for each test are summarised in Table B5-1.

The undrained shear strength (s_u^C) is defined as the shear stress at 10 % axial strain if no distinct peak occurred at lower strain levels. For use in design, reference is made to Part A. The undrained shear strengths from the static tests are plotted on the various boring profiles in Part B1.

B5.3 Evaluation of clay sample quality

The quality of the undisturbed clay specimens used for the CAU tests has been evaluated based on change in void ratio (Δe), relative to initial void ratio when consolidating the specimens back to the best estimate of in situ stresses according to the recommendations given by Lunne et al. (1998). As can be observed in Table B5-1, the sample quality is “good to fair” in the samples evaluated.

For further details on sample quality and the limitations of this method, reference is made to Part B7.

TABLE SUMMARY OF TRIAXIAL TESTS

Boring No.	Tube part test	Depth m	INDEX PROPERTIES Water content w_i %	w_f %	I_p %	Clay cont. %	Unit weight kN/m^3	Type of test 1)	CONSOLIDATION Estim. p_o' kPa	σ_a' final kPa	σ_r' final kPa	ε_{vol} %	ε_{ac} %	B %	UNDR. STATIC TESTING s_u kPa	U_f kPa	ε_f %	s_u/σ'_{ac} -	$\Delta e/e_i$ 2) -	Sample quality 3)	COMMENTS	FIGURE REFERENCE
2013-509GC	3-A-1	2.47	23.4	22.2	11.8	17	20.9	CAUC	23.5	23.5	16.4	2.19	0.47	98.4	24.0	1.1	10.0	1.02	0.056	2		B5.1-B5.2
2013-512GC	4-A-1	3.45	24.5	23.2	12.5	18	20.6	CAUC	32.8	32.7	18.0	2.08	0.69	99.4	26.2	0.4	10.0	0.80	0.052	2		B5.3-B5.4
2013-512GC	4-A-1	3.52	22.8	21.9	12.5	18	20.8	CAUC	33.4	33.4	20.1	1.64	0.57	98.6	31.3	-1.4	10.0	0.94	0.042	2		B5.5-B5.6

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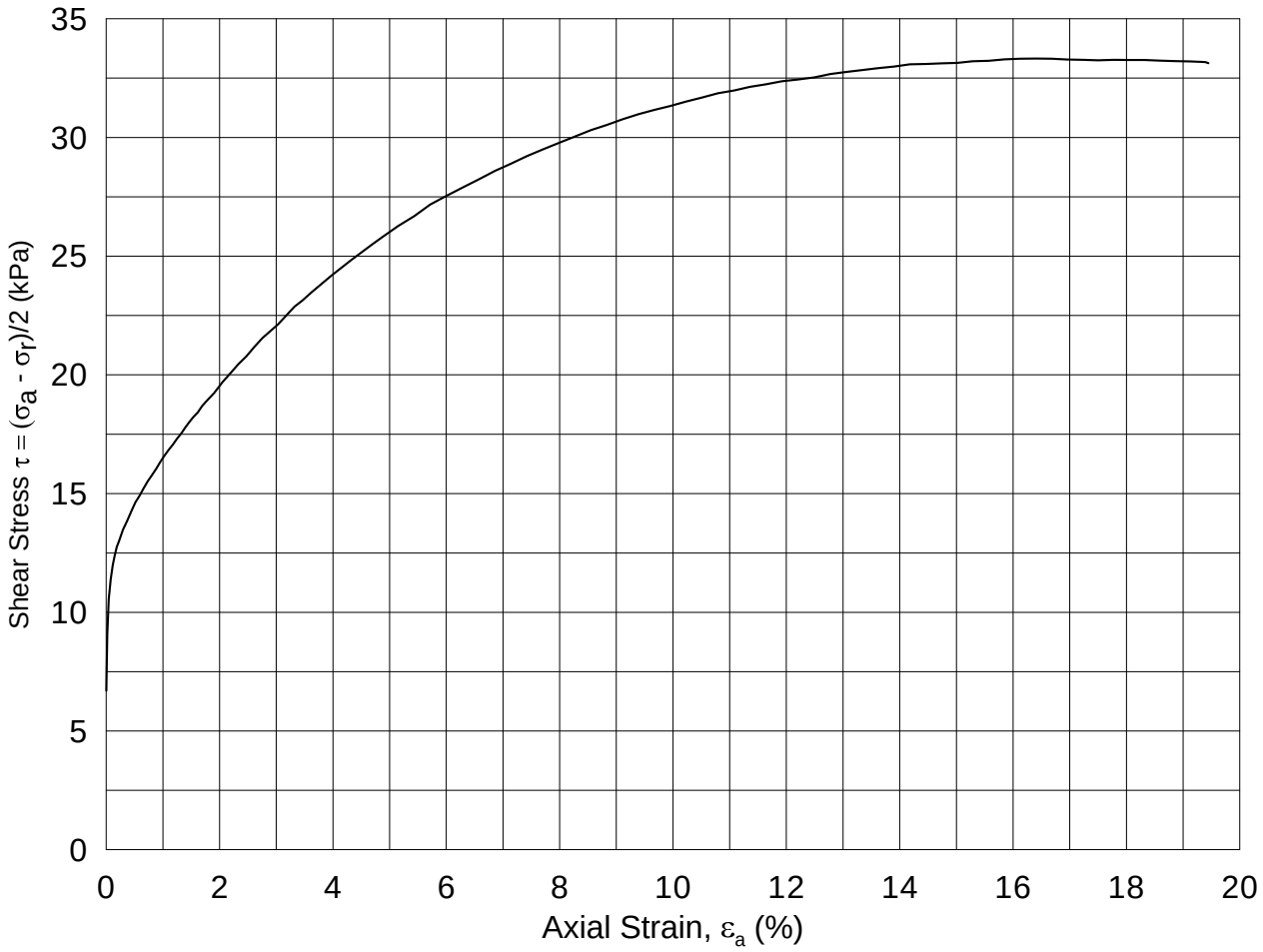
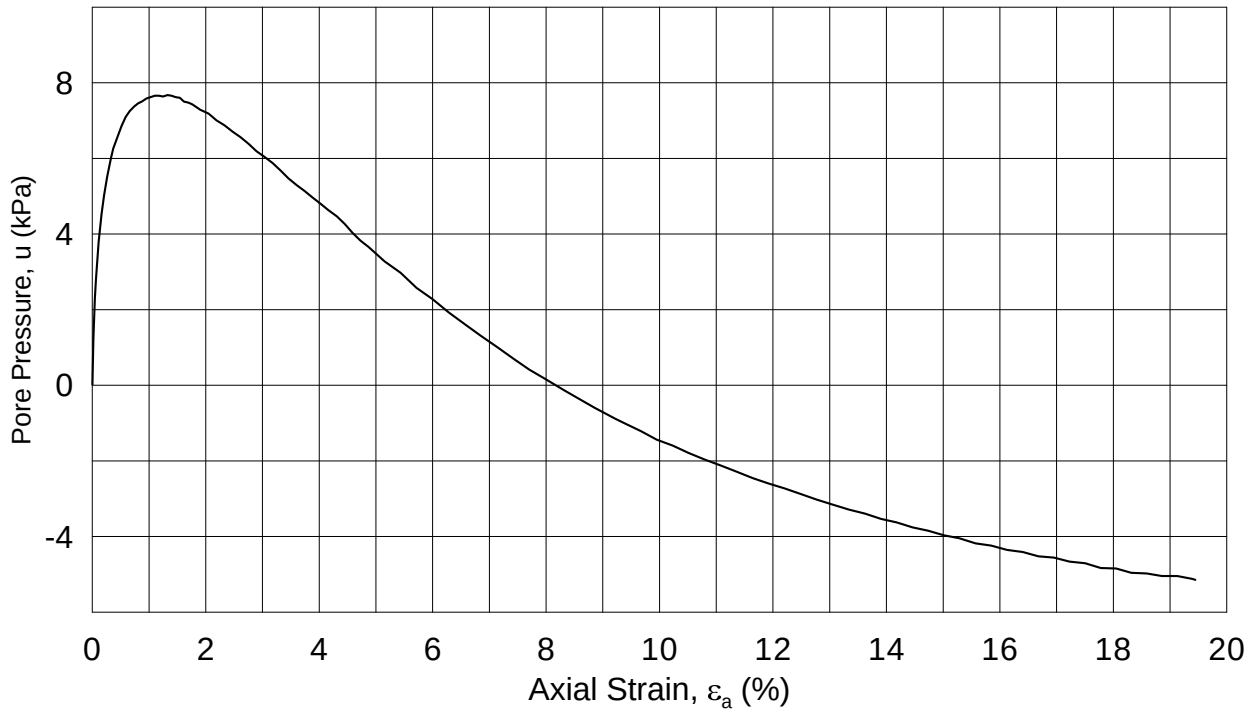
NGI's criteria for sample quality				
OCR	$\Delta e/e_i$			
1-2	<0.04	0.04-0.07	0.07-0.14	>0.14
2-4	<0.03	0.03-0.05	0.05-0.10	>0.10
4-6	<0.02	0.02-0.035	0.035-0.07	>0.07
Quality:	1	2	3	4

LEGEND 1) CAUC = Consolidated Anisotropic Undrained test in Compression
CAUE = Consolidated Anisotropic Undrained test in Extension
2) $\Delta e/e_i$, where $\Delta e = \varepsilon_{vol}(1+e_i)$ and $e_i = 2.75 * w_i$
3) 1 - very good to excellent, 2 - good to fair,
3 - poor, 4 - very poor (Ref. Lunne et al., 1998).
NA = Not applicable

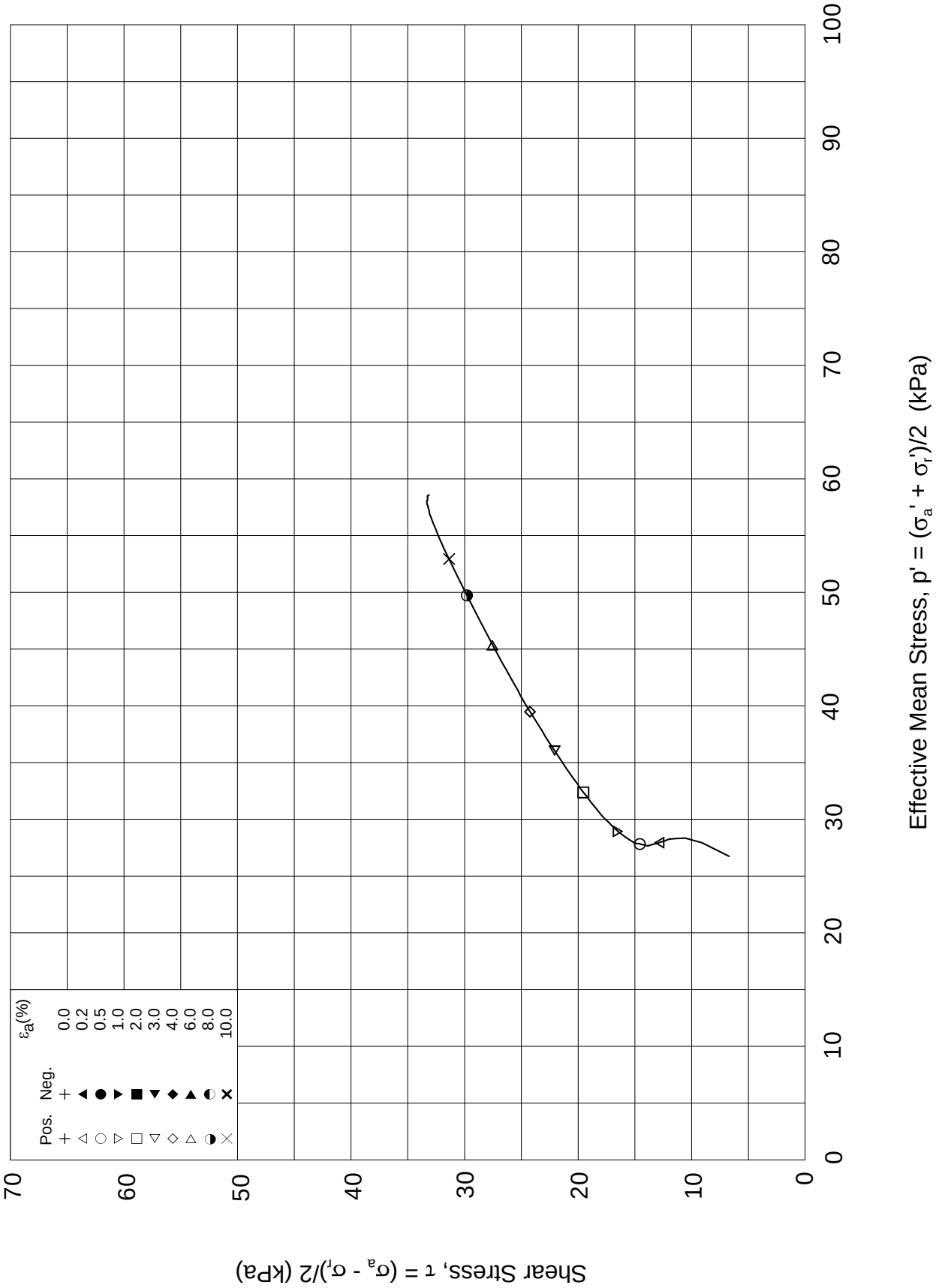




Date/Rev.: 2009-08-05/01

U-864-2013 SOIL SURVEY								Document No.	20120738-01-R
Triaxial test: **CAUC**								Date	2013-03-06
Boring: **2013-509GC**	Depth =	**3.52**	m	Consolidation stresses				Figure No.	B5.1
Tube: **4**	p_o' =	**33.4**	kPa	(kPa)	max.	min.	final		
Part: **A**	w_i =	**22.8**	%	σ_{ac}' =	-	-	**33.4**	Drawn by	MAS
Test: **1**	w_c =	**21.9**	%	σ_{rc}' =	-	-	**20.1**		

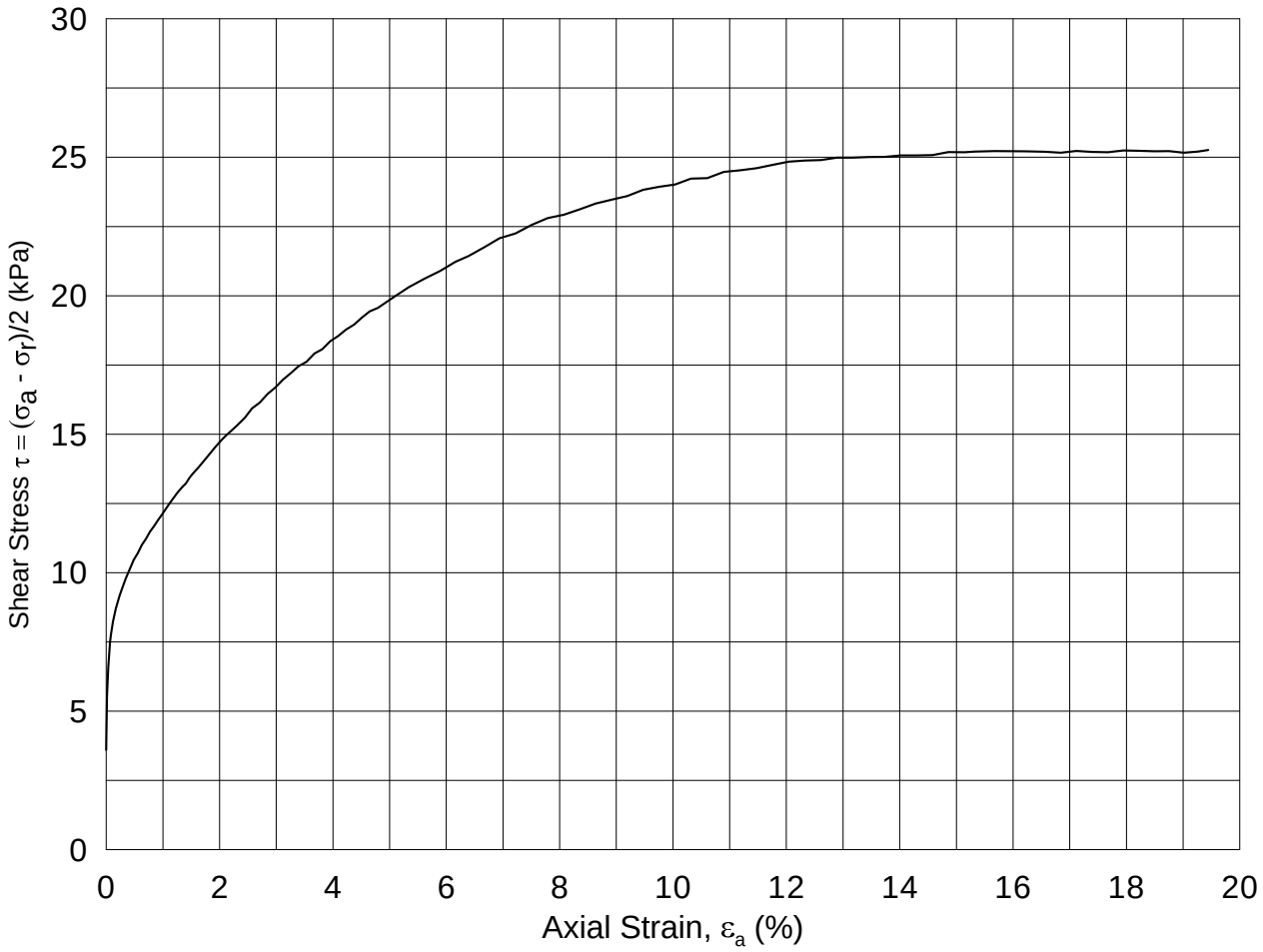
2013-509GC-4-A-1.Plot1.grf

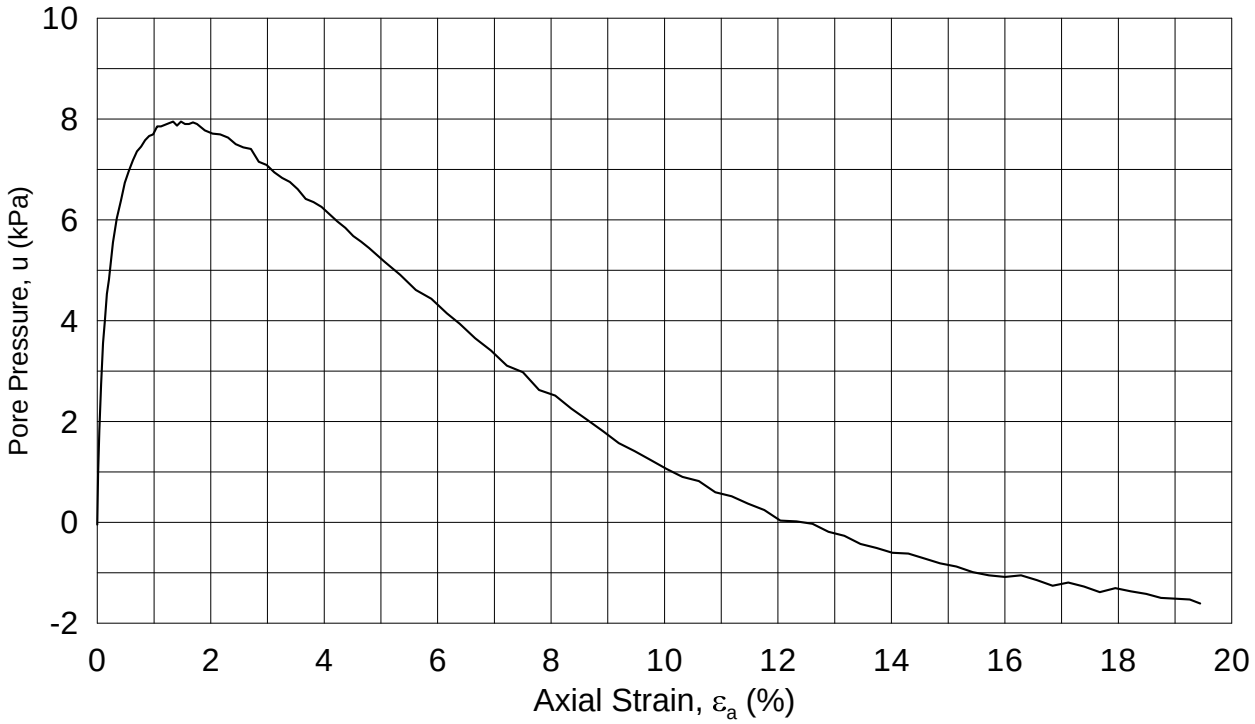


Date/Rev.: 2009-08-04/01

U-864-2013 SOIL SURVEY								Document No. 20120738-01-R	
Triaxial test: **CAUC**								Date 2013-03-06	
Boring: **2013-509GC**	Depth =	**3.52**	m	Consolidation stresses				Figure No. B5.2	NGI
Tube: **4**	p_o' =	**33.4**	kPa	(kPa)	max.	min.	final		
Part: **A**	w_i =	**22.8**	%	σ_{ac}' =	-	-	**33.4**	Drawn by MAS	
Test: **1**	w_c =	**21.9**	%	σ_{rc}' =	-	-	**20.1**		

2013-509GC-4-A-1.Plot2.grf

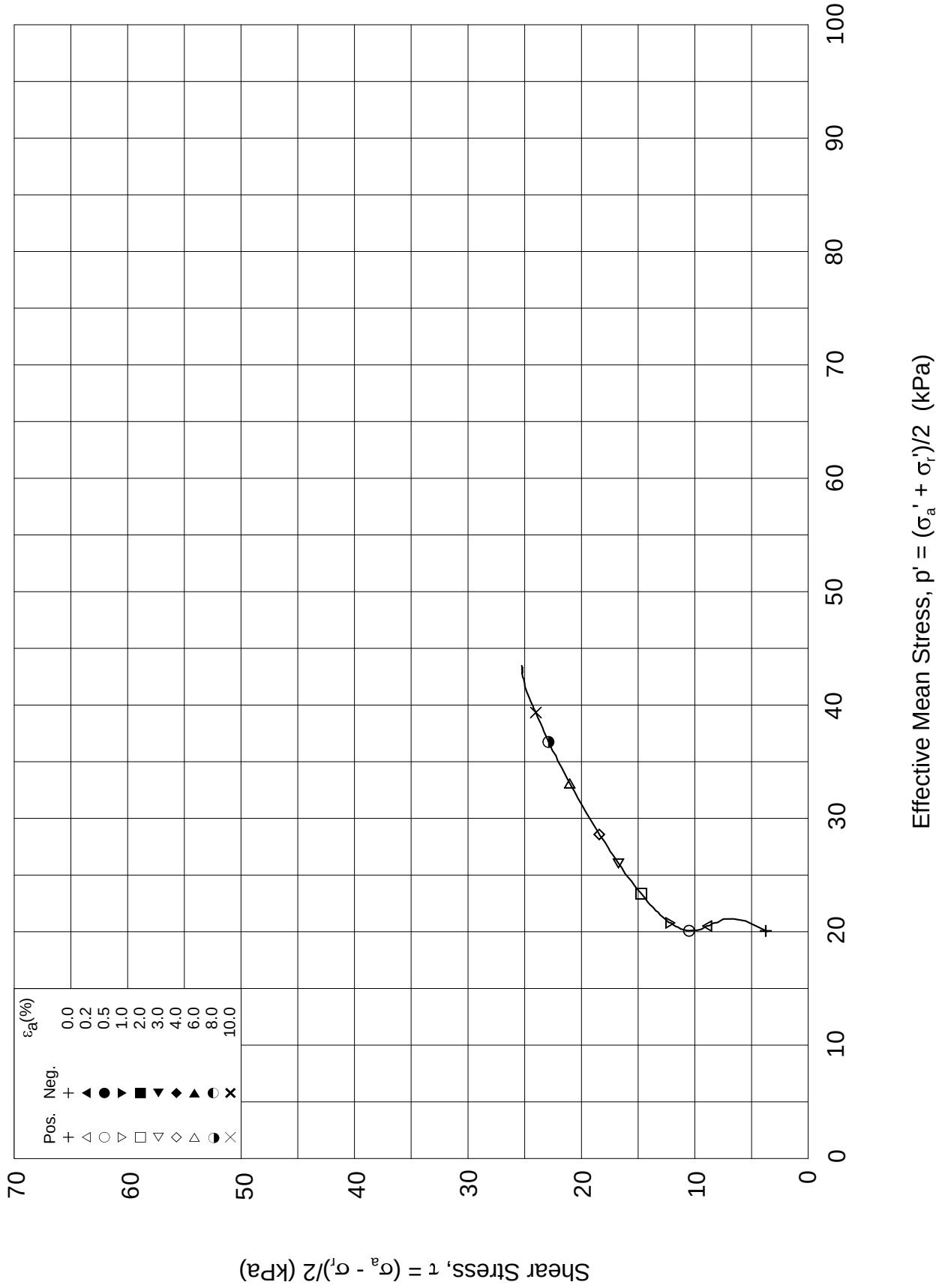




Date/Rev.: 2009-08-05/01

U-864-2013 SOIL SURVEY								Document No.	20120738-01-R
Triaxial test: **CAUC**								Date	2013-03-06
Boring: **2013-512GC**	Depth =	**2.47**	m	Consolidation stresses				Figure No.	B5.3
Tube: **3**	p_o' =	**23.5**	kPa	(kPa)	max.	min.	final		
Part: **A**	w_i =	**23.4**	%	σ_{ac}' =	-	-	**23.5**	Drawn by	MAS
Test: **1**	w_c =	**22.2**	%	σ_{rc}' =	-	-	**16.4**		

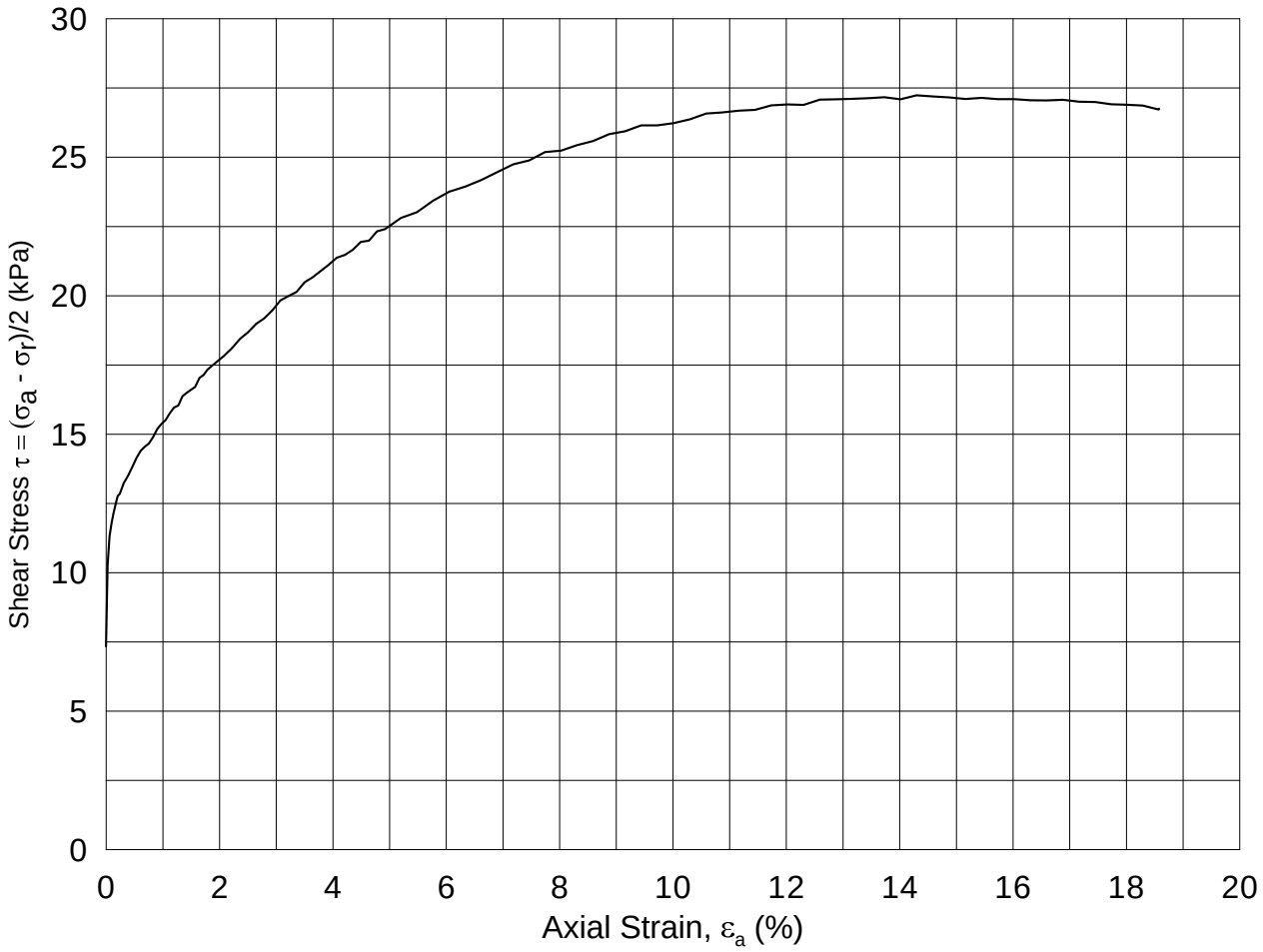
2013-512GC-3-A-1.Plot1.grf

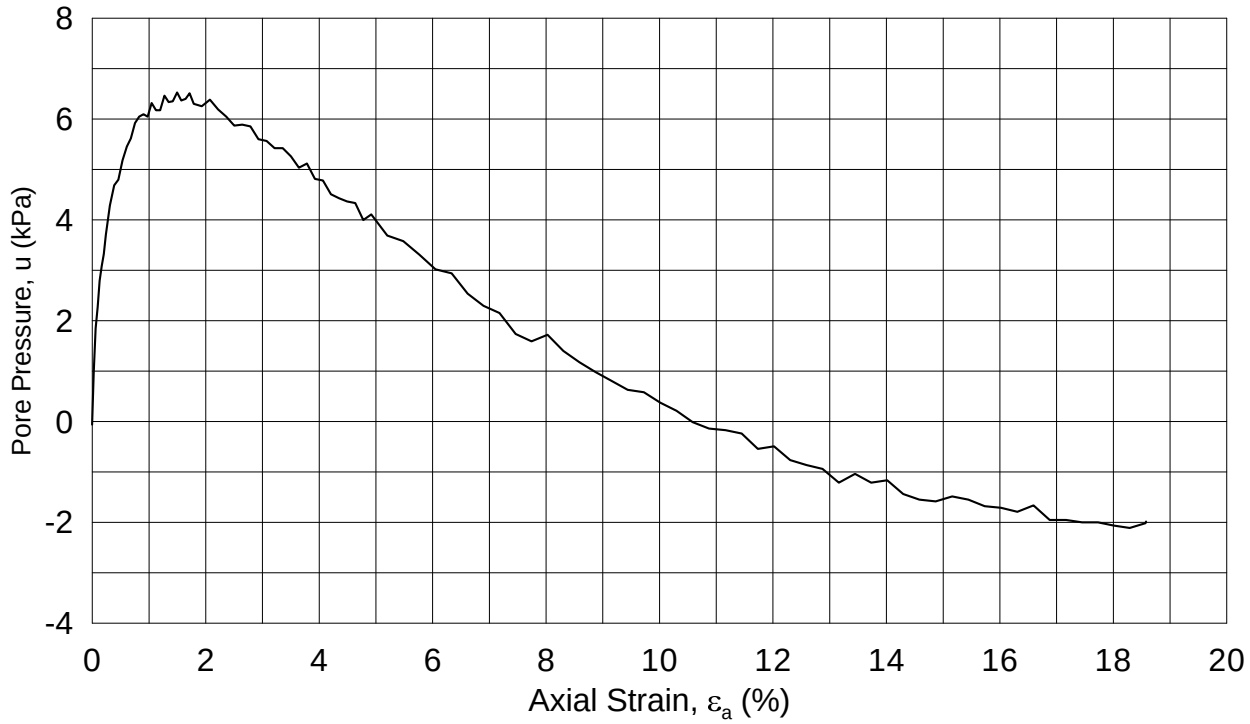


Date/Rev.: 2009-08-04/01

U-864-2013 SOIL SURVEY								Document No. 20120738-01-R	
Triaxial test: **CAUC**								Date 2013-03-06	
Boring: **2013-512GC**	Depth =	**2.47**	m	Consolidation stresses				Figure No. B5.4	NGI
Tube: **3**	p_o' =	**23.5**	kPa	(kPa)	max.	min.	final		
Part: **A**	w_i =	**23.4**	%	σ_{ac}' =	-	-	**23.5**	Drawn by MAS	
Test: **1**	w_c =	**22.2**	%	σ_{rc}' =	-	-	**16.4**		

2013-512GC-3-A-1.Plot2.grf

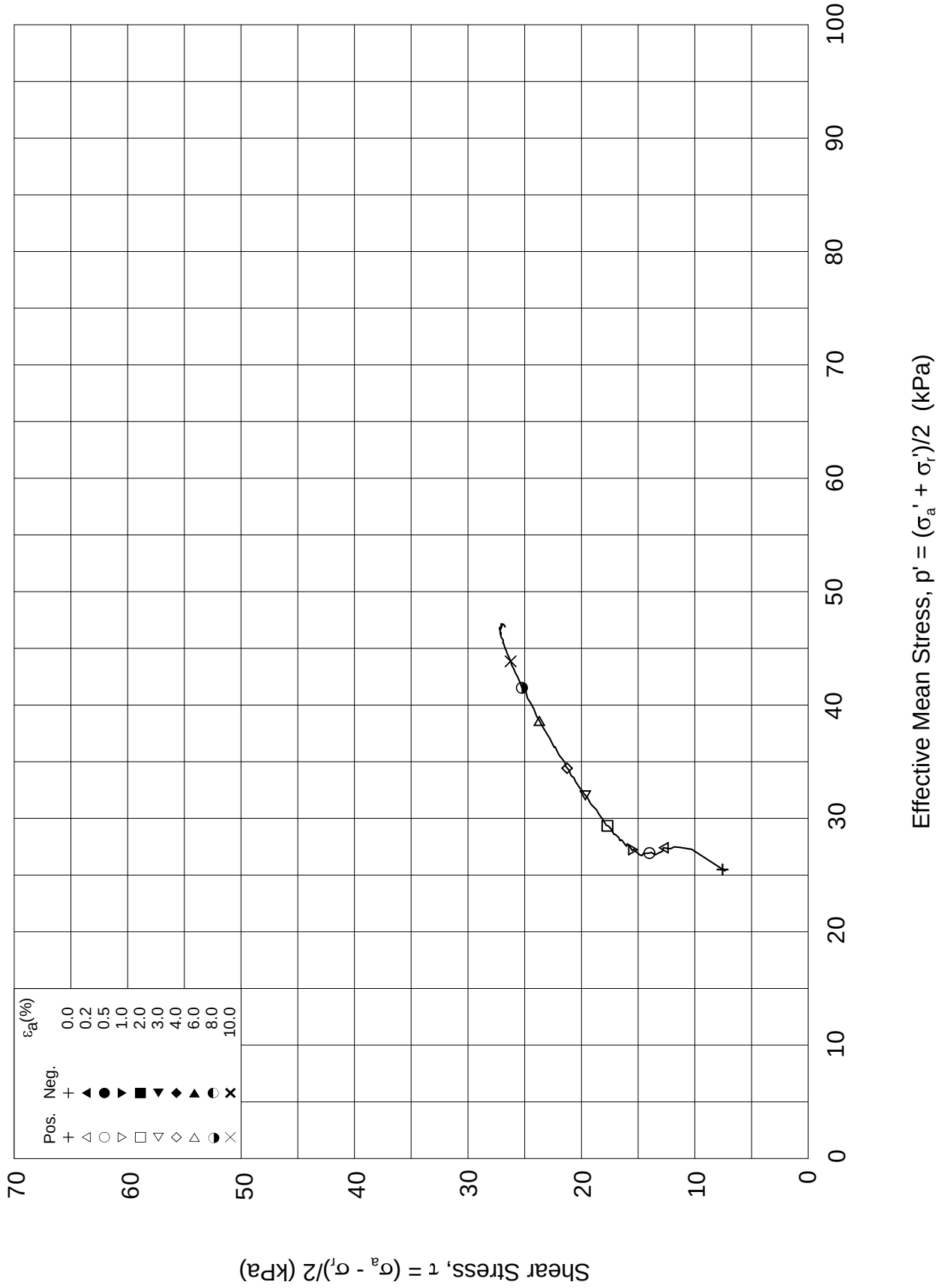




Date/Rev.: 2009-08-05/01

U-864-2013 SOIL SURVEY								Document No.	20120738-01-R
Triaxial test: **CAUC**								Date	2013-03-06
Boring: **2013-512GC**	Depth =	**3.45**	m	Consolidation stresses				Figure No.	B5.5
Tube: **4**	p_o' =	**32.8**	kPa	(kPa)	max.	min.	final		
Part: **A**	w_i =	**24.5**	%	σ_{ac}' =	-	-	**32.7**	Drawn by	MAS
Test: **1**	w_c =	**23.2**	%	σ_{rc}' =	-	-	**18.0**		

2013-512GC-4-A-1.Plot1.grf



Date/Rev.: 2009-08-04/01

U-864-2013 SOIL SURVEY								Document No. 20120738-01-R
Triaxial test: **CAUC**								Date 2013-03-06
Boring: **2013-512GC**	Depth =	**3.45**	m	Consolidation stresses				Figure No. B5.6
Tube: **4**	p_o' =	**32.8**	kPa	(kPa)	max.	min.	final	
Part: **A**	w_i =	**24.5**	%	σ_{ac}' =	-	-	**32.7**	Drawn by MAS
Test: **1**	w_c =	**23.2**	%	σ_{rc}' =	-	-	**18.0**	NGI

2013-512GC-4-A-1.Plot2.grf

Part B6 - Direct Simple Shear Tests

Contents

B6.1 Summary **2**
B6.2 Direct simple shear (DSS) test **2**
B6.2.1 Consolidation 2
B6.2.2 Results 3
B6.3 Evaluation of clay sample quality **3**

Table

B6-1 Summary of DSS tests on clay

Figures

B6.1 – B6.4 Individual DSS results

B6.1 Summary

The general purpose of the direct simple shear (DSS) tests is to provide horizontal shear strength parameters for engineering design of various foundations and consequently anisotropy ratios. The program consisted of 2 DSS (static direct simple shear) tests on intact clay specimen.

The DSS tests were performed as consolidated constant volume tests (CCV).

B6.2 Direct simple shear (DSS) test

B6.2.1 Consolidation

The DSS specimens had a cross sectional area of 35 cm^2 and a height of 16 mm. The rate of shearing was approximately 5 % shear strain/hour.

The effective vertical in situ stress (p_0') was estimated using the submerged unit weight based on water content measurements and the direct measurement of the total unit weight offshore.

Undisturbed clay specimen on overconsolidated material was consolidated to what was believed to be a low estimate of the preconsolidation stress, p_c', and then unloaded to the estimated in situ effective vertical stress, p_0', before shearing. This method was used to ensure complete contact between the specimen and the reinforced membrane and thus to develop representative lateral stresses on the specimen, and to some degree counteract the negative effect of stress release and other disturbance effects during sampling and extrusion.

The preconsolidation stress used for maximum vertical loading before unloading to p_0', was obtained from the relationship s_u/p_0', I_p, OCR presented by Andresen et al. (1979) using s_u values from index testing and the CPTUs.

Typically, clay specimens with estimated OCR higher than about 1.5 are consolidated to 0.75×p_c' and then unloaded to p_0' before shearing, whereas specimens with OCR less than about 1.5 are consolidated directly to the estimated in situ effective vertical stress (p_0') before shearing.

Details from the consolidation stage are presented in Table B6-1. A description of the laboratory test procedures is given in Part B7.

B6.2.2 Results

Static DSS results are presented as plots of horizontal shear stress and pore pressure versus shear strain and plots of effective stress paths in Figures B6.1 to B6.4.

The undrained shear strength s_u^{DSS}, (i.e. τ_f) is taken as the shear stress at 15 % shear strain if no distinct peak occurred at lower strain levels. The static strength values and key parameters for each test are presented in Table B6-1.

For use in design, reference is made to Part A.

B6.3 Evaluation of clay sample quality

Generally no direct measurement of strain at p_0' during primary loading is performed in a DSS test. Therefore, the procedure for evaluating sample quality is generally not directly applicable for this test type.

However, since these 2 DSS tests were loaded directly to p_0' prior to shearing it is possible to evaluate the sample quality for these tests as well. The sample quality is evaluated as poor for these two tests.

TABLE SUMMARY OF DSS TESTS

Boring No.	Tube part test	Depth m	INDEX PROPERTIES Water content w_i %	w_f %	I_p %	Clay cont. %	Unit weight kN/m^3	Type of test 1)	CONSOLIDATION Estim. p_0' kPa	$\sigma'_{a\,max}$ kPa	$\sigma'_{a\,min} = \sigma'_{ac}$ kPa	ε_{ac} %	τ_c kPa	γ_{hc} %	STATIC TESTING s_u^{DSS} kPa	U_f kPa	γ_f %	s_u^{DSS}/σ'_{ac} -	$\Delta e/e_i$ 2) -	Sample quality 3)	COMMENTS	FIGURE REFERENCE
2013-512GC	3-A-2	2.66	26.5	23.5	11.8	17.0	19.6	DSS	33.9	33.9	33.9	4.22	-0.10	0.00	18.0	10.1	15.0	0.53	0.100	3		B6.1-B6.2
2013-512GC	4-A-2	3.57	26.5	23.8	12.5	18.0	19.6	DSS	25.3	25.3	25.3	3.89	-0.10	0.00	17.1	1.4	15.0	0.68	0.092	3		B6.3-B6.4

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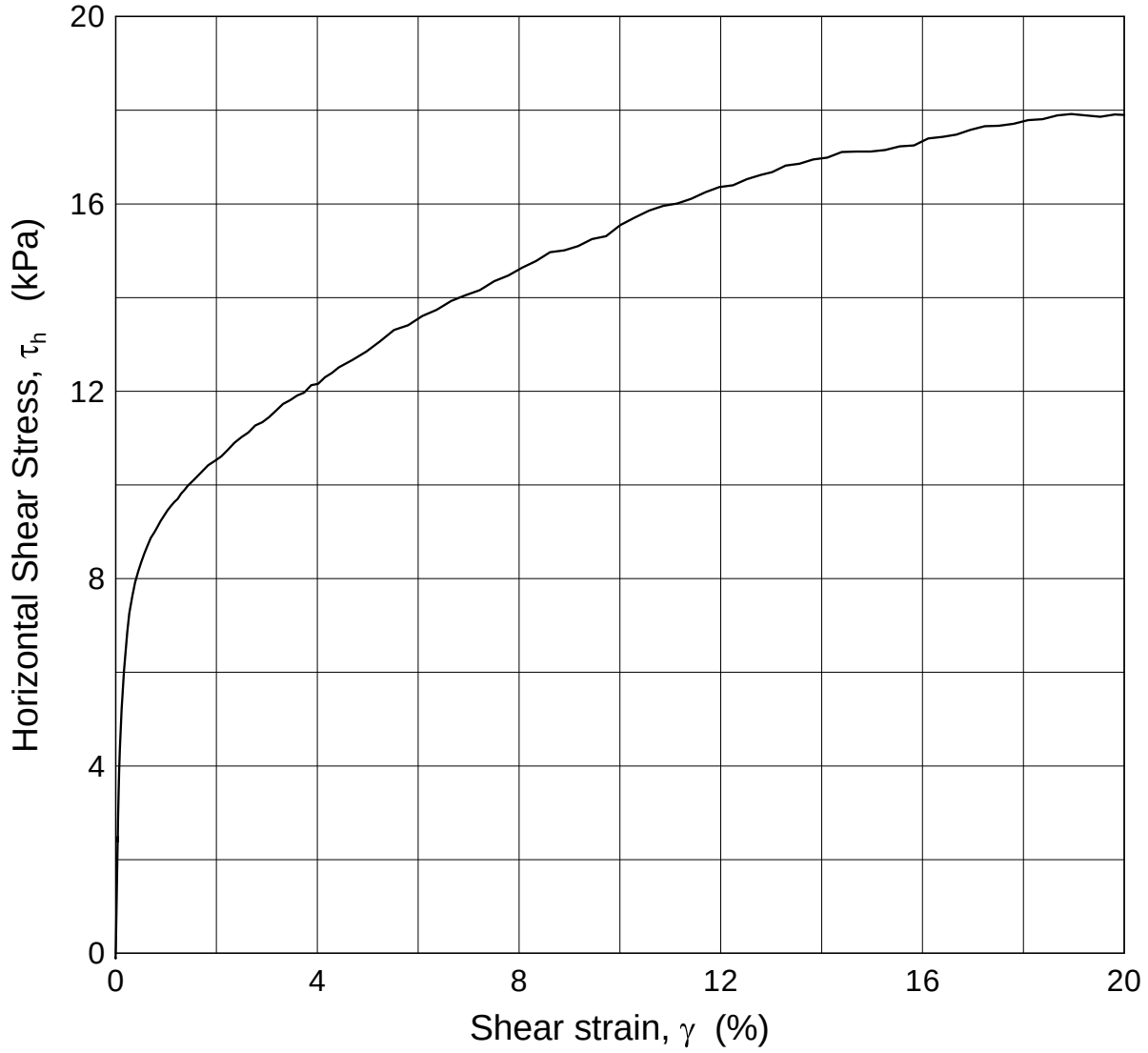
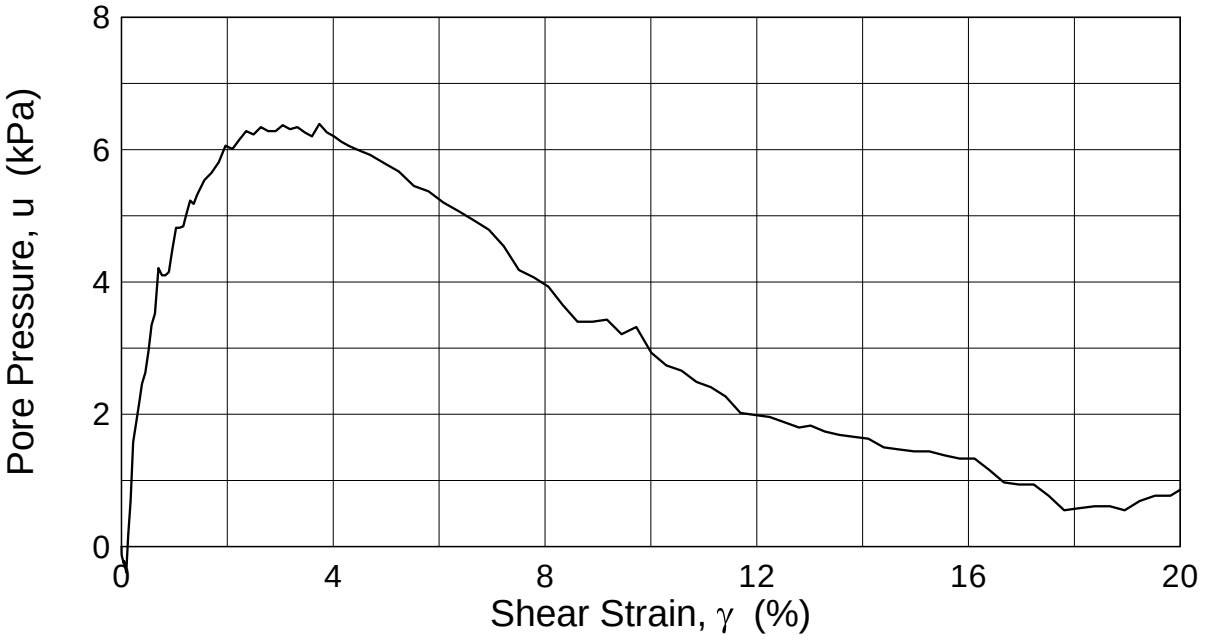
LEGEND

1) DSS = Direct Simple Shear, static test

2) $\Delta e/e_i$, where $\Delta e = \varepsilon_{vol}(1+e_i)$ and $e_i = 2.75 * w_i$

3) 1 - very good to excellent, 2 - good to fair,
3 - poor, 4 - very poor (Ref. Lunne et al., 1998).
NA = Not applicable





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U-864-2013 SOIL SURVEY

Document No. 20120738-01-R

Direct Simple Shear Test

Date 2013-03-06

Boring:	**2013-512GC**	Depth =	**2.66**	m	Consolidation stresses			
Tube:	**3**	p_o' =	**25.3**	kPa	(kPa)	max.	min.	final
Part:	**A**	w_i =	**26.46**	%	σ_{ac}' =	33.0	-	**25.3**
Test:	**2**	γ_i =	**19.59**	kN/m³	τ_c' =	-	-	**-**

Figure No. B6.1

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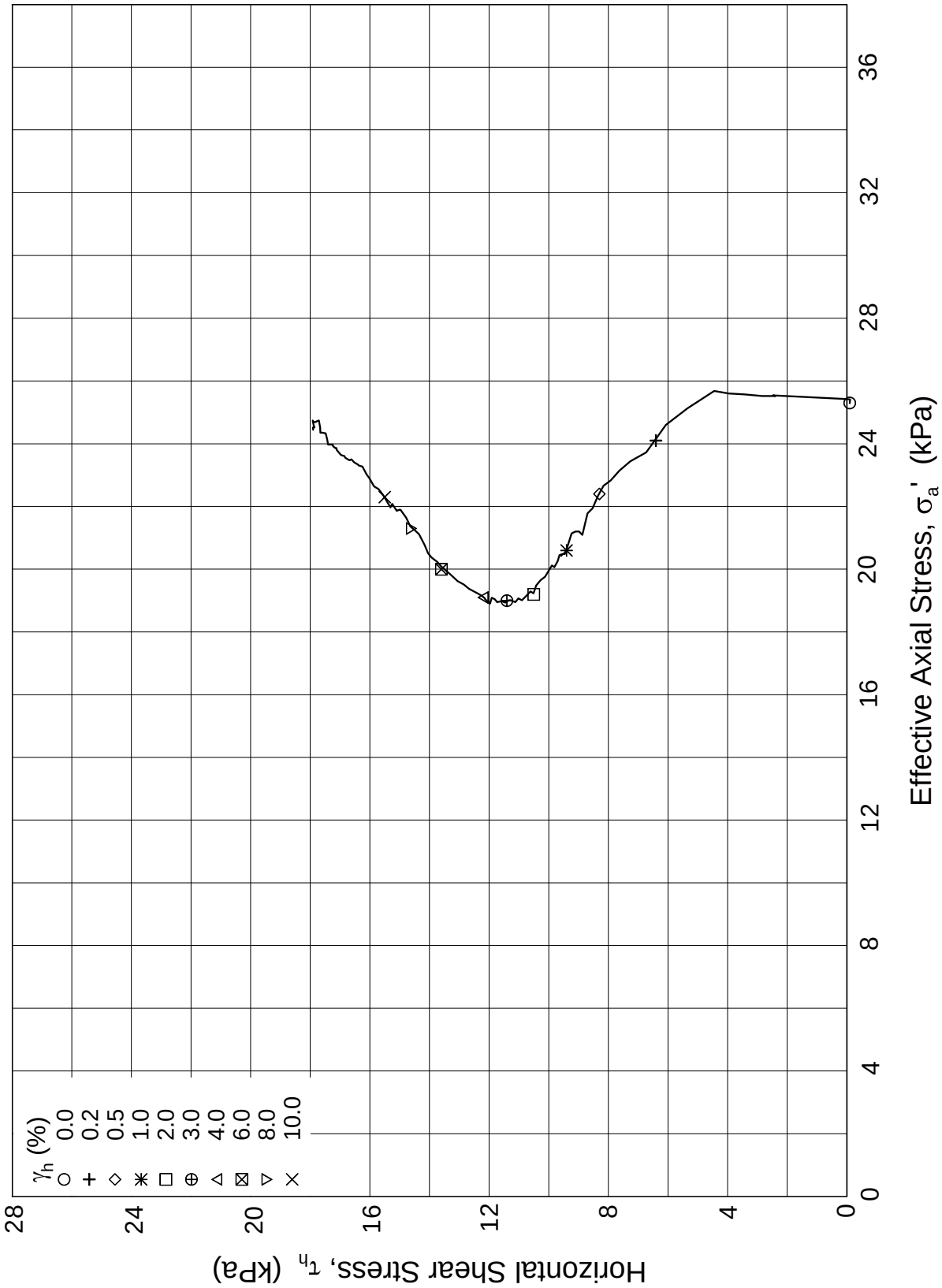
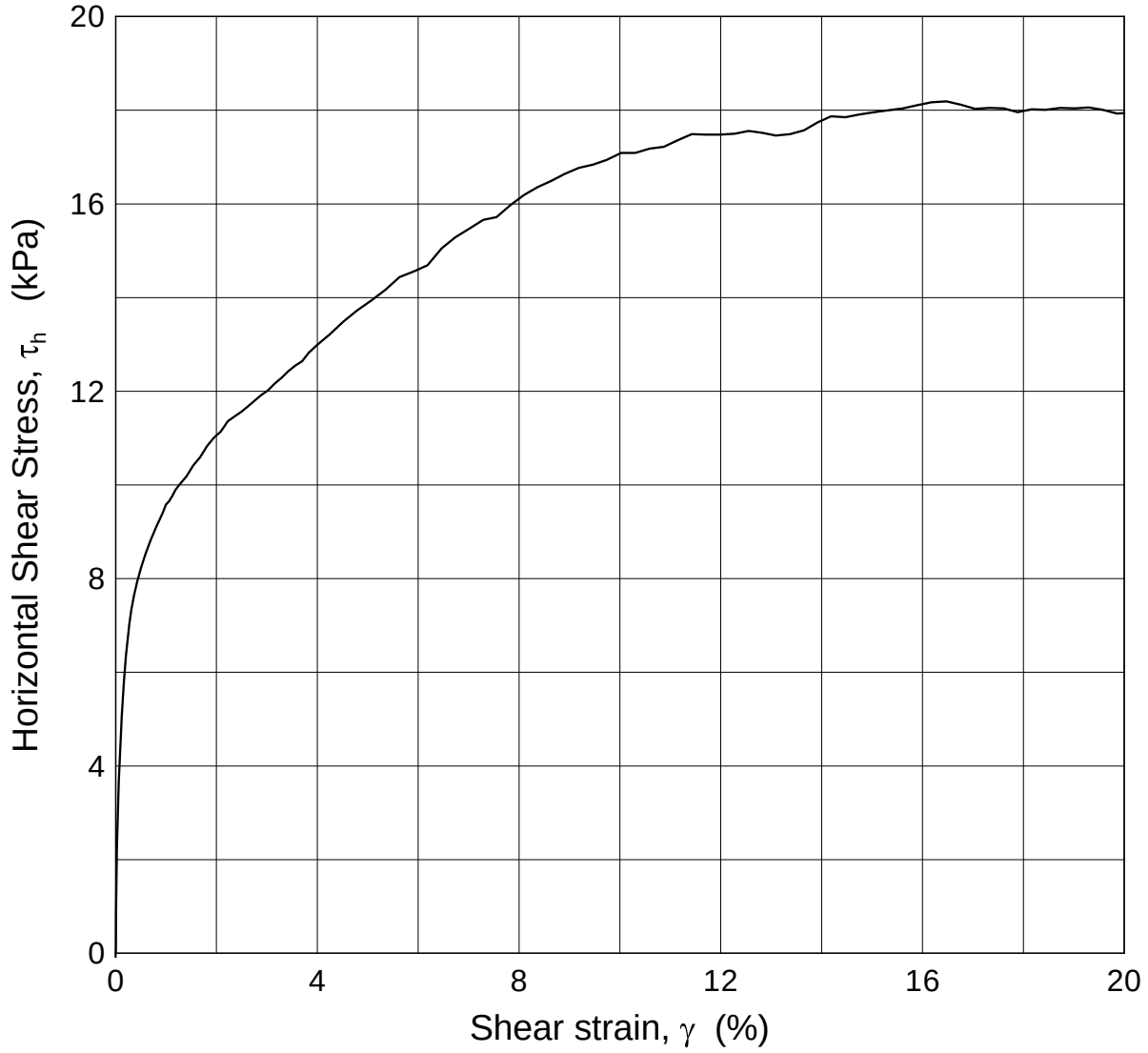
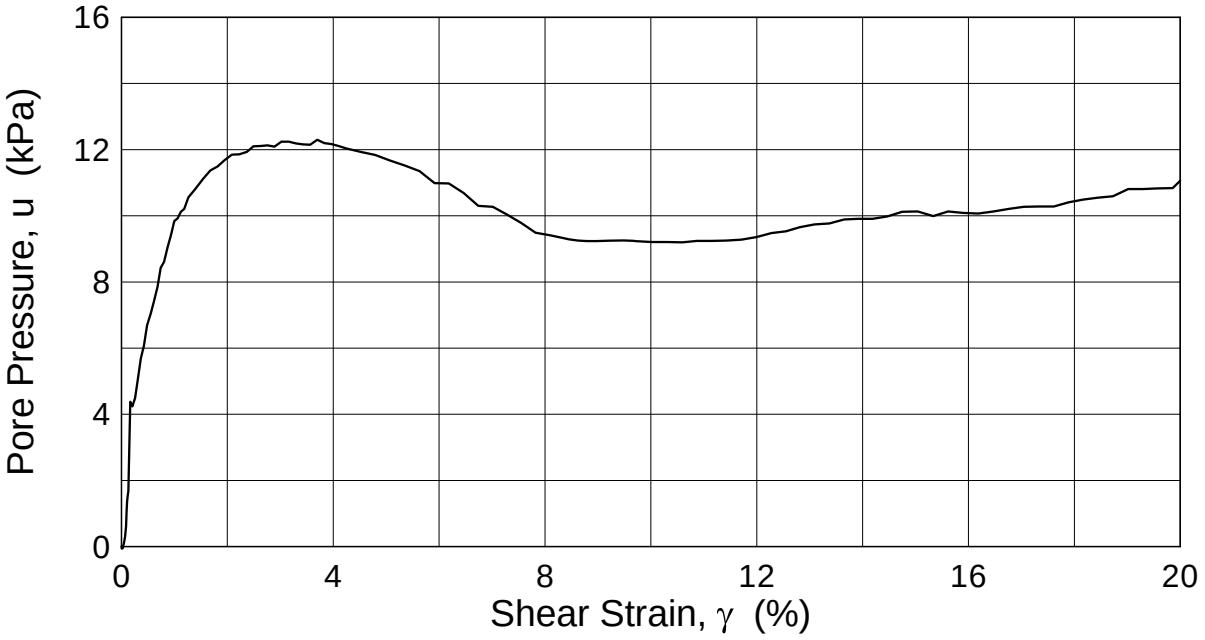


Date/Rev.: 2009-08-07/1

U-864-2013 SOIL SURVEY			Document No. 20120738-01-R
Direct Simple Shear Test			Date 2013-03-06
Boring: **2013-512GC**	Depth = **2.66** m	Consolidation stresses	Figure No. B6.2
Tube: **3**	p_o' = **25.3** kPa	(kPa) max. min. final	
Part: **A**	w_i = **26.46** %	σ_{ac}' = 33.0 - **25.3**	Drawn by JLa/
Test: **2**	γ_i = **19.59** kN/m³	τ_c' = - - **-**	NGI

P:\2012\07\20120738\Lab\dss-results\Fig B6_2 2013-512gc-3-a-2-2(ccv1348).grf





Date/Rev.: 2011-09-15/2

U-864-2013 SOIL SURVEY

Document No. 20120738-01-R

Direct Simple Shear Test

Date 2013-03-06

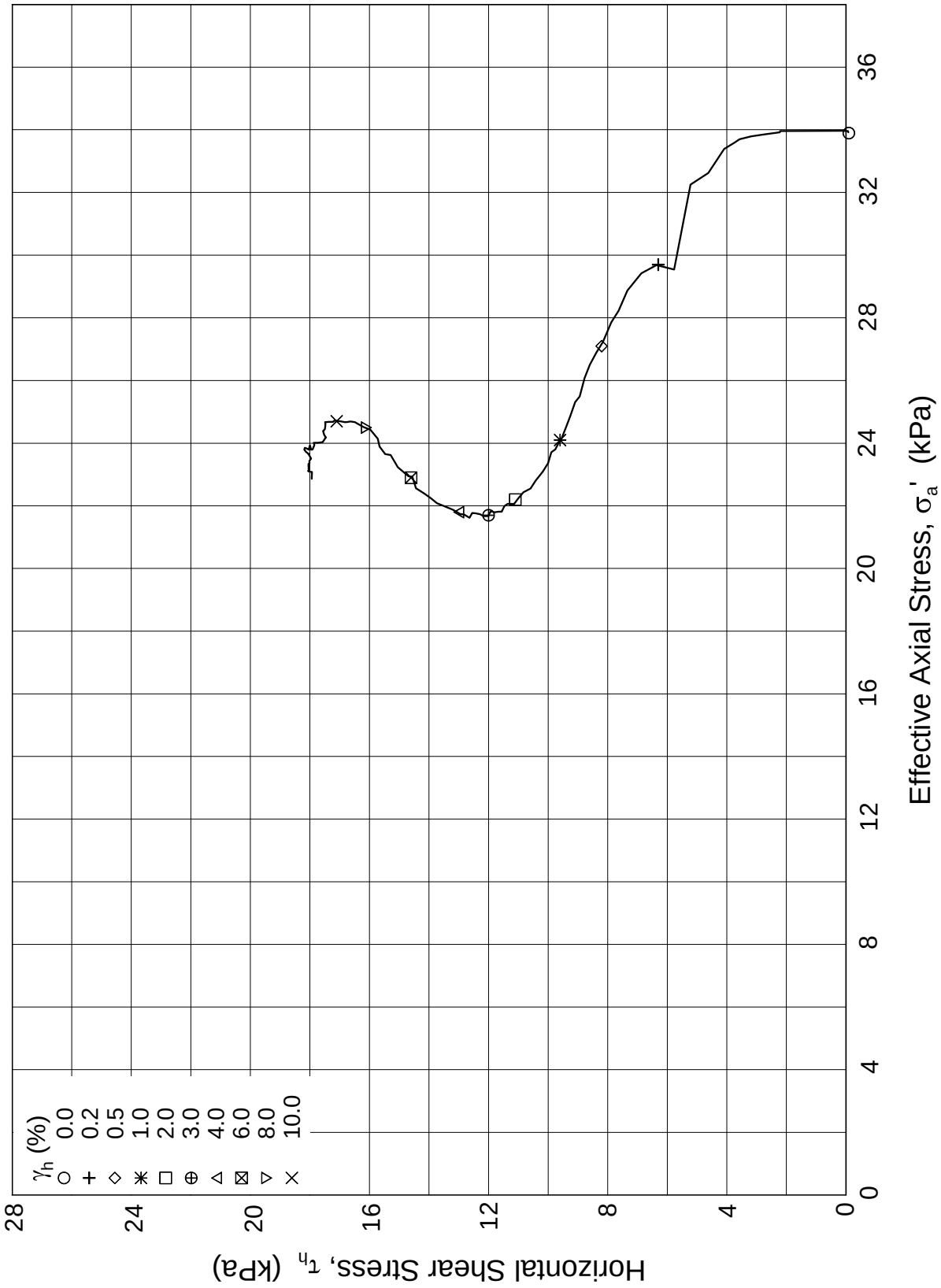
Boring:	**2013-512GC**	Depth =	**3.57**	m	Consolidation stresses			
Tube:	**4**	p_o' =	**33.9**	kPa	(kPa)	max.	min.	final
Part:	**A**	w_i =	**26.49**	%	σ_{ac}' =	-	-	**33.9**
Test:	**2**	γ_i =	**19.61**	kN/m³	τ_c' =	-	-	**-**

Figure No. B6.3

Drawn by JLa/

NGI

P:\2012\07\20120738\Lab\dss-results\Fig B6_3 2013-512gc-4-a-2-1(ccv1347).grf



Date/Rev.: 2009-08-07/1

U-864-2013 SOIL SURVEY								Document No. 20120738-01-R
Direct Simple Shear Test								Date 2013-03-06
Boring: **2013-512GC**	Depth =	**3.57**	m	Consolidation stresses				Figure No. B6.4
Tube: **4**	p_o' =	**33.9**	kPa	(kPa)	max.	min.	final	
Part: **A**	w_i =	**26.49**	%	σ_{ac}' =	-	-	**33.9**	Drawn by JLa/
Test: **2**	γ_i =	**19.61**	kN/m³	τ_c' =	-	-	**-**	NGI

P:\2012\07\20120738\Lab\dss-results\Fig B6_4 2013-512gc-4-a-2-2(ccv1347).gif

Part B7 - Description of Laboratory Test Procedures

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B7.1 Water content

B7.1.1 General

Water content (w) is the mass of water in the sample expressed as a percentage of the mass of solids. The method is described in detail in NS 8013 Part 5.

B7.1.2 Procedure

The water content is found by weighing a representative part of the soil sample before and after 17-20 hours of oven drying at approximately 110°C.

B7.2 Density and unit weight

B7.2.1 General

Density of a soil specimen is the total mass of soil per unit volume. The various laboratory methods are described in NS 8011.

B7.2.2 Procedure

Density, ρ, of a soil specimen is determined by measuring its diameter and length and then weighing it. Unit weight, γ, is equal to ρ · g. Unit weight is given in kN/m^3 and density in Mg/m^3 or g/cm^3.

The unit weight is also calculated from the water content by using the formula below.

$$UW = \frac{g \cdot \rho_S \cdot (1 + w/100)}{1 + (\rho_S \cdot w/S_r)}$$

Where UW Unit weight (kN/m^3)
g Acceleration of gravity (m/s^2)
ρ_s Density of solid particles (Mg/m^3 or g/cm^3)
w Water content (%)
S_r Saturation (S_r = 100%, assumed fully saturated)

B7.3 Density and unit weight of solid particles

B7.3.1 General

This procedure describes how to determine the density of soil material with grain size less than 4 mm. The method is described in detail in NS 8012.

B7.3.2 Procedure

Density of solid particles, ρ_s, is measured by means of a density bottle. Unit weight of solid particles, γ_s, is equal to $\rho_s \cdot g$, where $g = 9.807$ m/s^2.

For each test two determinations are made, and the average of the two is the reported unit weight value, provided the difference is less than 0.25 kN/m^3.

B7.4 Atterberg limits

B7.4.1 General

Liquid limit (w_L) and plastic limit (w_P) are the highest and lowest water contents, respectively, at which the remoulded soil material is in a plastic state. Standard method described in NS 8003 is used to determine w_P and a standard method described in NS 8002 is used to determine w_L.

B7.4.2 Procedures

The liquid limit, w_L, is performed according to the single point method as described in NS 8002, Part 5.2 by means of a 60 g fallcone. When the cone penetration falls between 7.0 and 15.0 mm, the water content of the sample is determined and the Liquid limit can be calculated according to the Standard.

The plastic limit, w_p, is performed according to NS 8003. The plastic limit is defined as the water content at which a tread of soil with a diameter of 3.2 mm crumbles.

B7.5 Grain size distribution

B7.5.1 General

Determination of the grain size distribution of sand and coarser material is performed according to NS 8005. Samples containing mainly silt or clay are subject to the falling drop method (Moum, 1965), as described below.

B7.5.2 Procedures

The grain size distribution is determined by the following two procedures:

I. Samples that contain mainly sand and coarser material are subjected to an ordinary dry sieve analysis. Materials containing more than 5-10% silt and clay particles are wet sieved on a 75 mm sieve before dry sieving. The method is described in NS 8005.
II. For samples containing mainly silt or clay, the falling drop method is used (Moum, 1965). The falling drop method is a sedimentation method based

upon Stoke's Law. A small sample of moist material is suspended in water, washed through a 75 µm sieve before being poured into a sedimentation tube. Droplets from a certain depth in the sedimentation tube are sampled with a calibrated micropipette after certain time intervals and then ejected into a glass column containing an organic liquid. The time required for each droplet to fall a certain distance in the organic liquid is measured. The concentration of suspended particles in each droplet can then be read from a calibration chart.

B7.6 Fall cone tests

B7.6.1 General

The fall cone test is used to establish a quick measure of the undrained shear strength of the soil, both the undisturbed and the remoulded strength. The method is described in detail in NS 8015.

B7.6.2 Procedure

The fall cone apparatus is produced by Geonor A/S. It measures the penetration of a cone into the specimen after it has been released from an initial stationary position with the tip of the apex at the surface of the specimen. Cones with different apex angles and masses are used. For hard clays, a 400 g cone with an apex angle of 30° is used, and for soft clays, a 100 g cone with an apex of 30°, or a 60 g cone with an apex angle of 60° is used.

To determine the sensitivity of a soil in the laboratory, a fall cone test is conducted on an undisturbed and on a remoulded specimen. The sensitivity is the ratio between the fall cone shear strength of the undisturbed and of the remoulded specimen.

B7.7 Oedometer tests

B7.7.1 General

Oedometer tests on undisturbed material are performed to determine the preconsolidation stress of the material as well as the compressibility and permeability. A detailed description of equipment and procedures used at NGI is given by Sandbækken et al., 1986.

B7.7.2 Procedures

B7.7.2.1 General

A cylindrical specimen with cross-sectional area 20 cm^2 or 35 cm^2 and height 20 mm is placed within a steel ring which prevents radial deformation of the

specimen. An axial (vertical) stress is applied on the top of the specimen and the resulting vertical compression of the specimen is measured.

Clay specimens, which initially may have a high negative pore pressure, are mounted with dry filter stones to prevent the specimen from swelling. Water of correct salinity, is added to the filter stones when a vertical stress high enough to prevent swelling has been applied. An unloading - reloading loop is often done when the vertical stress has become equal to about twice the preconsolidation stress (see below). The purpose with this loop is to be able to correct for sample disturbance and to obtain reloading parameters. A second unloading – reloading loop is done at the end of the test in order to determine reloading parameters at high stress levels.

The test is designed to determine the compressibility (or constrained modulus) and the coefficient of consolidation of the specimen tested. The coefficient of consolidation, c_v, is calculated from the equation

$$c_v = \frac{M \cdot k}{\gamma_w}$$

where M is the constrained modulus and k the coefficient of permeability. The k-values are checked by constant head permeability tests if there is any doubt about k-values back-calculated from time-compression curves (incremental loading) or from measured pore pressures (continuous loading). The uncertainty by deriving c_v from time-compression curves or measured pore pressures alone is then avoided and the c_v - value can be based on M-values corrected for sample disturbance and on k-values of in situ porosity and temperature.

For undisturbed specimens the test is also used to determine the effective vertical stress where the compressibility of the specimen starts to increase. This stress is represented by a more or less sharp bend in the stress-strain curve and is called the pre-consolidation stress (denoted p_c').

B7.7.2.2 Continuous loading (CRS)

This is the preferred method at NGI, with reference to NS 8018. In the continuous loading test the specimen is compressed with a constant rate. A vertical effective stress is applied in one step by using deadload. The continuous loading is then started and readings of the axial stress and strain are taken at certain time intervals. The specimen is allowed to drain freely at the top, but is undrained at the bottom. The rate of strain is selected such that the pore pressure at the bottom preferably shall be less than about 5% of the total applied stress. However, the rate of strain is not changed unless the bottom pore pressure exceeds 15% of the total applied stress.

B7.8 Direct simple shear tests

B7.8.1 General

The Direct Simple Shear apparatus enables the determination of soil anisotropy in an efficient way. A test can be performed drained (constant vertical load) or undrained (constant volume), static or cyclic. A cyclic test can be performed stress-controlled or strain-controlled.

A cylindrical specimen with cross-sectional area of 20, 35 or 50 cm^2, and height of 16 mm is placed within a reinforced rubber membrane which prevents radial deformation but allows the specimen to be deformed in simple shear. The apparatus for this test is described by Bjerrum and Landva (1966) and Andresen et al. (1979).

B7.8.2 Procedures

B7.8.2.1 Static tests

A consolidated, constant volume test (DSS-CCV) is the most common static test perfomed. The axial (vertical) stress is increased in steps to the estimated effective consolidation pressure. At approximately 50 % of the estimated consolidation stress the porous stones are saturated with water of approximately the same salt concentration as the pore water of the clay. After saturation the specimen is loaded to σ'_{max} and then unloaded to the specified axial stress before shearing. The reason for loading to σ'_{max} before unloading to σ'_{min} is that it is believed that the specimen thereby experiences correct radial stresses before start of shearing.

After consolidation the specimen is sheared by applying a horizontal shear stress. Keeping the volume constant simulates undrained conditions. The volume is kept constant by increasing or decreasing the axial stress during shearing. Normally a strain rate of 5% shear strain per hour is used. The change in the axial stress for a constant volume test is equal to the change in pore pressure for an undrained test where the total axial stress is kept constant. The reason for performing a constant volume instead of an undrained test is that drainage cannot be completely prevented and the saturation by means of back pressure cannot be performed in the simple shear device.

B7.9 Consolidated triaxial tests

B7.9.1 General

The triaxial test is carried out in order to measure the stress-strain behaviour and the shear strength parameters of a soil specimen under controlled stress conditions. The triaxial equipment used at NGI is described by Berre (1982).

A cylindrical soil specimen is enclosed in a rubber membrane and placed inside a pressure chamber called a triaxial cell. An isotropic stress is applied to the

specimen through the chamber pressure. In addition to the chamber pressure, the specimen is loaded axially by a piston passing through the top of the cell.

B7.9.2 Procedures

B7.9.2.1 Static tests

Mounting, undisturbed material
Due to the possible existence of a negative pore pressure in the clay specimens, special care is taken to avoid swelling due to the presence of free water. This is achieved by using dry porous stones at the start of the consolidation.

Except for very soft clays, filter strips are placed on the side of clay specimens to speed up drainage during consolidation and pore pressure equalisation during undrained shearing. The filter paper strips are moist, but free water on the surface of the strips is wiped away before they are placed on the specimen. The strips are placed in spirals around the specimens to avoid filter paper correction on measured stresses.

Saturation
Clay specimens are first subjected to an isotropic stress equal to the estimated value of the initial negative pore pressure. Water, with approximately the same salt concentration as the pore water of the soil is then flushed through the porous stones and immediately afterwards a 0-indicator is connected to the drainage lines. Any sign of volume change of the specimen is prevented by regulating the cell pressure until stable conditions have been reached.

A back pressure is applied to increase the degree of saturation of the sample and of the pore pressure measuring system, after the swell-pressure is applied.

For specimens assumed to be fully saturated in the field, an attempt is made to reach a B-value of at least 0.95 for static tests, and 0.98 for cyclic tests. For undrained tests on very soft clays, a back pressure of about 200 kPa may be sufficient. For very stiff clays and dense sand, back pressures up to 1500 kPa may be required.

Consolidation
The specimen is then loaded to the specified consolidation stresses. The specimen is first consolidated up to the in situ, or to the specified horizontal stress, isotropically. The specimen is then loaded up to the vertical in situ or specified stress in steps. The rate of loading is depending on the consolidation rate.

Shearing
Static, anisotropic consolidated, undrained tests (CAU).
The specimen is sheared at a constant rate of axial strain. The total radial stress is kept constant while the total axial stress is increased in compression tests and decreased in extension tests. During the undrained anisotropically consolidated tests

carried out on clay material (CAU), no drainage is allowed during shearing so that excess pore pressures may develop. The rate of strain is 1.4%/hour.

Dismounting specimen
After the cell pressure has been reduced to zero, the specimen is carefully removed from the triaxial cell and weighed. Material for classification testing may then be taken out.

B7.10 Evaluation of sample quality

B7.10.1 General

The quality of an undisturbed clay specimen used for oedometer, DSS, triaxial or resonant column testing can be evaluated based on change in void ratio (Δe), relative to initial void ratio (e_i) when consolidating the specimens back to the best estimate of in situ stresses. A system with empirical recommendations has been established, as described by Lunne et al. (1998, 2006) and NGI (2000).

B7.10.2 Procedure

When a clay specimen is reconsolidated back to the best estimate of in situ effective stresses, the measured volume change may be used as an indication of sample quality. The volume change is expressed as the change in void ratio relative to the initial value, $\Delta e/e_i$.

NGI's criteria for sample quality				
OCR	$\Delta e/e_i$			
1-2	<0.04	0.04-0.07	0.07-0.14	>0.14
2-4	<0.03	0.03-0.05	0.05-0.10	>0.10
4-6	<0.02	0.02-0.035	0.035-0.07	>0.07
Quality	1	2	3	4

The suggested qualities are as follows:

1: Very good to excellent
2: Good to fair
3: Poor
4: Very poor

B7.10.3 Limitations

The empirical background for these recommendations is a database with normally consolidated to slightly overconsolidated clays where any overconsolidation is caused by ageing only. The data base consists mainly of laboratory tests on samples in the upper 25 m below ground level. For OCR>6, the recommendations should be used with great caution and only used in a relative sense.

Also, for specimens consolidated to other stresses than the in situ stresses the recommendations are not relevant. The sample quality criteria in the above table are not valid for data from incremental loading (IL) tests that use long load durations (e.g. 24 h) because of added secondary compression. The sample quality criteria can be used, however, if the IL test is conducted using relatively short load durations [e.g. 1 h to 3 h as suggested by Sandbækken et al. (1986)]. If longer duration load increments are used, the deformation-time curves should be interpreted to determine the end of primary strain for the relevant load increments needed to estimate $\Delta e/e_i$.

Part B8 - References

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B8.1 References

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Part C - Field Operations

Contents

Part C1 Coordinates (DOF Subsea)
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Part C3 Cone Penetration Testing (GeoEngineering)
Part C4 Field Laboratory (NGI)

Part C1 - Coordinates (DOF Subsea)

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C1-1 Sample locations ROV sampler
C1-2 Sample locations CPTU
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C1.1 Summary

The tables in this section present coordinates for the geotechnical and geochemical samples obtained from the vessel Skandi Skolten during the 2013 soil survey near the U-864 submarine.

Geodetic Parameters				
Spheroid		:	WGS'84	
UTM Zone		:	Zone 32° (CM9°)	
Datum shift		:	None	
Vertical datum		:	MSL	

Table C1-1 Sample locations ROV sampler

			From target positions		Actual positions			
Date	Time	WP NAME	WP EAST	WP NORTH	Actual East	Actual North	Actual Depth	Sample name
12.01.2013	13:56	2013-87	261 426.00	6745 113.00	261 427.90	6745 112.62	140.32	**2013-87SS**
12.01.2013	14:09	2013-38	261 424.00	6745 135.00	261 423.02	6745 135.14	141.95	**2013-38SS**
12.01.2013	14:21	2013-88	261 468.00	6745 108.00	261 469.68	6745 106.53	138.81	**2013-88SS**
12.01.2013	14:48	2013-317	261 463.00	6745 149.00	261 465.15	6745 152.83	141.77	**2013-317SS 2nd attempt**
12.01.2013	15:05	2013-83	261 381.00	6745 112.00	261 382.50	6745 112.05	142.73	**2013-83SS**
12.01.2013	15:13	2013-31	261 383.00	6745 144.00	261 381.89	6745 145.27	144.90	**2013-31SS**
12.01.2013	15:21	2013-316	261 341.00	6745 135.00	261 340.78	6745 134.67	147.09	**2013-316SS**
12.01.2013	15:30	2013-315	261 345.00	6745 184.00	261 344.78	6745 184.49	152.33	**2013-315SS**
12.01.2013	16:43	2013-Sed-08	261 414.00	6745 270.00	261 413.20	6745 271.10	178.14	**2013-Sed-08SS**
12.01.2013	17:11	2013-28	261 415.00	6745 227.00	261 428.33	6745 231.78	168.89	**2013-28SS**
12.01.2013	17:23	2013-313	261 359.00	6745 280.00	261 359.15	6745 280.05	180.09	**2013-313SS**
12.01.2013	17:34	2013-320	261 359.00	6745 233.00	261 357.17	6745 231.97	168.70	**2013-320SS**
12.01.2013	17:49	2013-36	261 447.00	6745 211.00	261 445.15	6745 213.36	164.60	**2013-36SS**
12.01.2013	18:13	2013-30	261 394.00	6745 187.00	261 365.63	6745 184.36	153.67	**2013-30B SS**
12.01.2013	20:27	2013-35	261 470.00	6745 239.00	261 469.58	6745 240.10	177.61	**2013-35SS**
12.01.2013	20:39	2013-308	261 599.00	6745 315.00	261 597.23	6745 314.52	154.43	**2013-308SS**
12.01.2013	20:48	2013-302	261 543.00	6745 276.00	261 543.37	6745 275.82	174.94	**2013-302SS**
12.01.2013	20:55	2013-34	261 492.00	6745 268.00	261 491.03	6745 267.02	177.88	**2013-34SS**
12.01.2013	21:04	2013-146	261 573.00	6745 250.00	261 574.37	6745 250.10	177.60	**2013-146SS**
12.01.2013	21:13	2013-312	261 432.00	6745 307.00	261 432.48	6745 307.61	176.20	**2013-312SS**
12.01.2013	21:22	2013-301	261 508.00	6745 241.00	261 507.28	6745 240.47	177.88	**2013-301SS**
12.01.2013	21:33	2013-32	261 557.00	6745 317.00	261 556.78	6745 314.15	161.01	**2013-32SS**
12.01.2013	22:41	2013-306	261 698.00	6745 275.00	261 697.75	6745 275.70	153.22	**2013-306SS**
12.01.2013	22:50	2013-324	261 673.00	6745 112.00	261 671.83	6745 111.66	160.03	**2013-324SS**
12.01.2013	22:57	2013-155	261 624.00	6745 133.00	261 624.69	6745 133.00	164.77	**2013-155SS**
12.01.2013	23:09	2013-142	261 689.00	6745 250.00	261 685.60	6745 249.60	152.76	**2013-142SS**
12.01.2013	23:21	2013-210	261 638.00	6745 064.00	261 640.27	6745 064.14	143.76	**2013-210SS**
12.01.2013	23:40	2013-213	261 608.00	6745 087.00	261 607.30	6745 083.54	147.03	**2013-213SS**
13.01.2013	00:50	2013-332	261 621.00	6744 997.00	261 622.40	6744 998.66	144.58	**2013-332 SS**
13.01.2013	01:01	2013-331	261 600.00	6745 037.00	261 600.27	6745 036.66	147.61	**2013-331 SS**
13.01.2013	01:10	2013-211	261 615.00	6745 056.00	261 615.01	6745 056.95	146.84	**2013-211SS**
13.01.2013	01:19	2013-204	261 684.00	6745 086.00	261 683.23	6745 090.19	151.11	**2013-204SS**
13.01.2013	01:19	2013-334	261 700.00	6744 998.00	261 701.00	6744 998.77	148.71	**2013-334 SS**
13.01.2013	01:53	2013-333	261 654.00	6744 984.00	261 653.78	6744 987.66	142.38	**2013-333 SS**
13.01.2013	02:03	2013-206	261 648.00	6745 035.00	261 646.86	6745 035.22	147.51	**2013-206SS**

Table C1-2 Sample locations CPTU

			From target positions		Actual positions			
Date	Time	WP NAME	WP EAST	WP NORTH	Actual East	Actual North	Actual Depth	Sample name
11.01.2013	**01:23**	2013-503	261 555.00	6745 200.00	261 554.78	6745 200.31	174.72	**2013-503 CPT**
11.01.2013	**01:39**	2013-503A	2m OFFSET		261 554.35	6745 202.13	174.72	**2013-503A CPT**
11.01.2013	**03:06**	2013-504	261 602.00	6745 191.00	261 603.29	6745 191.66	174.73	**2013-504 CPT**
10.01.2013	**23:41**	2013-505	261 597.00	6745 220.00	261 597.92	6745 221.73	176.93	**2013-505 CPT**
11.01.2013	**00:29**	2013-506	261 569.00	6745 230.00	261 569.51	6745 230.03	178.13	**2013-506 CPT**
10.01.2013	**22:35**	2013-509	261 628.00	6745 203.00	261 627.89	6745 201.78	175.96	**2013-509 CPT**
11.01.2013	**02:12**	2013-510	261 581.00	6745 198.00	261 580.91	6745 197.97	175.45	**2013-510 CPT**
11.01.2013	**04:20**	2013-511	261 581.00	6745 180.00	261 580.45	6745 183.54	172.65	**2013-511 CPT**
10.01.2013	**17:08**	2013-512	261 652.00	6745 192.00	261 652.01	6745 192.32	175.56	**2013-512 CPT**

Table C1-3 Sample locations vibro/gravity core

			From target positions		Actual positions			
Date	Time	WP NAME	WP EAST	WP NORTH	Actual East	Actual North	Actual Depth	Sample name
			Vibro coring					
11.01.13	16:55	2013-401	261 548.00	6745 100.00	261546.51	6745102.08	150.93	**2013-401VC**
10.01.13	03:24	2013-402	261 554.00	6745 093.00	261553.14	6745093.83	149.14	**2013-402VC**
10.01.13	01:58	2013-403	261 560.00	6745 086.00	261559.10	6745086.00	149.19	**2013-403VC**
09.01.13	23:00	2013-404	261 566.00	6745 078.00	261563.48	6745076.48	148.91	**2013-404VC**
11.01.13	08:18	2013-405	261 578.00	6745 155.00	261576.93	6745152.58	166.20	**2013-405VC**
11.01.13	14:57	2013-406	261 572.00	6745 145.00	261571.56	6745147.93	163.19	**2013-406VC**
11.01.13	15:40	2013-407	261 566.00	6745 135.00	261564.61	6745135.31	160.35	**2013-407VC (VC Sampler tilted)**
11.01.13	15:52	2013-407	261 566.00	6745 135.00	261565.60	6745135.49	156.46	**2013-407VC 2nd attempt**
11.01.13	16:37	2013-408	261 560.00	6745 126.00				**2013-408VC WORK ABORTED**
		CPT location Gravity coring						
12.01.13	10:36	2013-509	261 628.00	6745 203.00	261626.53	6745205.03	175.96	**2013-509GC**
12.01.13	11:40	2013-512	261 652.00	6745 192.00	261649.71	6745194.58	175.56	**2013-512GC**

Part C2 - Sampling (MSH)

Contents

C2.1 Summary 2

Table

C2-1 Sample recovery

C2.1 Summary

The table in this section present sample recovery depth for the samples obtained during the 2013 soil survey near the U-864 submarine.

Table C2-1 Sample recovery

Location ID	Comment	Vibro core recovery	Date
2013-401	Aft wreck	2.65 m	2013-01-11
2013-402	Aft wreck	3.40 m	2013-01-10
2013-403	Aft wreck	1.40 m	2013-01-10
2013-404	Aft wreck	2.40 m	2013-01-10
2013-405	Forward wreck	2.60 m	2013-01-11
2013-406	Forward wreck	3.40 m	2013-01-11
2013-407	Forward wreck	1.25 m	2013-01-11
		Gravity core recovery	
2013-509	CPT-site	3.90 m	2013-01-12
2013-512	CPT-site	3.90 m	2013-01-12

Part C3 - CPTU

Contents

C3.1 Summary 2

C3.1 Summary

Seabed cone penetration tests were performed during the investigation using a 5 cm^2 subtraction cone. Geo-Engineering performed the testing. Digital signals from the cones were transmitted for subsequent computer processing and included:

- Penetration
- Cone resistance (q_c)
- Sleeve friction (f_s)
- Pore water pressure (u_2)

The Field Report from Geo-Engineering is included together with the calibration sheet for the cone used.

Field Report

CPTu-Survey, U-864
Skandi Skolten (January 2013)

Client: **Marine Sampling Holland BV**
Wijkermeerweg 7
1951 AH Velsen-Noord

Contractor: **Geo-Engineering.org GmbH**
Leobener Straße
MARUM Gebäude
28359 Bremen

Bremen, den 29.01.2013
Rev. 01

Rev.	Date	Pages Total	Pages Appendix	Editor	Audited	Modifications
0	22.01.2013	9	4	JB	TM	-
01	29.01	11	4	TM	JB	Operation and Data chapter added

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2 Executive office and involved personnel 4
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4 Operation 7
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6 Conclusion 10

Attachments

Attachment 1 CPT “GOST” data sheet (GOST_Flyer_01_2013.pdf)
Attachment 2 Derived data (2013-U-864SkandiSkolten.zip)
Attachment 3 Calibration sheet of used cone “JESSICA” (Cone_Calib_sheet_JESSICAv1_2013_01_07.pdf)

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Fig. 2: Rigging of CPT tool on crane. 6
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Fig. 4: Data example of Site 2013-506. 9

1 Introduction

The investigation area was a morphological trough with sediment infilling in the north east of the front section of U-864. Twelve locations were chosen by the client respectively NGI. Eight of those twelve locations were investigated with a total of 9 CPT soundings. Four locations were called off by the client (grey in table 1).
Table 1 shows planned locations of the investigation points. Figure 1 shows a map with the planned locations.

The operation took place between the 1st of January 2013 and the 13th of January 2013. The CPTu-investigation work was done at 10th of January 8:00 to 11th of January 7:30 including preparation and sea-fastening.

Table 1: Planned coordinates for cpt-tests. Grey lines were cancelled by the client.

	planned	
Name	**Easting**	**Northing**
2013-501	261601	6745142
2013-502	261598	6745162
2013-503	261555	6745200
2013-504	261602	6745191
2013-505	261597	6745220
2013-506	261569	6745230
2013-507	261613	6745158
2013-508	261634	6745164
2013-509	261628	6745203
2013-510	261581	6745198
2013-511	261581	6745180
2013-512	261652	6745192

Coordinates in UTM32, CM9°E, WGS84

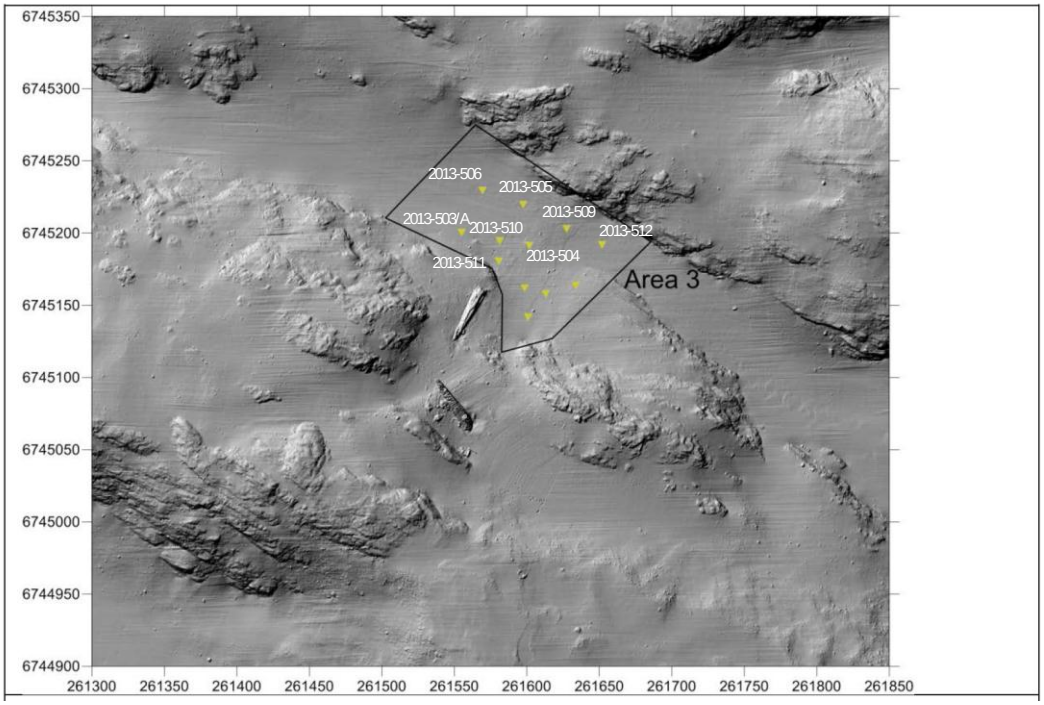

Fig. 1: Chart of test locations for CPT work (Coordinates in UTM32, CM9°E, WGS84)

2 Executive office and involved personnel

The performance of the measurement was performed by GEO-ENGINEERING.org GmbH. The personnel from GEO-ENGINEERING.org GmbH on board of the Skandi Skolten was

Tobias Mörz	Party Chief (Prof. Dr. rer. nat.)
Wolfgang Schunn	Chief Engineer and Operator (Dipl. -Ing. FH)
Johannes Brock	Chief CPT-Operator, Reporting and Project Organization (M.Sc. Geoscience)

3 Used equipment and technical data

3.1 CPT-Unit "GOST"

Fig. 1: Seafloor CPTu GOST

Tool origin:	Engineered during a joint project by: MARUM / Uni-Bremen & Geo-Engineering.org GmbH
Cone:	
Tip-area:	5cm²
Diameter:	25.24mm
Cone are ratio:	0.67 […] – due to diff. pore-pressure measurement ***full pressure compensation of the cone interior via rod end***
Depth classification:	400bar = 4000m
Material:	hardened stainless steel1.4112
Tip resistance & sleeve friction	
Standard resolution:	30N or 0.06 MPa with 5cm² cone
Highest resoluion:	5N or 10 kPa
Max.range:	60 kN oder 120 MPa
Sleeve friction modus:	Subtraction
Power supply:	2 DMS bridges, linear
Differential & absolute pore-pressure:	
Location of pore pressure sensor:	u2
Range:	21 bar
Resolution digital:	0.0002 kPa
Electrical cutout:	overvoltage protection and protection regarding reverse
Tests & calibration:	In MARUM high pressure tank and MARUM triaxial load frame

3.2 Rigging on crane

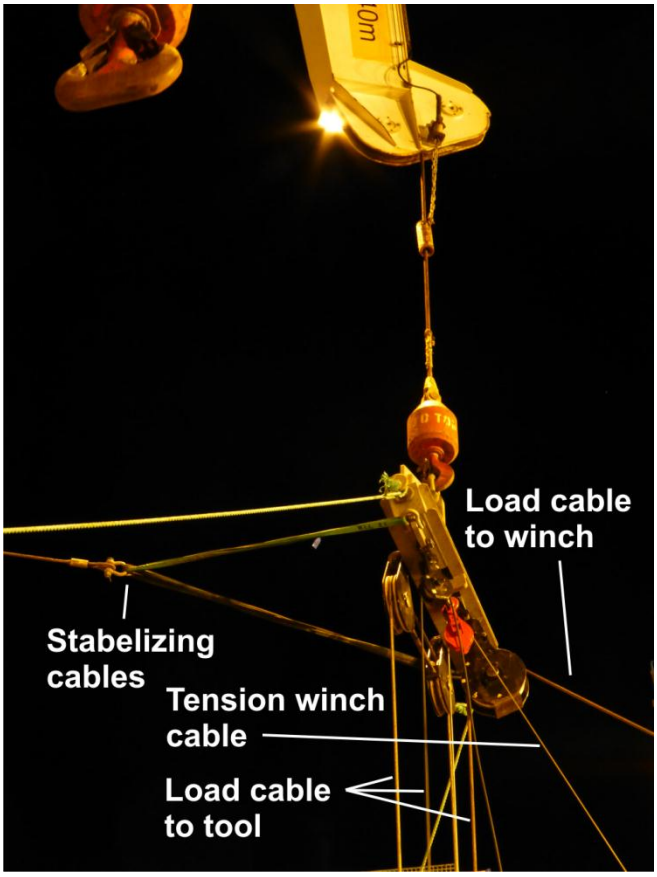

Fig. 2: Rigging of CPT tool on crane.

The tool was rigged up with a spreader bar to a single crane hook of the main cranes secondary cable. Lateral side stabilization was given by a crane rigger winch using a Y-setup.
The spreader bar is equipped with a double block and a chief block for the load cable, a block for the electrical cable and a block for the rod tension cable. The traverse was held stable above the moon pool during raise, lowering and measurements.
The setup is shown in Fig. 2.

3.3 Used winches

3.3.1 Load Winch:

The load winch was provided by DOF-Subsea. It was connected with an electrical hydraulic power pack also provided by DOF-Subsea. It was only used for lowering and raising the tool. To fit the required cable length on the drum, the winch was equipped with an 22 mm cable instead of an 24 mm cable. A threefold cable run was used to prevent GOST from rotating.

Fig. 3 shows the load winch.

Fig. 3: Load winch provided by DOF Subsea

Load winch data:

- 18 Tonnes WLL (First Layer Pull)
- Hagglunds Hydraulic Motors
- Maximum wire capacity 400 metres of 28mm wire rope
- Suitable for operation in non hazardous or hazardous areas
- Overall Dimensions 1200mm long x 1550mm wide x 1460mm high
- Tare Weight 2600Kgs excluding wire rope
- Gross Weight 4500Kgs

3.3.2 Tension winch

The tension winch is necessary to keep the rod in an upright position during pushing and lowering and to provide heave compensation when the tool is on the seafloor. It is an automated hydraulic constant tension winch with an 8mm cable (1500 m capacity), connected to its own hydraulic power pack (diesel fueled). The cable tension can be adjusted between 0 and 1000 kg of pull. A load cell is providing the actual tension information. A fast MOOG valve controls the rope length given to keep the set tension constant.

4 Operation

Prior to the first deployment a USBL transducer was fitted to the GOST unit to allow direct positioning avoiding uncertainties due to current drifting. All seafloor deployments of GOST were observed and guided by excellent ROV video data and a very experienced geophysical crew. The seafloor CPTu GOST was operated in a pogo style mode – only lifting the tool for a couple of meters of the seafloor after each test. Transit to the next sites was done under DP. The three-fold cable guidance provided stable and turn free deployments. A one time breaking of the rod occurred when the tool tilt exceeded 12° on the seafloor. The rod was fully recovered via the tension winch.

5 Data and data quality

Fig. 4 shows a typical data example of the tested soil. The majority of the overall observed tip values are below 0.4 MPa. This very soft and fine grained consistency is in accordance with the previous data collected in 2006 (NGI Report 20061348-1). On some locations the seafloor down to two meter is a bit coarser grained, containing more silts and sands. Throughout the investigated sequence stones or harder sand lenses are encountered. Scattered in between the very low tip resistant values distinct peeks of higher values (up to 17 MPa) are present which point toward medium sized isolated stones which were pushed aside by the cone during penetration. In general all sites were investigated down to slightly more than 6 meters below the seafloor making use of the full setup length. .Only at one site (2013-503 and 2013-503A) the cone was automatically stopped when the tip resistance exceeded 30 MPa.. The test was repeated and the same observation was made so that it can be concluded that bedrock has been reached at a depth of 1.4-1.7 meters below the seafloor at the SW trough shoulder.
Although the soil strength is very low, already challenging for industry CPTu cones, the collected tip data is of excellent resolution and quality making full use of the 24 Bit data resolution sampled every ~4 mm down depth. In this respect greater detail and resolution has been achieved when compared to the 2006 data. The collected sleeve values fit in magnitude the 2006 data and might be slightly tip influenced by a striped off o-ring likely lost during an early stone impact. The differential pore pressure data shows no sign of excess in situ pore pressure.

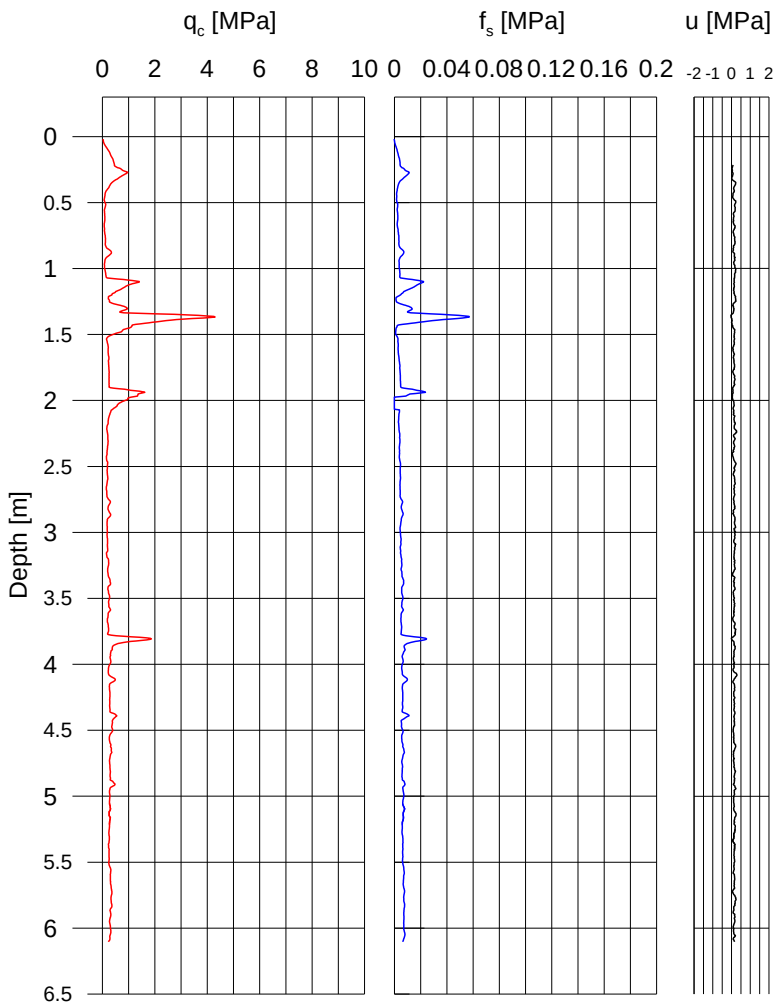

Fig. 4: Data example of Site 2013-506.

6 Conclusion

The geotechnical measurements with the CPT-unit GOST for this project were finished successfully during calm weather conditions and excellent support by the DOF and marine crew of Skandi Skolten. A faster deployment winch would have been beneficial to the economics of the project. In similar geologies penetration depths of up to 40 m have been achieved. Additional data like a penetration velocity log and tri-axial acceleration data can be provided upon request.

Prof. Dr. Tobias Mörz
Project Leader

Dipl. Ing. (FH) Wolfgang Schunn
Chief Engineer

MSc. Johannes Brock
Chief CPT-Operator, Reporting and Project Organization

GOST

Geotechnical Offshore Seabed Tool

GOST is an innovative geotechnical tool to characterize the subsoil by means of *'push-in'* technique, i.e. **cone penetration testing** along with pore pressure and inclination measurements, known as **CPTu**.

The primary focus of ***GOST*** is **offshore** site investigation but due to its **modular layout**, the system also works **onshore**, for instance mounted on a truck. Thus, ***GOST*** can be operated from almost any platform which can handle between 3-9 tons of weight.

GOST is mainly designed to **operate from the seafloor**. It is powered and controlled via a standard single wire coaxial cable. During continuous offshore surveys, the tool is only slightly lifted from the seafloor and hanging within the water column during site-transit – called "***dangling- or pogo-style operation***". ***GOST*** stays under water without the need of full recovery until all sites are penetrated. This leads to a large number of tests in considerable **less valuable vessel time** than any other top-pressed CPT tool would be capable of.

GOST can handle **rod setups** of many diameters. So far, we use a 'digital subtraction cone' of 5 cm^2 in conjunction with a differential pore pressure system on a rod of 2 cm diameter.

- On- & offshore use, 4000 m depth rating
- Modular depth of penetration:
  - Straight Rod: length 6 – 40 m
- Adjustable penetration pressure 0 – 80 kN ~ 7.9 to
- Full digital 24 bit data collection
- Exact control on push velocity → data compatible to highest international standards, exceeding DIN 4094 requirements
- Short mobilization times, own mobile winch (0 – 420 m)
- Modular replacements: tips & rods
- 'Open' system to adapt additional sensors, probes and testing modes

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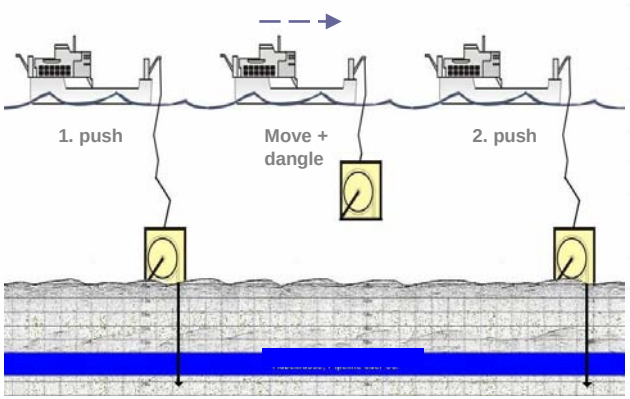
Email wschunn@uni-bremen.de

Fields of Application

- ***Site Investigation on-/offshore***
- ***Foundation Investigation***
- ***Cable Route/ Pipeline Surveys***
- ***Environmental Mapping***



Seafloor based "dangling operation"

The GOST System

GOST in operation

Technical Details

CPT Cone

Tip Cross Section:	5 cm²
Material:	hardened stainless steel1.4112
Resolution:	30N or 0,06MPa
Range:	60kN or 120MPa
Sleeve Friction Mode:	Subtraction
Force detection:	Two linear DMS load cell
Digital Interface:	Industry RS485 BUS, 28Hz Data rate
A/D Converter:	24bit resolution 0.00919 N/bit 250Hz sampling rate
Processing:	Averaging of 10 values
Electrical Cutout:	Overvoltage and reverse-polarity protection
Tests & Calibration:	At MARUM high pressure tank and tri-axial CPTu calibration frame

Differential Pore Pressure

Sensor location:	Directly within the tip
1. Port:	@ Tip: u2 position
2. Port:	@ Rod end as reference
Range:	+/- 1400 kPa
Resolution (digital):	0.0002 kPa

Inclination Sensors for Cone & Frame

Spatial Directions:	X & Y-Axes
Range of Inclin. Angle:	± 35°
Resolution Digital:	0.1°
Acceleration:	Z-Axis

Lifting appliance

- o Three Point Suspension
- o very high turning protection
- o mobil 10.000kg winch
- o mobil 1500kg Tension winch
- o load messure bolt inside the bloc
- o electronic Regulator for Tension winch
- o mobil hydraulic power unit

Hydraulic

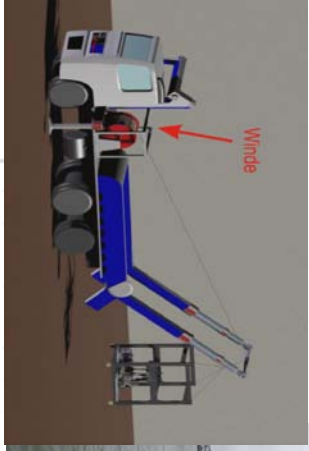
- o 8.000kg hydraulic push force
- o infinitely variable hydraulic pressure 0 – 200bar
- o pressure compensated hydraulic system
- o Powerful and fast MOOG servo-valve
- o dynamic push speed adaptation
- o Advanced modes: VIBRO, dissipation, remolding – plate loading testing
- o hydraulic leveling (optional)

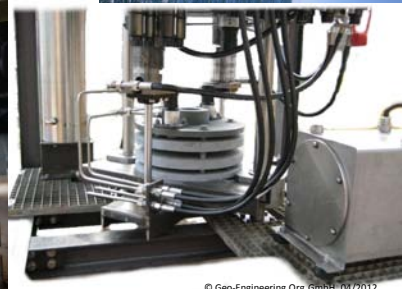
Truck

- o off-road 6x6 drive
- o full winch assembly
- o mobil A-Frame
- o cross beam with bloc
- o 10.000t winch
- o 1500kg tension winch (elektronic regulated)
- o full config. Lifting allliance
- o short time for mobilization
- o powerfull hydraulic on board

Telemetrie

- o Datakomunication with LongRange Modem
- o max range 10km and data rate 330kbit/s
- o max. 3500W Electrical power at the seafloor unit
- o 1500V Voltage at the coaxial cable





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Center for Marine Environmental Sciences

FB 05 Geowissenschaften
Leobenerstr.
MARUM Gebäude, Raum 2210
28359 Bremen

Postfach 33 04 40
28334 Bremen

Cone Calibration Sheet

Number	JESSICA
Type	Subtraction Cone, 5 cm²
Date	November 24th 2012
Engineer	Wolfgang Schunn
Calibration Sheet Number	010113v1JESSICA
Cone Calibration Equipment	HBM S9M 50kN (calibration sensor) AST AE 703 (analog/digital converter) LabView via USB (data aquisition unit/logger)
HBM Certificate Number	1472828A – FL1194

	resolution [kN/digit]	**zero offset [kN]**	**maximum Inaccuracy* [% of maximum load]**
Tip Resistance	0.00000842	-0.77307	+ 0.36 - 0.25
Tip + Sleeve	0.00000919	1.3196	+ 0.56 - 0.3
	resolution [kPa/digit]	**zero offset [kPa]**	**maximum Inaccuracy* [% of maximum load]**
Pore Pressure	0.000216	31.845	+ 0.5 - 0.5
Acceleration	**resolution [m/s²/digit]**	**zero offset [m/s²]**	**nonlinearity [%] interaxis alignment error [°] cross axis sensitivity [%]**
x-axis	0.070323	-35.407	± 0.2 ± 0.1 ± 1
y-axis	0.068601	-34.301	± 0.2 ± 0.1 ± 1
z-axis	0.068842	-35.006	± 0.2 ± 0.1 ± 1

Cone Specifications

Cone base area	500	mm^2
Area ratio	0.67	[-]
Nominal tip load	50	kN
Friction sleeve area	7500	mm^2
Nominal sleeve load	50	kN
Nominal load pore pressure	700	kPa
Temperature compensation (all sensors)	0… +40	^oC
Maximum overload capacity (all sensors)	100	%

Remarks All calibrations are done linear – upon special request higher resolutions can be achieved for selected data ranges using non linear calibration funcions

Approved **Date:** **November 24th**
Technicians: **Daniel Otto/Ehsan Jorad**

Prof. Dr. Tobias Moerz
Marine Engineering Geology, MARUM/FH-IWES, University Bremen, GER

Part C4 - Field Laboratory (NGI)

Contents

C4.1 Summary **2**
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C4.3 Laboratory test procedures **4**
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C4.3.2 Index undrained shear strength and sensitivity 4

Table

C4-1 Sample list

C4.1 Summary

The tests results presented herein are those obtained in the laboratory onboard the vessel during the offshore fieldwork. The geotechnical testing in the offshore laboratory consisted of the following:

- Soil description and soil classification
- Water content determination
- Index shear strength testing

In addition to the geotechnical testing the measurements of the concentration of mercury in the samples were performed by NIVA.

The results from the geotechnical testing performed offshore are presented in the borehole logs in Part B1.

The samples were obtained in plastic liners (diameter ~100 mm) acquired using the vibro core and the gravity core samplers. Surface samples were obtained using the ROV sampler.

The vibro/gravity core samples were obtained in 6 m nominal lengths and cut into 1 m sections. In general, the top 20 cm of each section is cut and removed to allow offshore laboratory testing. These 20 cm samples were extruded offshore.

Focusing on the mercury concentration for the samples obtained close to the wreck parts, the depth interval between 0.5 m and 0.6 m below seafloor were also tested offshore.

The plastic liners were then sealed and shipped back to the onshore laboratory. No waxed samples were obtained.

The ROV samples are 0.5 m nominal in depth. The contents were extruded offshore and tested for mercury concentration by NIVA. Geotechnical sample description was performed.

Table C4-1 contains a soil description of relevant parts extruded offshore.

C4.2 Classification tests

C4.2.1 Water content

Water content determination is a classification test performed on the section brought to the offshore laboratory. Material from the inner part of the sample is taken to avoid disturbed material from the outer parts that may influence the water content measurement.

The derived water contents are presented graphically on the borehole logs in Part B1.

C4.2.2 Total unit weight

Unit weight is determined from all water content determinations assuming the soil is 100% saturated and assuming a unit weight of solid particles of 27.3 kN/m^3. The values are presented on the borehole logs in Part B1.

C4.2.3 Index undrained shear strength and sensitivity

Index shear strength determinations are made in the top 20 cm of each of the plastic liner sections extruded offshore. Fall cone was used to measure index undrained shear strength. The undrained shear strengths determined from these index tests are plotted versus depth in the borehole logs in Part B1.

Fall cone is also used to determine the remoulded undrained shear strength. The ratio of the undrained shear strength to the remoulded undrained shear strength is the sensitivity of the material.

C4.3 Laboratory test procedures

C4.3.1 Water content

Water content (w) is the mass of water in the sample expressed as a percentage of the mass of solids. It is found by weighing a representative part of the sample before and after 17-20 hours of oven drying at approximately 110°C.

C4.3.2 Index undrained shear strength and sensitivity

The fall cone apparatus measures the penetration of a cone into the specimen after it has been released from an initial stationary position with the tip of the apex at the surface of the specimen. Cones with different apex angles and masses are used. At least 3 releases of the cone are carried out on the specimen for each test. Based on the average value of penetration, the undrained shear strength is estimated from empirical correlations between cone type and penetration. The weight of the cones used for this project was 10, 60 and 100 g.

To calculate soil sensitivity in the laboratory, a test is conducted on an undisturbed specimen of 3-4 cm thickness and a second test on the remoulded specimen. The ratio between the shear strength estimates from the former and the latter is the sensitivity.

Table C4-1 Sample List, U-864

Boring No.	Sample type	Sample No.	Depth m	Recovery cm	Part	Tube/Bag Wax/Plexi	Depth,m from	Depth,m to	Length cm	Soil G/S/Si/C	Sample discription
2013-404	Vibro core	1	0.00	100	C	Bag	0.00	0.20	20	S	SAND, clayey, with coarse gravel, with shell fragments, GLEY 4/1, dark greenish grey
					B	Tube	0.20	0.80	80	S/C	Stored in tube
					A	Bag	0.80	0.90	10	C	CLAY, slightly silty, with pockets of sand and scattered grains of coarse gravel, GLEY 3/1, very dark grey
					B	Bag	0.90	1.00	10	C	As above
		2	1.00	100	A	Tube	1.00	1.80	80	C	Stored in tube
					B	Bag	1.80	2.00	20	C	CLAY, silty, with scattered grains of gravel, 3/1 very dark grey, becoming sandy with depth
		3	2.00	45	A	Tube	2.00	2.40	40	C	As above
2013-403	Vibro core	1	0.00	100	A	Bag	0.00	0.20	20	C	CLAY, silty, very soft, with pockets of sand, shell fragments, GLEY 3/1, very dark gray, occ scattered grains of medium gravel
					B	Tube	0.20	0.50	30	C	As above
					C	Bag	0.50	0.60	10	C	As above
					D	Tube	0.60	1.00	40	C	As above
		2	1.00	45	A	Bag	1.00	1.20	20	C	CLAY, silty, sandy, gravely, GLEY3/1, very dark grey
2013-402	Vibro core	1	0.00	100	A	Bag	0.00	0.20	20	S	SAND, silty, with shell fragments, GLEY1 3/1, vey dark grey
					B	Tube	0.20	0.50	30	S	As above
					C	Bag	0.50	0.60	10	C	CLAY, silty, sandy, slightly gravelly, GLEY1 3/1, vey dark grey
					D	Tube	0.60	1.00	40	C	As above
		2	1.00	100	A	Bag	1.00	1.15	15	C	CLAY, silty, slightly sandy with occasional scattered grains of gravel, GLEY 1, 3/1, very dark grey
					B	Tube	1.20	2.00	80	C	As above
		3	2.00	100	A	Bag	2.05	2.15	10	C	CLAY, silty, sandy, slightly gravelly, medium, with traces of shell fragments, GLEY 1, 3/1, very dark grey
					B	Tube	2.20	3.00	80	C	As above
		4	3.00	40	A	Tube	3.00	3.40	40	C	As above
2013-405	Vibro core	1	0.00	100	A	Plexi	0.00	0.20	20	S	SAND; silty, gravelly, occ. Shell fragments, GLEY 1 4/1, dark greenish grey
					B	Tube	0.20	0.50	30	S	As above
					C	Plexi	0.50	0.60	10	S	As above, but less shell fragments
					D	Tube	0.60	1.00	40	S	As above
		2	1.00	100	A	Plexi	1.00	1.10	10	C	CLAY, silty, grains of gravel, GLEY 1 4/1, dark greenish grey, 1 coarse gravel ca 3 cm in diam
					B	Plexi	1.00	1.10	10	C	As above
					C	Bag	1.10	1.20	10	C	As above
					D	Bag	1.10	1.20	10	C	As above
					E	Tube	1.20	2.00	80	C	As above
		3	2.00	100	A	Plexi	2.00	2.10	10	C	CLAY, silty, very soft, with black spots, dark grey
					B	Plexi	2.00	2.10	10	C	As above
					C	Bag	2.10	2,2	10	C	As above
					D	Bag	2.10	2.20	10	C	As above
					E	Tube	2.20	3.00	80	C	As above
		4	3.00	20	A	Bag	3.00	3.10	10	C	CLAY, silty, grains of gravel, GLEY 1 4/1, dark greenish grey, black spots
					B	Bag	3.10	3.20	10	C	As above but with numerous coarse gravels in bottom
					C	Tube	3.20	3.40	20	C	As above
2013-406	Vibro core	1	0.00	100	A	Bag	0.00	0.10	10	S	SAND, clayey. NOTE: Withmercury
NOTE: Sample 2013-406 was not shipped to NGI Oslo due to high mercury content					B	Bag	0.10	0.20	10	C	CLAY, sandy, grains of gravel, dark greenish grey. GLEY 1 4/1. NOTE: Withmercury
						Tube	0.20	0.50	30	C	As above
					C	Bag	0.50	0.60	10	C	CLAY. Note:Mercuryappears in the sample with lots of pearls.
						Tube	0.60	1.00	40	C	As above
		2	1.00	100	A	Tube	1.00	1.20	20	C	CLAY. Note:Mercuryappears in the sample. This sample is note opened any further
					B	Tube	1.20	2.00	80	C	As above
					C	Tube	2.00	2.60	60	C	As above
2013-407	Vibro core	1	0.00	100	A	Bag	0.00	0.10	10	S	SAND, with shell fragments, very dark grey. Disturbed sample
					B	Bag	0.10	0.20	10	S	As above
						Tube	0.20	0.50	30	S	As above
					C	Bag	0.50	0.60	10	S	As above
						Tube	0.60	1.00	40	S	As above
						Tube	1.00	1.25	25		
2013-401	Vibro core	1	0.00	100	A	Bag	0.00	0.20	20	S	Sand, silty, slightly clayey, with shell, occ. Scattered pebbles and a few grains of gravel, very soft, very dark greenish grey
						Tube	0.20	0.50	30	S	As above
					B	Bag	0.50	0.60	10	C	CLAY, slightly silty, sandy
						Tube	0.60	1.00	40	C	As above
		2	1.00	100	A	Bag	1.00	1.20	20	C	CLAY, silty, sandy, some fragments of shell, with few fine coarse gravel, very soft GLEY 1 2.5/N. Disturbed
						Tube	1.20	2.00	80	C	As above
		3	2.00	65	A	Bag	2.00	2.20	20	C	CLAY as above
						Tube	2.20	2.65	40	C	As above
2013-509	Gravity core	1	0.00	100	A	Bag	0.00	0.15	15	S	SAND, gravel, greyish brown
					B	Plexi	0.15	0.20	5	C	CLAY, sandy, very soft, grains of gravel, dark greenish grey
					C	Tube	0.20	1.00	80	C	As above
		2	1.00	100	A	Plexi	1.00	1.10	10	C	CLAY, very soft, grains of gravel, dark grey
					B	Bag	1.10	1.20	10	C	As above
					C	Tube	1.20	2.00	80	C	As above
		3	2.00	100	A	Plexi	2.00	2.10	10	C	CLAY. very soft, silty, less gravel than above, slightly sandy, very dark greenish grey
					B	Plexi	2.10	2.20	10	C	As above
					C	Tube	2.20	3.00	80	C	As above
		4	3.00	90	A	Plexi	3.00	3.10	10	C	CLAY as above
					B	Plexi	3.10	3.20	10	C	As above
					C	Tube	3.20	3.90	70	C	As above
2013-512	Gravity core	1	0.00	100	A	Bag	0.00	0.20	20	S	SAND, gravel, shell fragments, greenish grey
					B	Tube	0.20	1.00	80	S	As above
		2	1.00	100	A	Plexi	1.00	1.10	10	C	CLAY, silty, very soft, grains of gravel, dark greenish grey
					B	Plexi	1.10	1.20	10	C	As above
					C	Tube	1.20	2.00	80	C	As above
		3	2.00	100	A	Plexi	2.00	2.10	10	C	CLAY, silty, very soft to soft, grains of gravel, with shell fragments, dark greenish grey
					B	Plexi	2.10	2.20	10	C	As above
					C	Tube	2.20	3.00	80	C	As above
		4	3.00	90	A	Plexi	3.00	3.10	10	C	CLAY as above
					B	Plexi	3.10	3.20	10	C	As above
					C	Tube	3.20	3.90	70	C	As above
2013-08	ROV sample	1	0.00	18	A	Bag	0.00	0.18	18	S	SAND, slightly silty, fine, gravelly, shell fragments
2013-28	ROV sample	1	0.00	5	A	Bag	0.00	0.05	5	S	SAND, gravelly, slightly silty, occ. shell fragments becoming CLAY
2013-30B	ROV sample	1	0.00	19	A	Bag	0.00	0.19	19	S	SAND, with a fine gravel and few shell fragments, becoming CLAY, very soft, slightly silty, with a few pockets/partings of sand/silt
2013-31	ROV sample	1	0.00	22	A	Bag	0.00	0.22	22	S	SAND, gravelly, shell fragments becoming CLAY, silty, sandy, shell fragments
2013-32	ROV sample	1	0.00	32	A	Bag	0.00	0.32	32	S	SAND, slightly gravely, becoming CLAY, silty, sandy, gravely
2013-34	ROV sample	1	0.00	23	A	Bag	0.00	0.23	23	S	SAND, with fine to coase gravel, occ. shell fragments, becoming CLAY, silty, slightly gravely
2013-35	ROV sample	1	0.00	9	A	Bag	0.00	0.09	9	S	SAND, with shell fragments
2013-36	ROV sample	1	0.00	1	A	Bag	0.00	0.01	1	S	SAND, medium to coarse
2013-38	ROV sample	1	0.00	17	A	Bag	0.00	0.17	17	S/C	0.0 - 0.15 m: SAND, gravelly, shell fragments. 0.15-0.17 m: CLAY
2013-83	ROV sample	1	0.00	24	A	Bag	0.00	0.24	24	S	SAND, gravelly followed by CLAY, silty
2013-87	ROV sample	1	0.00	22	A	Bag	0.00	0.22	22	S/C	0.0-0.1 m: SAND, gravelly, shell fragments 0.1-0.2 m: CLAY, silty, sandy, shell fragments
2013-88	ROV sample	1	0.00	2	A	Bag	0.00	0.02	2	S	SAND, with fine to coarse gravel, of shell fragments
2013-142	ROV sample	1	0.00	3	A	Bag	0.00	0.03	3	G	GRAVEL, sandy with shell fragments
2013-146	ROV sample	1	0.00	7	A	Bag	0.00	0.07	7	S	SAND, silty, with shell fragments, a few coarse gravel
2013-155	ROV sample	1	0.00	4	A	Bag	0.00	0.04	4	C	CLAY, sandy, silty
2013-204	ROV sample	1	0.00	4	A	Bag	0.00	0.04	4	S	SAND, gravelly with shell fragments
2013-206	ROV sample	1	0.00	10	A	Bag	0.00	0.10	10	C	CLAY, sandy, silty, gravelly
2013-210	ROV sample	1	0.00	25	A	Bag	0.00	0.25	25	S	SAND, slightly gravelly, with shell fragments, becoming CLAY, silty, slightly sandy/gravelly
2013-211	ROV sample	1	0.00	12	A	Bag	0.00	0.12	12	S	SAND with shell fragments and a few pebbles becoming CLAY, silty, sandy
2013-213	ROV sample	1	0.00	23	A	Bag	0.00	0.23	23	S	SAND, with shell fragments becoming CLAY, silty, with pockets of sand and gravel
2013-301	ROV sample	1	0.00	12	A	Bag	0.00	0.12	12	S	SAND, slightly gravelly, with shell fragments
2013-302	ROV sample	1	0.00	9	A	Bag	0.00	0.09	9	C	CLAY, silty, sandy, with shell fragments, a few pebbles
2013-306	ROV sample	1	0.00	25	A	Bag	0.00	0.25	25	S	SAND, slightly gravelly with shell fragments becoming CLAY, silty, slightly gravelly, very soft, pockets and seams of sand, shell fragments
2013-308	ROV sample	1	0.00	30	A	Bag	0.00	0.30	30	S	SAND, with a few grains of gravel and a few pebbles becoming CLAY, very soft, with a few scattered traces of sand and shell fragments
2013-312	ROV sample	1	0.00	12	A	Bag	0.00	0.12	12	S	SAND, gravelly, slightly silty, a few gravel, shell fragments
2013-313	ROV sample	1	0.00	2	A	Bag	0.00	0.02	2	S	SAND, gravelly
2013-315	ROV sample	1	0.00	22	A	Bag	0.00	0.22	22	S	SAND, silty, slightly clayey becoming CLAY, silty, gravelly
2013-316	ROV sample	1	0.00	27	A	Bag	0.00	0.27	27	S	SAND, occ. shell fragments, a few fine to meium gravel becoming SILT, SAND, GRAVEL with occ. shell fragments, clayey
2013-317	ROV sample	1	0.00	31	A	Bag	0.00	0.31	31	S	SAND, slightly silty, a few gravel, shell fragments becoming CLAY, very soft, slightly silty, with a few grains of gravel
2013-320	ROV sample	1	0.00	1	A	Bag	0.00	0.01	1	G	GRAVEL, sandy
2013-324	ROV sample	1	0.00	6	A	Bag	0.00	0.06	6	S	SAND, gravelly with shell fragments
2013-331	ROV sample	1	0.00	26	A	Bag	0.00	0.26	26	S	SAND, slightly gravelly, silty with shell fragments
2013-332	ROV sample	1	0.00	1	A	Bag	0.00	0.01	1	G	GRAVEL, sandy with shell fragments
2013-333	ROV sample	1	0.00	1	A	Bag	0.00	0.01	1	S	SAND
2013-334	ROV sample	1	0.00	10	A	Bag	0.00	0.10	10	S	SAND, gravelly, silty with shell fragments and a few pebbles

Total recovery:	2892	cm
Total length in tubes:	1910	cm
Total length wax:	0	cm
No. of bags:	65	#
No. of waxed:	0	#
No. of tubes:	35	#
No. of plexi:	18	#

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1. INTRODUCTION

On 9th February 1945 the German submarine U-864 was on its way from Germany to Japan via Norway when it sank, due to being torpedoed by the British submarine HMS Venturer. Old documents claim the submarine was holding cargo of about 65 tons of mercury, stored in steel-containers. The wreck of U-864 was discovered by the Norwegian Navy in March 2003. The submarine is located west of Fedje, on depths of 150 meters.

The wreck is split into two main sections. The bow section is located on sloping seabed with slope angel of about 15^0, whereas the stern section lies in a nearly flat seabed area uphill of the bow part. Surrounding seabed is contaminated.

The scope of this note is to summarize the analyses of wreck stability for the case with staged rock/sand installation and soil consolidation in combination with increased capping height of the wreck sections.

The tehcnincal note comprises:

- Determination of soil parameters for use in the analyses
- Methodology statement
- Static stability calculations to determine adequate geometry of the wreck and seabed capping comprising sand and crushed rock as erosion protection
- 3D modelling of the capping design and required counterfilling
- Estimate of total volume

2. SUMMARY

Soil conditions:

The seabed in the area is characterised by a relatively flat area in the south, at water depth around 145 - 150 m, where the stern wreck section is located. Just south of the stern section and in north-east there are steep seabed slopes with exposed bedrock. Exposed bedrock is also present in the local seabed ridge west of the stern section.

Towards the bow section in north, the water depth increases gradually from 150 m to 175 m with an average slope angle of 15^0. East of the bow section the seabed is characterised by a local ridge with outcropping bedrock in the local steep areas and local infill with sand and gravel in between the bedrock exposures. The area with largest water depth in north is characterised by a valley widening towards north-east from approximately 50 m to about 100 m. The bottom of the valley is nearly flat with thick sediment layers.

The sediment stratigraphy comprises in general three sediment units:

Unit I:	Top layer of loose gravelly sand
Unit II:	Very soft clay, silty and sandy
Unit III	Moraine overlying bedrock

Assumptions / limitations in the analysis

Documentation of the detailed design of the rock encapsulation and capping of the contaminated seabed performed in 2010 are presented in Ref. /7/. Compared to the 2010 design, the required thickness of the capping has been increased with about 2.3 m in the areas with high contamination close to the wreck-parts and about 0.5 m in the areas with low contamination.

- The design presented in this note is based on the rock cover geometry from 2010 and new stability analyses along section 11. Section 11 intersects the highest rock fill height over the upper wreck part (stern) and is considered to be most critical.
- Detailed requirements for the capping close to the wreck parts are not determined. The total rock fill height is based on the requirements for a passive cover given in Ref. /5/.
- The thickness of the capping layer over the wreck section in the slope (bow) has not been checked due to uncertainty in the actual wreck height above seabed.
- Only the total volume of the capping model presented in this note. The volume has not been split in different capping materials and erosion protection layers.

The safety requirements applied in the design of the encapsulation and capping reflect the regulations for structural design of load-bearing structures regarding the principle of partial coefficients (load and material coefficients) in the design of submarine gravel supports. The recommendations complies with the strictest requirements of Statoil with respect to safety margins for submarine gravel supports used as foundation for subsea structures or pipelines.

Stability during earthquake loading has not been evaluated for the rock cover presented in this report. Earthquake loading was however assessed in geotechnical analysis of the rock cover presented in Ref. /7/. Due to the moderate changes in the rock cover the permanent displacements during the 10^{-2} earthquake load event are expected to be negligible. For the 10^{-4} load event the permanent displacements are estimated to be less than 20 cm which are also considered to be hardly noticeable.

The overall conclusion is that earthquake loading is not critical for the wreck encapsulation and seabed capping. Figure 2-1 shows the final geometry of the encapsulation and capping.

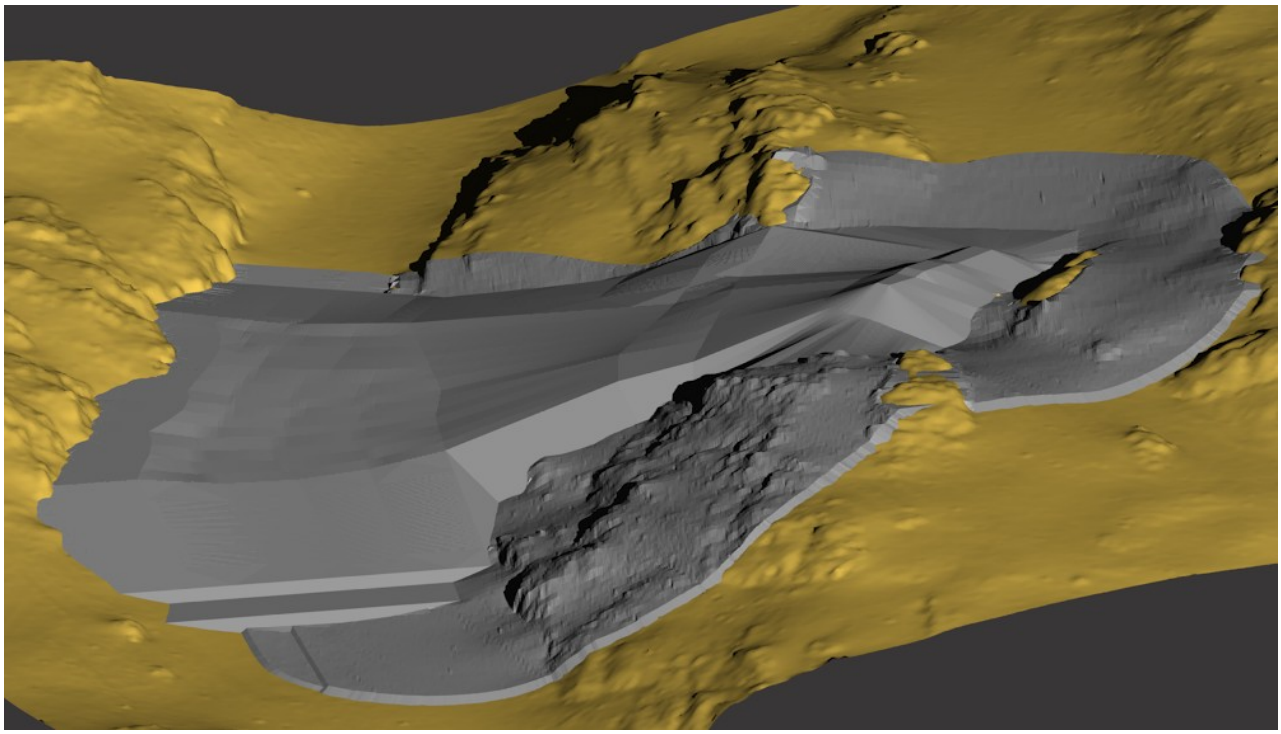

Figure 2-1 3D view towards south-west of finalised encapsulation and capping.

The total volume of the model is 235 236 m^2 which is very close to the total volume of the model presented in Ref. /7/.

3. ANALYSIS BASIS

3.1 Soil Conditions

The soil conditions are presented in Ref. /7/.

3.2 Rock Parameters

Typical rock parameters for a 1-5” gradation is:

Submerged unit weight:	γ'_{rock}	= 9.1 kN/m^3
Internal friction:	tanφ	= 0.85
Attraction:	a	= 0 kPa

The given value of submerged weight is an average value representative for crushed rock delivered from the quarries in the Bergen area, Ref. /2/. The characteristic strength in terms of internal friction and attraction are based on experience data, Refs. /3, 4/.

3.3 Safety Requirements

The safety requirements reflect the regulations for structural design of load-bearing structures, Ref. /8/ regarding the principle of partial coefficients (load and material coefficients) in the design of submarine gravel supports. The recommendations given in Table 3.3-1 complies with the strictest requirements of Statoil with respect to safety margins for submarine gravel supports used as foundation for subsea structures or pipelines.

Load conditions	**Loads**	**Load coefficient**			**Material coefficient**
		γ_L ULS-O	**γ_L ULS-E**	**γ_L PLS-A**	**γ_m**
Static stability, weight of sand and rock reduces stability (acting load)	P	1.3	N/A N/A	N/A N/A	1.5 in clay, 1.25 in rock and sand
Static stability, weight of sand and rock improves stability (counteracting load)	P	1.0	N/A N/A	N/A N/A	1.5 in clay, 1.25 in rock and sand

γ_L = Load coefficient
γ_m = Material coefficient
N/A = Not applicable
P = Permanent load

Table 3.3 - 1 Load and soil material coefficients for stability analyses of wreck capping.

The design loads are determined from a characteristic load multiplied by the associated load coefficient. Minimum soil material coefficient for rock and sand is 1.25. The undrained shear strength of clay is scaled down by the ratio 1.25/1.5 in the analyses to allow for an average soil material coefficient for the entire shear surface through both rock and clay.

Adequate shear mobilisation in frictional materials (crushed rock and sand) is 0.8 corresponding to a material coefficient of 1.25. Stricter requirements are according to our interpretation valid for soft clay with contractant behaviour and in case of sparse soil information. The value of 1.5 reflects the uncertainty in clay strength, the shear strength value and the clay behaviour under loading.

3.4 Strength increase due to increased effective stress (consolidation).

The weight of the capping fill materials and the counterfill of crushed rock will result in increased vertical stresses in the soft clay layers. During consolidation the increased stress will gradually result in increased effective stress and increased shear strength in the clay. A conceptual study of this effect is presented in Ref /10/ showing that a nearly constant strength with depth may be achieved after about 12 months of consolidation for a 6 m thick clay layer. The actual clay layer thickness is less (2 - 4m) in most of the area in question resulting in shorter consolidation time than 12 months.

In the stability analysis the shear strength after 1 year of consolidation has been as:

$s_u = 0.25 \cdot \gamma_{cover}' \cdot H_{cover}$ + (1 kPa increase per meter)

Where γ_{cover}' and H_{cover} are the submerged unit weight of the rock fill and the height of the rock fill respectively. The consolidated strength ($s_u = 0.24\ \sigma_v'$) is chosen according to the recommendations in Ref /1/.

The clay at the site shows an increase in strength with depth of 5.8 kPa per meter. A small increase in strength with depth was therefore included in the in the consolidated strength to avoid unrealistic low shear strength close to the bedrock/moraine.

4. GEOMETRY OF WRECK CAPPING

The thickness requirements for different combinations of capping are given in Ref /5/. For a passive layer which results in the largest thickness the a total height of 2.90 m is found for the areas with high contamination close to the wreck parts while a thickness of 1.15 m is found for the area with contamination. The total heights include a 0.20 m thick erosion protection layer and 0.40 m for installation tolerance.

In the design presented in this report it is assumed that the 2.90 m requirement is relative to both seabed and the wreck parts as shown in Figure 4-1. This results in a fill height of 13.5 m above seabed at the highest part of the stern section of the wreck.

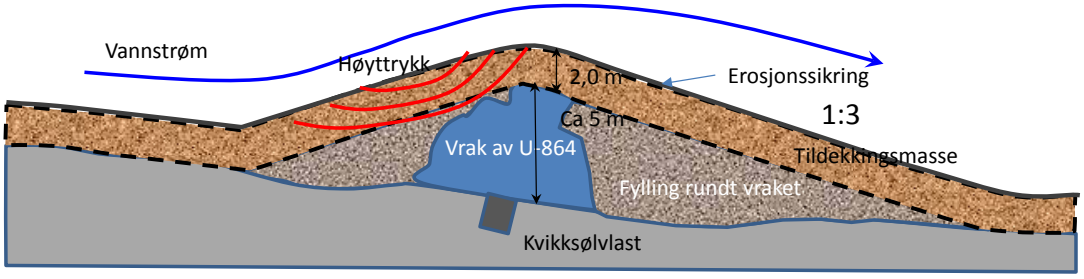

Figure 4-1 Principle design of the capping layer from Ref /5/.

5. METHODOLOGY

5.1 Stability Analyses

The method of stability calculation is based on the General Procedure of Slices (GPS), according to Janbu, Ref. /9/ and the computer program SLIDE, which is also based on the method of slices, Ref. /6/.

The rock/olivine fill stability is checked for several trial shear surfaces. The critical shear surface contains the lowest safety margin.

In case counterfill is required, the dimensions are determined by three failure modes:

Failure mode 1: Local shear surface with outcrop through the counterfill gives the minimum counterfill height.

Failure mode 2: Local shear surface at the edge of the counterfill gives the maximum allowable height at the outer edge.

Failure mode 3: Global shear surface extending from the main fill and outcrops in the seabed outside the counterfill edge gives the minimum length of the counterfill.

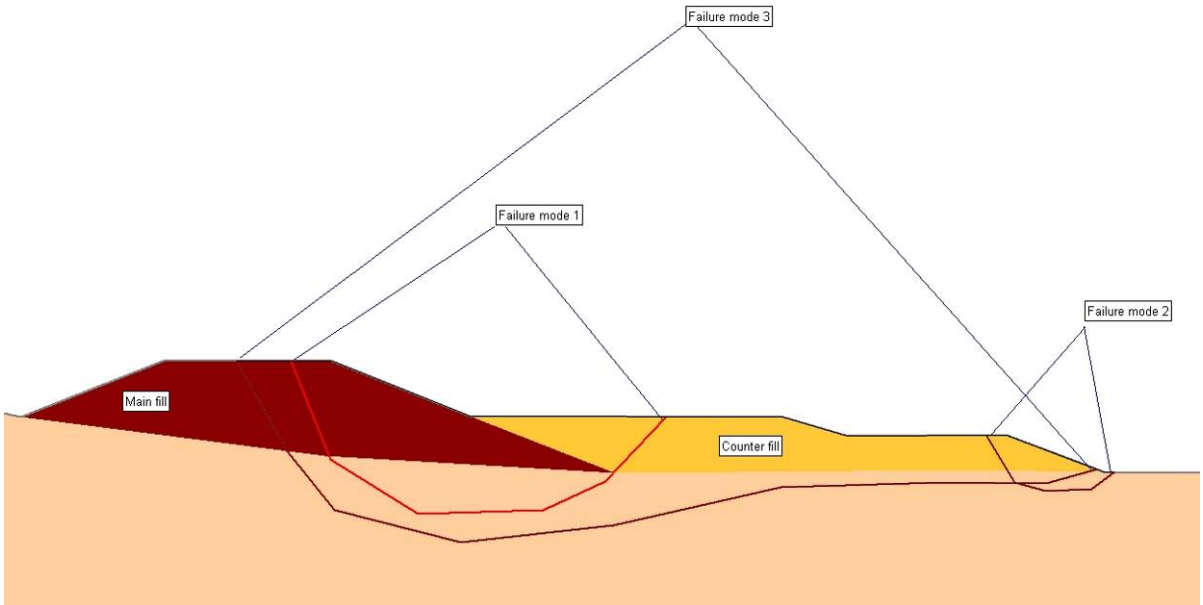

Figure 5.1-1 Failure modes to be analyzed for determination of counterfill dimensions

6. CAPPING MODEL AND VOLUME

6.1 3D Modelling as Basis for Stability Evaluations

The survey data provided, Ref. /11/, was used to produce a digital terrain model (DTM) of the seabed. By studying the DTM sections of interest Section 11 was selected for the new stability analyses. Figure 6-1 shows a top view of the area. In total 20 sections were evaluated in the previous phase due to the large size of the area and the rugged seabed.

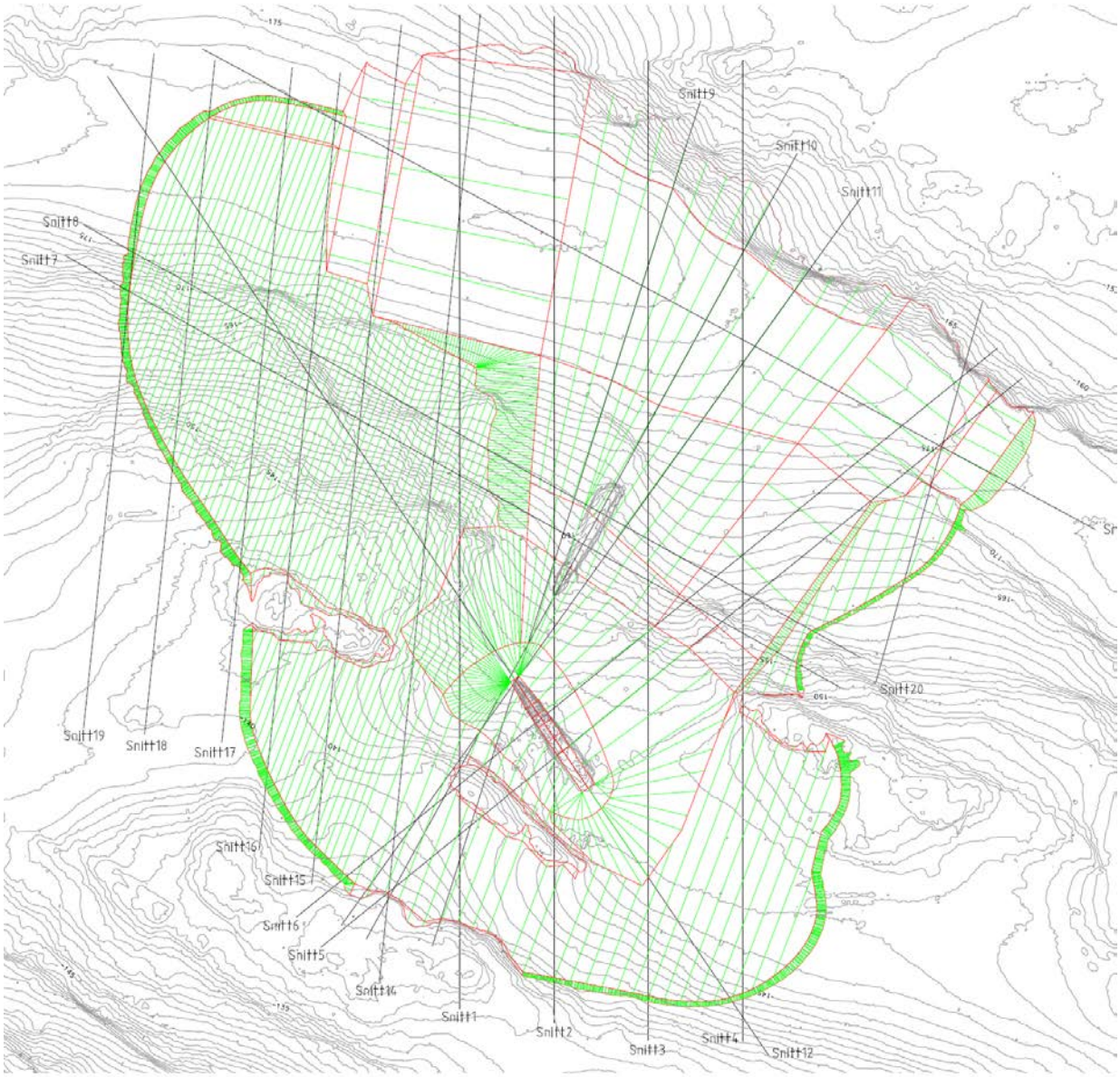

Figure 6-1 Overview of sections for evaluation produced by the 3D model.

6.2 Stability Analyses

Documentation of the detailed design of the rock encapsulation and capping of the contaminated seabed performed in 2010 are presented in Ref. /7/. Compared to the 2010 design, the required thickness of the capping has been increased with about 2.3 m in the areas with high contamination close to the wreck-parts and about 0.5 m in the areas with low contamination.

The design presented in this note is based on the rock cover geometry from 2010 and new stability analyses along section 11. Section 11 intersects the highest rock fill height over the upper wreck part (stern) and is considered to be most critical. Detailed requirements for the capping close to the wreck parts are not determined. The total rock fill height is based on the requirements for a passive cover given in Ref. /5/. The thickness of the capping layer over the wreck section in the slope (bow) has not been checked due to uncertainty in the actual wreck height above seabed. In the stability analysis a one m thick layer of sand with friction angle 35° and submerged unit weight 11 kN/m^3 is underlying the rock fill.

The present analyses assume sand and rock installation in three phases.

Figure 6-2 shows the results from the stability analyses of Section No 11 in Phase 1. In Phase 1 a 10 m thick counterfill is installed at the bottom of the slope. The thickness is then gradually reduced to 2.3 m at the intersection with the stern wreck part.

Figure 6-3 shows the result from the stability analyses of Section No 11 in Phase 2. Phase 2 can be installed minimum one year after Phase 1. In Phase 2 additional counterfill is installed with height increasing from 0 to 4 m from the bottom of the slope to the position of the bow part of the wreck. The height is reduced to 0 m at the stern part.

Figures 6-4 shows the results from the stability analyses of Section No 11 in Phase 3. Phase 3 can be installed 1 year after Phase 2. The increased strength due to consolidation is required to achieve sufficient stability. In Phase 3 the cover over the stern part of the wreck can be completed. The stability for rock cover over the stern part is calculated using a load factor of 1.3 on the unit weight if the crushed rock.

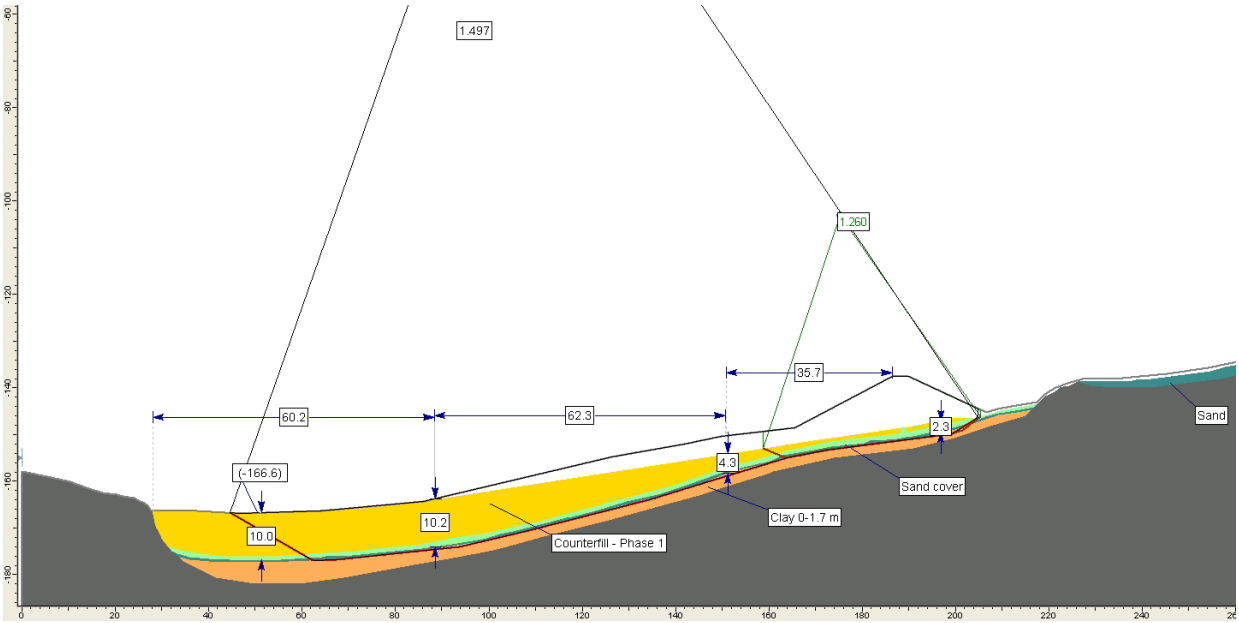

Figure 6-2 Stability along Section No 11 Phase 1

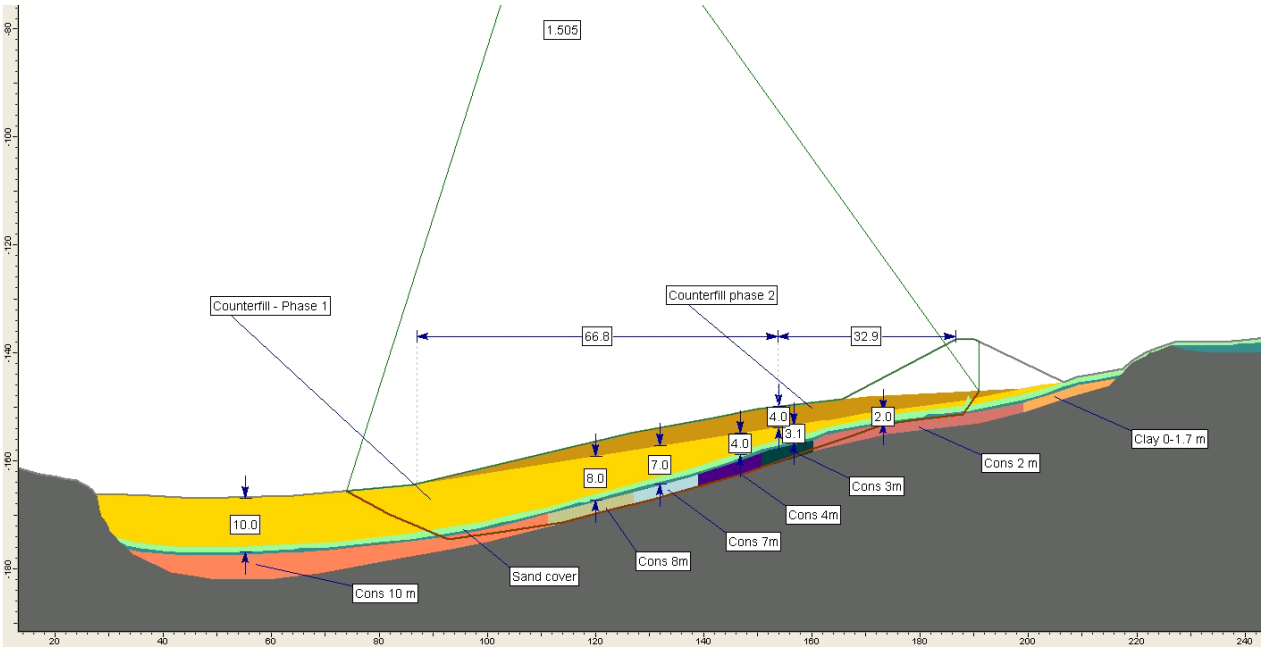

Figure 6-3 Stability along Section No 11 Phase 2

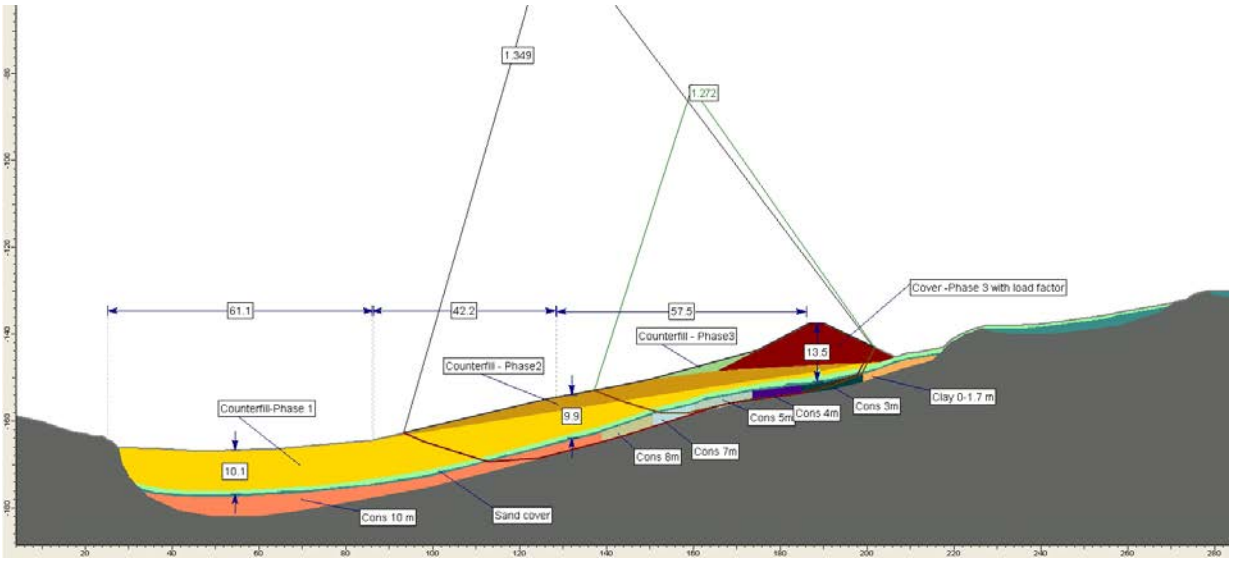

Figure 6-4 Stability along Section No 11 Phase 3

6.3 Model and volume

Figure 6-5 shows a 3-D view of the completed seabed capping and counterfill. Compared to the design from 2010 the cover height is increased in the upper parts covering the wreck parts and reduced with 2 m in the counterfill at the bottom of the slope. The consolidation effects compensated for the increased cover heights.

The total volume of the model is 235 236 m^2 which is very close to the total volume of the model presented in Ref. /7/.

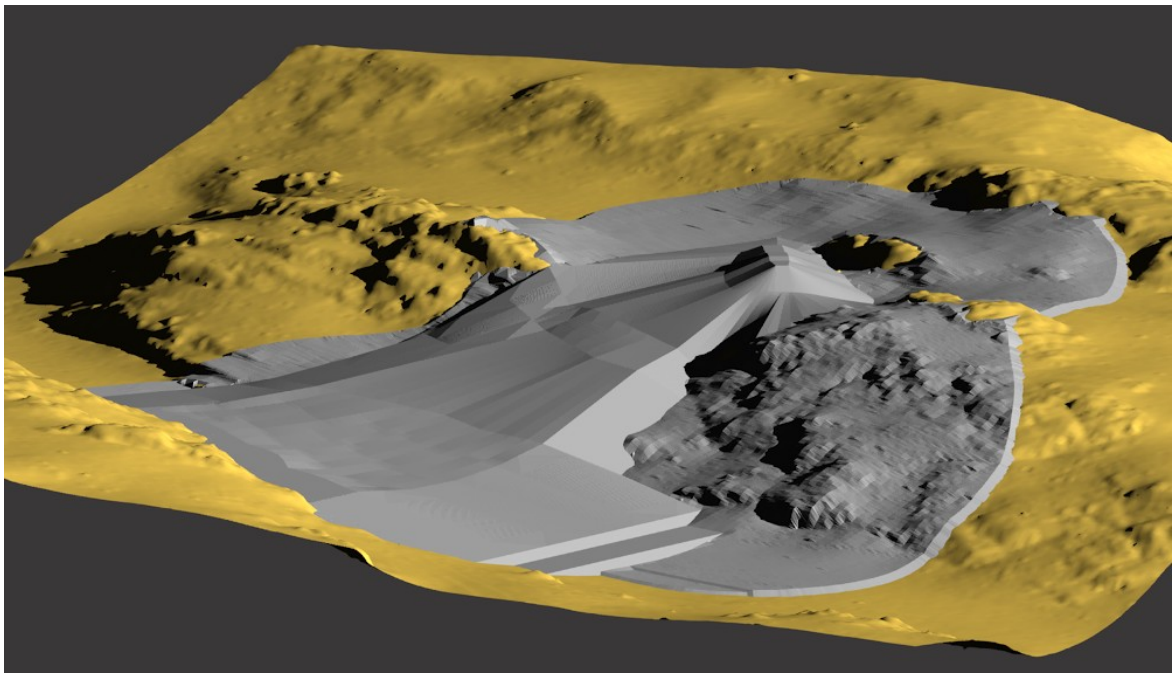

Figure 6-5 3D view of the finalised encapsulation and seabed capping.

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/10/ NGI Technical Note (2014): "Effect of consolidation on shear strength" Doc No. 20130288-02-TN

/11/ Geoconsult (2006): Sluttrapport U-864-Fase 2, 2006. Kartlegging og fjerning av kvikksølvforurensning".
Dokument nr 14021-SUR-O15-00001-06B.

Technical Note

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Effect of consolidation on shear strength

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1 Introduction

NGI has prepared by request from DNV (mail 2014) a technical note demonstrating the effect of consolidation on the undrained shear strength of a clay layer subjected to load by a 7m high counter fill.

The German submarine U-864 was sunk by the British submarine Venturer on 9th February 1945, whilst being on its way from Germany via Norway to Japan with a cargo of war material. According to historical documents, U-864 was carrying about 65 tonnes of metallic (liquid) mercury, stored in steel containers. The wreck of the U-864 was found by the Royal Norwegian Navy in March 2003 on 150 meters depth. The wreck lies approximately 2 nautical miles west of the island Fedje in Hordaland, Norway and is broken into two main parts as a result of the torpedo hit. The position of the wrecks and the water depths is given in Figure 1.1.

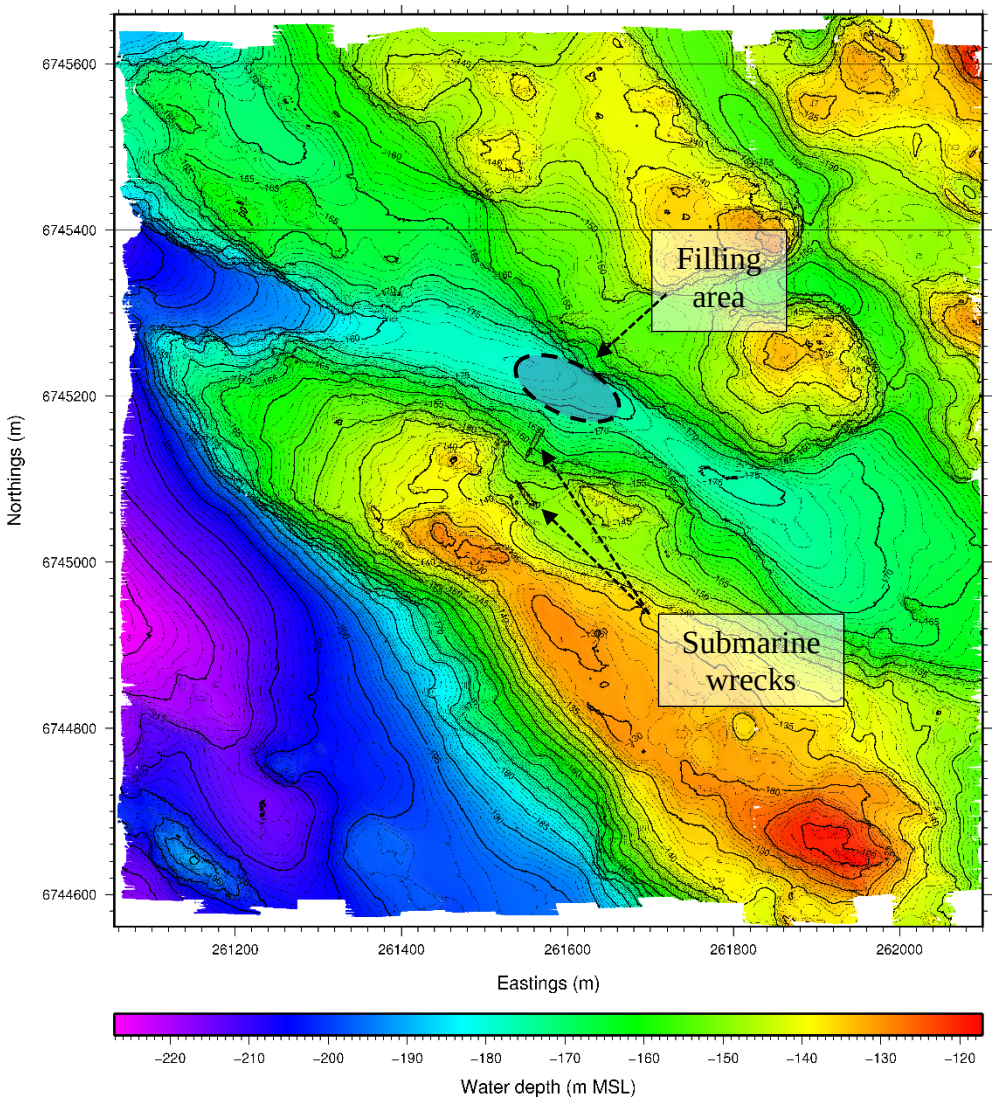

Figure 1.1 Bathymetry date and wreck locations

As a part of an environmental protection of the area around the submarine wreck, a capping design is investigated. One part of the submarine is located on a slope and the weight of the capping reduces the slope stability. In order to keep a secure slope, a filling may be needed in the bottom of this slope. A sketch of the slope with a typical capping and counter filling is shown in Figure 1.2.

The construction process is divided into two phases: first is the counter filling installed, and afterwards the capping on the slope is constructed.

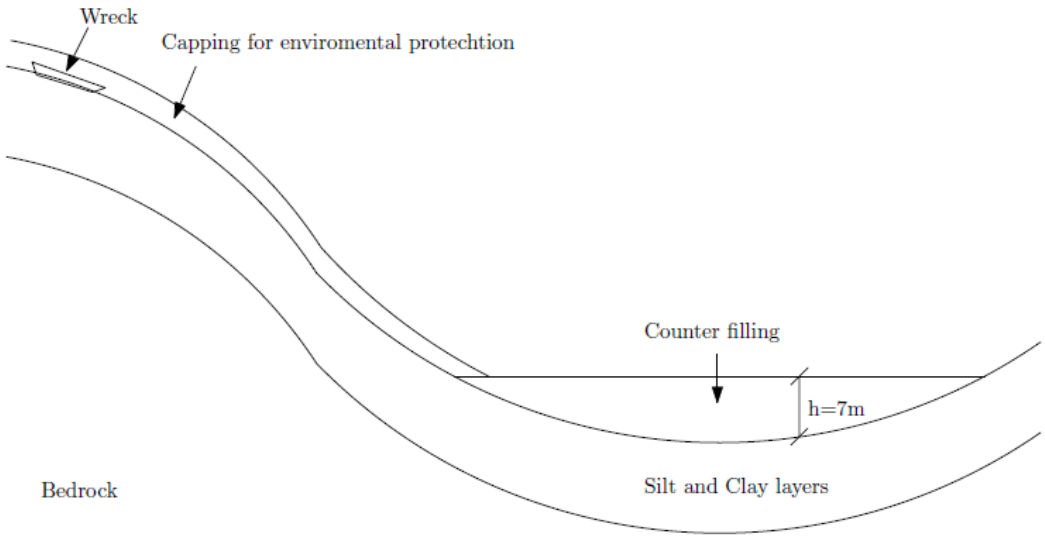

Figure 1.2 Cross section sketch of slope with capping and counter filling

The time between construction of counter filling and capping is not decided, but the height of the counter filling may be reduced if the effect of consolidation of the clay layer under the filling on the undrained shear strength of the clay is taken into account.

Rock/gravel is used to construct the counter filling on top of the clay layer. As a result, the clay layer will consolidate, involving an increase in effective stresses in the clay layer over time. This effective stress increase also involves an increase in the undrained shear strength over time.

This technical note presents the potential effect of consolidation on the undrained shear strength over time of the clay layer when loaded by the counter filling.

2 Soil data

Soil investigations were performed in 2006 (NGI, 2006) and in January 2013 (NGI, 2013). The soil data used in this technical note is based on the findings from these two surveys.

2.1 Soil stratigraphy

In total 12=4+8 CPTs and 3=1+2 vibrocores were carried out in the bottom of the slope. The layering of the area is based on interpretation of the CPT results, see Figure 2.1. The soil investigations revealed quite homogenous soil conditions in the area.

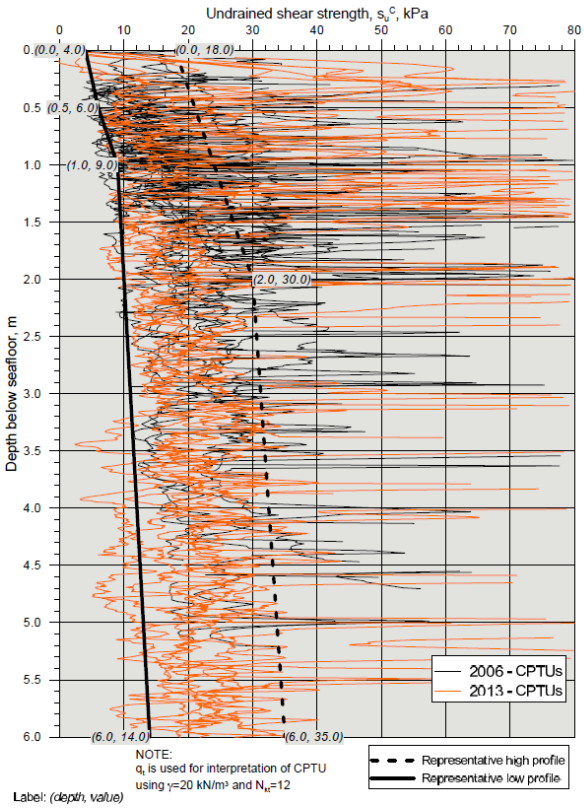

Figure 2.1 Corrected cone resistance versus depth, from NGI (2013)

The following two soil layers were encountered:

Unit I: SILT, sandy, clayey or SAND, clayey, silty
Unit II: CLAY, soft to medium

The thickness of the two soil units is varying across the area. The thickness of Unit I was found to vary between 0 - 1.7 m and the bottom of Unit II was not found.

2.2 Soil parameters

Two different soil units located above bedrock/moraine were identified in the two soil investigation reports. Table 2-1 summarises the findings. The presented parameters are from NGI (2013) report.

Table 2-1 Summary of soil parameters, from NGI (2013)

	w [%]	γ [kN/m^3]	I_p [%]	S_t [-]	OCR [-]
Unit I	25	20			
Unit II	25	20	15	3	~1

Two oedomemeter tests were carried out in the NGI (2013) survey. The tests are designed to determine the compressibility (or constrained modulus) and the coefficient of consolidation of the specimen tested. The coefficient of consolidation, c_v, is calculated from Equation 1.

$$c_v = \frac{M \cdot k}{\gamma_w}$$

Equation 1

where M is the constrained modulus, k is the coefficient of permeability and γ_w is the unit weight of water. From NGI (2013) the coefficient of consolidation, c_v, was found to be $3.0 \cdot 10^{-7}$ m^2/s.

3 Undrained shear strength increase as a function of time

To demonstrate the effect of consolidation, a simplified example is assumed where a soil layer consisting of Unit II clay is lying on top of an impermeable bedrock. A 7.0 meter high rock filling is placed on top of this clay layer. The clay layer is therefore one-way drained. The effective unit weight of the filling is assumed to be γ'=10 kN/m^3 and the surcharge from the counter filling on the clay layer is p=10·7=70 kPa. The simplified example is illustrated in Figure 3.1. The clay layer is assumed to be normally consolidated.

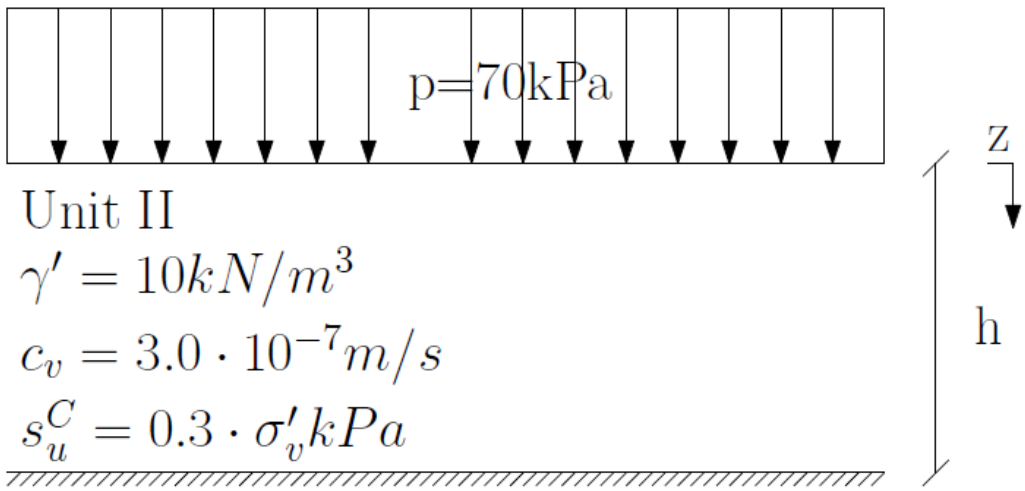

Figure 3.1 Simplified model

The non-dimensional consolidation time is given by Equation 2.

$$T = \frac{c_v}{h^2} t$$

Equation 2

The pore pressure distribution for one-way consolidation as a function of depth and time is given by Equation 3 (Verruijt 2012):

$$\frac{\Delta u}{p} = \frac{4}{\pi} \sum_{j=1}^{\infty} \frac{(-1)^{j-1}}{2j-1} \cos\left((2j-1)\frac{\pi}{2}\frac{(h-z)}{h}\right) e^{\left(-(2j-1)^2 \cdot \frac{\pi^2}{4} \cdot T\right)}$$

Equation 3

The effective stress is calculated as:

$$\sigma'_v = z \cdot \gamma' + p \cdot \left(1 - \frac{\Delta u}{p}\right)$$

Equation 4

Assuming that the clay is normally consolidated, the compression shear strength is calculated as:

$$s_u^C = 0.3 \cdot \sigma'_v$$

Equation 5

The shear strength increase in different depths as a function of time can then be calculated; this is done in Figure 3.2. The effect of consolidation during construction of the filling and the load spread of the filling is here disregarded. The consolidation response is calculated assuming two different thickness of the clay layer: h=6 m and h=12m.

End of consolidation of the two clay thicknesses is found after:

$$t_{\infty,h=6m} = T\frac{H^2}{c_v} = 2\frac{6^2}{3.0 \cdot 10^{-7}} = 2.4 \cdot 10^8 s \approx 8\ years$$

Equation 6

$$t_{\infty,h=12m} = T\frac{H^2}{c_v} = 2\frac{12^2}{3.0 \cdot 10^{-7}} = 9.6 \cdot 10^8 s \approx 30\ years$$

Equation 7

It can be seen that end of consolidation will occur approximately four times faster for the 6 m clay layer than for the 12 m clay layer.

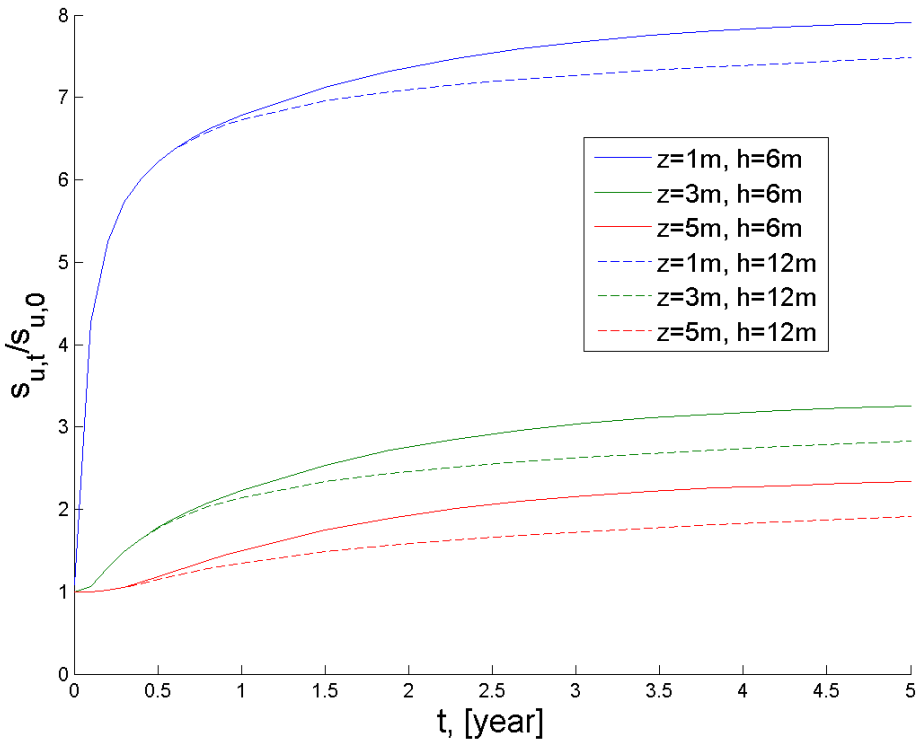

Figure 3.2 Increase in undrained shear strength increase versus time for a clay layers with different thichness consolidated with a load of p=70kPa

Figure 3.2 shows the increase in undrained shear strength as a ratio between undrained shear strength before the filling is constructed ($s_{u,0}$) and the undrained shear strength at a given time after construction of the filling ($s_{u,t}$).

In Figure 3.2 it is shown that the increase in shear strength is relative high for lower depths. The strength increase is practically identical for the two thickness until approximately half a year consolidation. After this point the strength increase is faster for the h=6m thickness.

As an example, the effect of consolidation for a clay thickness of h=6m is calculated for different times after construction of the filling. The results are shown in Figure 3.3. The increase in undrained shear strength is large in the upper part of the clay layer and reduces with depth.

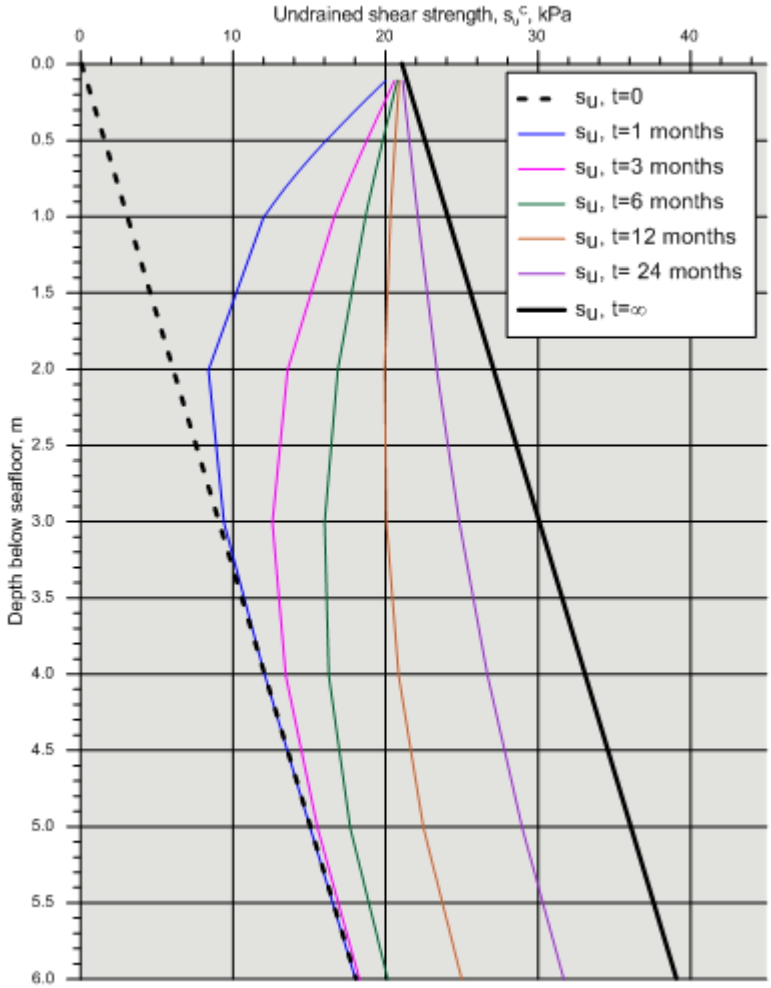

Figure 3.3 Undrained compression shear strength for a clay layer with a thickness of h=6m as a function of consolidation time, for a consolidation load of p=70kPa.

4 Conclusion

This technical note illustrates the potential effect of consolidation on the undrained shear strength by means of a simplified example. A significant increase in undrained shear strength in the top of the underlying clay layer may be expected already a short time after filling construction. The estimation of the effect of consolidation is, however, based on simplifications and should be re-evaluated in a detailed design of the counter filling.

It is recommended to consider a potential undrained shear strength increase due to consolidation in a detailed design of a possible filling. Here, the effect of consolidation during construction of the filling and the load spread of the filling should be included.

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Kommune/*Municipality*	**Feltnavn/*Field name***
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V0.07.02	Mobilisation and Calibration Report	DOF Subsea	32
V0.07.03	Identification of oil leak and position verification of U-864	DOF Subsea	10
V0.07.04	U-864 2013 Soil servey (tilsvarende som Vedlegg V0.04, derfor ikke lagt ved)	NGI	199
V0.07.05	Oil recovery for the ship wreck of U-864	FRAMO	15
V0.07.06	Report on the search and identification of U 864	Admiral Consulting	12
V0.07.07	Investigations of mercury during a survey near submarine U-864 outside Fedje in 2013	NIVA	26

Phase 3A Survey and Geotechnical Campaign Report

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KYSTVERKET

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Contract Number: **2012/2998**	*System:*	*Project Code*	*Orig. Code*	*Area / System*	*Disc. Code*	*Doc. Type*	*Seq. No.*	*Rev.*

SUMMARY

Kystverket (KyD) / Norwegian Coastal Administration assigned in November 2012 DOF Subsea Norway AS a contract (2012/2998) for a final data collecting campaign, (phase 3A) in order to obtain additional information regarding the two pollution abatement alternatives to be evaluated for the submarine wreck U-864 West of Fedje. The project was performed in cooperation with the subcontractors Admiral Consulting, Franzefoss, GEO Engineering, Marine Sampling Holland, FRAMO, NGI, and NIVA. The work was conducted with a dynamic positioned vessel endowed with 1 working ROV and heave-compensated crane. The project was performed without any adverse events related to health, safety and environment (HSE).

The purpose of the tasks were to obtain additional information regarding the two alternatives to be evaluated by the Kystverket. The alternatives are as stated below.

- Seal-in the polluted area, utilizing sand with special characteristics
- Retrieve the Hg cans from the keel section and seal-in the polluted area

The project was based on the results and the experience from U-864 Phase 1 and Phase 2, conducted in 2005 and 2006.

This report contains the descriptions and results from the work conducted during the U-864 Phase 3A. There are also done a comparison between the measures from 2006 with the new information collected in 2013.

The following tasks were planned for Phase 3A:

- Multibeam echo sounder area survey of 2km by 2km
- High Definition video survey
- Geotechnical survey
- Height, trim and list measurements
- Sub Bottom Profile survey of the rotation pits
- Oil Recovery

Multibeam echo sounder area survey of 2km by 2km

The multibeam (MBE) survey 2km by 2km centred over the U-864 wreck produced 100% coverage of the survey area, with exceptions of vertical or near vertical slopes. No sign of any additional wreckage or anomalous features were found in the survey area.

Establishment of clear zones with High Definition video survey

This task consisted of a High Definition video survey to the West and South West of the wreckage for establishment of a clear zone with regard to possible explosives on the seabed. Sixty-eight (68) targets / objects of metal debris were observed in the clear zone, of these 32 were new targets. No debris or targets were identified as possible explosive and none were considered to be significant in terms of Hg contamination. Targets previously identified during Phase 1 and 2 were found to be in the same locations and in a similar condition to that previously reported.

High Definition video survey of wreck and debris

This task consisted of High Definition video survey (detailed inspection) of the major wreck sections and larger debris to identify features unique to the missing centre section of the U-864 and to establish what, if any, deterioration had taken place in the wreck's condition since Phase 2.

Significant observations made during the inspection, were the discovery of an internal bulkhead on the stern section, this resulted in revision of the estimated point at which the U-864 had been damaged by the torpedo impact and the discovery of the loss of the extreme end of the stern. The

total length of the intact keel are up to 4.0m longer than earlier calculations. The Keel on the Stern section is exposed for approximately 2.5m.

The positive identification of the U-864 snorkel that was mounted amidships and in close proximity to the conning tower, the entire pressure (water tight) section of the conning tower, a part of the saddle tank from the area of the control room, the upper works of the conning tower and "Wintergarden" and the attack periscope are all main parts of the "missing" mid section. They were all found in close vicinity to the stern section. The mounting pedestal for the "Underwasserzieloptic" (UZO) from the port forward area of the conning tower of U-864 was identified and recovered to surface for further investigations.

Geotechnical survey
The geotechnical work consisted of cone penetration tests (CPT) down to 6.1m depth at 8 locations, sampling with Vibro corer down to 3.4m depth at 7 locations and sampling with Gravity corer down to 4m at 2 locations. For the mercury pollution level monitoring additional 35 soil samples were taken using an ROV mounted system After the field work NGI and NIVA conducted laboratory work on the collected data.

The 2013 NGI geotechnical survey describes relative homogeneous soil conditions with a soil unit consisting of sandy, clayey SILT or clayey, silty SAND (soil unit I) over a unit of soft to medium CLAY (soil unit II). A lower unit reported in 2006 of consolidated SAND/ GRAVEL over bedrock was not encountered in 2013.

The 2013 NIVA analyses of the sediments showed an increase in the level of mercury for some of the sediment stations north and west of the submarine, compared to the 2006 results. Sediment stations east and southeast of the submarine had low concentration of mercury and did not show any evidence of increase since 2006. This result falls into agreement with the direction of the water current in this area, which goes in a north western direction (ref /4/).

Height, trim and list measurements
This task consisted of a low fly MBE survey directly over the stern wreck section of U-864 to assess any movement of the section when compared to the previous survey in 2006 (Phase 2) and that collected during Phase 3A. From the evidence available it is believed that any movement of the stern section is negligible.

Sub Bottom Profile survey of rotation pits
This task consisted of an Sub-Bottom Profile (SBP) Survey of the proposed rotation pits. This consisted of 18 lines in total covering both the Bow and Stern section rotation pits. There were no bedrock outcrops or large rocks identified within the location of the rotation pits. In addition to the cross lines at the wreck site a supplementary cross line was ran in the trough North of the wreck site to tie the data in, and also gain more information for this area with respect to possible backfilling.

Oil Recovery
The main task of the Oil Recovery consisted of recovering any oil residue from the tanks of the U-864. This specific operation was performed by FRAMO.

The conditions of the weld seems for the outer shell of the fuel tanks were found in a poor condition. Due to the poor state of condition, the focus changed during operation from oil recovery to verification survey for most of the fuel tanks. If there were any uncertainty, oil recovery of a tank was commenced. Oil recovery was done for 3 of the 16 tanks on the U-864, and only minor quantities of oil was recovered from those 3 tanks.

VOR 02 – Air pockets

Main task was to evacuate possible air pocket inside the aft wreck section, to resolve the issue with unknown wreck stability.

A cut was performed in the aft section pressure hull, and air evacuation continued for approximately 6hrs. It is assumed that aft water tight sections have been completely flooded.

VOR 03 – Oil Leak and position of U-864

A few days after completion of the VOR 02 operation, DSNO was asked to perform an investigation of oil leakage from U-864. Oil was then found to leak from the pressure hull cut done during the VOR 02 operation (see above section). Oil was spotted coming out of cracks around the aft section, however this is most likely oil trapped inside or under fuel tank plates. The level of oil leak was measured to be approximately 0.3L/hr, no oil was visible on sea surface.

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1 INTRODUCTION

1.1 PROJECT DESCRIPTION

The German submarine U-864 was sunk outside Fedje, west of Bergen, in 1945. The submarine was torpedoed amidships by a British submarine, broke in two and sank. The wreck is located at approximately 150m water depth. Both wreck sections are standing on the seabed on their keels, with a list of 24 and 15 degrees for forward and aft section respectively. The aft wreck section is situated on flat terrain and the forward section in a relatively steep slope with its bow pointing upwards.

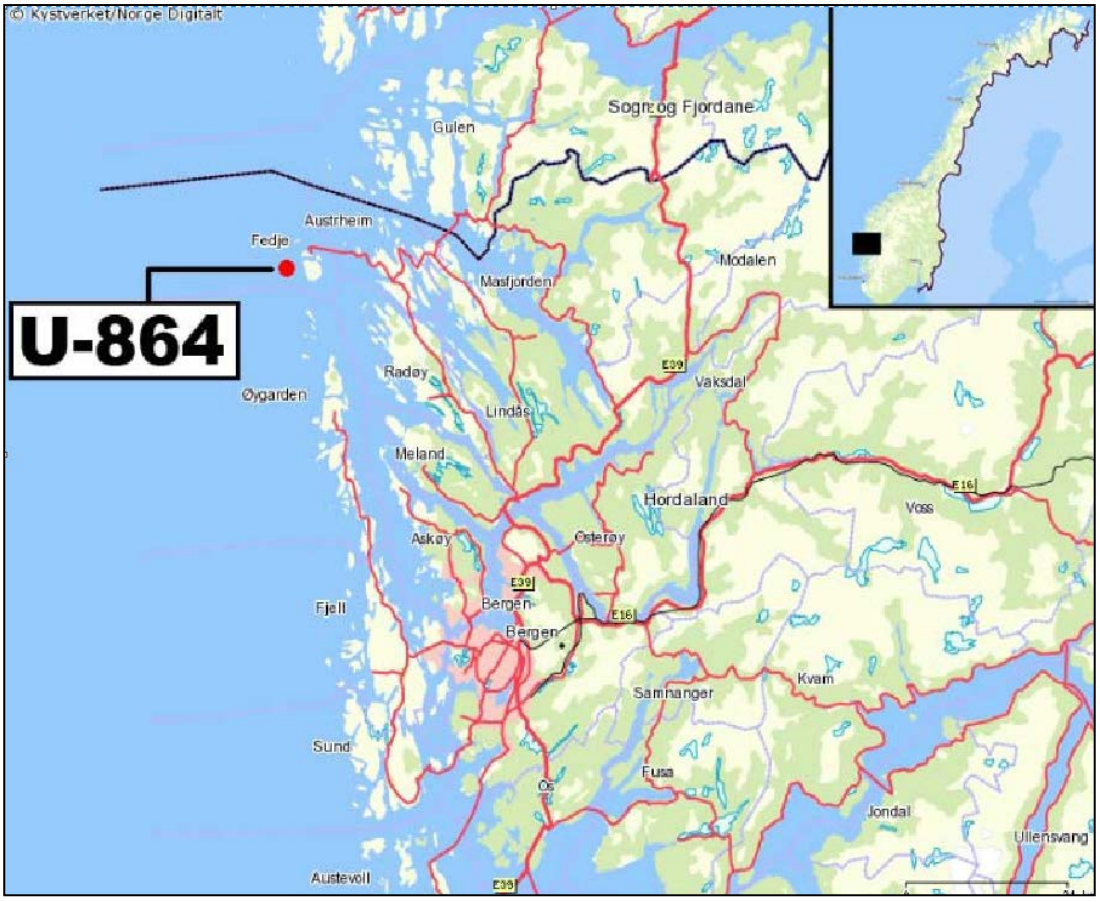


Figure 1.1 Map of U-864 location

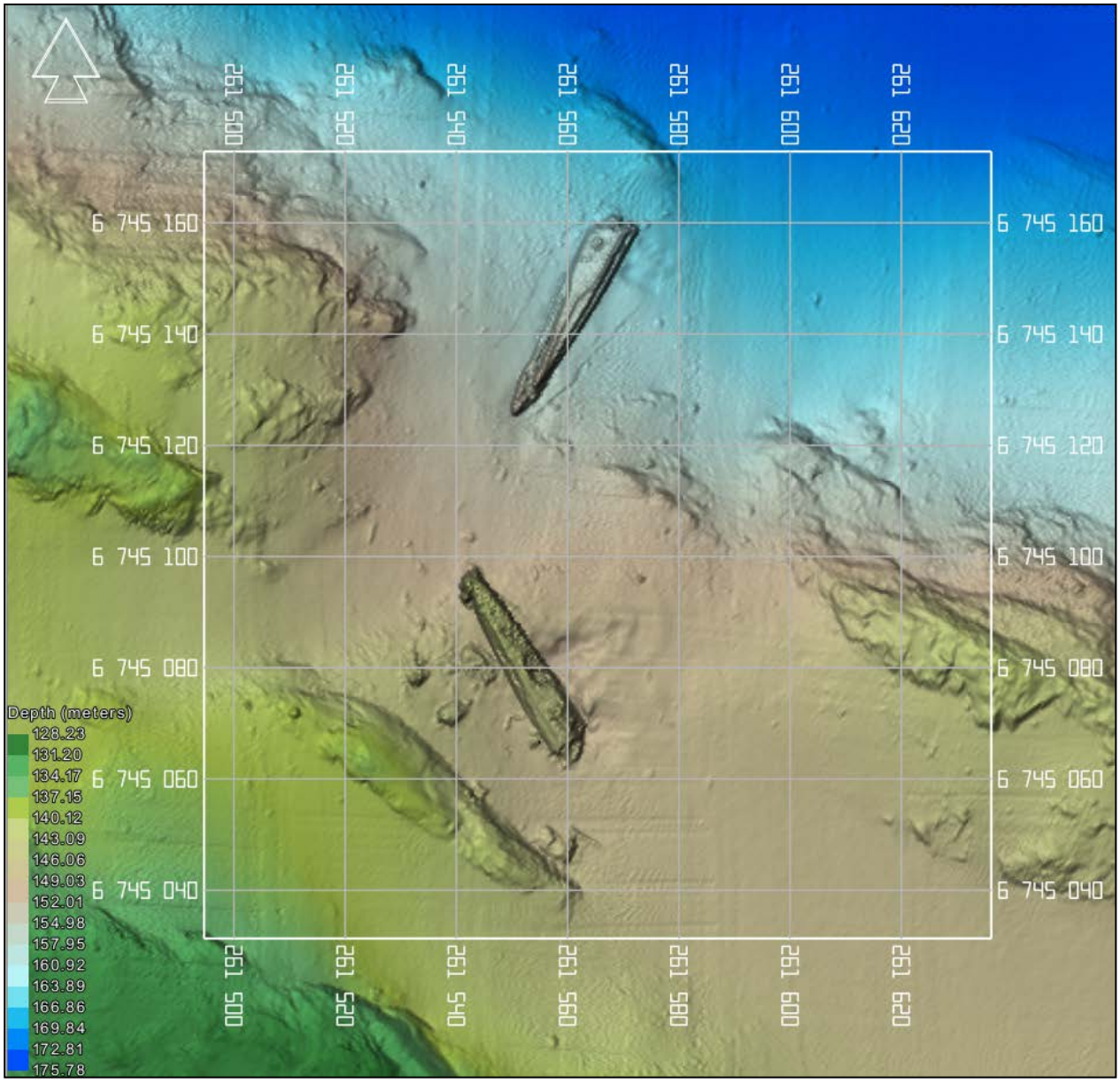


Figure 1.2 U-864 wreck and orientation on sea bed (From Phase 3A Survey, 2013)

U-864 is assumed to contain 67 tons of liquid mercury (Hg), stored in 1857 carbon steel cans in compartments inside the keel. When torpedoed, the mid-section of the submarine was blown up and a substantial number of the stored Hg cans were destroyed. This led to significant Hg pollution of the seabed below. The number of Hg cans that have corroded and started to leak is unknown. It is assumed that there are intact Hg cans inside the keel compartments of both wreck sections, but the number of Hg cans and their condition is not known.

Kystverket has performed two offshore survey campaigns of the wreck site, Phase 1 in 2005 and Phase 2 in 2006. Based on the information obtained Kystverket has given recommendations to the Ministry for Fisheries how to minimize the effects of the Hg pollution.

The authorities have decided to further evaluate two different methods of pollution abatement:

1. Seal the polluted area, utilizing sand with special characteristics.
2. Retrieve the Hg cans from the keel section and in the polluted area, and then seal the polluted area, utilizing sand with special characteristics area.

This report contains the findings from the Phase 3A Survey and Geotechnical campaign performed January 2013.

1.2 DEFINITIONS AND ABBREVIATIONS

C-O	Calculated minus Observed
CPT	Cone Penetration Test
CTD	Conductivity, Temperature and Density
DGPS	Differential Global Positioning System
DSNO	DOF Subsea Norway AS
DTM	Digital Terrain Model
GPS	Global Positioning System
HAIN	Hydro-acoustic Aided Inertial Navigation
HiPAP	High Precision Acoustic Positioning system
HSE	Health, Safety and Environment
INS	Inertial Navigation System
MBE/ MBES	MultiBeam Echo Sounder
ROV	Remotely Operated Vehicle
SBP	Sub Bottom Profiler
S/N	Serial Number
SVP	Sound-Velocity Probe/profile
USBL	Ultra Short Baseline (acoustic positioning)
UTM	Universal Transverse Mercator projection

1.3 REFERENCES

Table 1.1 Task Plan Listing

No.	Task Plan	Description of Task	Date
/1/	600225-SSKO-001	Task plan HiPAP Cal Byfjorden	04.01.2013
/2/	600225-SSKO-002	Task plan MBE Cal Byfjorden - Copy	04.01.2013
/3/	600225-SSKO-003	Task 1 MBE Grid Survey	05.01.2013
/4/	600225-SSKO-004	Task 7 GVI Wreck Sections	07.01.2013
/5/	600225-SSKO-005	MBE Survey U864	07.01.2013
/6/	600225-SSKO-006	MBE verification	07.01.2013
/7/	600225-SSKO-007	Video Survey Clear Areas U864	08.01.2013
/8/	600225-SSKO-008	Geotechnical work for U-864 Rev 2	10.01.2013
/9/	600225-SSKO-009	SBP Survey	11.01.2013

Table 1.2 DSNO Procedures

No.	Document No.	Title
/1/	DG-PY-0002	Policy - Health, safety and working environment
/2/	DSA-SV-ST-0002	Global Standard - Dimensional Control Vessel and ROV
/3/	DSA-SV-GL-0002	Guideline - Motion Calibration System, Javad Navigation Systems (Javad/Vessel)
/4/	DSA-SV-TMP-0005	Procedure - Heading Sensor Calibration, DSNO
/5/	DSNO-SV-PR-0001	Procedure – Doppler and HAIN system checks
/6/	DSNO-SV-PR-0002	Procedure – SAIV SD204 STD/CTD Operation
/7/	DSNO-SV-PR-0004	Procedure – Vessel Mobilisation
/8/	DSNO-SV-PR-0008	Survey Acceptance Test, DSNO
/9/	DSNO-SV-PR-0010	Procedure – DGPS Configuration
/10/	DSNO-SV-PR-0016	Procedure – Sound Velocity Sensor Verification
/11/	DSNO-SV-PR-0017	Procedure – Transfer of Data and Information to Online Surveyor
/12/	DSNO-SV-PR-0021	Procedure – Paroscientific Digiquartz Depth Sensor Configuration and Operation
/13/	DSNO-SV-PR-0028	Procedure – DGPS Health Check
/14/	DSNO-SV-PR-0029	Procedure – Leica Builder R200m Total Station
/15/	DSNO-SV-PR-0032	Procedure – Motion Reference Sensor Calibration and Verification
/16/	DSNO-SV-PR-0033	Procedure – USBL Calibration and Verification
/17/	DSNO-SV-PR-0035	Procedure – Survey QA Checklists
/18/	DSNO-SV-PR-0036	Procedure – Collection of survey Data
/19/	DSNO-SV-PR-0037	Procedure – Control and Calibration of Total Stations
/20/	DSNO-SV-PR-0039	Procedure – Survey Process
/21/	DSNO-SV-PR-0044	Procedure – HiPAP Calibration using Kongsberg's APOS
/22/	DSNO-SV-PR-0045	Procedure – Multibeam Echo-sounder Calibration and Verification
/23/	DSNO-SV-PR-007	Procedure - Pressure Sensor for Draught Measurement
/24/	DSA-SV-MN-0001	Process Management – Geology
/25/	DSA-GO-GL-0002	Guideline - Video Eventing
/26/	DSNO-SV-PR-0004	Procedure - Visualsoft
/27/	DSA-SV-ST-0015	Global Standard – Data Processing
/28/	DSA-SV-ST-0016	Global Standard – Project start-up and Crew Change
/29/	DSA-SV-ST-0017	Global Standard - Survey Data Corrections
/30/	DSA-SV-ST-0018	Global Standard - Terrain Modelling
/31/	DSA-SV-ST-0019	Global Standard – Data Presentation
/32/	DSA-SV-ST-0020	Global Standard - Internal Reporting
/33/	DSA-SV-ST-0021	Global Standard – INS-HAIN Post Processing in Navlab
/34/	DSNO-SV-PR-0050	Procedure – Water column - use of CTD/SVP Data
/35/	DSA-SV-GL-0016	Guideline - NaviEdit
/36/	DSA-SV-GL-0017	Guideline - Imaging
/37/	DSA-SV-GL-0019	Guideline - Surfer
/38/	DSA-SV-PR-0018	Procedure - Cfloor
/39/	DSA-SV-PR-0019	Procedure - Navimodel
/40/	DSA-SV-GL-0027	Guideline - GIS
/41/	DSA-SV-GL-0021	Guideline - Autochart
/42/	DSA-SV-GL-0022	Guideline – Data Export from AutoCad to ARCGIS
/43/	DSA-SV-GL-0008	Guideline – Seabed Topography Reporting, creating diagrams
/44/	DSA-SV-GL-0023	Guideline - Isopach Modelling
/45/	DSA-SV-GL-0024	Guideline - Pipeline Inspection
/46/	DSA-SV-ST-0026	Global Standard - AutoCad -Designing and Maintaining Production Line
/47/	DSA-SV-PR-0016	Procedure – Sub Bottom Profiler (SBP) Operation DOF Subsea
/48/	DSA-SV-PR-0017	Procedure – Sidescan Sonar (SSS) Operation DOF Subsea
/49/	DSA-SV-ST-0004	Global Standard - Sub-bottom Profiler (SBP) Data Interpretation
/50/	DSA-SV-ST-0005	Global Standard - Side-scan sonar (SSS) Data Interpretation
/51/	600225-PJ-O03-12-0003	Kystverket U-864 Phase 3A Operational Survey Procedure
/52/	600225-PJ-O03-12-0004	Kystverket U-864 Phase 3A Geotechnical operations

Table 1.3 Reports and Field Memos

No.	Document No	Title	Rev.	Date
/1/	600225-SSKO-O15-13-0001	Kystverket U-864 Phase 3A: M/V Skandi Skolten Mobilisation and Calibration Report	02	10.01.2013
/2/	Report on the search and identification of U 864	Report on the search and identification of U 864 (Admiral Consulting)	02	21.02.2013
/3/	NGI 20120738-01-R	Geotechnical Report U-864 2013 Soil Survey	0	17.04.2013
/4/	NIVA 6499-2013	Investigation of mercury during a survey near submarine U-864 outside Fedje in 2013		02.04.2013
/5/	FRAMO 616917/3A	Completion Report Oil Recovery for the ship wreck of U-864		11.03.2013
/6/	600225-SSKO-O15-0001	Identification of Oil Leak, and Position Verification of U864	02i	25.03.2013

Table 1.4 Changes since last revision

Rev. No.	Issue Date	Purpose	List of updated/modified sections if any
03	18.04.2013	Issue for Company Comments	DOCUMENT NUMBER CHANGED FROM: 600225-SSKO-O15-0001 to 600225-DSNO-O15-0001.

2 SURVEY DESCRIPTION

2.1 SCOPE OF WORK

The following survey tasks were included in U-864 Phase 3A:

- **A multibeam echo sounder area survey of 2km by 2km.** The MBE survey was intended to identify any additional areas of wreckage outside the immediate wreck area.

- **A High Definition video survey** was undertaken to the West and South West of the wreckage to identify existing debris and ensure no further undetected wreck sections were in the area. Additionally a detailed inspection of the major wreck sections and larger debris was undertaken to identify features unique to the missing centre section of the U864 and to establish what, if any, deterioration had taken place in the wreck's condition since Phase 2.

- **Geotechnical survey.** For the Geotechnical stage of the project, three different methods of sampling took place:
  1. ROV Sediment Sampling to identify extents of Hg pollution
  2. Vibro coring and Gravity coring to find depth of Hg contamination in sediment
  3. Seabed CPT to establish sediment layering and shear strength

- **Height, trim and list measurements.** After consultation with the Vessel Representative it was decided to use a comparison from the new and previous MBE data sets to assess any movement of the wreck section. This was considered to be the most accurate method to achieve the desired result.

- **A Sub Bottom Profile Survey of rotation pits.** The objective for the SBP survey was to identify any outcrops, large sub bottom rocks or other debris which could be a potential hazard to a later dredging campaign

2.2 EQUIPMENT AND SUBCONTRACTORS

For the execution of the project MV Skandi Skolten with one work class Triton XLX ROV system were used. For support of the project and to attend special function the following subcontractors were used:

- Admiral Consulting – marine historical support and reporting of the wreck sections and fragmented wreck parts
- Franzefoss – responsible for HSE tasks and treatment of Hg polluted sediments and equipment onboard.
- GEO Engineering – responsible for geotechnical CPT unit “Gost”
- Marine Sampling Holland – responsible for geotechnical sampling with Vibro corer and Gravity corer
- NGI – planning and management of geotechnical field tasks. Geotechnical laboratory work and reporting of geotechnical results.
- NIVA – environmental related task inclusive analyses of sediment and water samples for Hg content.

For a detail overview of the equipment used during this project see the mobilisation report (ref./1/).

2.3 WORK PERFORMED

2.3.1 Mobilisation

The mobilisation of equipment and project personnel took place on the 3rd January 2013 at Dokken, Bergen. It was conducted in a safe manner and the alongside stage was completed on the 5th January 2013 when the vessel sailed to perform offshore calibrations.

2.3.2 Calibrations

The calibration of the survey sensors was carried out in five separate stages:

The calibration of Vessel heading and motion sensors. This was conducted on 23rd July 2012 whilst alongside in Tananger, Stavanger as part of a previous project. The JAVAD motion and heading calibration system was utilised and the results directly compared to the vessel POS-MV system.

DGPS Confidence check. The GPS antenna positions were logged at the same time as total station measurements on the quayside at Dokken, Bergen on the 3rd January 2013.

ROV heading and motion calibrations. This was carried out on the 4th January 2013 alongside Dokken, Bergen. The CDL Gyro was compared to the vessel sensor and measurements from a digital protractor to establish C-O’s for heading, pitch and roll.

HiPap verification. This was conducted in Byfjorden on the 4th January 2013.

Multibeam and Doppler calibrations. These were conducted in Byfjorden on the 5th January 2013.

For more information of the calibration results see 600225-SSKO-O15-13-0001 Mobilisation and Calibration Report in 8.1.

Definition of Geographical Co-ordinate system (Work Site).

Spheroid Parameters	
Datum	WGS84
Spheroid	WGS84
Semi-major axis	6 378 137.000 metres
Flattening (1/f)	1/298.2572235630

Projection Parameters	
Projection	UTM – Grid Zone 32 North
Central Meridian	9° East
Latitude of Origin	0° (Equator)
False Easting	500 000 metres
False Northing	0 metres
Scale Factor on CM	0.9996

NB: Calibrations were conducted in WGS84, UTM zone 30 and 31.

2.3.3 MBES grid survey

A 2000m x 2000m area centred on the wreck of the U-864 was surveyed using MBES, with line spacing at 40 metre intervals covering the debris field and surrounding area.

The work was carried out between the 5th and 8th of January 2013, line spacing and flying altitude ensured 100% coverage of the survey area. Results of the survey are discussed in Paragraph 3.1.

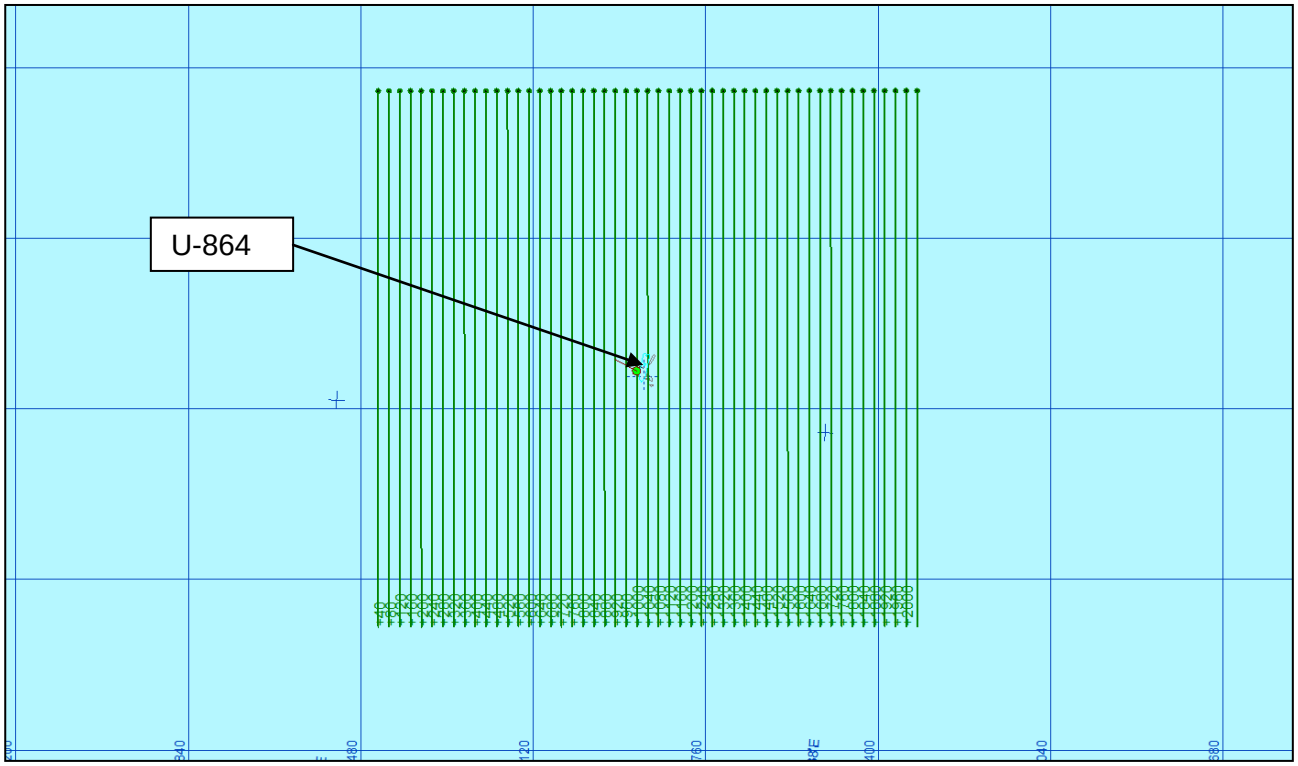


Figure 2.1 2000m x 2000m line plan used for the MBES survey

2.3.4 Establishment of clear zones with High Definition video survey

A visual survey was carried out to establish clear zones on the western side of each wreck section. The ROV was flown at 2m altitude with 4m line spacing to optimise video and ensure 100% coverage.

The survey was carried out on the 8th of January 2013. Results are discussed in Paragraph 0.

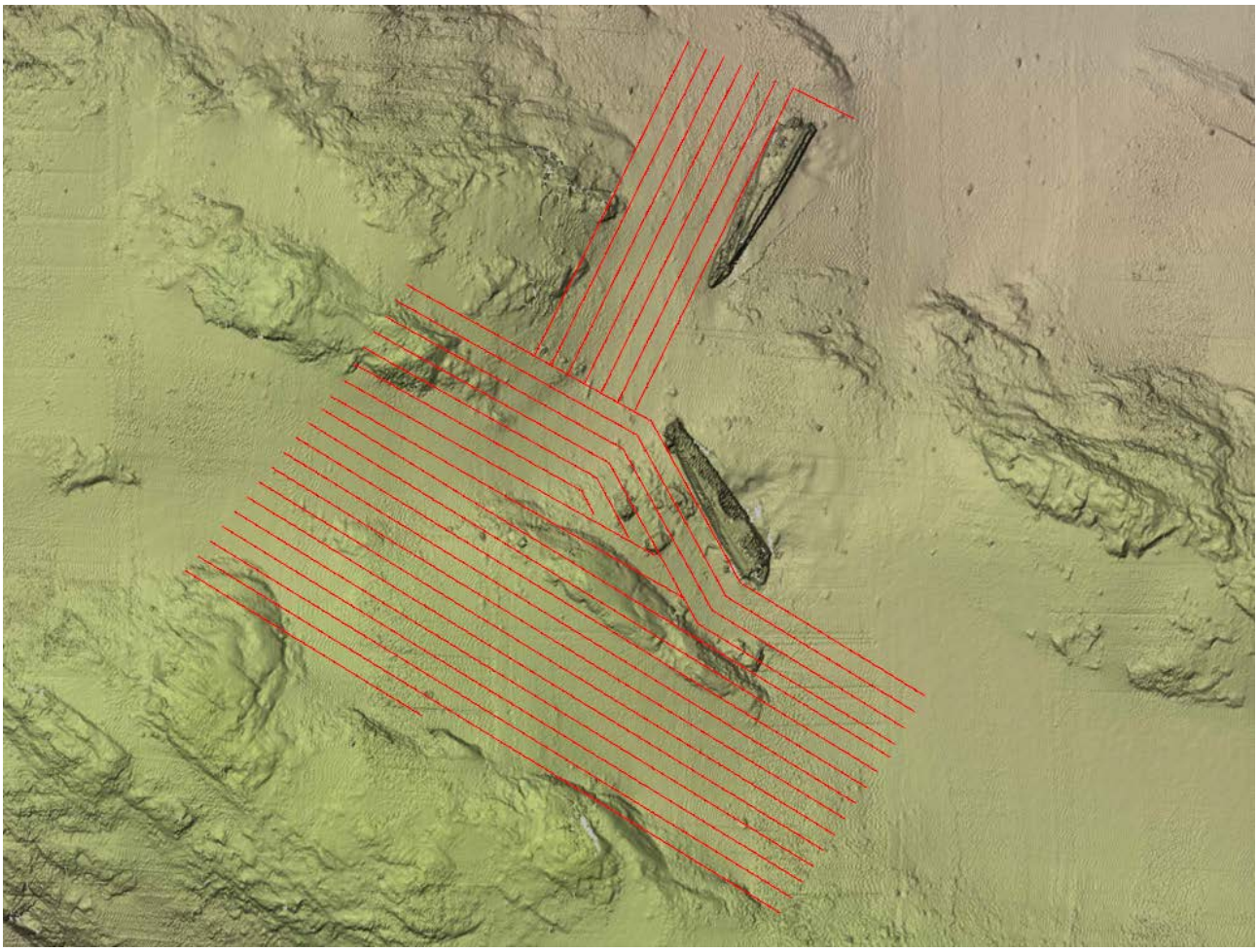


Figure 2.2 Runlines with DTM

2.3.5 High Definition video survey of wreck and debris

A detailed video survey was performed to assess any deterioration of the wreck and to attempt to positively identify features unique to the mid-section of the U-864. Additionally any lifting or handling points for future recovery/ relocation were to be identified. The location of any historically important features was also investigated during the survey (Paragraph 0).

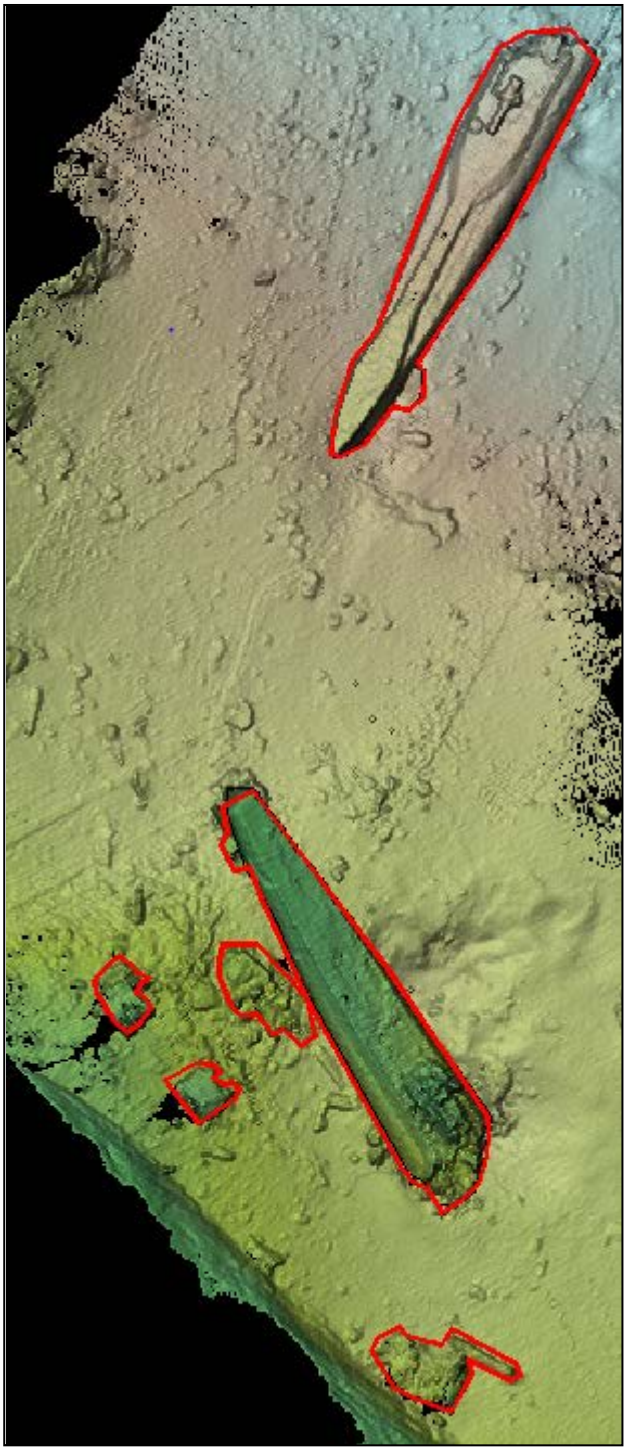


Figure 2.3 Areas covered in close visual inspection

2.3.6 Geotechnical Work

Geotechnical work included CPT, Vibro Core and Gravity Core sampling to establish slope stability, sediment depth and composition. Additional samples were also taken in the surrounding area to establish Hg pollution levels.

DOF Subsea utilised the services of NGI to perform the following tasks:

Planning and management of geotechnical services.
Geotechnical laboratory on/offshore.
Reporting of geotechnical results.

Geotechnical work was carried out between the 10th and 13th of January 2012, results are compiled separately in dedicated geotechnical reports but sample positions are included at paragraph 4.4.

2.3.7 SBP Survey

The Sub-Bottom Survey of the rotation pits consisted of 19 lines in total covering both the Bow and Stern section rotation pits (Figure 2.4).

The objective for the sub bottom profile survey was to identify any outcrops, large sub bottom rocks or other debris which could be a potential hazard to a later dredging campaign. One additional SBP line was surveyed in the valley north of the bow section to provide sub seabed information to support geotechnical assessment to be made prior to the sealing of the polluted area.

The survey commenced at 23:51 on the 11th January and was completed at 04:36 on the 12th January 2013.

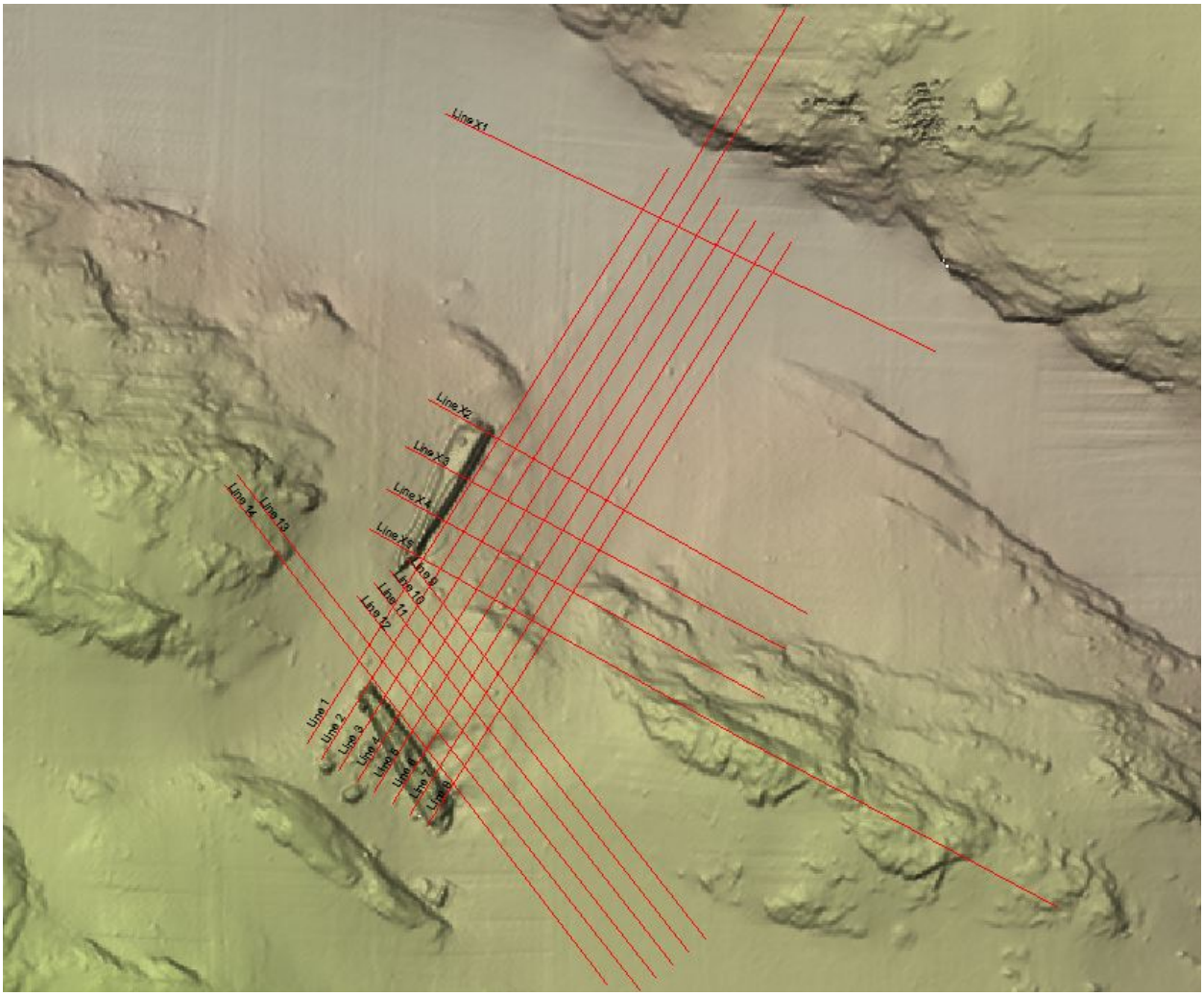


Figure 2.4 Runlines used for the SBP survey

2.3.8 Status / deviation

The following section summarizes the tasks performed during the U-864 Phase 3A with evaluations of deviation compared to the scope of work. With reference to Section 2.1 Scope of Work the status for the separate tasks listed in Table 2.1.

Table 2.1 Status completed work

Task	Status
A multibeam echo sounder area survey of 2km by 2km	Performed
High Definition video survey	Performed
Geotechnical survey	Performed, number of samples were reduced to the half after discussions beyond the involved parties as this was sufficient enough to cover the task
Height, trim and list measurements	Performed, as a comparison of the MBE data from 2006 and 2013
Sub Bottom Profile Survey of rotation pits	Performed

The following sections of the report give a detailed description of the different tasks performed during the survey.

3 SUMMARY OF RESULTS

The following chapter summarises the operations completed by the MV Skandi Skolten over the course of the U-864 Phase 3A Survey and Geotechnical Campaign.

The project benefited from the presence of the Kystverket Project Manager on board the Skandi Skolten during the project. This ensured that any queries regarding aims, objectives or variations could be addressed quickly and accurately ensuring that project objectives were completed in an effective manner.

All systems on board the Skandi Skolten performed well during the survey and produced data of a high standard.

3.1 MBES GRID SURVEY

With the exception of vertical, or near vertical slopes the MBE survey produced 100% coverage of the survey area around the wreck of the U-864. The resulting DTM (Figure 3.1) was inspected for signs of additional wreckage. Particular attention was also paid to the historical sinking position (see Figure 4.2) and the seabed below the debris found on the surface by HMS Venturer in 1945. No sign of any additional wreckage or anomalous features were found during the survey.

Examples of the soundings (.xyz) data from the survey can be seen in Figure 3.2 and Figure 3.3.

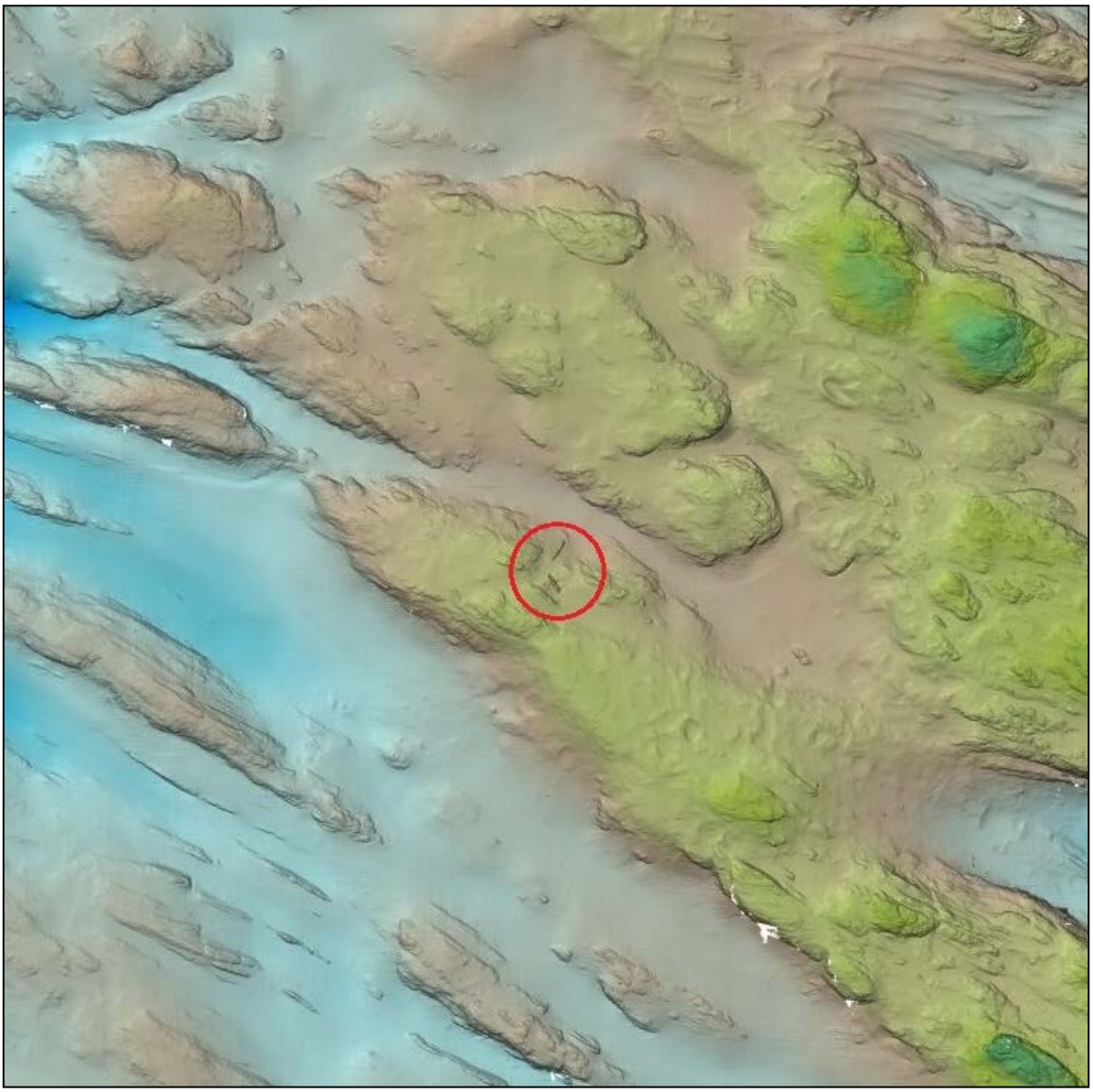


Figure 3.1 DTM of 2 x 2 km survey data around the U-864 (circled) North up

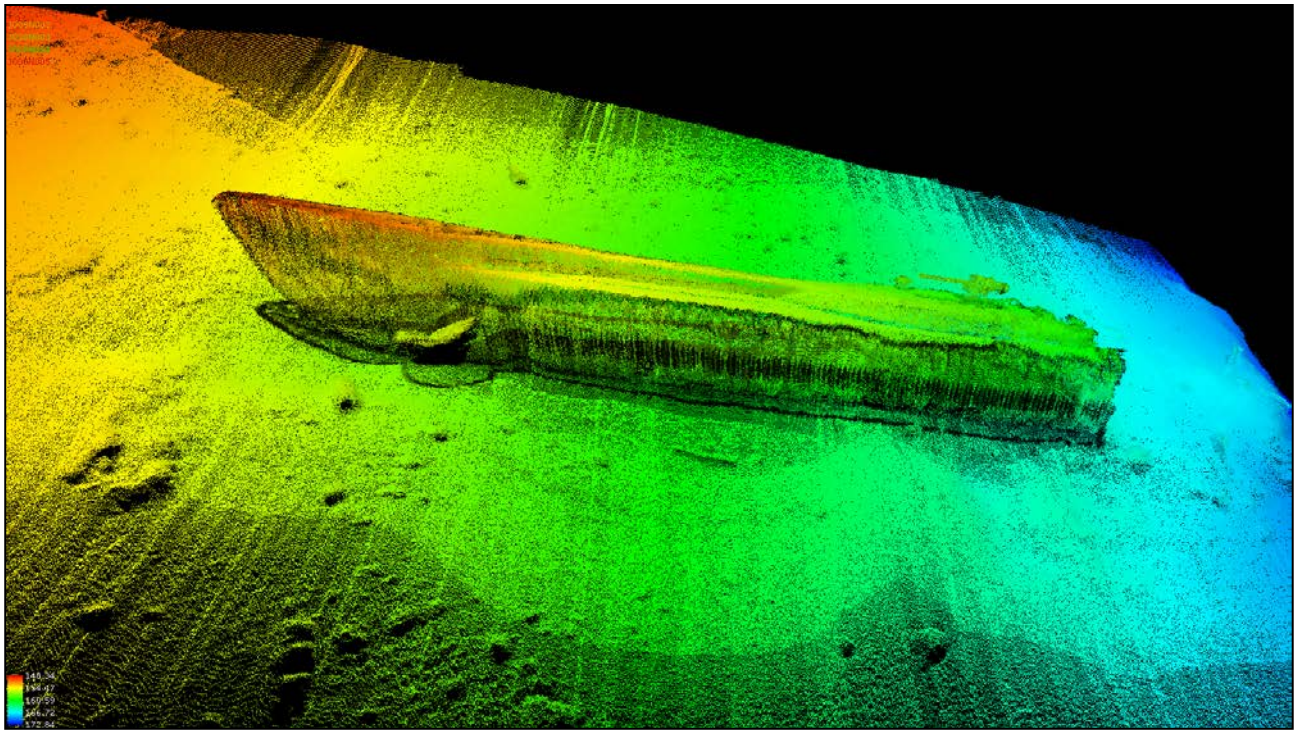


Figure 3.2 Example of soundings data from Bow section

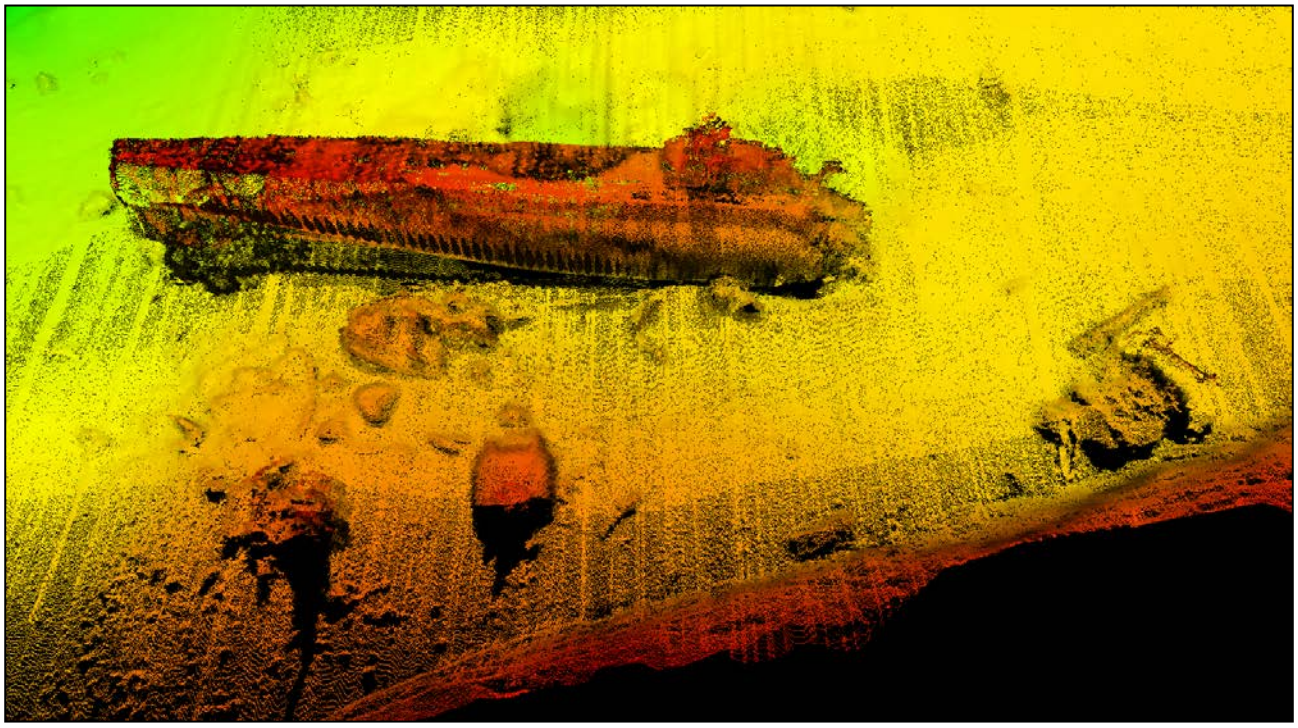


Figure 3.3 Example of soundings data from Stern section

3.2 ESTABLISHMENT OF CLEAR ZONES WITH HIGH DEFINITION VIDEO SURVEY

The survey was conducted over the area shown in Figure 3.4. A number of small new targets were located although none were considered to be significant in terms of Hg contamination or identification of the missing middle section. Targets previously identified during Phase 1 and 2 were found to be in the same locations and in a similar condition to that previously reported.

Further details along with images of identified objects are given in Paragraph 4.2.

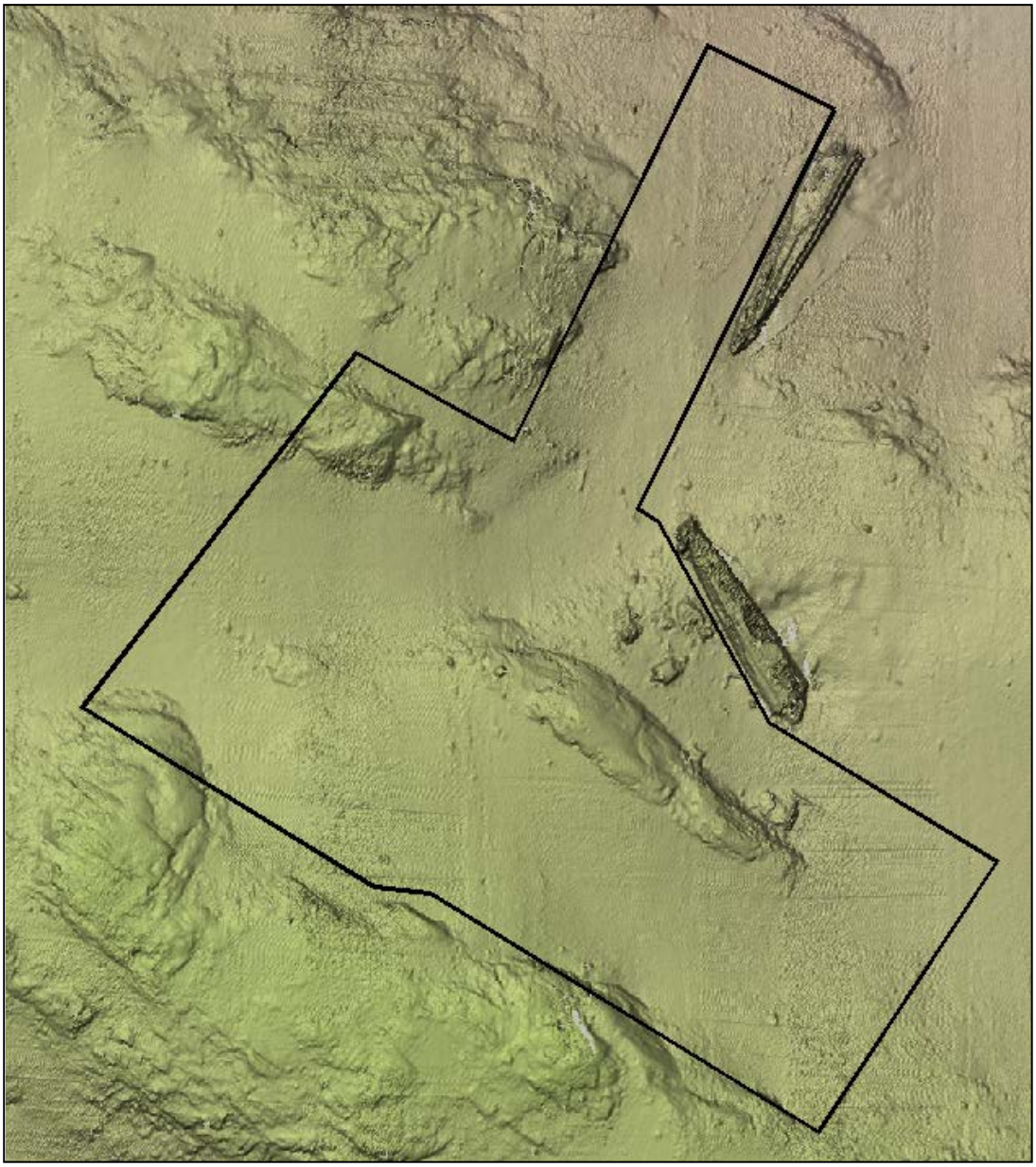


Figure 3.4 Clear Zone established during High Definition video survey

3.3 HIGH DEFINITION VIDEO SURVEY OF WRECK AND DEBRIS

The detailed survey of the wreck was undertaken in 6 stages (Figure 3.5):

1. The stern section
2. The bow section
3. Target 78
4. Target 66
5. Target 15
6. Target 8

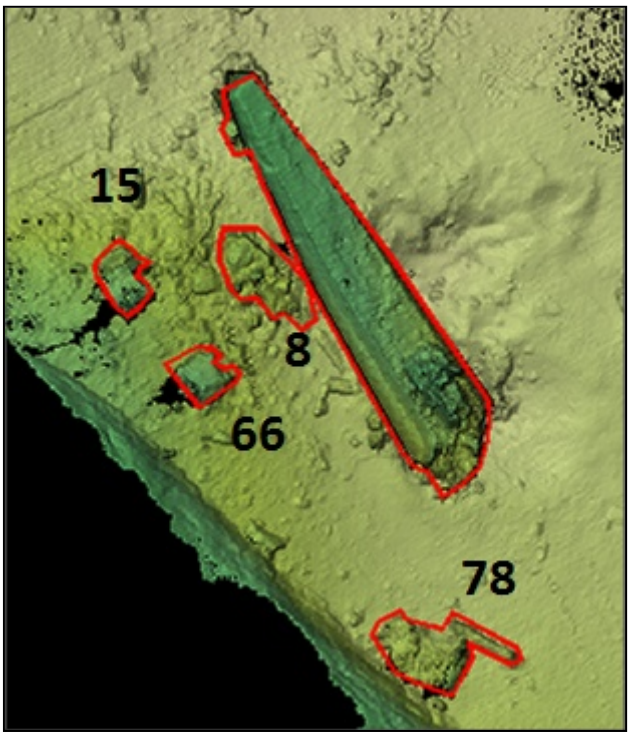


Figure 3.5 Video Survey targets near the stern section

3.3.1 The Stern Section

The stern section was found to be largely intact and in a similar condition to that seen in 2006. Significant observations during the survey of the stern section were the discovery of an internal bulkhead, the discovery of the loss of the extreme end of the stern and the exposed section of keel (approx 2.5m) at the starboard rear end of the stern.

The interior bulkhead was significant in that it allowed the project team to revise the estimated point at which the U boat had been damaged by the torpedo impact (Figure 3.6). The bulkhead was positively identified using an interior water tight hatch as a unique feature (Figure 3.7).

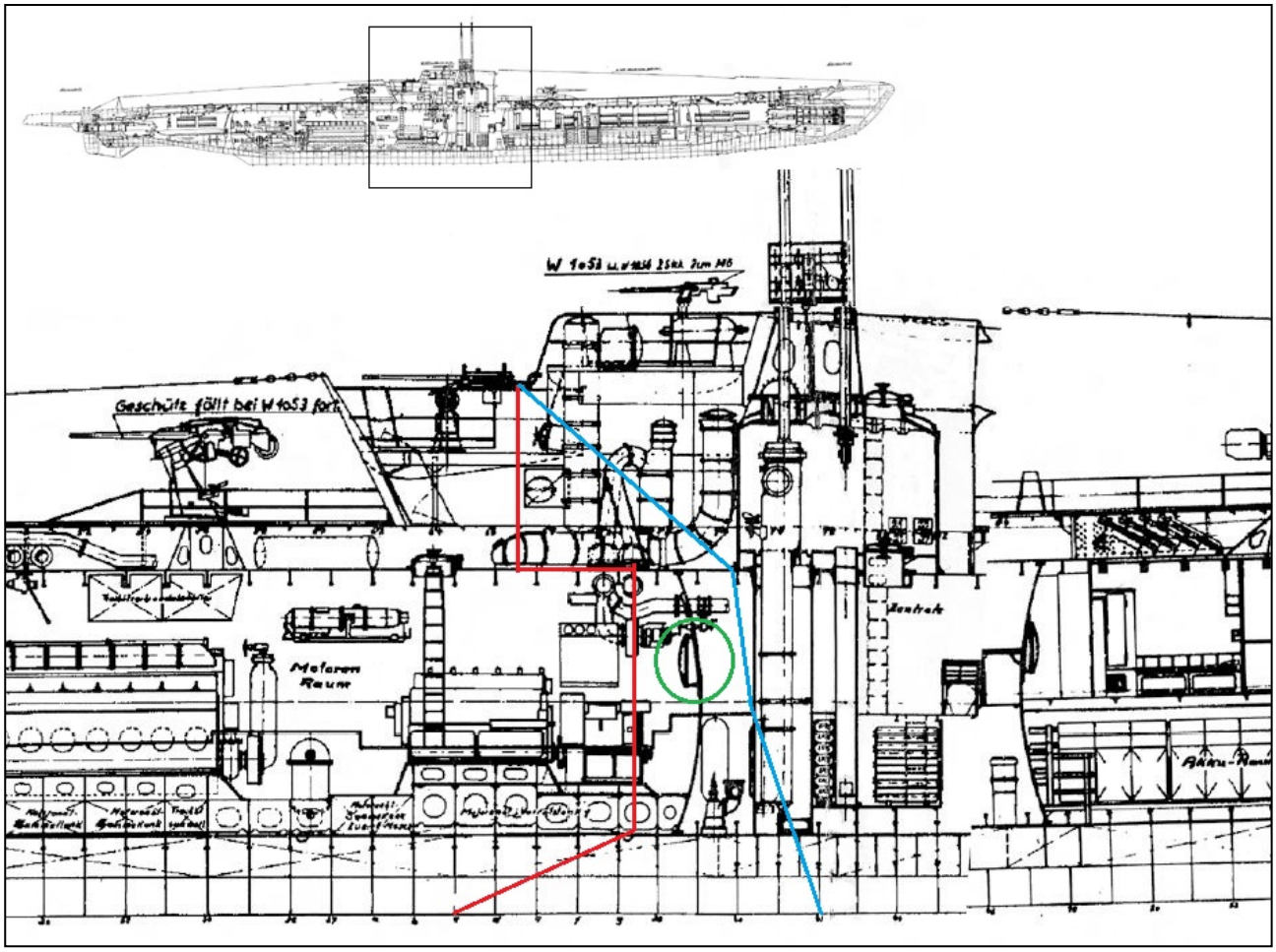


Figure 3.6 **2006 Estimate of extent of wreckage (red) and revised extent (blue). Identifying hatch circled**

Figure 3.7 **Interior watertight hatch, positively identifying the bulkhead**

The loss of the extreme stern of the U864 demonstrates the continued deterioration of the wreck (Figure 3.8-Figure 3.12). It should be noted that the dislodged piece does not form part of the vessel's pressure hull but is instead part of the outer streamlined exterior.

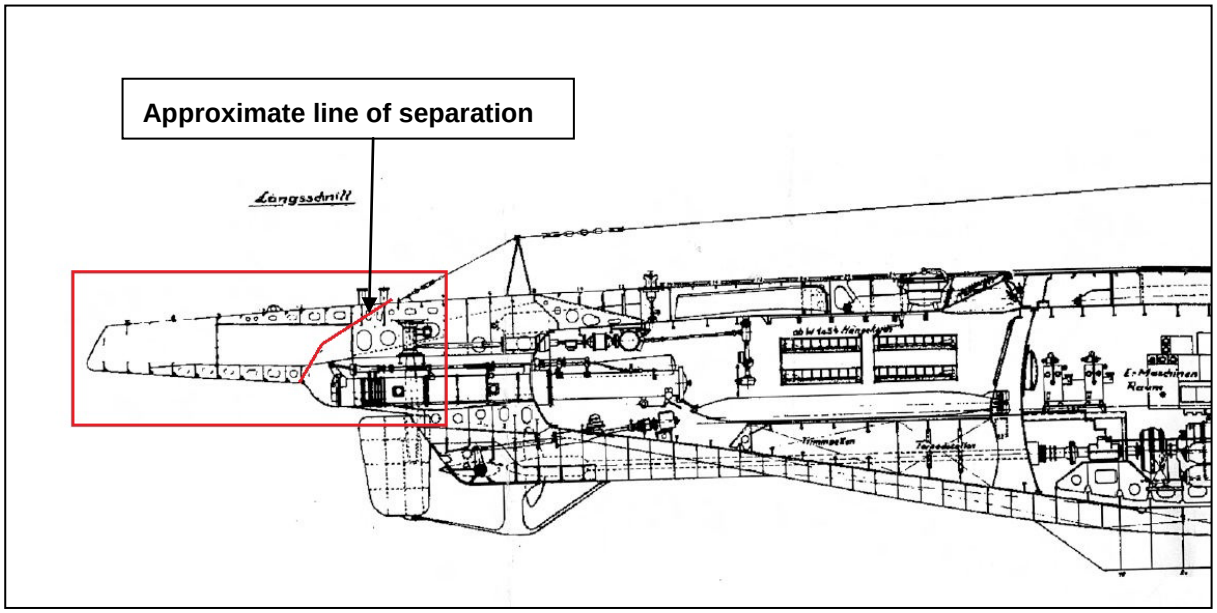


Figure 3.8 **Stern section schematic showing detached area**

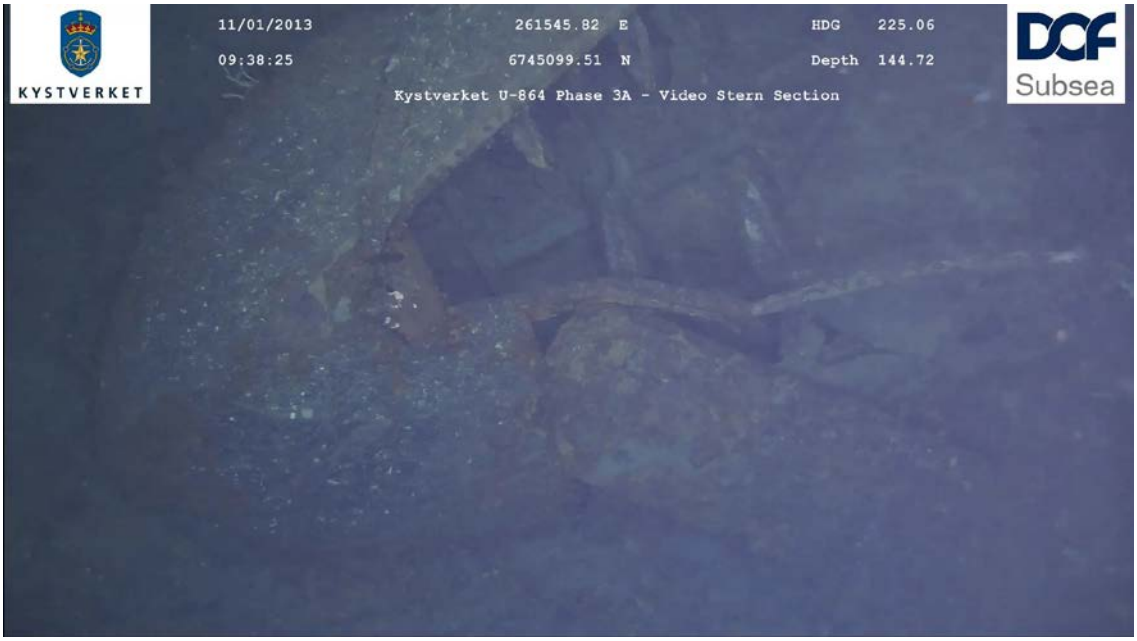


Figure 3.9 **Detached end section from Aft of stern on seabed**

Figure 3.10 **Detached end section from Aft of stern on seabed**

Figure 3.11 Aft of Stern section with extreme end detached

Figure 3.12 Aft of Stern section with extreme end detached

The keel was exposed for approximately 2.5m in length and up to 0.4m in height at the starboard rear end of the Stern Section (Figure 3.13 and Figure 3.14). This has not been reported in Phase 1 or 2. In Phase 2 of the project there was discussions of doing the dredging on starboard side of Stern Section, but because of the amount of debris and the heavy polluted sediments the decision were made for dredging on the port side.

Figure 3.13 The exposed keel (approx. 2.0m) at starboard rear end of the Stern Section

Figure 3.14 The exposed keel (approx. 2.0m) at starboard rear end of the Stern Section

3.3.2 The Bow Section

During the survey of the bow section a number of external storage containers which may contain historically valuable documents were identified. These are located under the vessel's removable decking and will require a detailed plan to be made if recovery is to be attempted.

The break point on the bow was reassessed during the survey and found to be similar to the 2006 estimate (Figure 3.15).

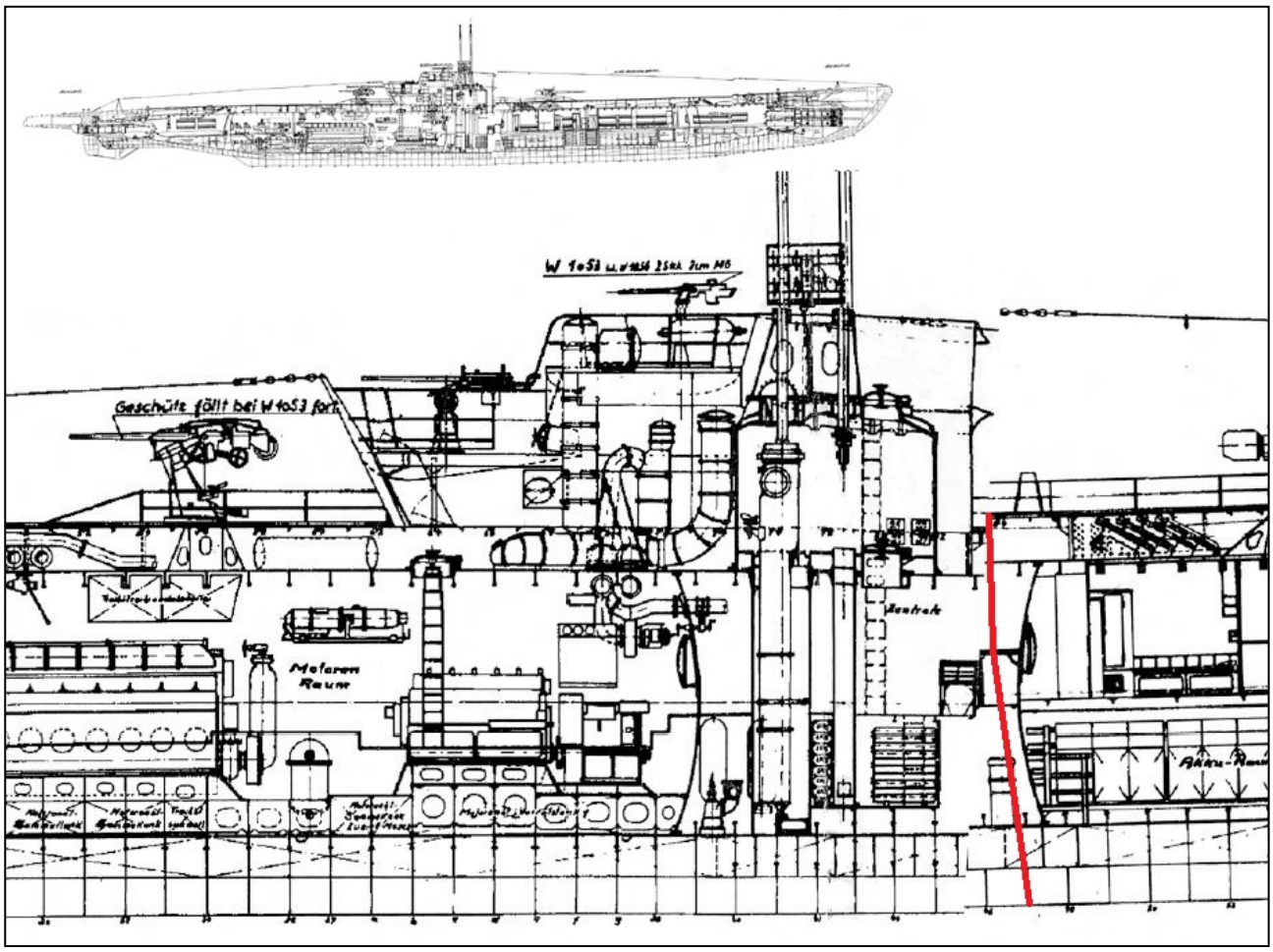


Figure 3.15 Approximate break point of the bow wreckage (red)

The most significant feature of the bow section is the 105mm deck gun. As can be seen in Figure 3.16 this is in excellent condition and is unchanged since the 2006 survey.

Figure 3.16 Image of 105mm Gun on Bow section

3.3.3 Target 78

Target 78 was believed to be part of the U864's external conning tower. During the investigation of this target a piece of wreckage was positively identified as the U Boat's snorkel. This was significant as the snorkel was mounted amidships and in close proximity to the conning tower. The snorkel have been separated from target 78 and given a separate target number 3A 034 (see Table 4.2).

The snorkel is of historical interest as it appears to be coated in a radar absorbent material "Tarnmatte".

Figure 3.17 Snorkel Head

Figure 3.18 Close up of snorkel head

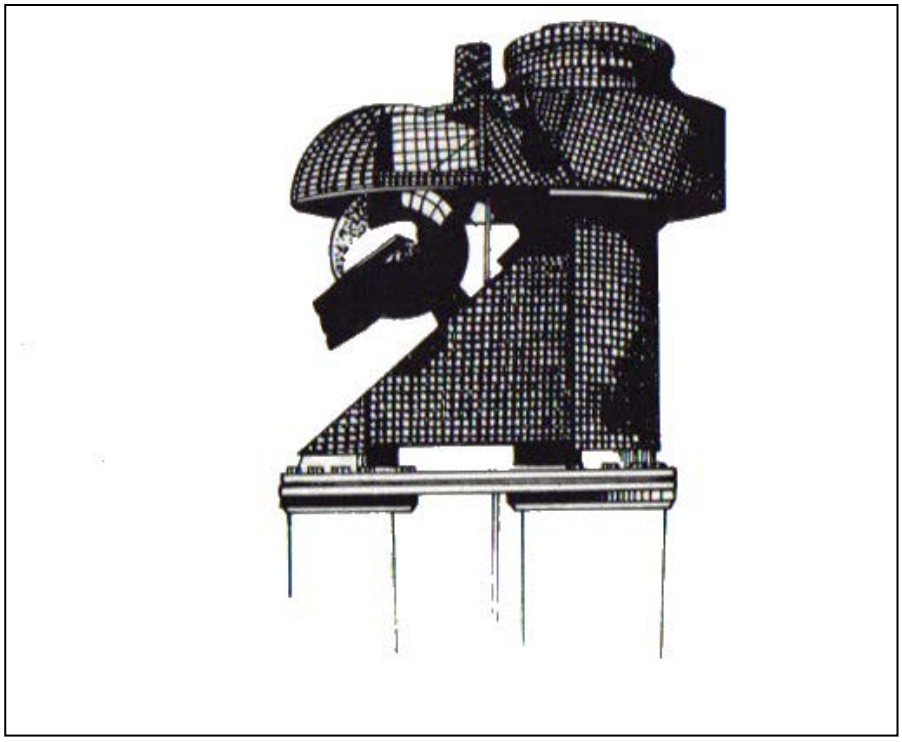


Figure 3.19 Image of snorkel head from WWII

3.3.4 Target 66

Target 66 was believed to be part of the conning tower of U-864. On closer inspection it was found to comprise the entire pressure (water tight) section of the conning tower (Figure 3.20).

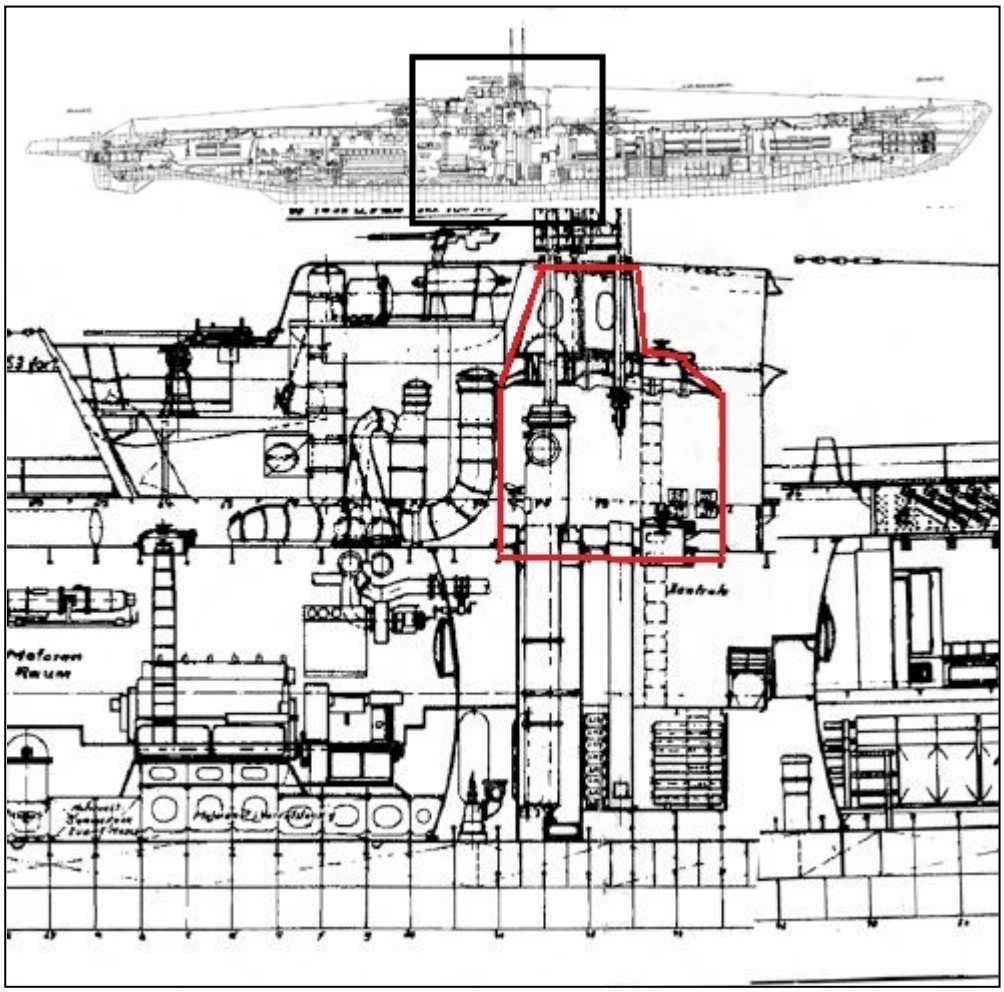


Figure 3.20 Conning tower and control room schematic. Target 66 Highlighted red

A number of unique identifying features allow a very high level of confidence in the identification of Target 66, although only the two main features will be listed here further details are given in paragraph 4.3.

Target 66 was found to be laying on its side, with the upper part of the structure pointing to the East. The features of the upper conning tower were clearly visible on this part of the wreckage.

It was noted that a piece of “cone shaped” steel had become partially detached from the main part of target 66 (Figure 3.21). The place where this structure was attached corresponds to the port forward area of the conning tower. Through examining a number of contemporary and modern photographs the “cone” was identified by the project team as the mounting pedestal for the “Underwasserzieloptic” (UZO). This device was used to gather data for torpedo attacks when the U boat was surfaced and is unique to the conning tower. As this item was detached from the wreck a decision was made to recover it to the surface for evaluation by experts on shore. The UZO pedestal was recovered on 12th January 2013.

Figure 3.21 **The U-864's UZO pedestal in position against the top of the conning tower**

Figure 3.22 **Image of UZO pedestal on deck of Skandi Skolten with example of WWII UZO (inlaid). 0.1m graduations on measuring stick**

Near the detached UZO was identified the very distinctive structure which supported and guided the two periscopes as they were raised and lowered. This structure is again unique to the conning tower (Figure 3.23 & Figure 3.24).

Figure 3.23 Periscope support structure on Target 66

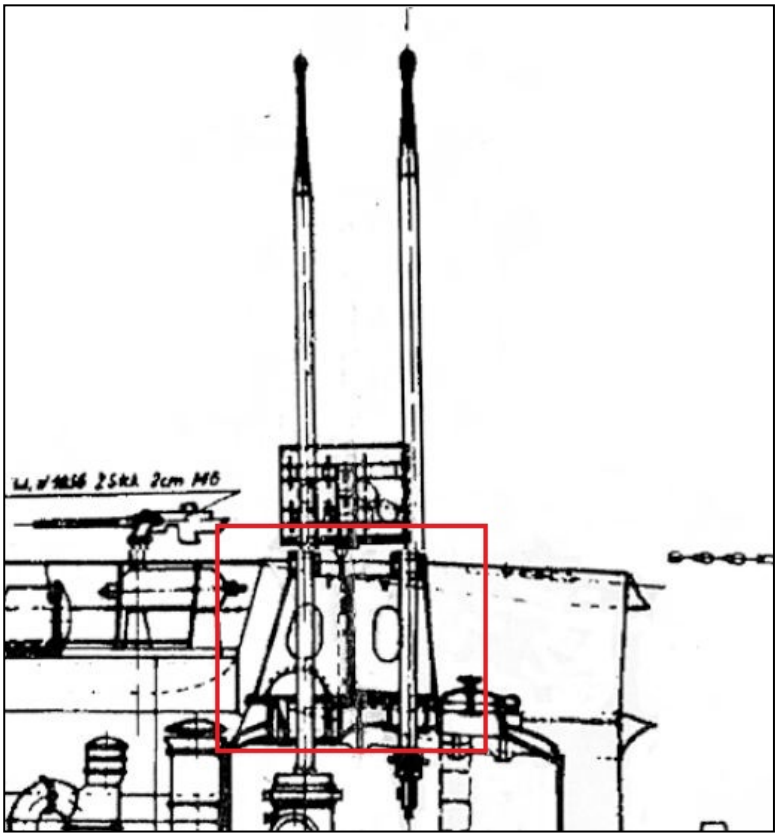


Figure 3.24 U boat schematic showing periscope support structure (highlighted)

3.3.5 Target 15

Target 15 was identified as a piece of saddle tank from the wreck (Figure 3.25). As the saddle tank is present along the length of the two main wreck sections this could only have come from the central area destroyed by the torpedo explosion. The structure of the frame is also consistent with the construction used in the saddle tank in the area of the control room (Figure 3.26).

Figure 3.25 **Target 15, section of saddle tank**

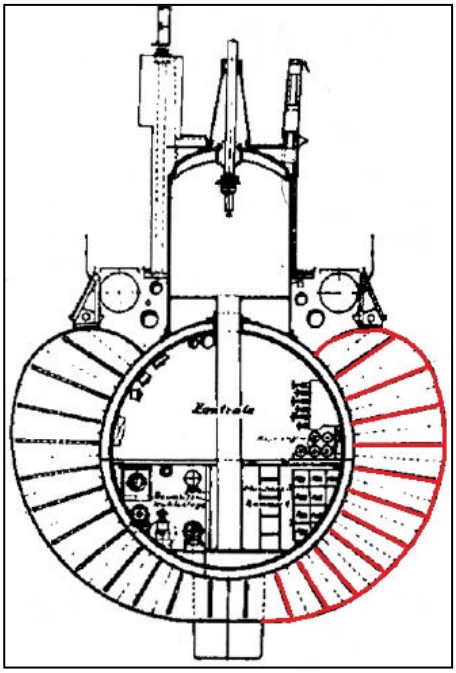


Figure 3.26 **Cross section of U boat schematic showing saddle tanks in the area of the control room (Saddle tank highlighted)**

3.3.6 Target 8

Target 8 was located next to the starboard side of the stern wreck section and was believed to comprise the upper works of the conning tower and “Wintergarten” anti-aircraft gun platforms.

The most significant find in target 8 was the location of the attack periscope protruding from under the plating (Figure 3.27). This periscope was the forward of the two periscopes on board the U864, both of which were in the control room of the vessel.

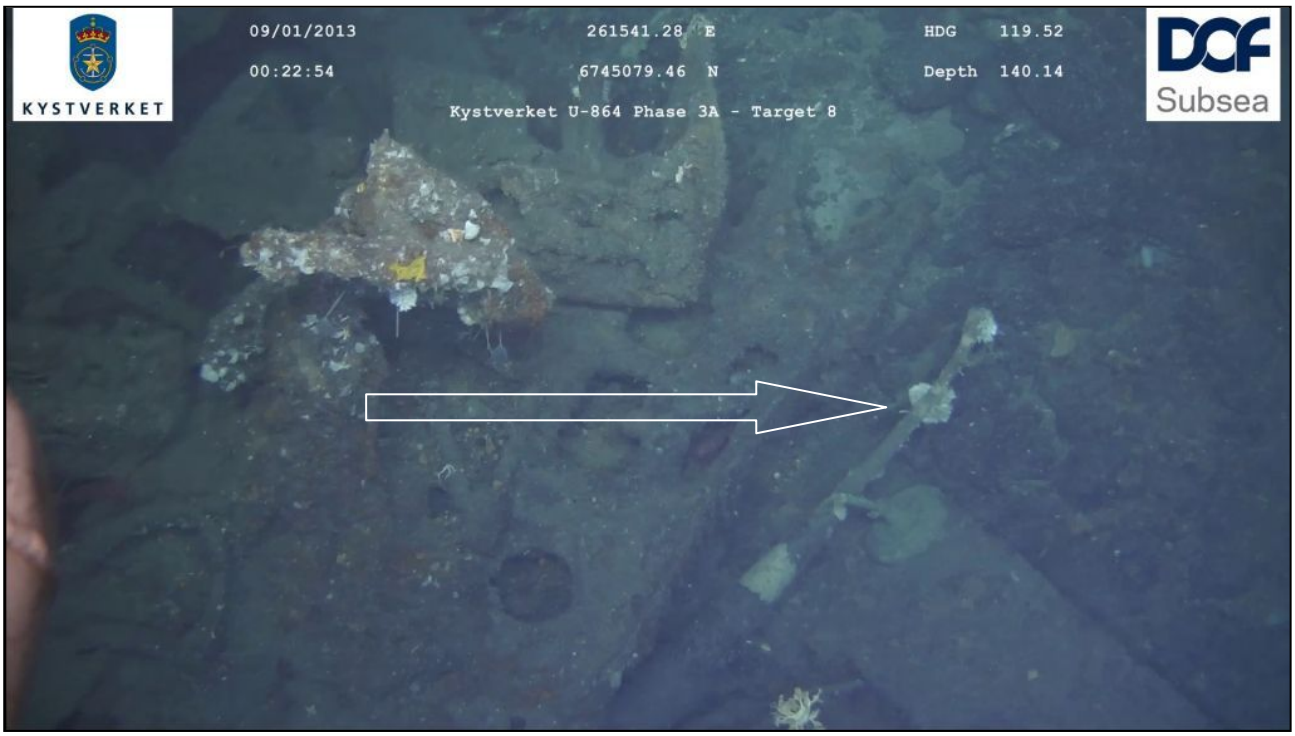


Figure 3.27 U-864 Attack Periscope

3.4 GEOTECHNICAL SAMPLING

The geotechnical operation was complicated by the necessary contamination testing and PPE requirements when recovering samples to deck.

Significant findings during the geotechnical sampling included the discovery of substantial visible mercury contamination in one of the core samples (Figure 3.28).

Sample 2013-406 and 407 were found to contain visible traces of mercury. The position of these samples close to the damaged area on the bow section of U-864 may indicate leaking canisters or may simply be residue from canisters damaged in the sinking.

The lack of surface mercury contamination from core samples taken near the stern of the wreck was probably because this area was dredged in previous project phases.

Figure 3.28 Visible Mercury contamination in sample 2013-406 (ringed)

NIVA performed mercury content analyses of the sediments from the 35 soil samples and from 7 vibrocores. The content of mercury was classified based on the classification system shown in the Table 4.4 below.

Table 3.1 Classification system for concentration of mercury in marine sediments (ref /4/)

	Class I Background	Class II Good	Class III Moderately polluted	Class IV Bad	Class V Very bad
Mercury (mg/kg) dry weight	**<0.15**	**0.15-0.63**	**0.63-0.86**	**0.86-1.6**	**>1.6**

16 of the 35 soil samples were taken at same locations as samples from 2006, and some of these showed an increase in mercury content. Especially the sample taken at target/ station 146 north of the wreck show a substantial increase in mercury content, from class II in 2006 to class V in 2013.

The results from all of the analyses done for previous years (2003, 2005, 2006 and 2013) are presented in the Figure 3.29 below, from NIVA report (ref /4/). This figure (Figure 3.29) illustrate that all samples classified as moderately polluted (Class III), bad (Class IIII) or very bad (Class V) are all located in the near vicinity of the wreck and west or north of the wreck. Samples taken east or south of the wreck is classified as good (Class II) or background (Class I).

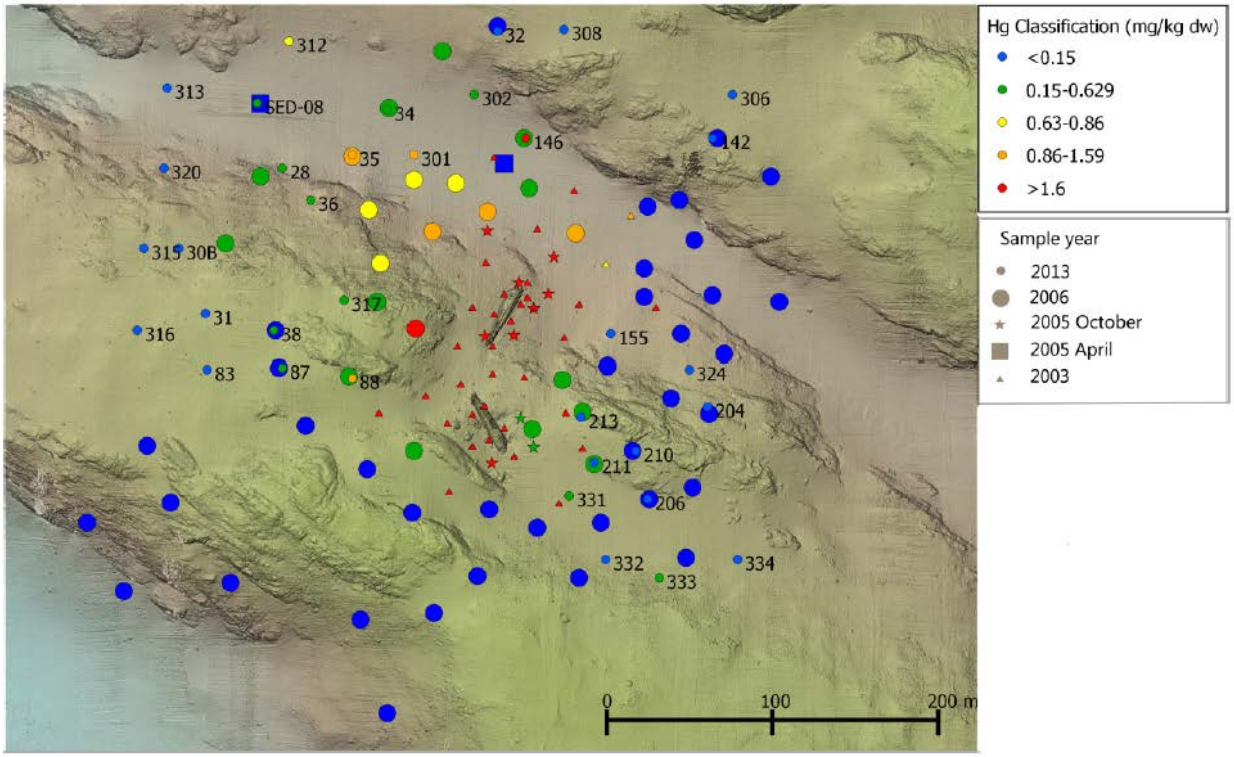


Figure 3.29 From NIVA report (ref /4/); Mercury content results for all years

The positions of the samples with highest mercury contamination agree with the direction of the water current (north western direction).

Result from the NGI report indicate a homogenous soil condition in the area, same was reported in 2006 (ref /3/).

The vertical thickness of the geotechnical soil unit I varied from 0.0/0.1m to 1.5m, and soil unit II from 0 to >6.1m. The soil Unit III from the 2006 campaign were not encountered in 2006.

3.5 HEIGHT, TRIM AND LIST MEASUREMENTS

A comparison of MBE data collected during the previous survey in 2006 and that collected during Phase 3A was conducted in order to identify any movement of the stern section of the wreck. Profiles were compared every 2m along the length of the stern section. An example of the compared profiles are shown below (Figure 3.30, Figure 3.31 and Figure 3.32) and all compared profiles are shown in Paragraph 4.5.

From the evidence available it is believed that any movement of the stern section is negligible. It should be noted that there is an apparent movement between the two available data sets but this is due to a small piece of wreckage becoming dislodged from the very stern of the wreck. See Paragraph 0 for more details.

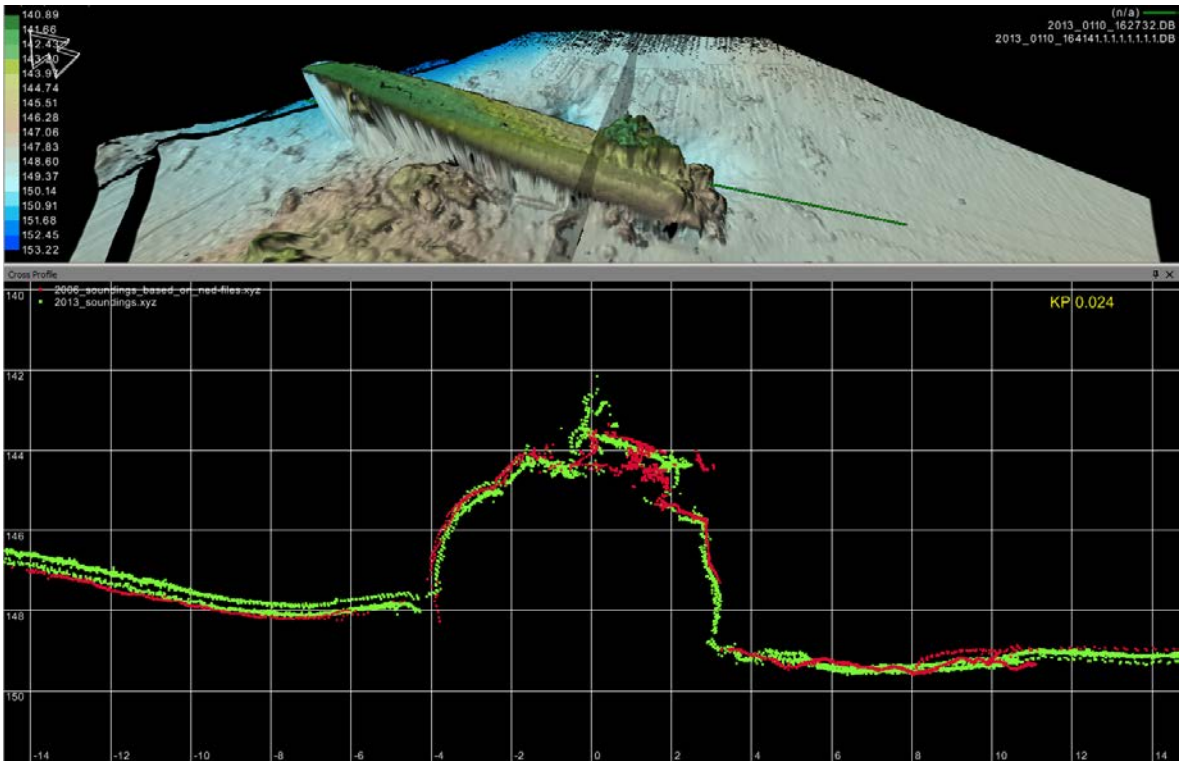


Figure 3.30 **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

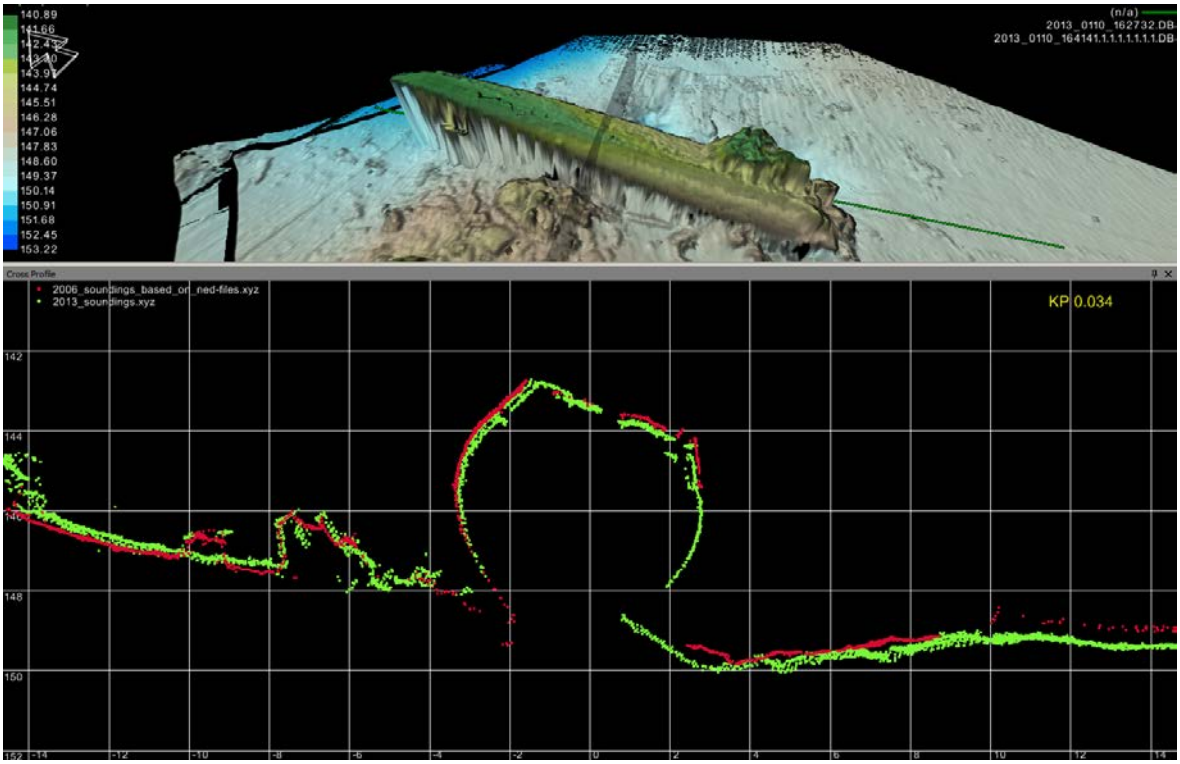


Figure 3.31 **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

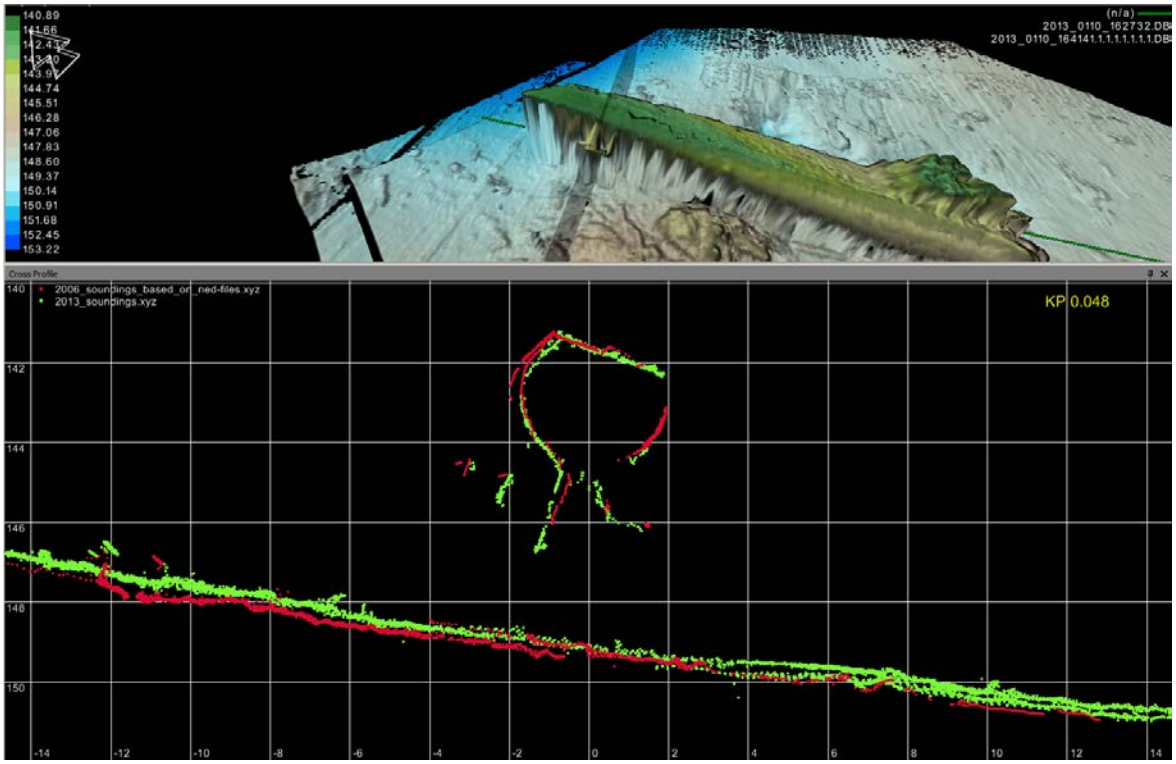


Figure 3.32 **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

3.6 SBP SURVEY

The Sub-Bottom stage of the project commenced at 23:51 on the 11th January and was completed at 04:36 on the 12th January 2013.

The data acquired was good throughout the survey, however due to the seabed characteristics the penetration achieved was limited. This limited penetration was caused by the presence of a surficial layer of sand throughout the survey area, as well as irregular occurrence of sand/ gravel layers in the underlying CLAY unit.

The Sub-Bottom Survey of the rotation pits consisted of 19 lines in total covering both the Bow and Stern section rotation pits.

The objective for the sub bottom profile survey was to identify any bedrock outcrops, large underlying rocks or other debris which could be a potential hazard to a later dredging campaign.

To summarise, there were no bedrock outcrops or large rocks identified within the location of the rotation pits.

3.7 OIL RECOVERY

The Oil Recovery stage of the project was performed from the 11th March 2013.

The main objective was to recover any oil residue from the tanks of the U-864. This specific operation was performed by FRAMO.

The conditions of the weld seems for the outer shell of the fuel tanks were found in a poor condition. Due to the poor state of condition, the focus changed during operation from oil recovery to verification survey for most of the fuel tanks. If there were any uncertainty, oil recovery of a tank was commenced. Oil recovery was done for 3 of the 16 tanks on the U-864, and only minor quantities of oil was recovered from those 3 tanks.

3.8 VOR02- AIR POCKETS

Initial scope of work for Phase 3A included evacuating possible air pockets inside the U-864 wreck, however this was put on hold until the Oil Recovery task was completed. The VOR02 of evacuating possible air pockets from the U-864 wreck was commenced the 17th March 2013.

Main task was to evacuate possible air pocket inside the aft wreck section, to resolve the issue with unknown wreck stability.

A cut was performed in the aft section pressure hull, air evacuation continued for approximately 6hrs. We assume that aft water tight sections have been completely flooded.

3.9 VOR03- OIL LEAK AND POSITION OF U-864

A few days after completion of the VOR02 (Section 3.8 above), DSNO was asked to perform an investigation of oil leakage from U-864 (VOR03). This work was commenced the 21th March 2013.

Oil was found to leak from the aft section at the cut done during the air pocket evacuation operation. Oil was spotted coming out of cracks around the stern section, however this is most likely oil trapped inside or under fuel tank plates. The level of oil leak was measured to be approximately 0.3L/hr, no oil was visible on sea surface upon arrival in calm sea with no wind. By

close inspection of the stern section it appears little or none movement of the wreck since the last "As-left" survey (17th March 2013).

A close visual inspection was performed of the front section, and no sign of movement or oil leaks was indentified.

4 DETAILED RESULTS

4.1 MBES GRID SURVEY

With the exception of vertical, or near vertical slopes the MBE survey produced 100% coverage of the survey area around the wreck of the U-864. The survey area was a 2000m x 2000m grid centred around the wreck site. The resulting DTM (Figure 4.3) was inspected for signs of additional wreckage. Particular attention was also paid to the historical sinking position and the seabed below the debris found on the surface by HMS Venturer in 1945.

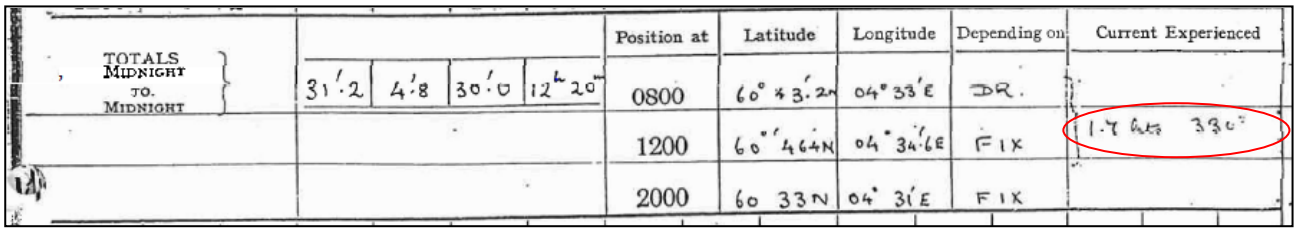
The historical sinking positions given in HMS Venturer's log (see Figure 4.2) were converted from the original Bessel NGO (New Norwegian) spheroid into the project WGS84 and plotted on the DTM (Table 4.1). These were then examined in detail for signs of additional wreckage. Large scale plots of these areas are shown in Figure 4.4 and Figure 4.5. A brief explanation on chart datum's can be found in Appendix B .

Table 4.1 Transformation parameters from New Norwegian to WGS84 (Courtesy of UKHO)

Datums]	Name	Method	Ellipsoid	X	Y	Z	rX	rY	rZ	scale
NORWEGIAN (NEW)	"Norwegian (New)"	BURSA	BESSEL NGO	278.3	93	474.5	7.889	0.05	-6.61	6.21

No sign of any additional wreckage was found at either of these locations.

From the plotted positions, the range and bearing from the strike position to the debris sighting was 845m at a Grid bearing of 333°. The surface current experienced by HMS Venturer at the time of the attack was 1.7kts at 330° (Figure 4.1) and the debris was sighted approximately 30 minutes after the attack. This is consistent with the debris moving with the current from the point of impact to its observed position.



					Position at	Latitude	Longitude	Depending on	Current Experienced
TOTALS MIDNIGHT TO MIDNIGHT	31'.2	4'.8	30'.0	12h 20m	0800	60° 43'.2N	04° 33'E	DR.	
					1200	60° 44'.4N	04° 34'.6E	FIX	1.7 kts 330°
					2000	60 33N	04° 31'E	FIX	

Figure 4.1 Excerpt from HMS Venturer's log showing current reading

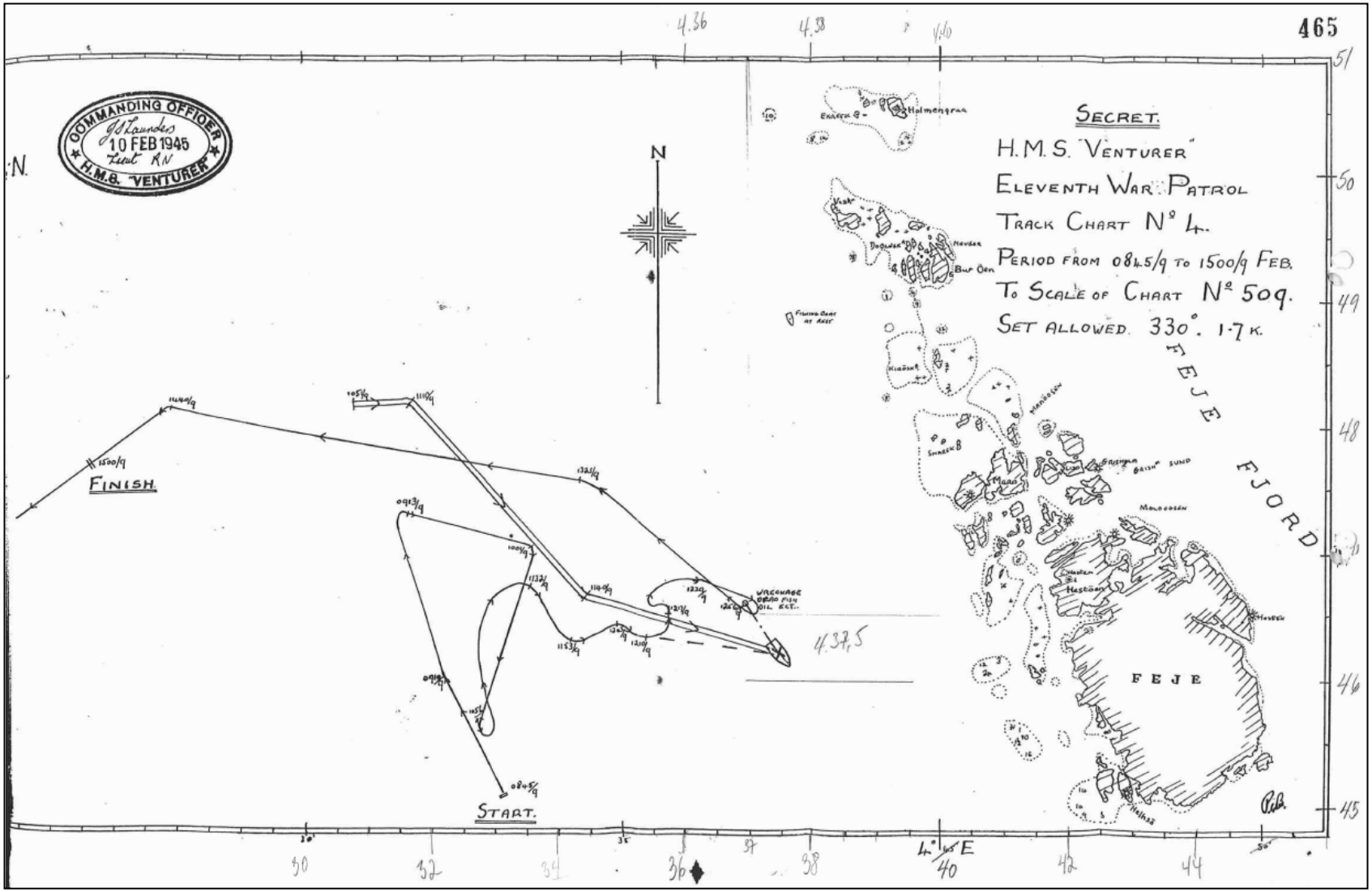


Figure 4.2 **Image of chart from HMS Venturer's log with positions taken from chart**

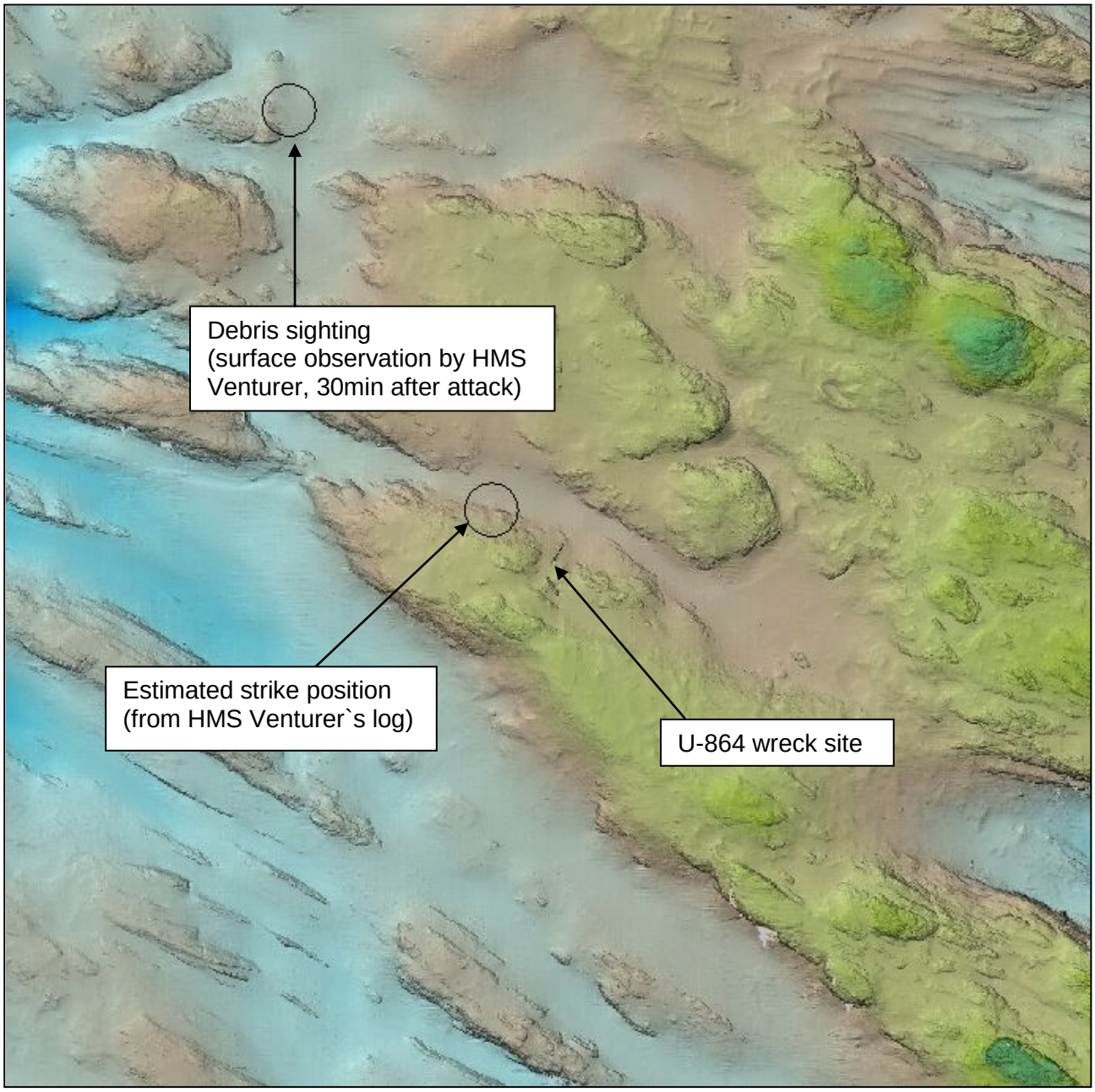


Figure 4.3 **Complete DTM from the 2013 survey, positions from HMS Venturer's log ringed**

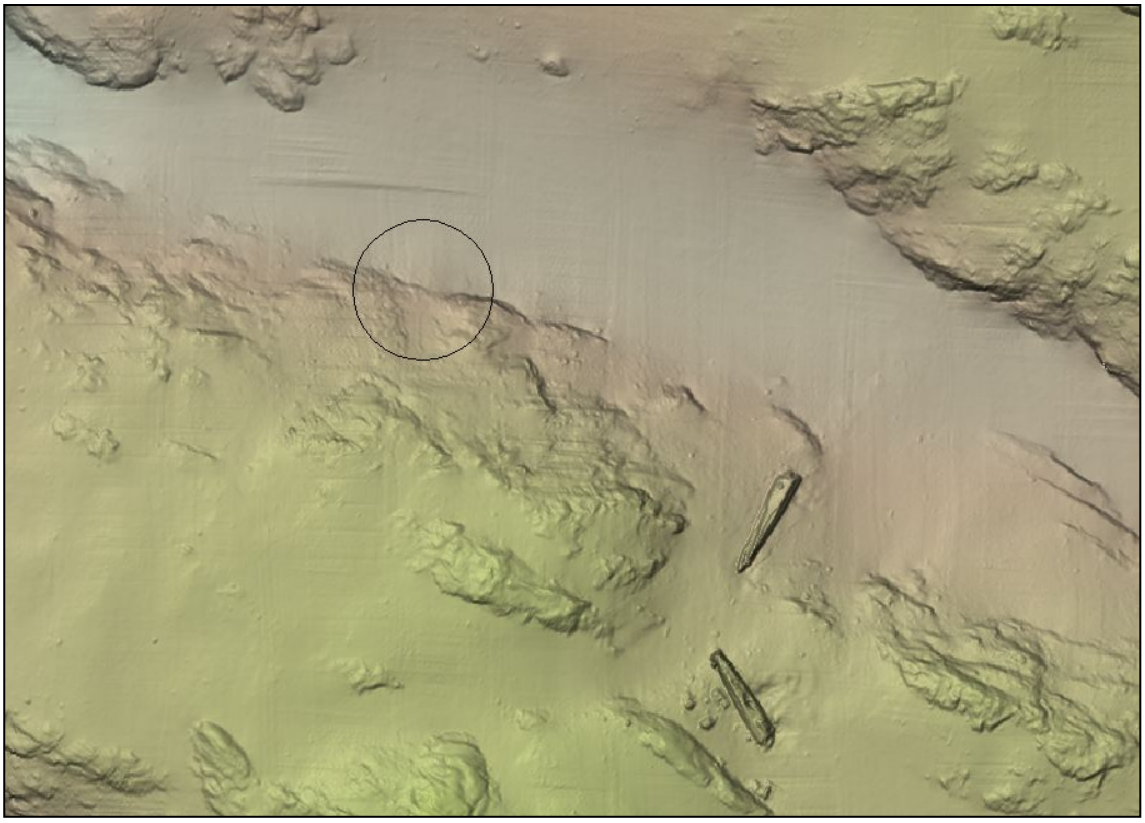


Figure 4.4 **Historical sinking position taken from HMS Venturer Log circled (25m radius). Actual wreck location can be seen to the SE**

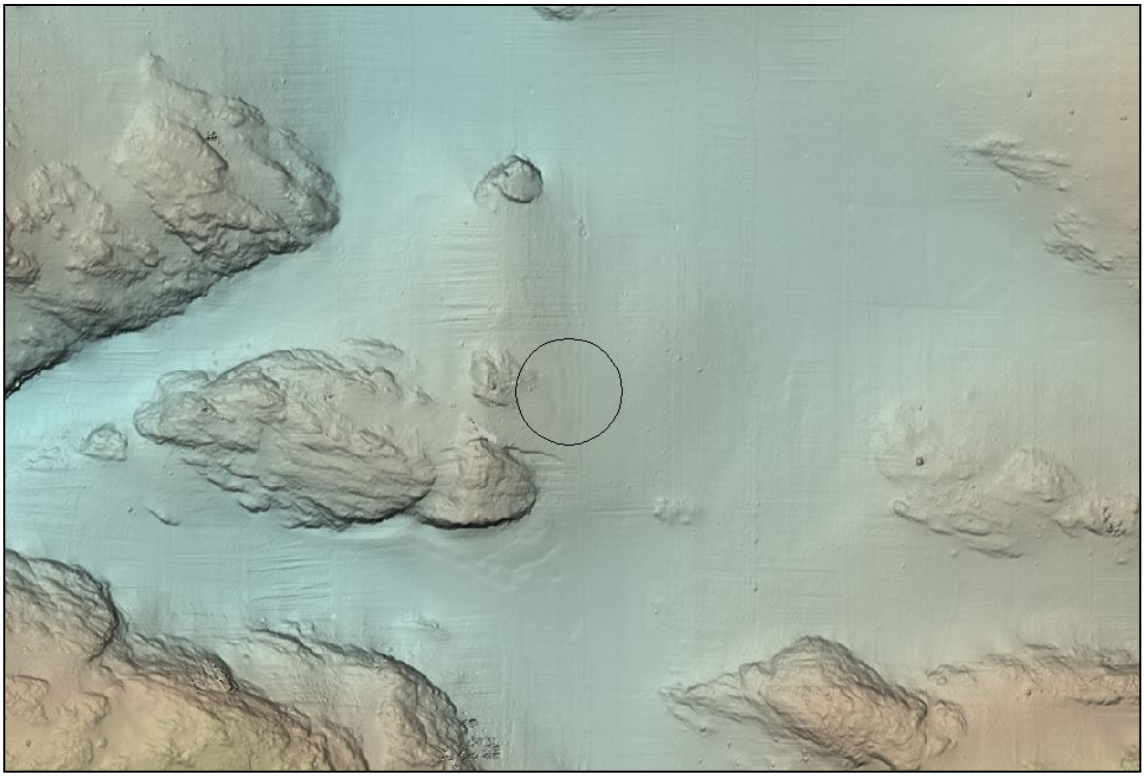


Figure 4.5 **Oil slick and floating debris position taken from HMS Venturer Log circled (25m radius)**

4.2 ESTABLISHMENT OF CLEAR ZONES WITH HIGH DEFINITION VIDEO SURVEY

During the Phase 3A survey 68 targets / objects of metal debris were observed in clear zones on the western side of the wreck sections (see Figure 2.2). Of these there were 32 new targets / objects of metal debris and 36 targets have been reported before. The targets reported earlier (2005) have kept the original ID number for making the comparison easier, but they all have got new dimensions measured from the 3D model / visual. Some of the debris are situated in clusters and are referred as one target / object. Target 78 have been divided into two targets / objects, where the snorkel (see Figure 3.20 and Figure 3.17) is separated out and got a new target ID 3A 034. Table 4.2 summarizes the targets / objects observed.

Table 4.2 Target / object listing

Easting	Northing	ID	Length (m)	Height (m)	Width (m)	Video observation
261562.08	6745158.12	01	1.2	0.2	0.2	Section of Pipe
261543.10	6745077.00	06	1.8	0.9	1.4	Metal debris
261534.00	6745088.00	07	3.0	0.7	0.8	Large debris
261543.70	6745080.00	08	9.0	1.8	5.9	Top of Winter garden and Conning Tower, “UZO”
261550.15	6745074.30	10	4.1	0.4	0.6	Large Metal Canister Next to the Keel
261533.60	6745079.00	15	6.0	3.9	5.3	Large Debris with ribs, pipe, part of outer Hull close to torpedo impact
261550.20	6745071.00	23	4.3	0.4	1.7	Large Bended Pipe
261566.60	6745168.58	35	1.0	0.2	0.1	Metal Piping
261524.80	6745104.00	54	3.8	0.5	0.4	Large Metal Canister
261531.73	6745102.17	56	1.4	0.5	1.1	Large Metal Sheet Debris
261534.23	6745097.18	57	1.2	0.6	0.4	Metal Sheet Debris
261530.90	6745093.00	61	2.8	0.3	1.0	Metal Structure
261538.20	6745071.00	66	6.2	3.8	4.1	Large cylindrical metal debris, part of the inner Conning tower
261553.60	6745068.00	69	2.4	1.2	1.6	Large Metal Structure close to the Keel
261554.47	6745066.01	71	2.0	1.8	0.6	Large Accumulation of Debris Part of Conning Tower
261558.03	6745048.58	78	7.0	1.6	5.0	Part of Conning tower
261551.20	6745097.00	81	1.1	0.3	0.6	Metal debris with Ring Attached
261569.65	6745168.19	A20	1.5	0.1	0.1	Metal Piping
261559.09	6745156.56	A30	3.0	0.1	0.1	Thin Metal pipe
261554.12	6745149.41	A31	1.0	0.1	0.1	Metal Rod
261529.33	6745107.26	A34	1.1	0.3	0.7	Metal Tubing, Metal sheet
261531.85	6745122.60	A37	1.6	0.7	0.3	Metal Sheet Debris
261520.31	6745115.41	A39	1.6	0.3	0.3	Metal Debris
261532.28	6745100.56	A70	1.5	0.2	1.0	Metal Debris
261535.11	6745095.28	A71	1.2	0.3	0.3	Metal Sheeting
261540.42	6745090.01	A72	1.0	0.2	0.2	Various Metal Piping
261562.23	6745055.33	A78	1.5	0.3	0.6	Metal Debris, Crushed Pipe
261565.80	6745061.00	A81	1.5	0.1	0.1	Metal Pipe
261532.70	6745092.00	A84	3.0	0.2	0.2	Several Pipes and Debris
261536.57	6745086.20	A85	3.9	0.3	0.4	Large pipe
261525.90	6745092.00	A92	0.4	0.1	0.1	Small piece of pipe

Easting	Northing	ID	Length (m)	Height (m)	Width (m)	Video observation
261524.52	6745085.35	A93	0.3	0.1	0.3	Metal Debris
261521.64	6745090.53	A97	0.5	0.2	0.2	Small Tube Section
261497.96	6745089.66	A101	0.3	0.1	0.2	Metal Debris, Pipe Section
261509.00	6745082.00	A102	1.8	0.4	0.4	Large Metal Cylinder
261510.00	6745062.00	A103	4.0	0.2	1.8	Metal Sheet, Part of hull casing section
261515.59	6745077.56	3A 002	1.2	0.6	0.2	Metal Debris
261544.18	6745058.60	3A 006	3.3	1.2	1.7	Piece of conning tower
261540.73	6745067.03	3A 008	2.6	0.6	0.7	Metal tubing
261496.12	6745104.25	3A 013	1.0	0.1	0.1	Metal Rod
261521.92	6745088.46	3A 015	0.5	0.2	0.2	Metal Debris
261524.63	6745088.11	3A 016	1.5	0.1	0.2	Metal Rod
261527.90	6745087.00	3A 018	0.4	0.1	0.4	Metal Plate
261540.42	6745050.09	3A 022	0.6	0.2	0.2	Possible canister
261482.81	6745098.59	3A 024	0.3	0.1	0.1	Metal Pipe/Canister
261516.09	6745080.95	3A 027	0.3	0.3	0.3	Metal Debris
261546.44	6745060.13	3A 029	1.5	0.2	0.2	Metal Pipe
261562.52	6745050.18	3A 034	6.0	0.9	0.8	Snorkel located on conning tower
261549.25	6745065.26	3A 037	2.0	0.3	0.3	Metal Ring
261508.62	6745110.12	3A 040	1.0	0.1	0.3	Metal Sheeting
261526.00	6745103.27	3A 042	2.0	0.1	0.1	Metal Piping
261528.23	6745102.75	3A 043	1.0	0.1	0.3	Large Metal Sheeting
261542.60	6745098.16	3A 045	3.0	1.2	2.0	Large Metal debris
261541.59	6745098.20	3A 046	3.0	0.2	3.0	Steel fragmented debris with canister
261563.79	6745159.71	3A 054	1.6	0.6	0.4	Metal Debris
261565.11	6745160.28	3A 056	2.0	0.1	0.1	Flexible hose within forward section
261564.77	6745165.58	3A 059	0.5	0.1	0.1	Metal Rod
261559.57	6745162.31	3A 060	0.2	0.1	0.1	Metal Rod
261557.39	6745153.99	3A 062	0.4	0.1	0.1	Metal Rod
261537.46	6745113.88	3A 064	1.0	0.1	0.3	Metal Structure
261536.86	6745112.96	3A 065	0.5	0.1	0.2	Metal Debris
261540.38	6745109.40	3A 066	1.9	0.3	0.4	Metal Debris
261533.51	6745108.36	3A 067	1.0	0.1	0.4	Various Metal Debris
261522.16	6745111.30	3A 074	2.4	0.2	0.1	Metal Debris
261526.04	6745120.58	3A 075	1.5	0.4	0.4	Metal Debris
261525.81	6745122.65	3A 076	0.5	0.4	0.4	Metal Cone
261528.88	6745131.55	3A 078	1.0	0.2	0.4	Metal Debris
261539.34	6745084.11	3A 084	7.4	0.3	1.5	Bended pipe

4.3 HIGH DEFINITION VIDEO SURVEY OF WRECK AREA AND DEBRIS

The detailed survey of the wreck was undertaken in 6 stages (Figure 4.6):

1. The stern section
2. The bow section
3. Target 78
4. Target 66
5. Target 15
6. Target 8

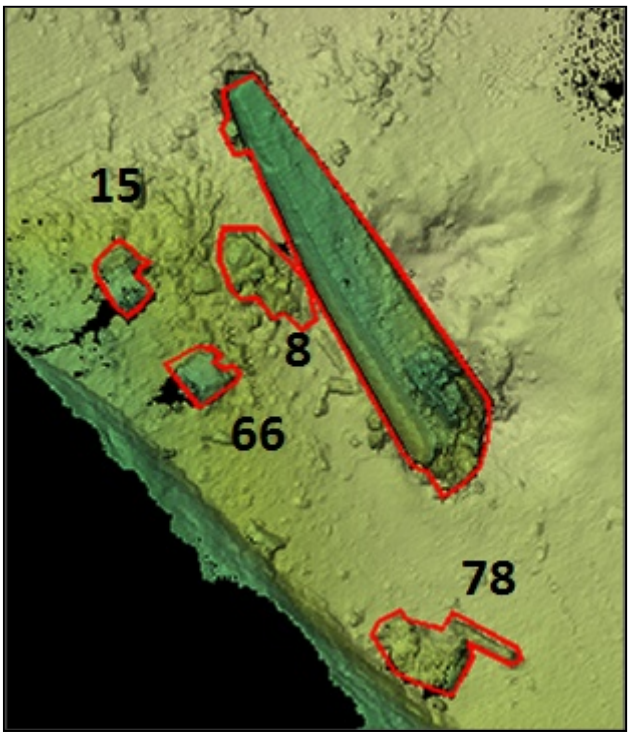


Figure 4.6 Video Survey targets near the stern section

4.3.1 Stern Section

The stern section was found to be largely intact and in a similar condition to that seen in 2006.

As was seen in 2006 the stern Dive planes were set to dive and the rudders were dead ahead, indicating the U-864 was diving and taking evasive action immediately before the impact of the torpedo.

4.3.2 The Bow Section

The bow section was found to be largely intact and in a similar condition to that seen in 2006.

In addition to the findings discussed in Paragraph 0 above an attempt was made to establish the condition of U864's four bow torpedo tubes. Some Type IX boats assigned to transport duties are known to have had the outer hatch of their torpedo tubes welded shut in order to utilise the tubes for storage. This would have an impact on the amount of torpedoes being carried by U864. Unfortunately the inspection proved inconclusive.

The bow dive planes were found to be in the “dive” position (Figure 4.7), again indicating the U-846 may have been attempting evasive action at the point of impact.

Figure 4.7 Bow dive plane in dive position

4.3.3 Target 78

Target 78 was believed to be part of the U864’s external conning tower. Apart from the snorkel discussed in Paragraph 0 the remainder of the wreckage has suffered extensive damage. From a number of features of the structure the project team have a high level of confidence that this is the forward outer skin of the conning tower, however non are unique or recognisable enough to be conclusive .

4.3.4 Target 66

Target 66 was believed to be part of the conning tower of U-864, on closer inspection it was found to comprise the entire pressure (water tight) section of the conning tower (Figure 4.8).

A number of unique identifying features in addition to those discussed in Paragraph 0 allow a very high level of confidence in the identification of Target 66.

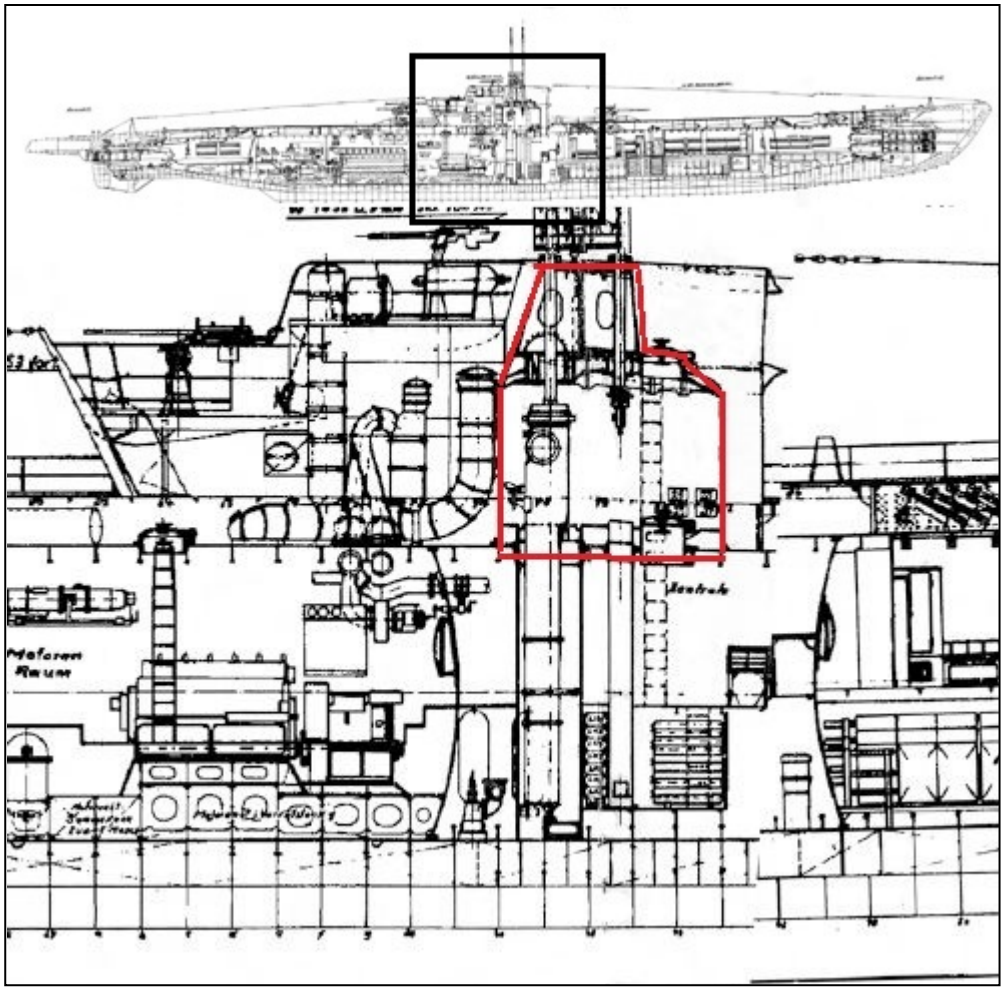


Figure 4.8 Conning tower and control room schematic. Target 66 Highlighted red

Target 66 was found to be laying on its side, with the upper part of the structure pointing to the East. The features of the upper conning tower were clearly visible on this part of the wreckage.

In close proximity to the previously discussed UZO was a small hatch which provided access to the interior of the tower from the observation area. On the lower part of target 66 was a corresponding hatch which provided access from the tower to the control room as seen in Figure 4.9.

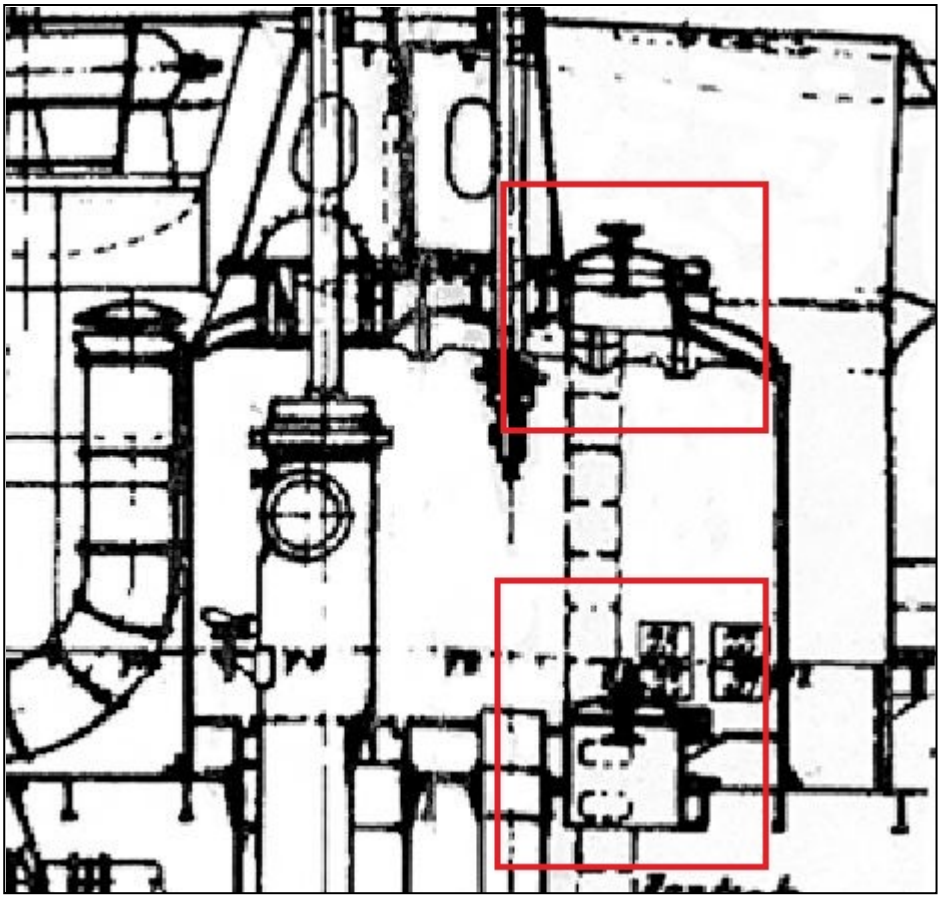


Figure 4.9 **U Boat Schematic showing Conning Tower Access Hatches (highlighted)**

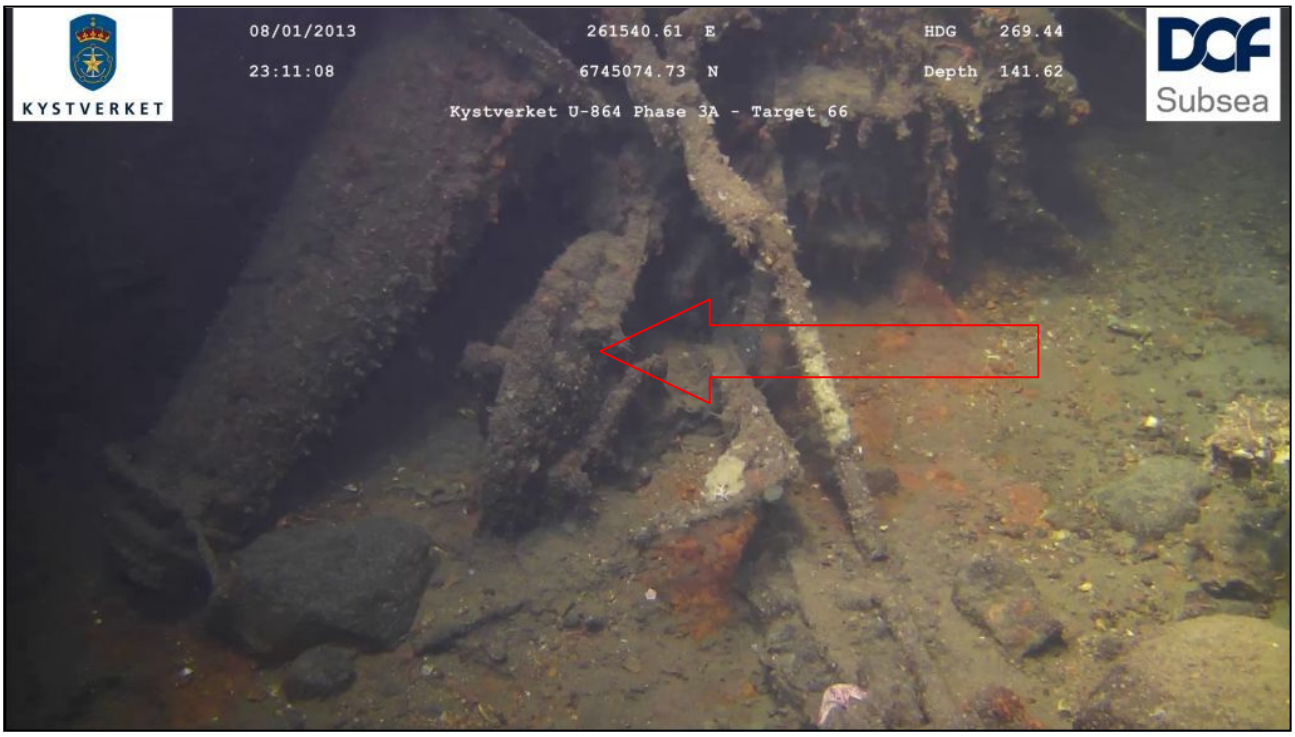


Figure 4.10 **Upper Conning Tower hatch**

Figure 4.11 Lower Conning Tower hatch

The final identifying feature on Target 66 was a severely damaged periscope. The periscope has been bent at 90° and may indicate that the conning tower parted from the hull and rolled to port. This is consistent with the impact of a torpedo on the starboard side. The periscope is sheared off shortly after the 90° bend (Figure 4.12).

Figure 4.12 Damaged observation periscope

4.3.5 Target 15

As previously discussed in paragraph 0 target 15 was identified as a piece of saddle tank from the wreck. Other than the features already mentioned no further significant findings were made.

4.3.6 Target 8

As previously discussed in paragraph 0 target 8 was located next to the starboard side of the stern wreck section and was believed to comprise the upper works of the conning tower and “Wintergarten” anti-aircraft gun platforms.

The wreckage has suffered extensive damage. From a number of features of the structure the project team have a high level of confidence that this is the upper Wintergarten platform. Among these are railings, a multi barrelled anti-aircraft weapon and other minor features, however non are unique or recognisable enough to be conclusive.

4.4 GEOTECHNICAL SAMPLING

Geotechnical operations were conducted between the 10th and 12 January 2013. A total of 7 Vibrocore locations, 2 Gravity core locations and 8 CPT locations were sampled. An additional 35 sediment samples were taken using an ROV mounted system for Hg pollution level monitoring.

Sample locations are shown in Figure 4.13 due to operational circumstances not all the locations could be completed. The exact timings and positions can be seen in (Table 4.6, Table 4.7, Table 4.8, Table 4.9).

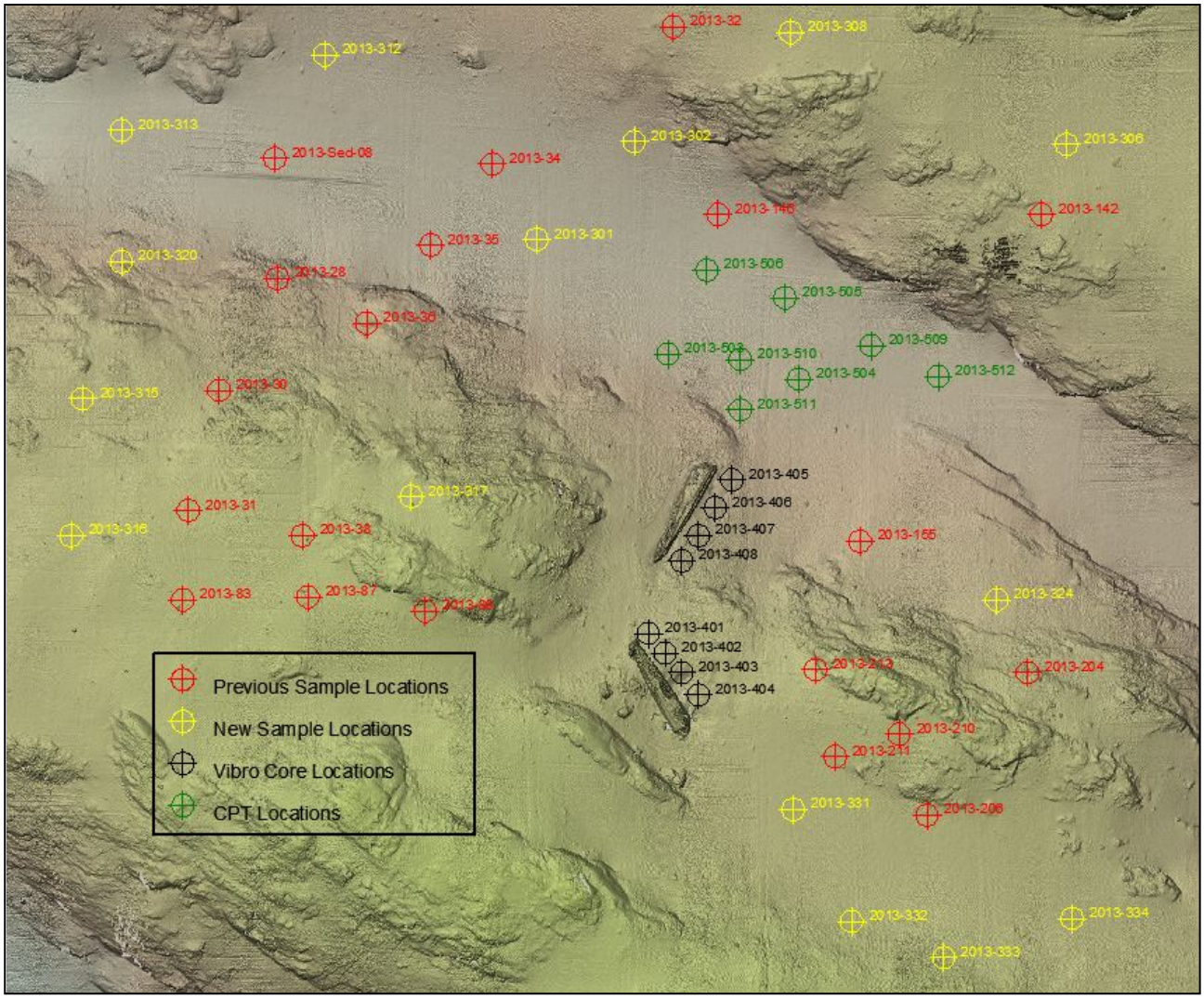


Figure 4.13 Geotechnical Sampling Locations (Not all completed)

4.4.1 Soil condition (NGI)

Result from the NGI report indicate a homogenous soil condition in the area, same was reported in 2006 (.ref /3/)

The geotechnical soil units 2006 and 2013 are shown in the Table 4.3 below.

Table 4.3 Geotechnical Soil Units (ref /3/)

Soil UNIT	Geotechnical Classification 2006	2013 Classification
I	SAND, gravelly, loose	Sandy, clayey SILT or clayey, silty SAND
II	CLAY, soft, silty, sandy	Soft to medium CLAY
III	SAND/GRAVEL, dense covering rock	***Not encountered 2013***

The vertical thickness of the geotechnical soil unit I varied from 0.0/ 0.15m to >1.7m, and soil unit II from 0/ >1.45m to >6.0m. The soil Unit III from the 2006 campaign were not encountered in 2013.

For further details regarding the results from the borehole logs, please see NGI report (ref /3/).

4.4.2 Mercury content analyses (NIVA)

NIVA performed mercury content analyses of the sediments from the 35 soil samples in Table 4.9 and from the 7 vibrocores in Table 4.6. The content of mercury was classified based on the classification system shown in the Table 4.4 below.

Table 4.4 Classification system for concentration of mercury in marine sediments (ref /4/)

	Class I Background	Class II Good	Class III Moderately polluted	Class IV Bad	Class V Very bad
Mercury (mg/kg) dry weight	**<0.15**	**0.15-0.63**	**0.63-0.86**	**0.86-1.6**	**>1.6**

The results from the 2013 mercury content analyses of the soil samples are shown in Figure 4.14 below, from NIVA report (ref /4/).

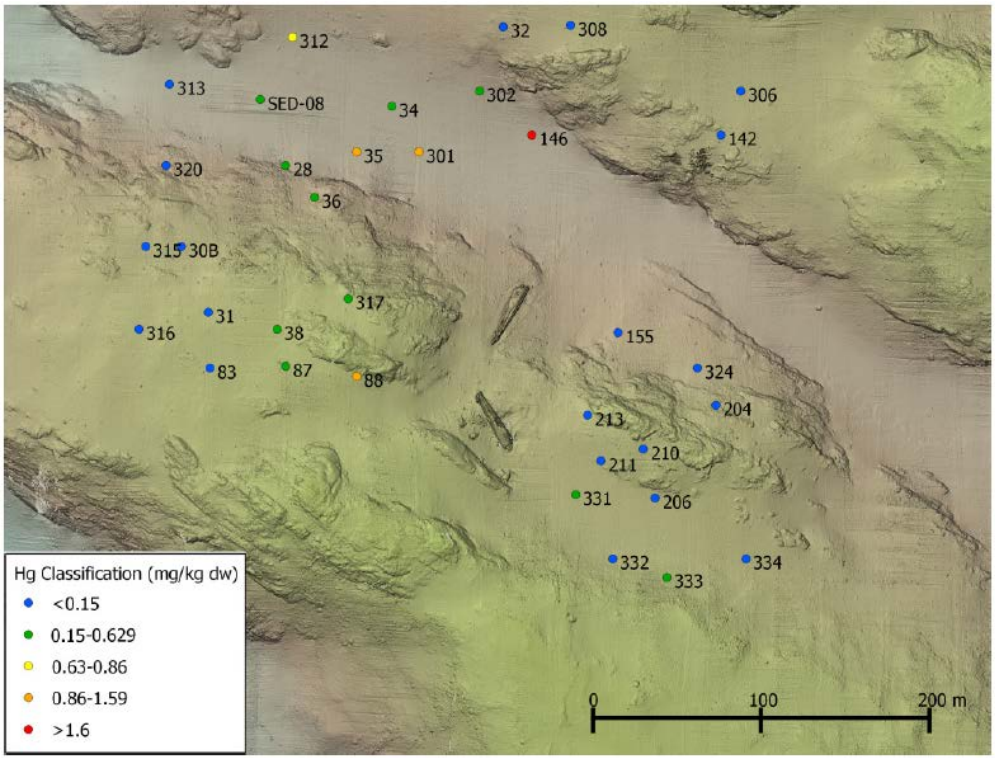


Figure 4.14 From NIVA report (ref /4/); mercury content in surface sediment (0-2cm) 2013

16 of the 35 soil samples were taken at same locations as samples from 2006, and 5 of these showed an increase in mercury content of more than 0,2 Hg (mg/kg). These five are listed in the

Table 4.5 below and are all located west or north from the wreck. The positions of the samples with highest increase of mercury contamination agree with the direction of the water current (north western direction).

Especially the sample taken at target/ station 146 north of the wreck show a substantial increase in mercury content, from class II in 2006 to class V in 2013.

Table 4.5 Increase of mercury content (2013-2006) of more than 0,2Hg (mg/kg)

Station	Hg (mg/kg) 2013	Hg (mg/kg) 2006	Difference 2013-2006
38	0,41	0,07	0,34
87	0,33	0,07	0,26
88	0,89	0,35	0,54
146	1,62	0,20	1,42
Sed-8	0,25	0,02	0,23

The other 11 samples at locations also taken in 2006, show more or less same value in 2013 (see NIVA report ref /4/ for full details).

The results from all of the analyses done for previous years (2003, 2005, 2006 and 2013) are presented in the Figure 4.15 below, from NIVA report (ref /4/).

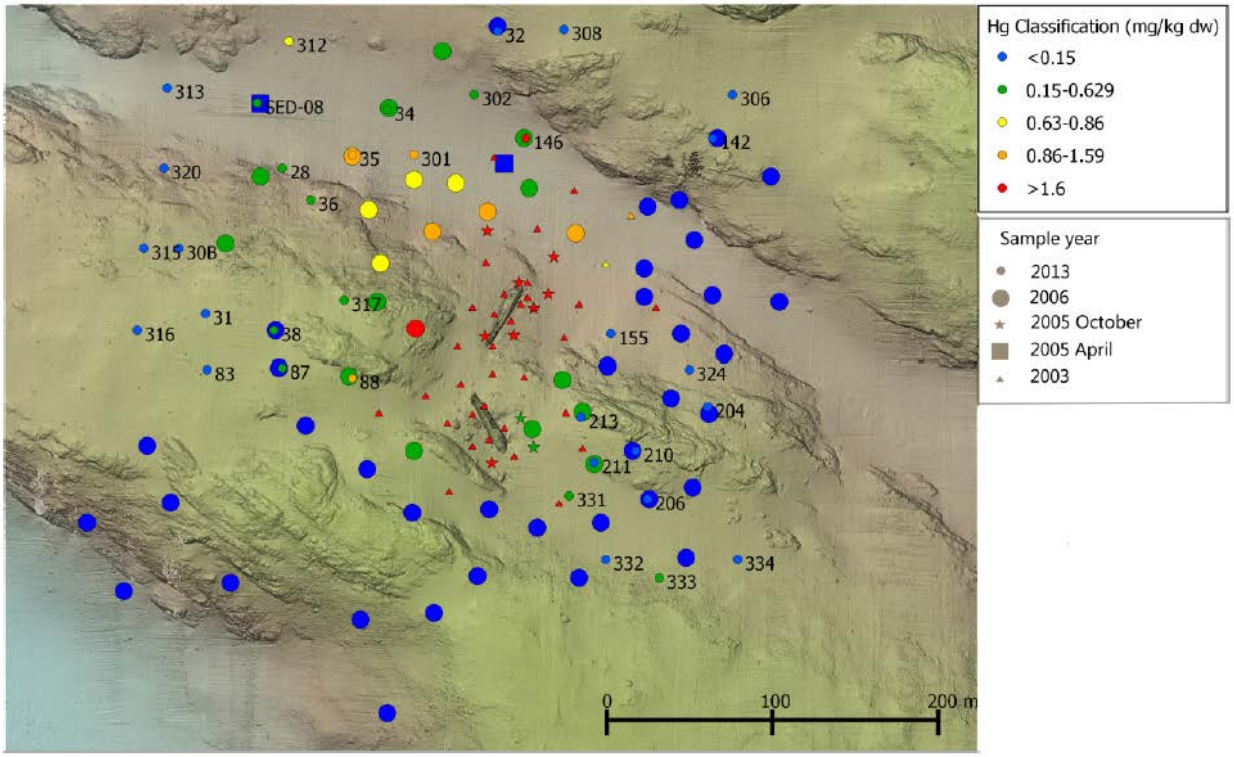
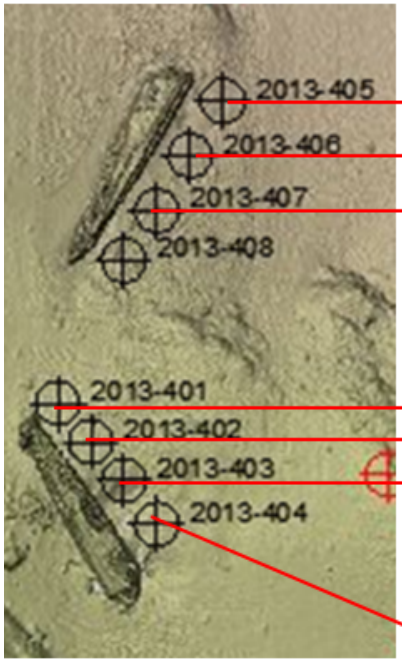


Figure 4.15 From NIVA report (ref /4/); Mercury content results for all years

The compilation of all the mercury analyses in the figure above (Figure 4.15) show that all samples classified as moderately polluted (Class III), bad (Class IIII) or very bad (Class V) are all located in the near vicinity of the wreck and west or north of the wreck. Samples taken east or south of the wreck is classified as good (Class II) or background (Class I).

The results from the vibrocores taken near the wreck all show a general high surface concentration of mercury (Figure 4.16), with decreasing contamination with sediment depth (ref /4/).



405	0-10 cm	87,6
405	50-60 cm	0,837
405	100-110 cm	0,128
405	110-120 cm	0,132
405	200-210 cm	0,075
405	210-220 cm	0,131
405	300-310 cm	0,060
405	310-320 cm	8,2

406	0-10 cm	3,0
406	10-20 cm	34,0
406	210-220 cm	23,8

407	0-10 cm	37,4
407	10-20 cm	18,4
407	50-60 cm	1,8

401	0-10 cm	3,6
401	10-20 cm	0,406
401	50-60 cm	0,365
401	100-110 cm	0,153
401	110-120 cm	0,103
401	200-210 cm	0,057
401	210-220 cm	0,137

402	0-10 cm	1,490
402	10-20 cm	0,018
402	50-60 cm	0,120
402	100-110 cm	0,092
402	110-120 cm	0,030
402	200-210 cm	0,039
402	210-220 cm	0,012

403	0-10 cm	0,067
403	10-20 cm	0,014
403	50-60 cm	0,006
403	100-110 cm	0,012
403	110-120 cm	0,036

404	0-10 cm	0,205
404	10-20 cm	0,209
404	80-90 cm	0,013
404	90-100 cm	0,002

Figure 4.16 Mercury analyses in vibrocores close to wreck

As seen from Figure 4.16 the mercury surface content in sample 2013-403 and 404 are low. This is most likely due to the dredging of surface sediments in this area in 2006. Sample 2013-402 is a few meters away from the dredged area.

Sample 2013-406 and 407 was found to contain visible traces of mercury, see Figure 4.17. The position of these samples close to the damaged area on the bow section of U-864 may indicate leaking canisters or may simply be residue from canisters damaged in the sinking. Sections of these cores with liquid mercury were not analysed (ref /4/).

Mercury was observed down to the end of sample 2013-405 and 406, however NIVA suggest this might be a result of contamination during cutting of the cores based on the lack of mercury in the middle of sample 2013-405 (ref /4/).

Figure 4.17 **Visible Mercury contamination in sample 2013-406 (ringed)**

Table 4.6 **Vibro core positions and timings**

Date	Time	Target	From target position		Actual position		Sample name
			Easting	Northing	Easting	Northing	
11.01.13	16:55	2013-401	261548.00	6745100.00	261546.51	6745102.08	2013-401VC
10.01.13	03:24	2013-402	261554.00	6745093.00	261553.14	6745093.83	2013-402VC
10.01.13	01:58	2013-403	261560.00	6745086.00	261559.10	6745086.00	2013-403VC
09.01.13	23:00	2013-404	261566.00	6745078.00	261563.48	6745076.48	2013-404VC
11.01.13	08:18	2013-405	261578.00	6745155.00	261576.93	6745152.58	2013-405VC
11.01.13	14:57	2013-406	261572.00	6745145.00	261571.56	6745147.93	2013-406VC
11.01.13	15:40	2013-407	261566.00	6745135.00	261564.61	6745135.31	2013-407VC (VC tilted)
11.01.13	15:52	2013-407	261566.00	6745135.00	261565.60	6745135.49	2013-407VC 2nd attempt
11.01.13	16:37	2013-408	261560.00	6745126.00	**Work Aborted**		2013-408VC

Table 4.7 **Gravity core positions and timings**

Date	Time	Target	From target position		Actual position		Sample name
			Easting	Northing	Easting	Northing	
12.01.13	10:36	2013-509	261 628.00	6745 203.00	261626.53	6745205.03	2013-509GC
12.01.13	11:40	2013-512	261 652.00	6745 192.00	261649.71	6745194.58	2013-512GC

Table 4.8 CPT positions and timings

Date	Time	Target	From target position		Actual position		Sample name
			Easting	Northing	Easting	Northing	
11.01.13	01:23	2013-503	261 555.00	6745 200.00	261 554.78	6745 200.31	2013-503 CPT
11.01.13	01:39	N/a	2m offset from 2013-503		261 554.35	6745 202.13	2013-503A CPT
11.01.13	03:06	2013-504	261 602.00	6745 191.00	261 603.29	6745 191.66	2013-504 CPT
10.01.13	23:41	2013-505	261 597.00	6745 220.00	261 597.92	6745 221.73	2013-505 CPT
11.01.13	00:29	2013-506	261 569.00	6745 230.00	261 569.51	6745 230.03	2013-506 CPT
10.01.13	22:35	2013-509	261 628.00	6745 203.00	261 627.89	6745 201.78	2013-509 CPT
11.01.13	02:12	2013-510	261 581.00	6745 198.00	261 580.91	6745 197.97	2013-510 CPT
11.01.13	04:20	2013-511	261 581.00	6745 180.00	261 580.45	6745 183.54	2013-511 CPT
10.01.13	17:08	2013-512	261 652	6745 192.00	261 652,01	6745 192,32	2013-512 CPT

Table 4.9 Soil sample positions and timings

Date	Time	Target	From target position		Actual position		Sample name
			Easting	Northing	Easting	Northing	
Previous locations							
12.01.13	17:11	2013-28	261 415.00	6745 227.00	261 428.33	6745 231.78	2013-28SS
12.01.13	18:13	2013-30	261 394.00	6745 187.00	261 365.63	6745 184.36	2013-30B SS
12.01.13	15:13	2013-31	261 383.00	6745 144.00	261 381.89	6745 145.27	2013-31SS
12.01.13	21:33	2013-32	261 557.00	6745 317.00	261 556.78	6745 314.15	2013-32SS
12.01.13	20:55	2013-34	261 492.00	6745 268.00	261 491.03	6745 267.02	2013-34SS
12.01.13	20:27	2013-35	261 470.00	6745 239.00	261 469.58	6745 240.10	2013-35SS
12.01.13	17:49	2013-36	261 447.00	6745 211.00	261 445.15	6745 213.36	2013-36SS
12.01.13	14:09	2013-38	261 424.00	6745 135.00	261 423.02	6745 135.14	2013-38SS
12.01.13	15:05	2013-83	261 381.00	6745 112.00	261 382.50	6745 112.05	2013-83SS
12.01.13	13:56	2013-87	261 426.00	6745 113.00	261 427.90	6745 112.62	2013-87SS
12.01.13	14:21	2013-88	261 468.00	6745 108.00	261 469.68	6745 106.53	2013-88SS
12.01.13	23:09	2013-142	261 689.00	6745 250.00	261 685.60	6745 249.60	2013-142SS
12.01.13	21:04	2013-146	261 573.00	6745 250.00	261 574.37	6745 250.10	2013-146SS
12.01.13	16:43	2013-Sed-08	261 414.00	6745 270.00	261 413.20	6745 271.10	2013-Sed-08SS
12.01.13	22:57	2013-155	261 624.00	6745 133.00	261 624.69	6745 133.00	2013-155SS
13.01.13	01:19	2013-204	261 684.00	6745 086.00	261 683.23	6745 090.19	2013-204SS
13.01.13	02:03	2013-206	261 648.00	6745 035.00	261 646.86	6745 035.22	2013-206SS
12.01.13	23:21	2013-210	261 638.00	6745 064.00	261 640.27	6745 064.14	2013-210SS
13.01.13	01:10	2013-211	261 615.00	6745 056.00	261 615.01	6745 056.95	2013-211SS
12.01.13	23:40	2013-213	261 608.00	6745 087.00	261 607.30	6745 083.54	2013-213SS
New locations							
12.01.13	21:22	2013-301	261 508.00	6745 241.00	261 507.28	6745 240.47	2013-301SS
12.01.13	20:48	2013-302	261 543.00	6745 276.00	261 543.37	6745 275.82	2013-302SS
12.01.13	22:41	2013-306	261 698.00	6745 275.00	261 697.75	6745 275.70	2013-306SS
12.01.13	20:39	2013-308	261 599.00	6745 315.00	261 597.23	6745 314.52	2013-308SS
12.01.13	21:13	2013-312	261 432.00	6745 307.00	261 432.48	6745 307.61	2013-312SS
12.01.13	17:23	2013-313	261 359.00	6745 280.00	261 359.15	6745 280.05	2013-313SS
12.01.13	15:30	2013-315	261 345.00	6745 184.00	261 344.78	6745 184.49	2013-315SS
12.01.13	15:21	2013-316	261 341.00	6745 135.00	261 340.78	6745 134.67	2013-316SS
12.01.13	14:34	2013-317	261 463.00	6745 149.00	261 465.60	6745 152.69	2013-317SS (no sample)
12.01.13	14:48	2013-317	261 463.00	6745 149.00	261 465.15	6745 152.83	2013-317SS 2nd attempt
12.01.13	17:34	2013-320	261 359.00	6745 233.00	261 357.17	6745 231.97	2013-320SS
12.01.13	22:50	2013-324	261 673.00	6745 112.00	261 671.83	6745 111.66	2013-324SS
13.01.13	01:01	2013-331	261 600.00	6745 037.00	261 600.27	6745 036.66	2013-331 SS
13.01.13	00:50	2013-332	261 621.00	6744 997.00	261 622.40	6744 998.66	2013-332 SS
13.01.13	01:53	2013-333	261 654.00	6744 984.00	261 653.78	6744 987.66	2013-333 SS

4.5 HEIGHT, TRIM AND LIST MEASUREMENTS

A comparison of MBE data collected during the previous survey in 2006 and that collected during Phase 3A was conducted in order to identify any movement of the stern section of the wreck. Profiles were compared every 2m along the length of the stern section. An example of the compared profiles are shown below.

From the evidence available it is believed that any movement of the stern section is negligible. It should be noted that there is an apparent movement between the two available data sets but this is due to a small piece of wreckage becoming dislodged from the very stern of the wreck. See Paragraph 0 for more details.

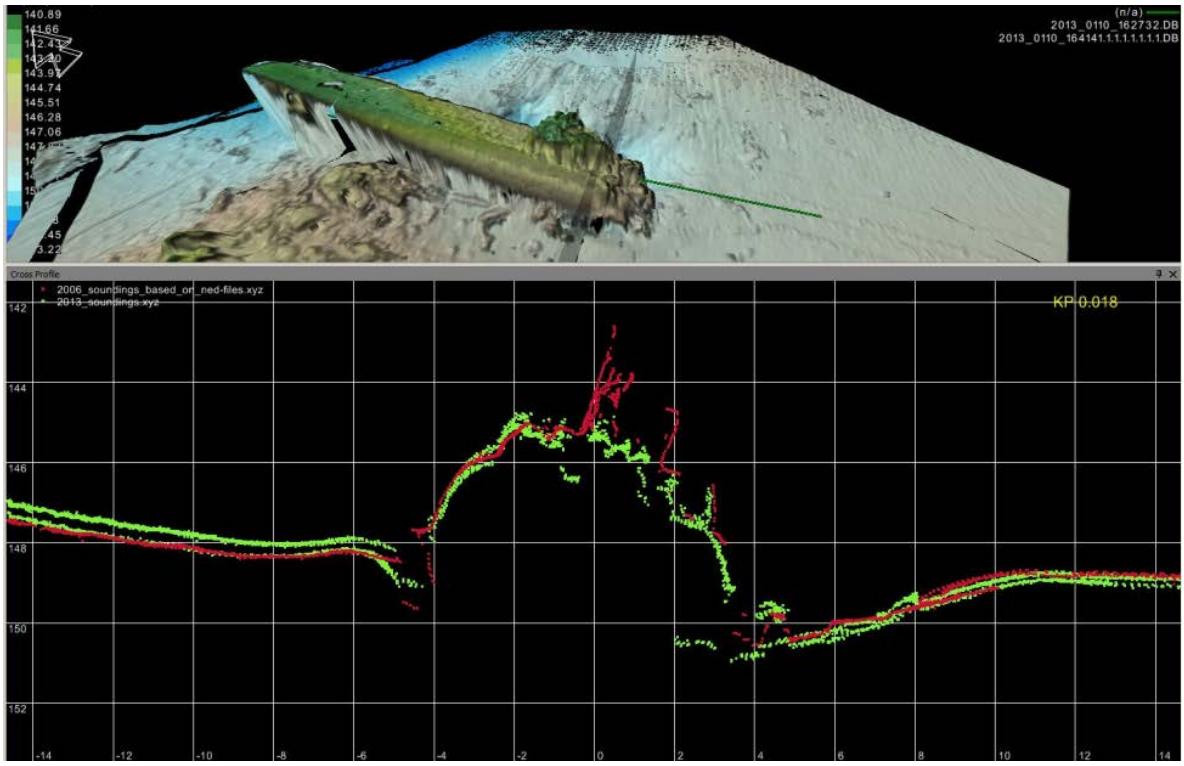


Figure 4.18 **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

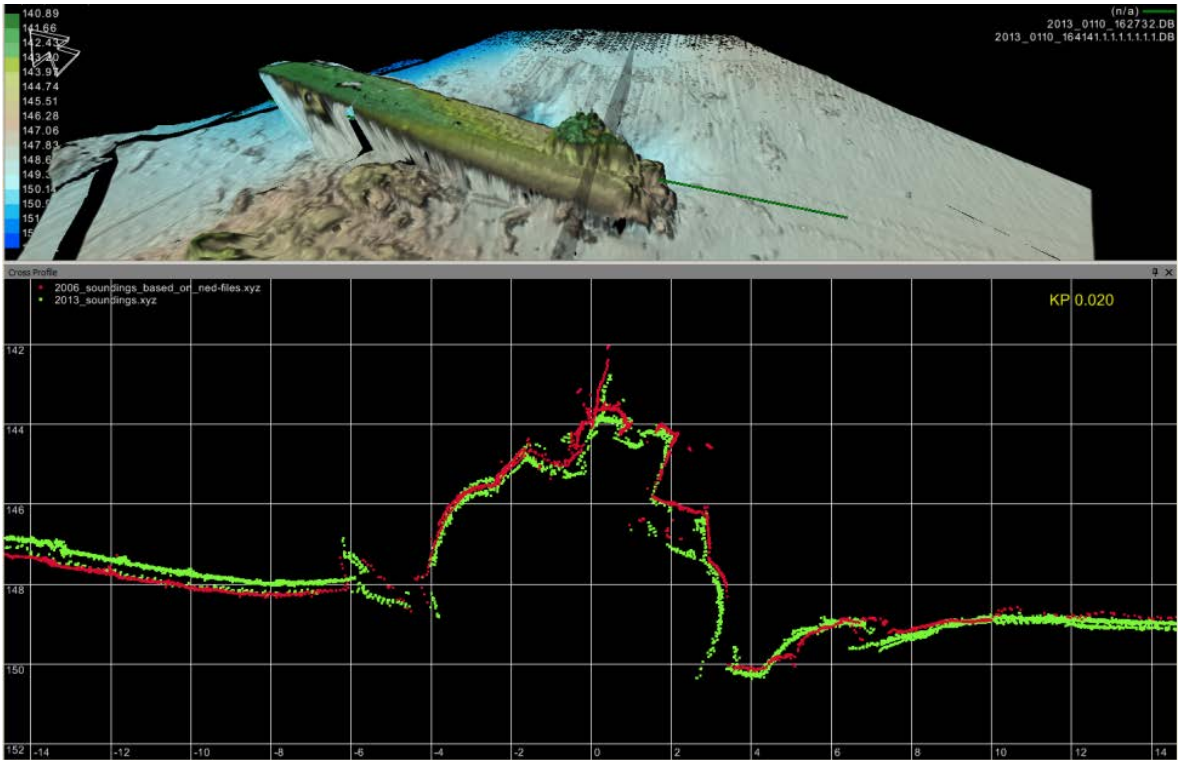


Figure 4.19 **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

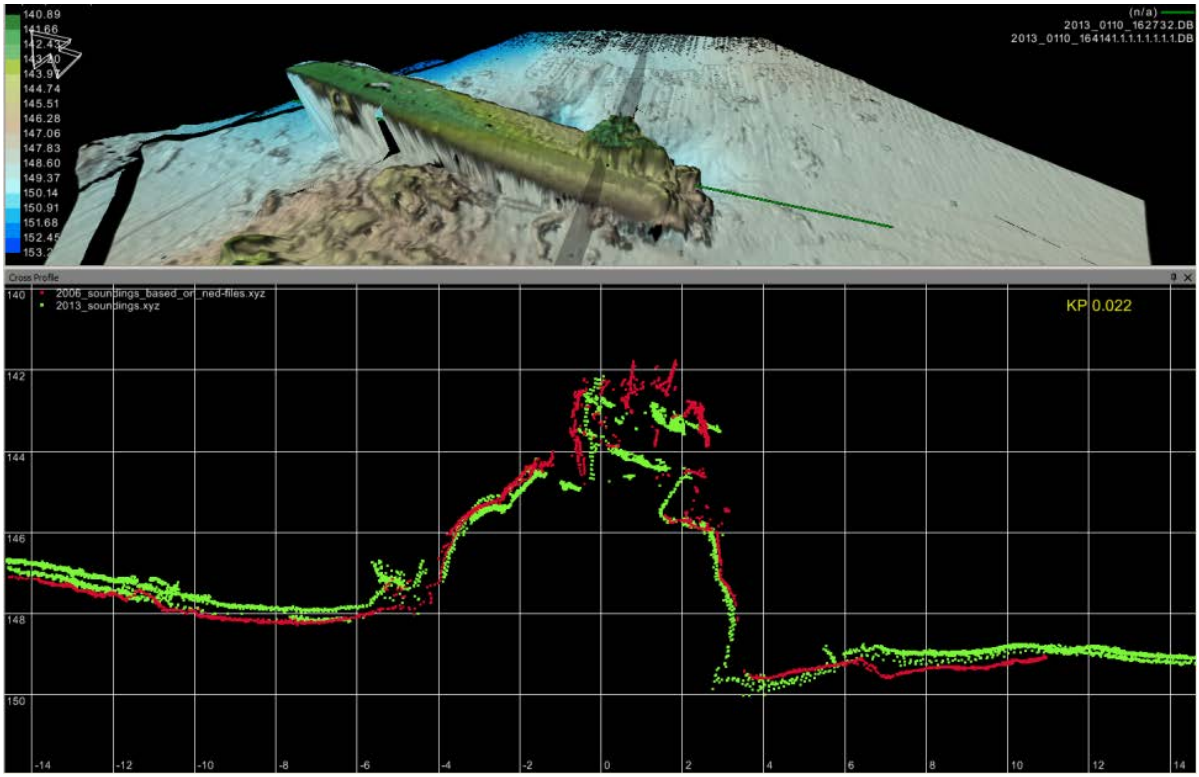


Figure 4.20 **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

.

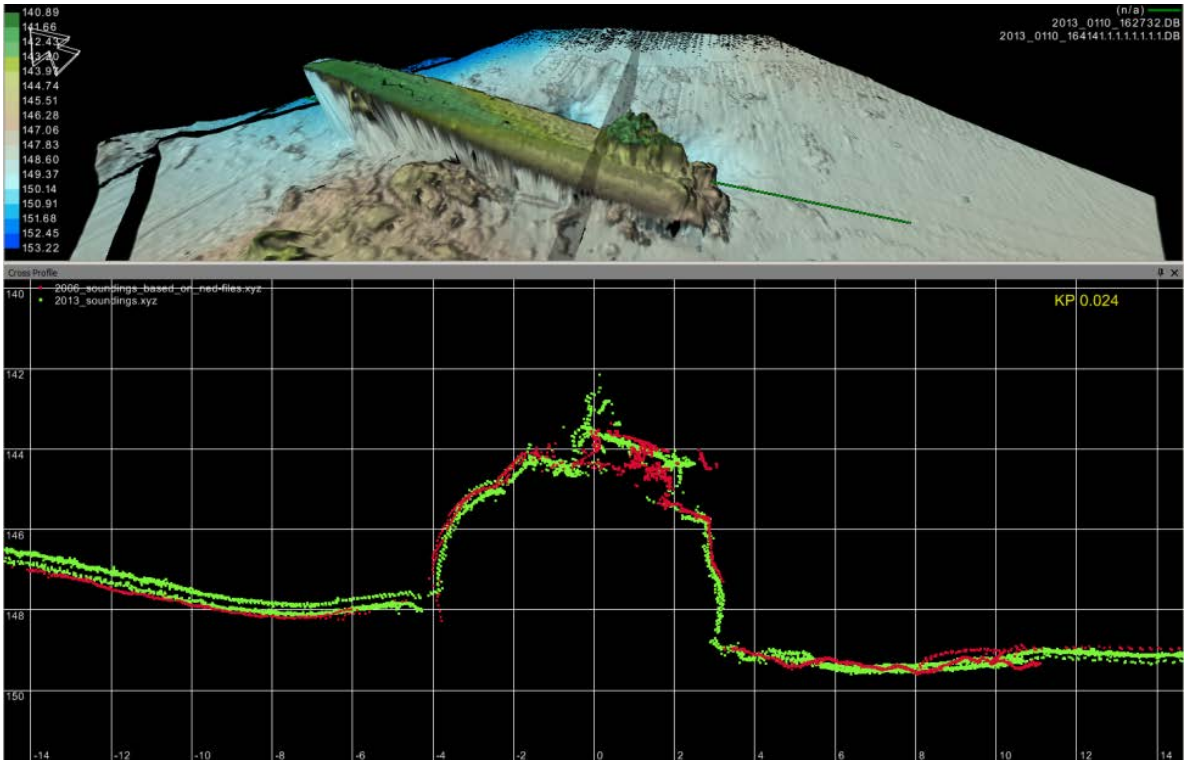


Figure 4.21 **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

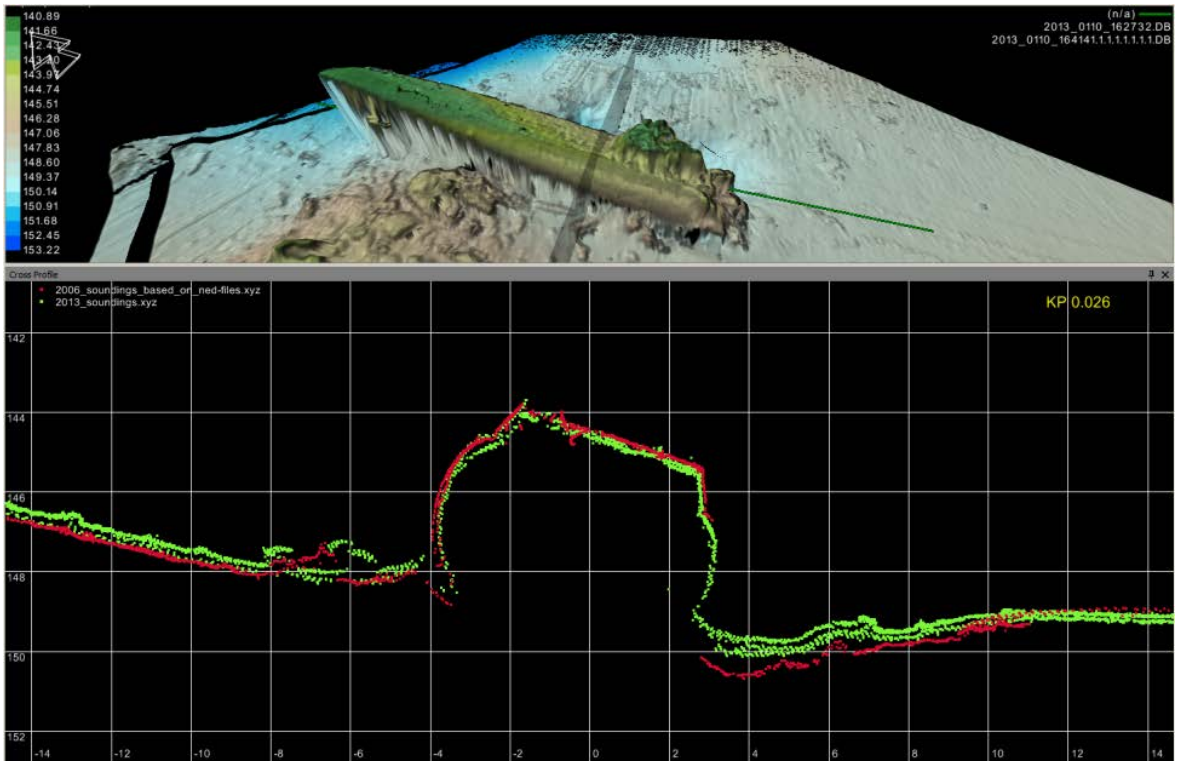


Figure 4.22 **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

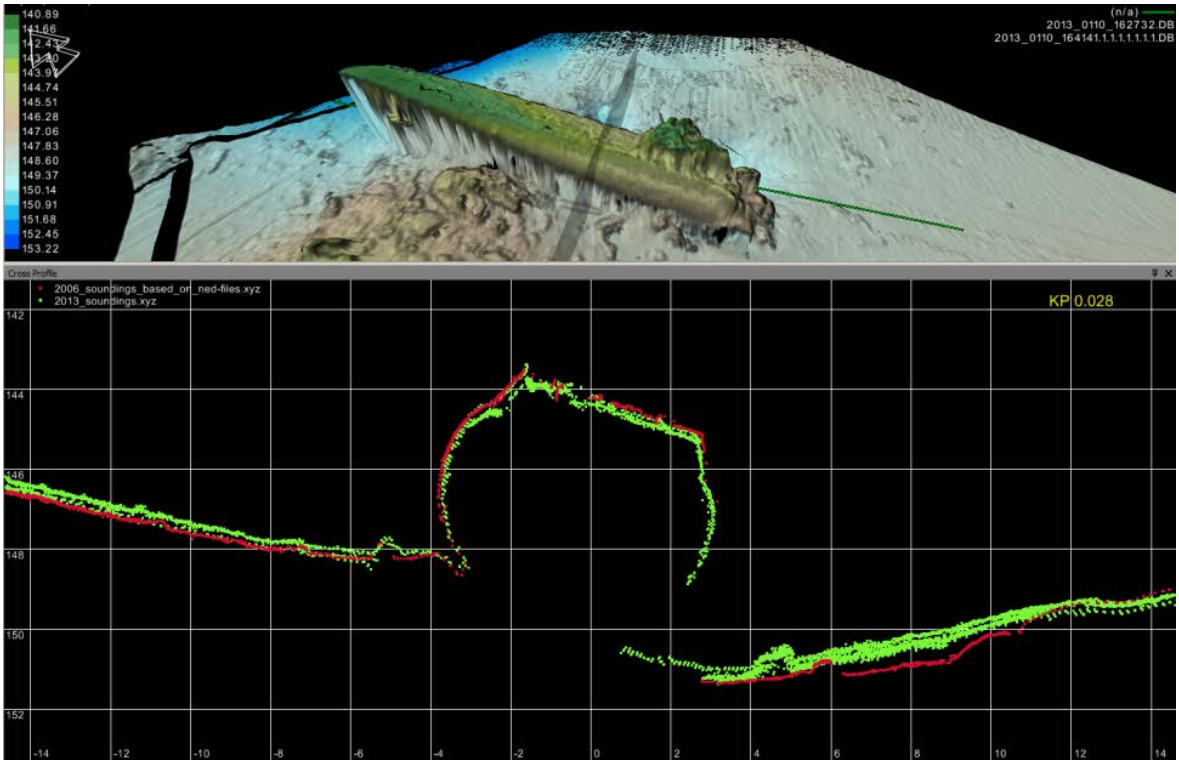


Figure 4.23 **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

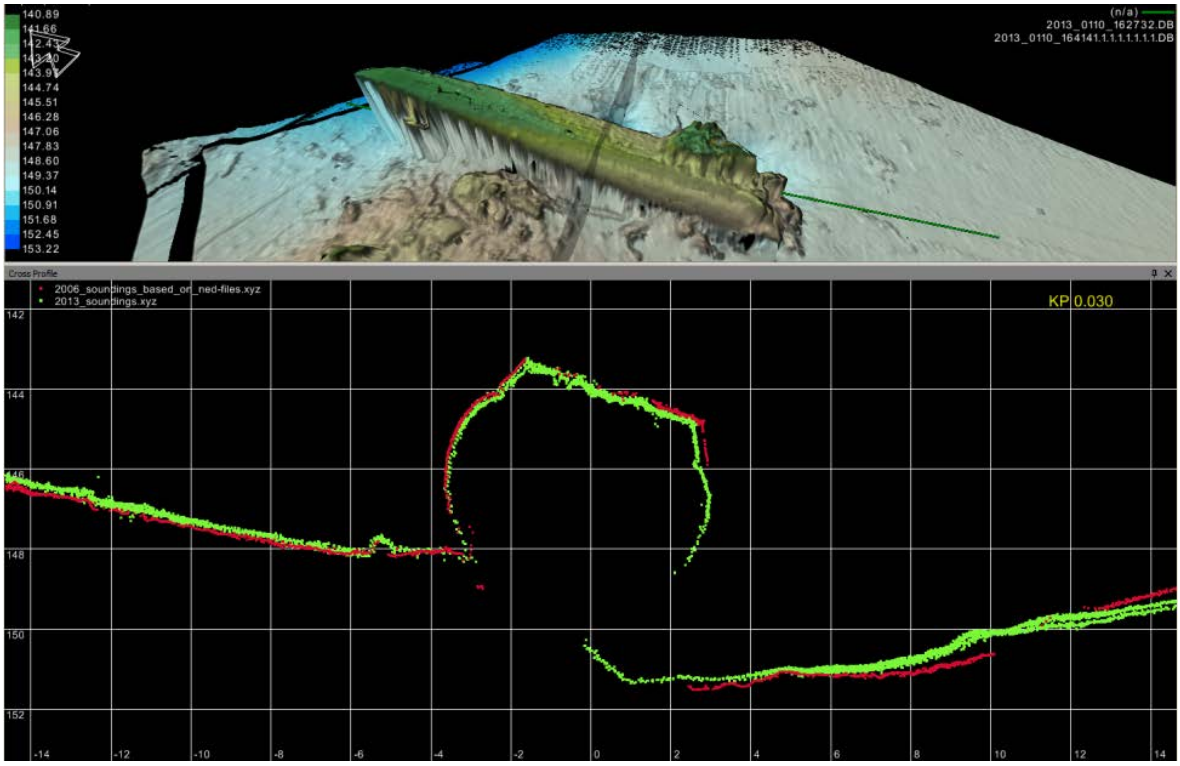


Figure 4.24 **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

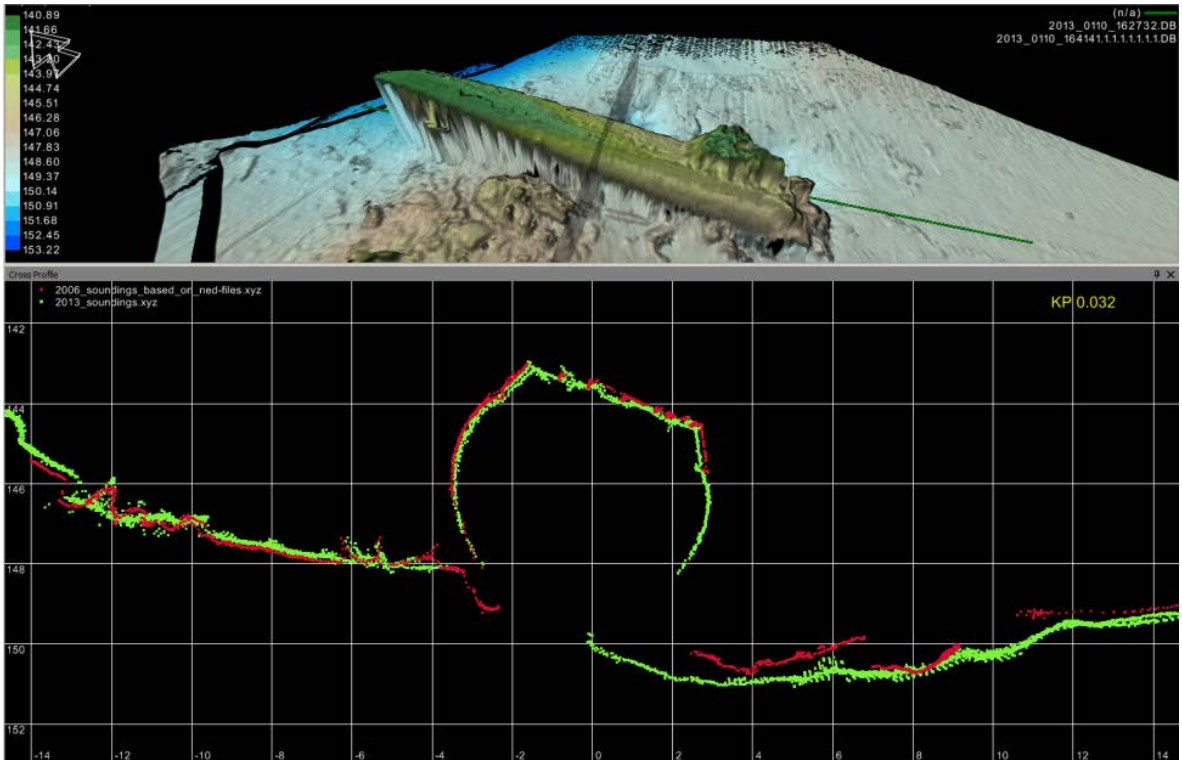


Figure 4.25 **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

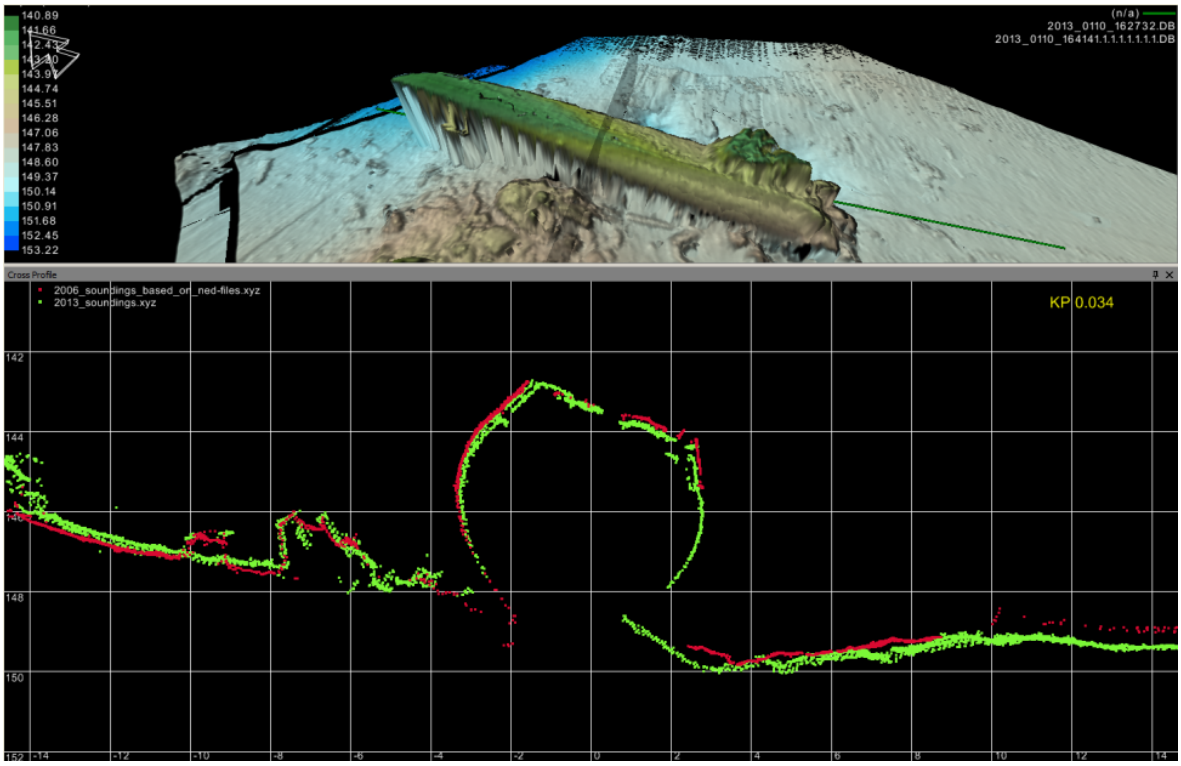


Figure 4.26 **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

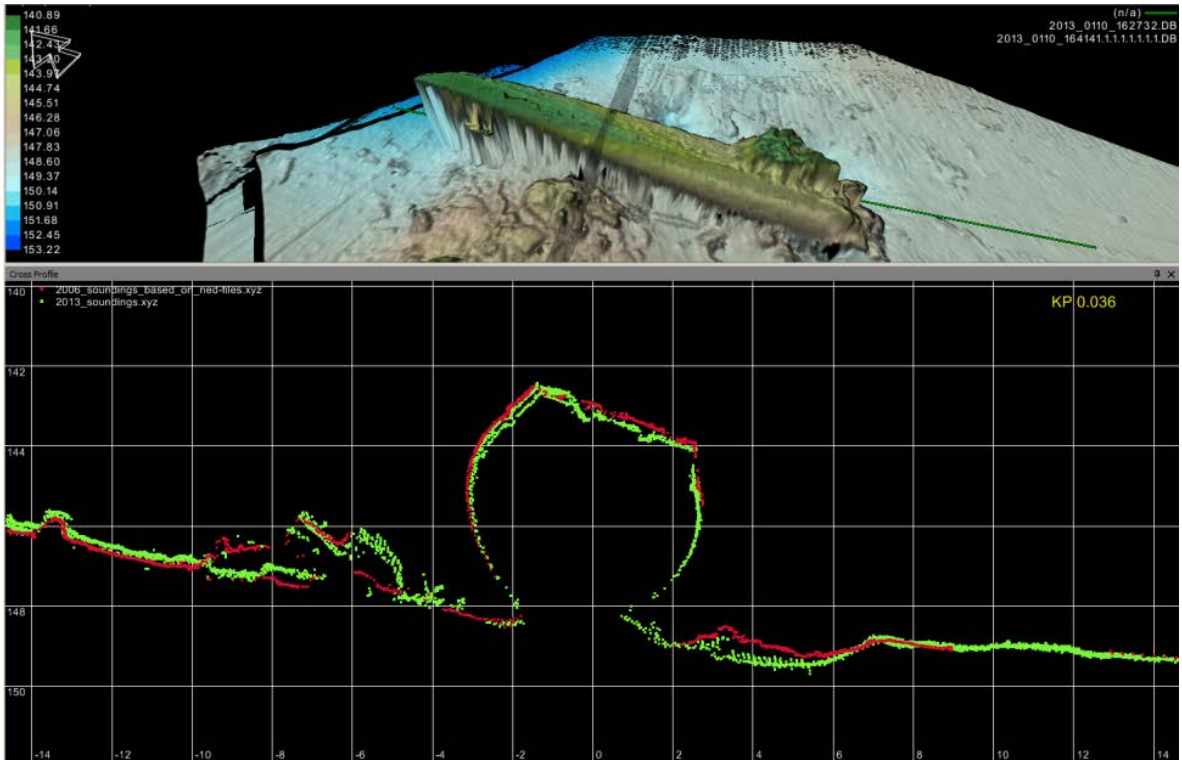


Figure 4.27 **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

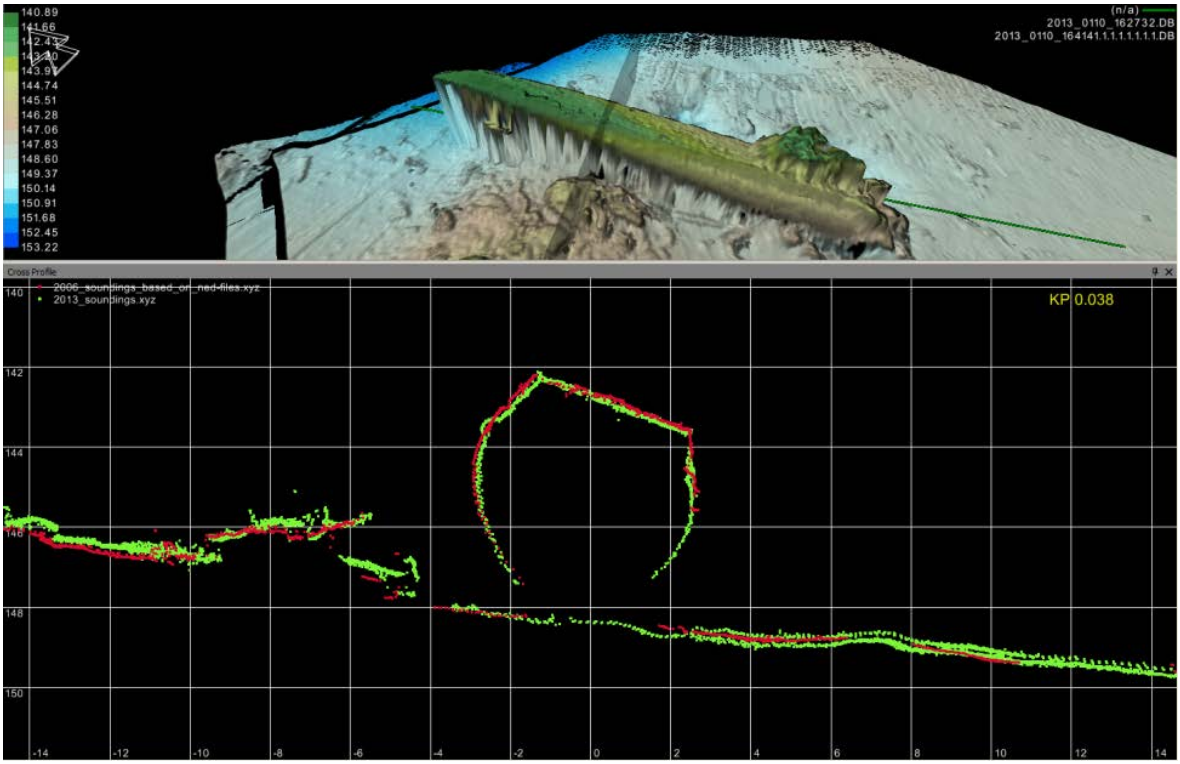


Figure 4.28 **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

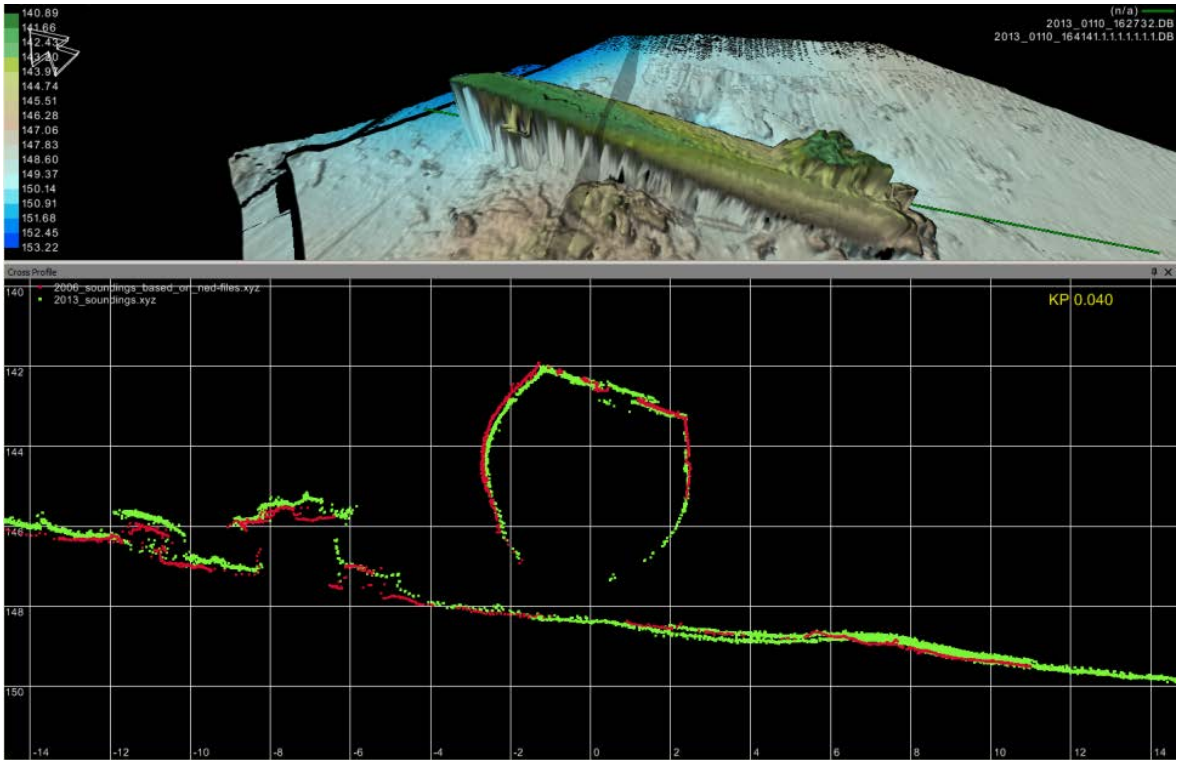


Figure 4.29 **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

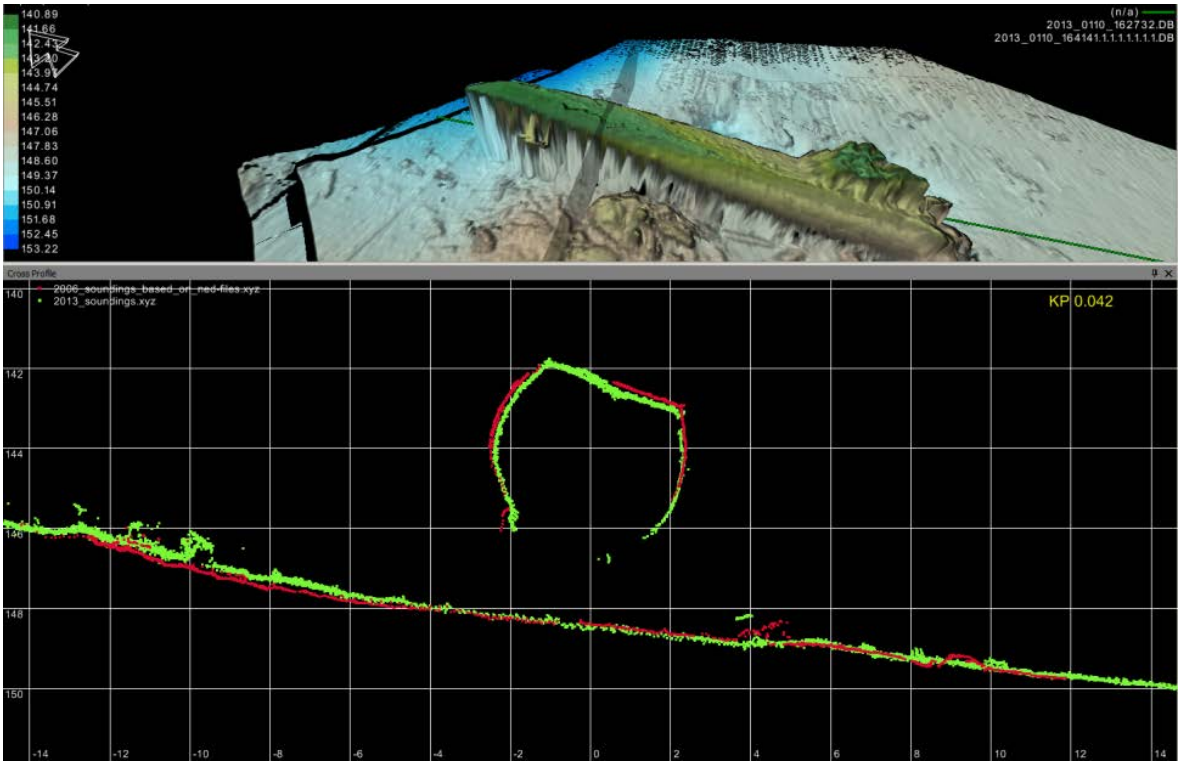


Figure 4.30 **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

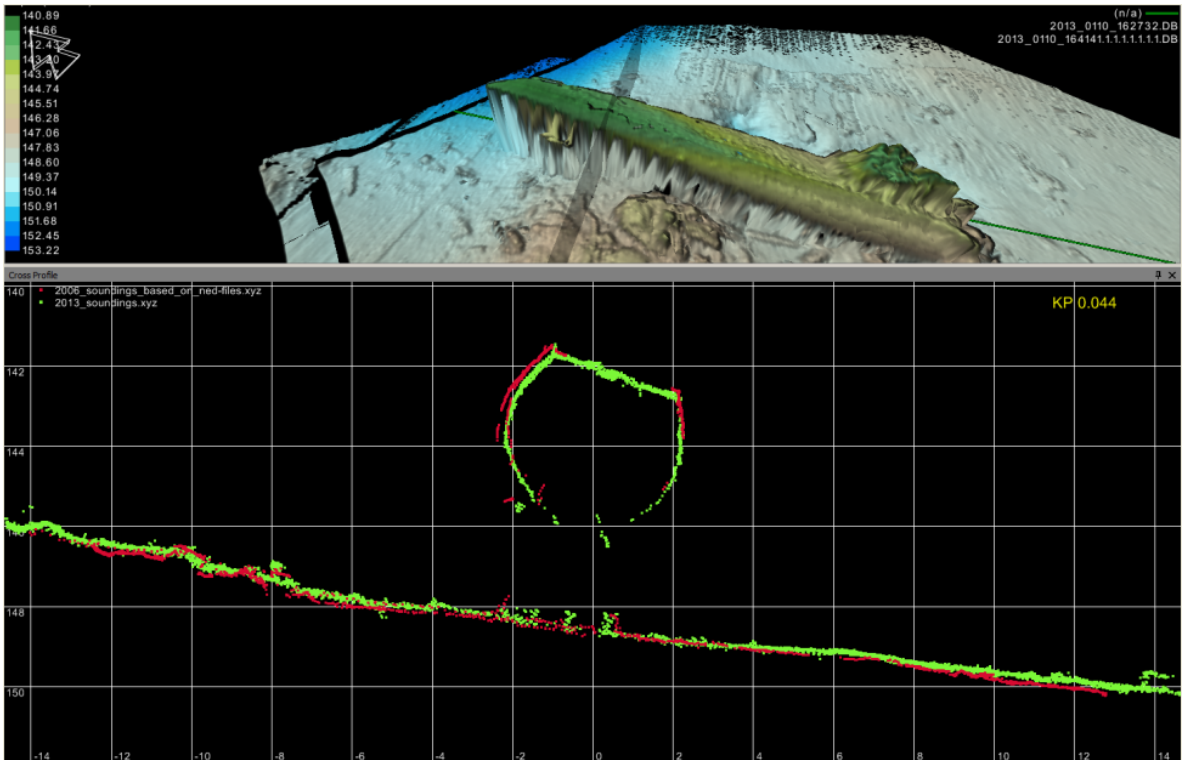


Figure 4.31 **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

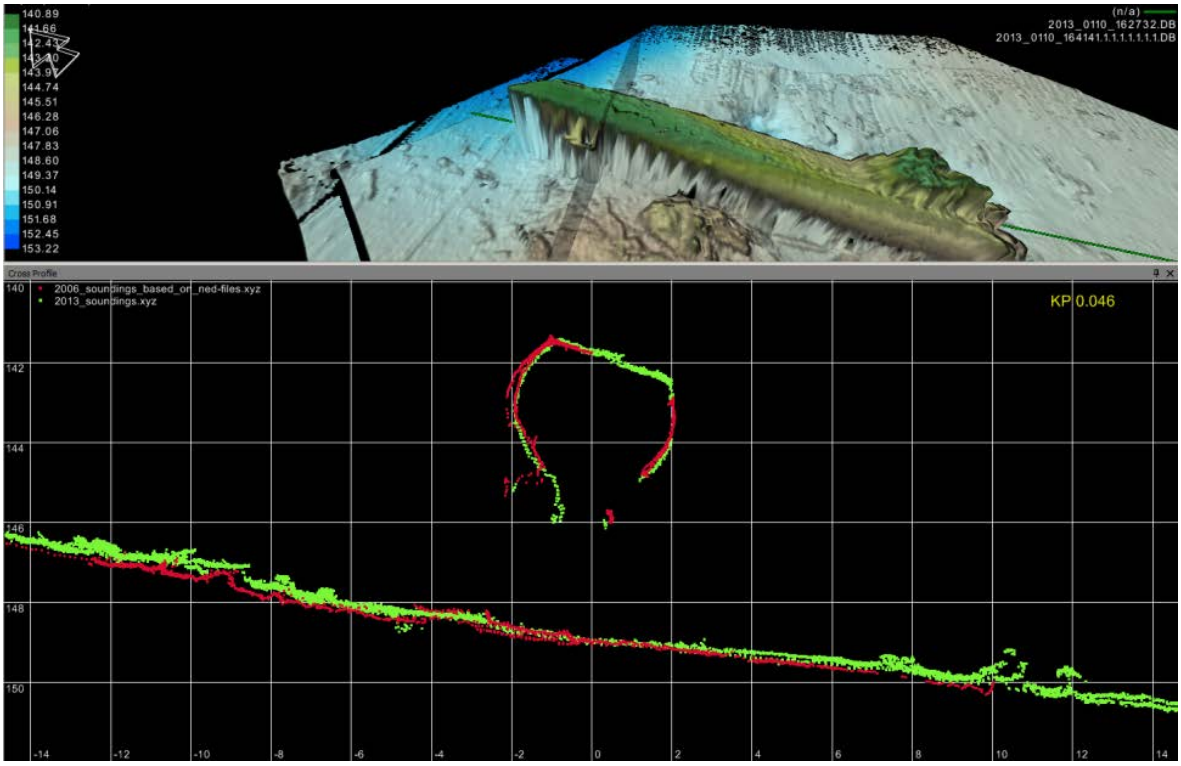


Figure 4.32 **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

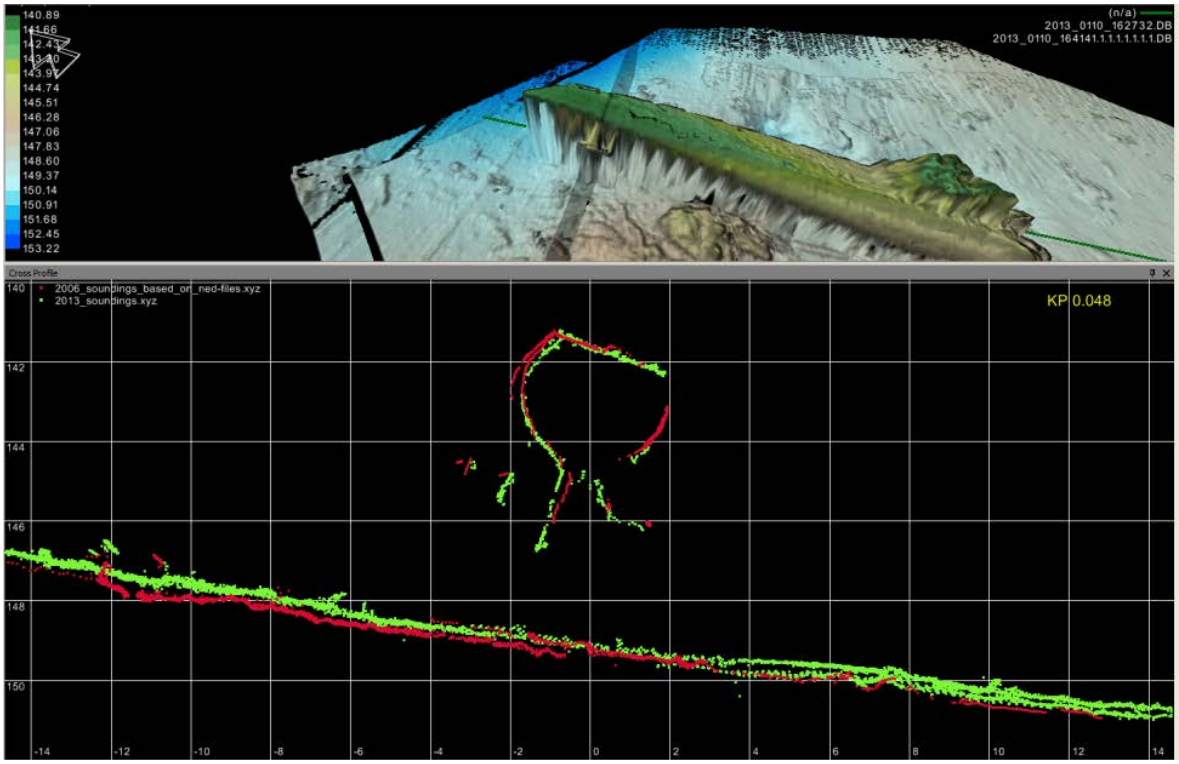


Figure 4.33 **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

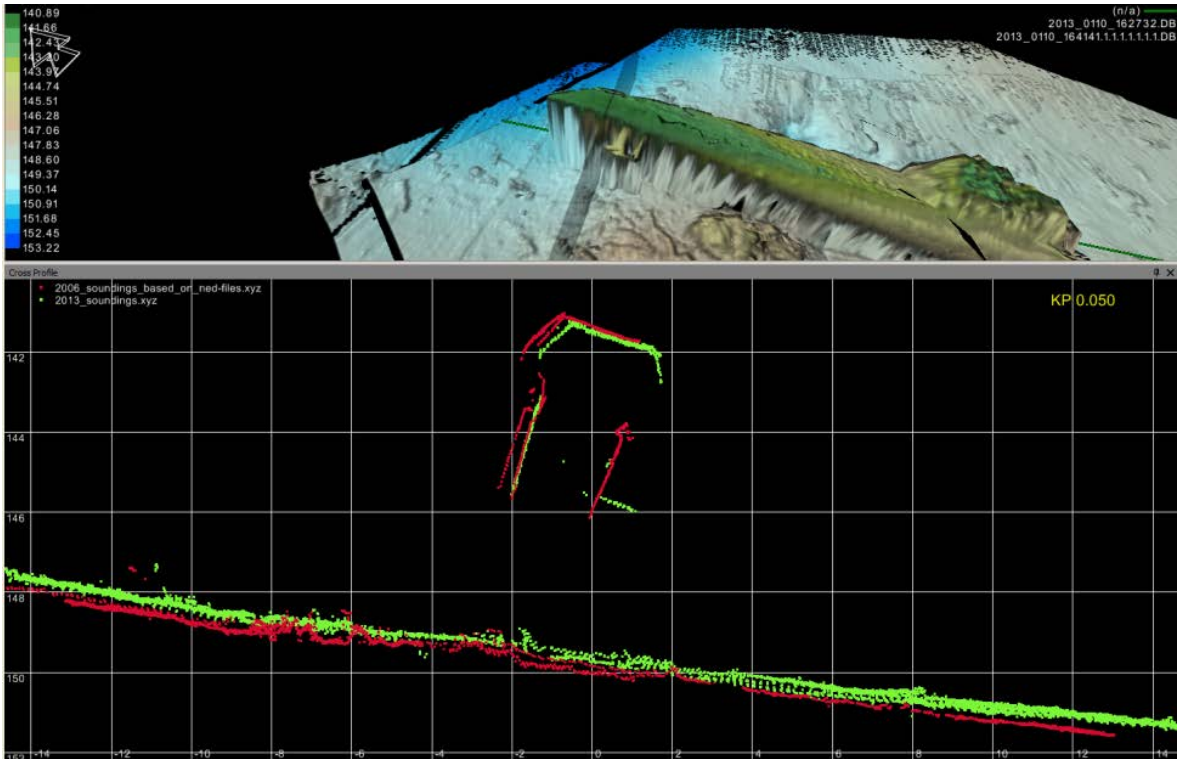


Figure 4.34 **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

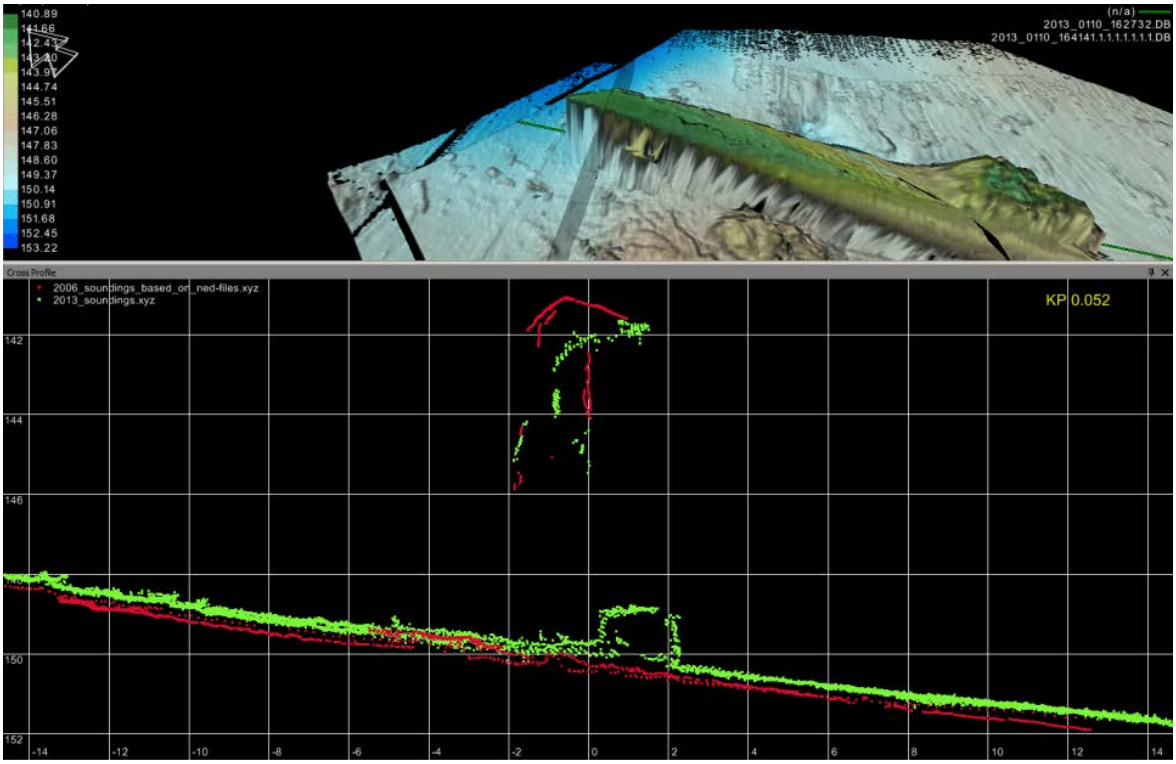


Figure 4.35 **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location. The fallen stern section can be seen centre of the profile**

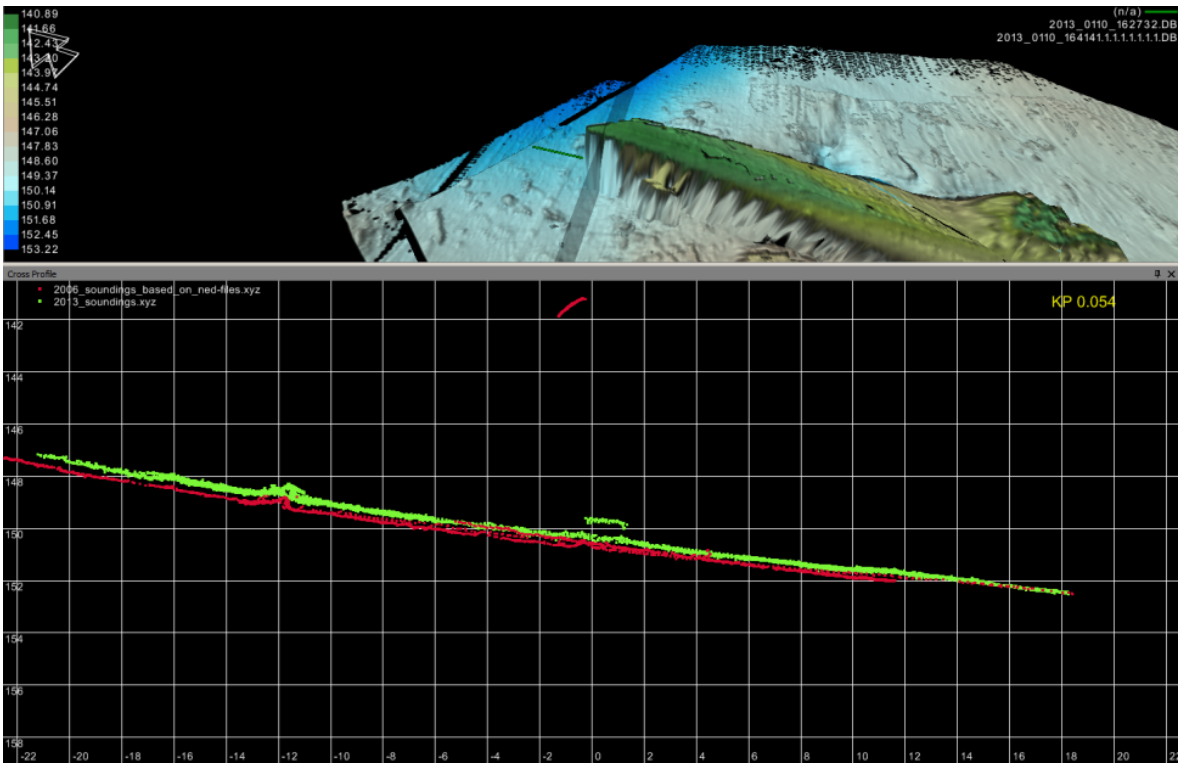


Figure 4.36 **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location. The fallen stern section can be seen centre of the profile**

4.6 SBP SURVEY

A survey was conducted using an Edgetech 2000 FSIU SBP system, with a CODA online acquisition system and processed offline, using DELPH Ixsea processing software. The survey was conducted between 23:51 on the 11th January 2013 and concluded at 04:36 on the 12th January 2013.

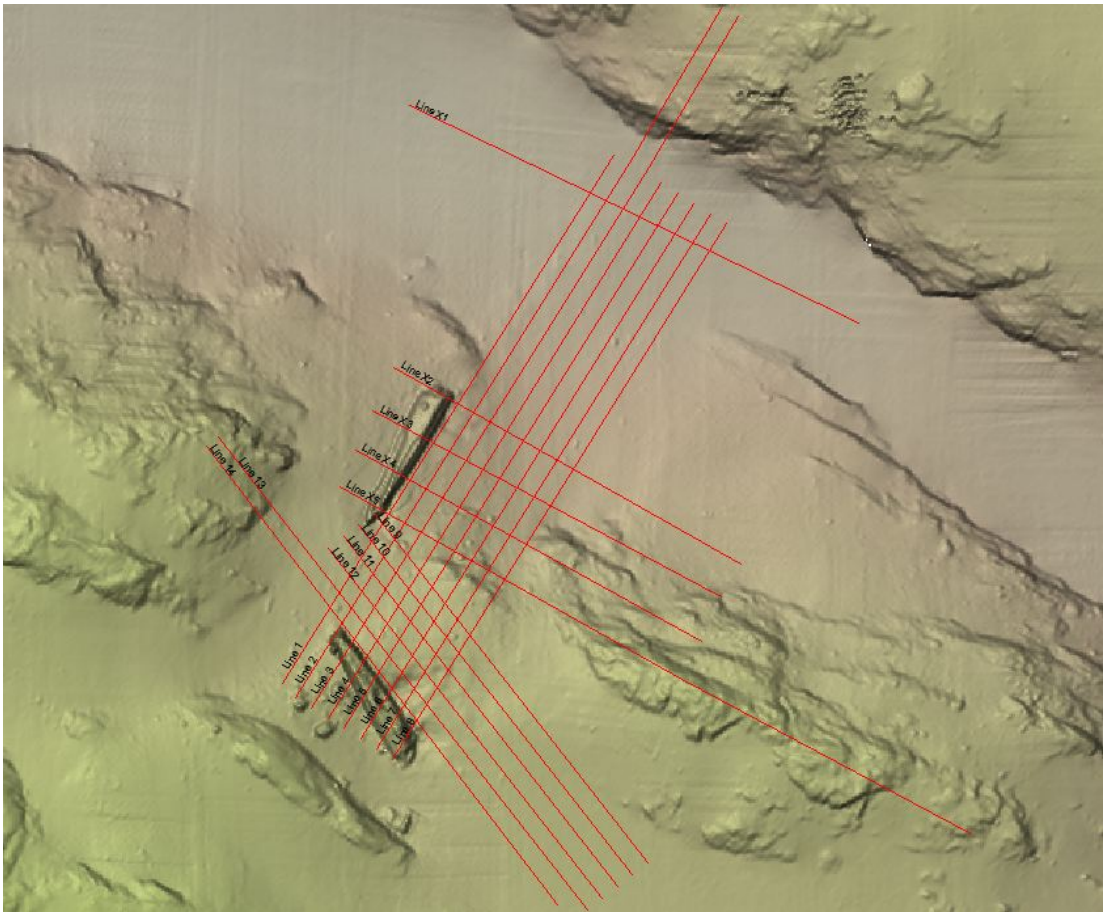


Figure 4.37

The data acquired was good throughout the survey, however due to the seabed characteristics the penetration achieved was limited.

This limited penetration was caused by the presence of a surficial layer of sand throughout the survey area.

The Sub-Bottom Survey of the rotation pits consisted of 18 lines in total covering both the Bow and Stern section rotation pits (Figure 2.4). In addition to the cross lines at the wreck site a supplementary cross line was ran in the trough North of the wreck site to tie the data in, and also gain more information for this area with respect to possible backfilling.

The objective for the sub bottom profile survey was to identify any bedrock outcrops, large underlying rocks or other debris which could be a potential hazard to a later dredging campaign.

To summarise, there were no bedrock outcrops or large rocks identified within the location of the rotation pits. The horizons (UNIT 1 & 2) were defined based on acoustic character and are defined in Table 4.10.

Table 4.10 SBP Unit Classification

Seismic UNIT	Acoustic Character	Geotechnical Classification
1	Largely Chaotic structure, with occasional slight internal structure. Limited penetration.	Surficial SAND with underlying soft-medium CLAY (soil units I and II)
2	No acoustic penetration	Consolidated CLAY/Glacial Till/Bedrock. (soil unit III from 2006)

Layers of sand/ gravel is also found within NGI`s Unit I and II (ref /3/). This can explain why the division between the seismic units (Table 4.10) are not always coherent with the division of the geotechnical soil units. This is furthermore most likely the reason why the seismic reflectors often appear to be intermittent.

Result for the NGI report indicate a homogenous soil condition in the area, same was reported in 2006.

For further details regarding the results from the borehole logs, please see NGI report (ref /3/).

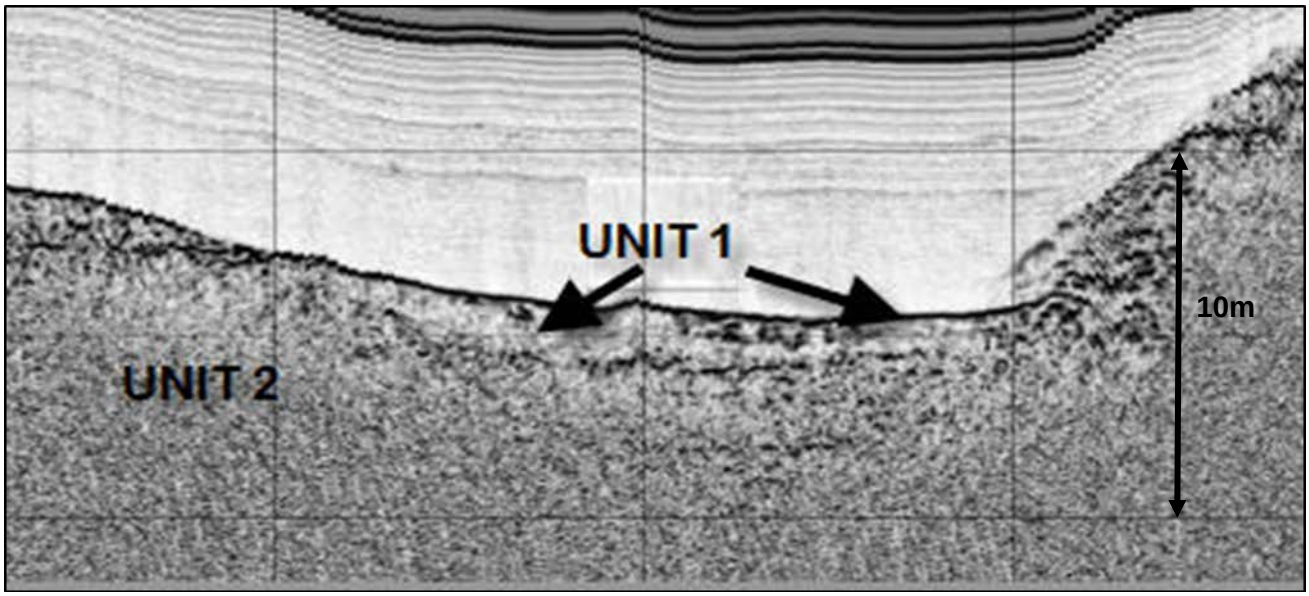


Figure 4.38 SBP data example from Line 8, showing Unit 1 & 2

One additional SBP line (X1) was surveyed in the northwest-southeast direction in the valley north of the bow section to provide sub-seabed information to support geotechnical assessment to be made prior to the sealing of the polluted area.

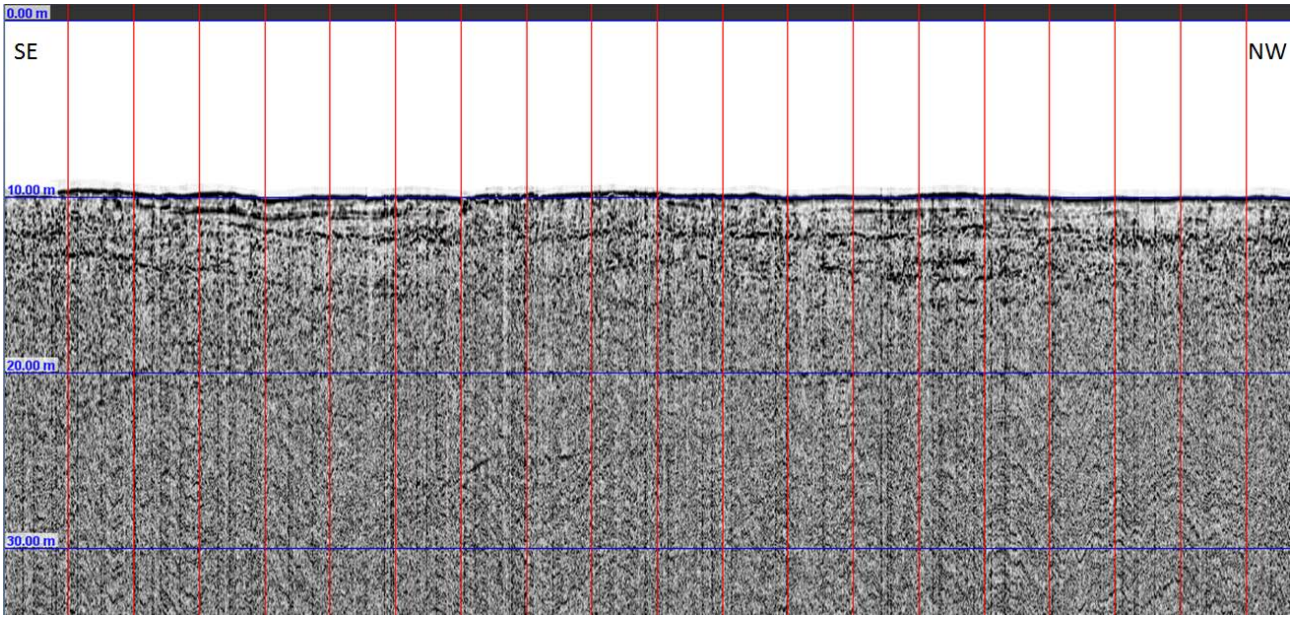


Figure 4.39 SBP line X1, vertical and horizontal scale lines 10m

4.7 OIL RECOVERY

The Oil Recovery stage of the project was completed the 12th March 2013.

The main objective was to recover any oil residue from the tanks of the U-864. This specific operation was performed by FRAMO (ref /5/).

The conditions of the weld seems for the outer shell of the fuel tanks were found in a poor condition. Due to the poor state of condition, the focus changed during operation from oil recovery to verification survey for most of the fuel tanks. If there were any uncertainty, oil recovery of a tank was commenced.

Oil recovery was done for 3 of the 16 tanks on the U-864 (tank 4A, 2 and 3A), and only minor quantities of oil was recovered from those 3 tanks (Figure 4.40).

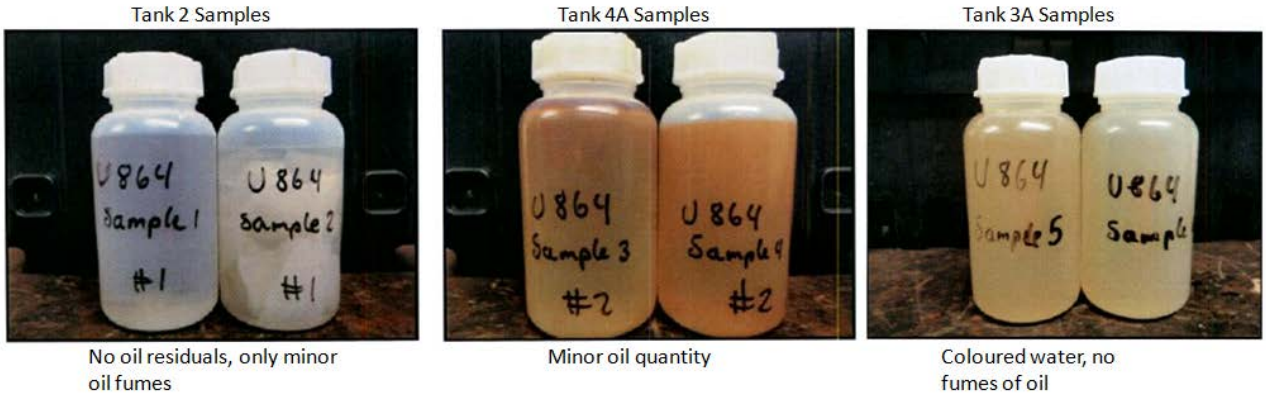


Figure 4.40 Oil recovery samples (ref /5/)

No further oil residuals or any leakage were observed at the final survey.

For more details of this operation, please refer to the completion report from FRAMO (ref /5/).

4.8 VOR02- AIR POCKETS

Initial scope of work for Phase 3A included evacuating possible air pockets inside the U-864 wreck, however this was put on hold until the Oil Recovery task was completed. The VOR02 of evacuating possible air pockets from the U-864 wreck was commenced the 17th March 2013.

Main task was to evacuate possible air pocket inside the aft wreck section, to resolve the issue with unknown wreck stability.

A cut was performed in the aft section pressure hull, air evacuation continued for approximately 6hrs. We assume that aft water tight sections have been completely flooded.

4.9 VOR03 - OIL LEAK AND POSITION OF U-864

A few days after completion of the Oil Recovery campaign, DSNO was required to perform an investigation of oil leakage from U-864. This work was commenced the 21th March 2013. No oil was visible on sea surface upon arrival in calm sea with no wind.

Oil was found to leak from the first cut at aft section done during the VOR02 operation, see Section 4.8 above.

Oil was spotted coming out of cracks around the stern section, however this is most likely oil trapped inside or under fuel tank plates. The level of oil leak was measured to be approximately 0.3L/hr (Figure 4.41).

Figure 4.41 Oil leak rate test

By close inspection of the stern section it appears little or none movement of the wreck since the last “As-left” survey (17th March 2013), see example in the Figure 4.42 below.

Figure 4.42 Position comparison of U-864

A close visual inspection was performed of the front section, and no sign of movement or oil leaks was indentified. For more details, please refer to the Identification of Oil Leak, and Position Verification of U864 Field Memo (ref /6/).

4.10 SURVEY CONCLUSIONS

The project were performed without any adverse events related to health, safety and environment.

The multibeam (MBE) survey 2km by 2km centred over the U-864 wreck, didn't show any sign of any additional wreckage or anomalous feature in the survey area.

The High Definition video survey of the West and South West side of the U-864 wreck resulted in the establishment of a clear zone area, as there were none identifications of debris or targets as possible explosives.

The High Definition video survey of the wreck and debris resulted in a revision of the estimated torpedo impact point and discovery of the loss of the extreme end of the stern section. The total length of the intact keel is possible up to 4.0m longer than earlier calculations, this may reduce the total amount of Hg pollution on the seafloor in the area.

The keel on the Stern end is exposed for approximately 2.5m at the starboard rear end.

The positively identification of the U-864 snorkel that was mounted amidships and in close proximity to the conning tower, the entire pressure (water tight) section of the conning tower, a part of the saddle tank from the area of the control room, the upper works of the conning tower and "Wintergarden" and the attack periscope are all main parts of the "missing" mid section. They are all found in close vicinity to the stern section. The mounting pedestal for the "Underwasserzieloptic" (UZO) from the port forward area of the conning tower of U-864 was identification and recovery to surface for further investigations.

Geotechnical survey was conducted with the purpose of obtaining geotechnical data in the rotation pits and to gain more information about the sediments on the slope and at the bottom of the trough.

The polluted area has been mapped and at one location the surficial sediments show significantly more pollution with Hg moving from class II (Good) to class V (Very bad).

The stern section of the wreck is situates in the same stable position as measured at end of Phase 2 in 2006. The difference seen in the multibeam (MBE) between the surveys are negligible.

No bedrock outcrops or large rocks was identified within the location of the rotation pits.

5 ASSESSMENT SUMMARY

This Section will give a short update of the facts used for the current assessment given in Phase 2 for the U-864 project.

1. The location of the mercury cargo is not documented, but the keel section is the most natural place for storage of the Hg canisters. No changes since 2006.

2. The condition of the keel is unknown. No changes since 2006, but the keel is exposed for a length of 2.5m and up to 0.4m in height at the starboard end of the Stern Section. This may enable a further survey of the exposed area.

3. The condition of the mercury canisters inside the wreck are unknown. No changes since 2006.

4. The geotechnical survey shows the slope where the Bow section is situated is unstable. No changes since 2006.

5. The condition and location of the ammunition in the wreck is not known. No changes since 2006.

6. It's not known how firmly the wreck parts are embedded in the seabed, and thus how much work will have to be done in order to release the wreck parts prior to recovery. Phase 2 of the project stated that the Stern Section of the wreck is not embedded in the clay. No changes since 2006.

7. A limited area of approximately 30 000m^2 of the seabed is so heavily polluted that further measures have to be implemented. The sediments around the wreck parts are particularly heavily polluted. A few soil samples showed an increase of mercury content between 2006-2013, all of them north or west of the wreck and in accordance with the water current direction. Besides from that, no changes since 2006.

8. Environmental monitoring of the dredging operations shows heavy mercury pollution of the sea water. Larger dredging operation should not be performed without adequate measures for stopping any further spread of mercury. No changes since 2006.

9. Covering the polluted area is environmentally necessary and technical feasible. There will have to be undertaken investigations regarding methods for covering the area with different topographical and geotechnical properties. No changes since 2006.

10. DNV strength measurements from 2005 shows that its technical possible to salvage the wreck parts. No changes since 2006.

11. The salvage of the wreck parts will lead to a significant marine operation in addition to that the polluted area may need to covered, which will be result in large expense. No changes since 2006.

6 DATA INDEX

6.1 HARD COPY DELIVERY

Not applicable for this delivery.

6.2 DIGITAL REPORT DELIVERY

6.2.1 REV. 02

Uploaded to the ftp server 20.02.2013: (/External-Users/Kystverket/600225-TR-DSNO-KVK-0010)
15 x Charts (PDF format)

Uploaded to the ftp server 21.02.2013: (/External-Users/Kystverket/600225-TR-DSNO-KVK-0011)
1 x Report (DOCX/PDF formats)
26 x DTM files (ASCII format)
2 x NaviModel Projects (NMP format)
1 x NaviModel Software (EXE format)
1 x Sounding file (ASCII format)

NOTE: Transmittal 600225-TR-DSNO-KVK-0008 was sent to Kystverket 18.01.2013 containing:
1 x USB disc (S/N: WX91EC1FFLF1) containing:
HD Video files (format mp4)
600225_U864_Video Index.xlsx
README.txt
VisualSoft program
600225_U864_DirPrint.txt

6.3 CHART INDEX

Chart No.	Rev.	Scale	Cart Title and Area
600225-SSKO-G59-0001	02	1:5000	Bathymetry for MBES Grid SUrvey
600225-SSKO-G59-0002	02	1:5000	Shaded Relief for MBES Grid Survey
600225-SSKO-G59-0003	02	1:2000	ROV Track for MBES grid Survey
600225-SSKO-G59-0004	02	1:2000	ROV Track for MBES grid Survey
600225-SSKO-G59-0005	02	1:2000	ROV Track for MBES grid Survey
600225-SSKO-G59-0006	02	1:2000	ROV Track for MBES grid Survey
600225-SSKO-G59-0007	02	1:1000	Geotechnical Samples Locations
600225-SSKO-G59-0008	02	1:250	UHD-864 – MBE and HD Video Surveys
600225-SSKO-G59-0009	02	1:500	SBP Survey of Rotation Pits – Longitudinal Profiles
600225-SSKO-G59-0010	02	1:500	SBP Survey of Rotation Pits – Longitudinal Profiles
600225-SSKO-G59-0011	02	1:500	SBP Survey of Rotation Pits – Longitudinal Profiles
600225-SSKO-G59-0012	02	1:500	SBP Survey of Rotation Pits – Longitudinal Profiles
600225-SSKO-G59-0013	02	1:500	SBP Survey of Rotation Pits – Longitudinal Profiles
600225-SSKO-G59-0014	02	1:500	SBP Survey of Rotation Pits – Longitudinal Profiles
600225-SSKO-G59-0015	02	1:5000	Bathy and Shaded Relief for MBES Grid Survey

6.4 DIGITAL VIDEO INDEX

ID1 Project name	ID2 P-line	ID3 Description	Video File	Date	Time	Duration	Comments
600225_U864	MBE Over Wreck		DATA_20130108005206157	08.01.2013	00:52:06	00:15:00	
600225_U864	MBE Over Wreck		DATA_20130108010707016	08.01.2013	01:07:07	00:15:00	
600225_U864	MBE Over Wreck		DATA_20130108012208015	08.01.2013	01:22:08	00:15:00	
600225_U864	MBE Over Wreck		DATA_20130108013709000	08.01.2013	01:37:09	00:15:00	
600225_U864	MBE Over Wreck		DATA_20130108015210000	08.01.2013	01:52:10	00:12:12	
600225_U864	MBE Over Wreck		DATA_20130108020443484	08.01.2013	02:04:43	00:00:05	
600225_U864	Clear zone Grid Survey		DATA_20130108070601187	08.01.2013	07:06:01	00:13:52	No targets
600225_U864	Clear zone Grid Survey		DATA_20130108072137078	08.01.2013	07:21:37	00:15:00	No targets
600225_U864	Clear zone Grid Survey		DATA_20130108073638094	08.01.2013	07:36:38	00:02:11	No targets
600225_U864	Clear zone Grid Survey		DATA_20130108074131641	08.01.2013	07:41:31	00:11:54	No targets
600225_U864	Clear zone Grid Survey		DATA_20130108075453063	08.01.2013	07:54:53	00:13:01	No targets
600225_U864	Clear zone Grid Survey		DATA_20130108080912609	08.01.2013	08:09:12	00:11:41	No targets
600225_U864	Clear zone Grid Survey		DATA_20130108082139859	08.01.2013	08:21:39	00:09:56	No targets
600225_U864	Clear zone Grid Survey		DATA_20130108083253765	08.01.2013	08:32:53	00:11:39	No targets
600225_U864	Clear zone Grid Survey		DATA_20130108084801812	08.01.2013	08:48:01	00:10:31	Target 3A 001 Part of hull casing section
600225_U864	Clear zone Grid Survey		DATA_20130108090127703	08.01.2013	09:01:27	00:13:48	Target 3A 002 Possible debris
600225_U864	Clear zone Grid Survey		DATA_20130108091731375	08.01.2013	09:17:31	00:13:25	Target 3A 003 Part of hull casing section

ID1 Project name	ID2 P-line	ID3 Description	Video File	Date	Time	Duration	Comments
600225_U864	Clear zone Grid Survey		DATA_20130108093232687	08.01.2013	09:32:32	00:13:06	No targets
600225_U864	Clear zone Grid Survey		DATA_20130108094543719	08.01.2013	09:45:43	00:15:00	Target 3A 004 Metal Cylinder - Target 3A 005 Part of steel - Target 78 from 2005-2006 Steel casing very large
600225_U864	Clear zone Grid Survey	dam	DATA_20130108100044000	08.01.2013	10:00:44	00:06:19	No targets
600225_U864	Clear zone Grid Survey		DATA_20130108100932375	08.01.2013	10:09:32	00:15:00	Target 3A 005, 006, 007, 008, 009, 010, 011, 012
600225_U864	Clear zone Grid Survey		DATA_20130108102433000	08.01.2013	10:24:33	00:07:13	Target 3A 013
600225_U864	Clear zone Grid Survey		DATA_20130108103407360	08.01.2013	10:34:07	00:15:00	Target 3A 014,15,16,17,18,19_Target 15 from 2005-2006 Metal Structure
600225_U864	Clear zone Grid Survey		DATA_20130108104907907	08.01.2013	10:49:07	00:02:47	Target 3A-020, 021
600225_U864	Clear zone Grid Survey		DATA_20130108105239078	08.01.2013	10:52:39	00:12:43	Target 3A-022, 023
600225_U864	Clear zone Grid Survey		DATA_20130108110528844	08.01.2013	11:05:28	00:14:26	Target 3A-024,025,026,027,028
600225_U864	Clear zone Grid Survey		DATA_20130108112002875	08.01.2013	11:20:02	00:12:47	Target 3A-029, 030
600225_U864	Clear zone Grid Survey		DATA_20130108113253859	08.01.2013	11:32:53	00:14:59	Target 3A-031, 032, 033, 034
600225_U864	Clear zone Grid Survey		DATA_20130108114754015	08.01.2013	11:47:54	00:00:27	No targets
600225_U864	Clear zone Grid Survey		DATA_20130108114826406	08.01.2013	11:48:26	00:15:00	Target 3A-035,036,037,038,039,040
600225_U864	Clear zone Grid Survey		DATA_20130108120327000	08.01.2013	12:03:27	00:00:07	No targets
600225_U864	Clear zone Grid Survey		DATA_20130108120338125	08.01.2013	12:03:38	00:15:00	Target 3A-041,042,043, 044, 045,046,047
600225_U864	Clear zone Grid Survey		DATA_20130108121839015	08.01.2013	12:18:39	00:15:00	Target 3A-048,049,050,051
600225_U864	Clear zone Grid Survey		DATA_20130108123340000	08.01.2013	12:33:40	00:03:14	No targets
600225_U864	Clear zone Grid Survey		DATA_20130108132414984	08.01.2013	13:24:14	00:15:00	Target 3A-048,049,050,051
600225_U864	Clear zone Grid Survey		DATA_20130108133916015	08.01.2013	13:39:16	00:03:24	Target 3A, 053, 054, 055, 056, 057

ID1 Project name	ID2 P-line	ID3 Description	Video File	Date	Time	Duration	Comments
600225_U864	Clear zone Grid Survey		DATA_20130108134533891	08.01.2013	13:45:33	00:13:17	Target 3A, 058,059,060,061,062,063,064,065,066,067,068,069,070,
600225_U864	Clear zone Grid Survey		DATA_20130108135858594	08.01.2013	13:58:58	00:04:00	Target 3A_071
600225_U864	Clear zone Grid Survey		DATA_20130108140304562	08.01.2013	14:03:04	00:13:14	Target 3A_072,073
600225_U864	Clear zone Grid Survey		DATA_20130108141623031	08.01.2013	14:16:23	00:08:46	Target 3A_074,075,076,077
600225_U864	Clear zone Grid Survey		DATA_20130108142515406	08.01.2013	14:25:15	00:09:28	Target 3A_078,079,080
600225_U864	Clear zone Grid Survey		DATA_20130108143449516	08.01.2013	14:34:49	00:05:51	No targets
600225_U864	Clear zone Grid Survey		DATA_20130108144108562	08.01.2013	14:41:08	00:09:55	No targets
600225_U864	Wreck Survey	Area_2	DATA_20130108190348781	08.01.2013	19:03:48	00:15:00	STERN SECTION - Break Point
600225_U864	Wreck Survey	Area_2	DATA_20130108191849016	08.01.2013	19:18:49	00:13:39	STERN SECTION - Break Point
600225_U864	Wreck Survey	Area_2	DATA_20130108194106406	08.01.2013	19:41:06	00:15:00	STERN SECTION - Mud line
600225_U864	Wreck Survey	Area_2	DATA_20130108195607047	08.01.2013	19:56:07	00:15:00	STERN SECTION - Mud line
600225_U864	Wreck Survey	Area_2	DATA_20130108201108000	08.01.2013	20:11:08	00:04:00	STERN SECTION - Mud line
600225_U864	Wreck Survey	Area_2	DATA_20130108201727547	08.01.2013	20:17:27	00:14:40	STERN SECTION - Midship Line
600225_U864	Wreck Survey	Area_2	DATA_20130108203520422	08.01.2013	20:35:20	00:10:14	STERN SECTION - Top Deck
600225_U864	Wreck Survey	Area_2	DATA_20130108204724328	08.01.2013	20:47:24	00:15:00	STERN SECTION - Top Deck High Fly
600225_U864	Wreck Survey	Area_2	DATA_20130108210225000	08.01.2013	21:02:25	00:00:27	STERN SECTION - Top Deck High Fly
600225_U864	Wreck Survey	Area_1	DATA_20130108211447562	08.01.2013	21:14:47	00:15:00	BOW SECTION - Break Point
600225_U864	Wreck Survey	Area_1	DATA_20130108212948031	08.01.2013	21:29:48	00:00:19	BOW SECTION - Break Point
600225_U864	Wreck Survey	Area_1	DATA_20130108213854390	08.01.2013	21:38:54	00:15:00	BOW SECTION - Mud line

ID1 Project name	ID2 P-line	ID3 Description	Video File	Date	Time	Duration	Comments
600225_U864	Wreck Survey	Area_1	DATA_20130108215354891	08.01.2013	21:53:54	00:03:23	BOW SECTION - Mud line
600225_U864	Wreck Survey	Area_1	DATA_20130108215856532	08.01.2013	21:58:56	00:15:00	BOW SECTION - Midship Line
600225_U864	Wreck Survey	Area_1	DATA_20130108221357000	08.01.2013	22:13:57	00:12:53	BOW SECTION - Midship Line
FromtrasadGeologi	tran	Area_1	DATA_20130108222932672	08.01.2013	22:29:32	00:09:52	BOW SECTION - Top Deck
600225_U864	Wreck Survey	Area_1	DATA_20130108224211062	08.01.2013	22:42:11	00:07:00	BOW SECTION - Keel
600225_U864	Wreck Survey	Area_7	DATA_20130108230408718	08.01.2013	23:04:08	00:15:00	Target 66 from 2005-2006
600225_U864	Wreck Survey	Area_7	DATA_20130108231909032	08.01.2013	23:19:09	00:15:00	Target 66 from 2005-2006
600225_U864	Wreck Survey	Area_7	DATA_20130108233410015	08.01.2013	23:34:10	00:15:00	Target 66 from 2005-2006
600225_U864	Wreck Survey	Area_7	DATA_20130108234910984	08.01.2013	23:49:10	00:15:00	Target 66 from 2005-2006 Removing of UZO (cone)at 00:00:00
600225_U864	Wreck Survey	Area_7	DATA_20130109000412016	09.01.2013	00:04:12	00:02:18	Target 66 from 2005-2006
600225_U864	Wreck Survey	Area_10	DATA_20130109001202406	09.01.2013	00:12:02	00:06:20	Target 15 from 2005-2006
600225_U864	Wreck Survey	Area_8	DATA_20130109002123453	09.01.2013	00:21:23	00:15:00	Target 8 from 2005-2006
600225_U864	Wreck Survey	Area_8	DATA_20130109003624000	09.01.2013	00:36:24	00:06:36	Target 8 from 2005-2006
600225_U864	Wreck Survey	Area_3	DATA_20130109004615406	09.01.2013	00:46:15	00:15:00	Target 78 from 2005-2006 (00:51:26 Botle)
600225_U864	Wreck Survey	Area_3	DATA_20130109010116000	09.01.2013	01:01:16	00:12:14	Target 78 from 2005-2006
600225_U864	Wreck Survey	Area_7	DATA_20130109011805625	09.01.2013	01:18:05	00:15:00	Target 66 from 2005-2006
600225_U864	Wreck Survey	Area_7	DATA_20130109013305968	09.01.2013	01:33:05	00:02:41	Target 66 from 2005-2006
600225_U864	Wreck Survey	Unidentified	DATA_20130109021549719	09.01.2013	02:15:49	00:05:09	
600225_U864	Coring	Vibro coring	DATA_20130109225213828	09.01.2013	22:52:13	00:15:00	

ID1 Project name	ID2 P-line	ID3 Description	Video File	Date	Time	Duration	Comments
600225_U864	Coring	Vibro coring	DATA_20130109230714031	09.01.2013	23:07:14	00:15:00	
600225_U864	Coring	Vibro coring	DATA_20130109232215015	09.01.2013	23:22:15	00:10:31	
600225_U864	Coring	Vibro coring	DATA_20130110000553531	10.01.2013	00:05:53	00:06:01	
600225_U864	Coring	Vibro coring	DATA_20130110002352719	10.01.2013	00:23:52	00:12:57	
600225_U864	Wreck Survey	Target 81	DATA_20130110010523500	10.01.2013	01:05:23	00:09:52	
600225_U864	NRK		DATA_20130110012109234	10.01.2013	01:21:09	00:00:08	With out overlay and logos
600225_U864	NRK		DATA_20130110012401031	10.01.2013	01:24:01	00:04:44	With out overlay and logos
600225_U864	Coring	Vibro coring	DATA_20130110015518375	10.01.2013	01:55:18	00:15:00	
600225_U864	Coring	Vibro coring	DATA_20130110021019000	10.01.2013	02:10:19	00:01:01	
600225_U864	Coring	Vibro coring	DATA_20130110031331297	10.01.2013	03:13:31	00:15:00	
600225_U864	Coring	Vibro coring	DATA_20130110032831984	10.01.2013	03:28:31	00:03:58	
600225_U864	Coring	Vibro coring	DATA_20130110043202313	10.01.2013	04:32:02	00:15:00	
600225_U864	Coring	Vibro coring	DATA_20130110044702969	10.01.2013	04:47:02	00:10:08	
600225_U864	Coring	CPT	DATA_20130110164014672	10.01.2013	16:40:14	00:15:00	
600225_U864	Coring	CPT	DATA_20130110165515000	10.01.2013	16:55:15	00:15:00	
600225_U864	Coring	CPT	DATA_20130110171016063	10.01.2013	17:10:16	00:15:00	
600225_U864	Coring	CPT	DATA_20130110172517015	10.01.2013	17:25:17	00:15:00	
600225_U864	Coring	CPT	DATA_20130110174018016	10.01.2013	17:40:18	00:15:00	
600225_U864	Coring	CPT	DATA_20130110175518890	10.01.2013	17:55:18	00:15:00	

ID1 Project name	ID2 P-line	ID3 Description	Video File	Date	Time	Duration	Comments
600225_U864	Coring	CPT	DATA_20130110181020016	10.01.2013	18:10:20	00:15:00	
600225_U864	Coring	CPT	DATA_20130110182520031	10.01.2013	18:25:20	00:15:00	
600225_U864	Coring	CPT	DATA_20130110184021031	10.01.2013	18:40:21	00:05:29	
600225_U864	Coring	CPT	DATA_20130110222214329	10.01.2013	22:22:14	00:15:00	
600225_U864	Coring	CPT	DATA_20130110223715031	10.01.2013	22:37:15	00:15:00	
600225_U864	Coring	CPT	DATA_20130110225216016	10.01.2013	22:52:16	00:15:00	
600225_U864	Coring	CPT	DATA_20130110230717031	10.01.2013	23:07:17	00:15:00	
600225_U864	Coring	CPT	DATA_20130110232218016	10.01.2013	23:22:18	00:15:00	
600225_U864	Coring	CPT	DATA_20130110233719015	10.01.2013	23:37:19	00:15:00	
600225_U864	Coring	CPT	DATA_20130110235220016	10.01.2013	23:52:20	00:15:00	
600225_U864	Coring	CPT	DATA_20130111000721032	11.01.2013	00:07:21	00:15:00	
600225_U864	Coring	CPT	DATA_20130111002222016	11.01.2013	00:22:22	00:15:00	
600225_U864	Coring	CPT	DATA_20130111003723015	11.01.2013	00:37:23	00:15:00	
600225_U864	Coring	CPT	DATA_20130111005224047	11.01.2013	00:52:24	00:15:00	
600225_U864	Coring	CPT	DATA_20130111010724906	11.01.2013	01:07:24	00:15:00	
600225_U864	Coring	CPT	DATA_20130111012226047	11.01.2013	01:22:26	00:15:00	
600225_U864	Coring	CPT	DATA_20130111013727016	11.01.2013	01:37:27	00:15:00	
600225_U864	Coring	CPT	DATA_20130111015228032	11.01.2013	01:52:28	00:15:00	
600225_U864	Coring	CPT	DATA_20130111020729016	11.01.2013	02:07:29	00:15:00	

ID1 Project name	ID2 P-line	ID3 Description	Video File	Date	Time	Duration	Comments
600225_U864	Coring	CPT	DATA_20130111022230031	11.01.2013	02:22:30	00:15:00	
600225_U864	Coring	CPT	DATA_20130111023731000	11.01.2013	02:37:31	00:15:00	
600225_U864	Coring	CPT	DATA_20130111025231984	11.01.2013	02:52:31	00:15:00	
600225_U864	Coring	CPT	DATA_20130111030732890	11.01.2013	03:07:32	00:15:00	
600225_U864	Coring	CPT	DATA_20130111032234016	11.01.2013	03:22:34	00:15:00	
600225_U864	Coring	CPT	DATA_20130111033735000	11.01.2013	03:37:35	00:15:00	
600225_U864	Coring	CPT	DATA_20130111035235922	11.01.2013	03:52:35	00:15:00	
600225_U864	Coring	CPT	DATA_20130111040737000	11.01.2013	04:07:37	00:15:00	
600225_U864	Coring	CPT	DATA_20130111042238016	11.01.2013	04:22:38	00:15:00	
600225_U864	Coring	CPT	DATA_20130111043739031	11.01.2013	04:37:39	00:15:00	
600225_U864	Coring	CPT	DATA_20130111045240016	11.01.2013	04:52:40	00:15:00	
600225_U864	Coring	CPT	DATA_20130111050741016	11.01.2013	05:07:41	00:15:00	
600225_U864	Coring	CPT	DATA_20130111052242032	11.01.2013	05:22:42	00:05:03	
600225_U865	Coring	Vibro_coring	DATA_20130111080922984	11.01.2013	08:09:22	00:15:00	
600225_U864	Wreck Survey	Stern section	DATA_20130111093752781	11.01.2013	09:37:52	00:14:45	
600225_U864	Wreck Survey	Cone survey	DATA_20130111105042062	11.01.2013	10:50:42	00:09:59	
600225_U864	Wreck Survey	Cone survey	DATA_20130111110720234	11.01.2013	11:07:20	00:00:03	
600225_U864	Wreck Survey	Stern Well investigation	DATA_20130111110755312	11.01.2013	11:07:55	00:00:22	
600225_U864	Wreck Survey	Stern Well investigation	DATA_20130111110822516	11.01.2013	11:08:22	00:15:00	

ID1 Project name	ID2 P-line	ID3 Description	Video File	Date	Time	Duration	Comments
600225_U864	Wreck Survey	Stern Well investigation	DATA_20130111112322968	11.01.2013	11:23:22	00:15:00	
600225_U864	Wreck Survey	Stern_Well_investigation	DATA_20130111113824000	11.01.2013	11:38:24	00:15:00	
600225_U864	Wreck Survey	Stern_Well_investigation	DATA_20130111115325000	11.01.2013	11:53:25	00:15:00	
600225_U864	Wreck Survey	Stern_Well_investigation	DATA_20130111120826000	11.01.2013	12:08:26	00:15:00	
600225_U864	Wreck Survey	Stern_Well_investigation	DATA_20130111122327000	11.01.2013	12:23:27	00:15:00	
600225_U864	Wreck Survey	Stern_Well_investigation	DATA_20130111123827922	11.01.2013	12:38:27	00:15:00	
600225_U864	Wreck Survey	Stern_Well_investigation	DATA_20130111125329000	11.01.2013	12:53:29	00:12:38	
600225_U864	NRK		DATA_20130111140700109	11.01.2013	14:07:00	00:02:07	
600225_U864	NRK		DATA_20130111140917234	11.01.2013	14:09:17	00:15:00	
600225_U864	NRK		DATA_20130111142418016	11.01.2013	14:24:18	00:09:08	
600225_U864	Coring	Vibro_coring	DATA_20130111153303031	11.01.2013	15:33:03	00:15:00	
600225_U864	Coring	Vibro_coring	DATA_20130111154804016	11.01.2013	15:48:04	00:11:43	
600225_U864	Coring	Vibro_coring	DATA_20130111163146922	11.01.2013	16:31:46	00:15:00	
600225_U864	Coring	Vibro_coring	DATA_20130111164648031	11.01.2013	16:46:48	00:15:00	
600225_U864	Coring	Vibro_coring	DATA_20130111165615312	11.01.2013	16:56:15	00:30:00	Recorded in PAL format
600225_U864	Coring	Vibro_coring	DATA_20130111170149047	11.01.2013	17:01:49	00:15:00	
600225_U864	Coring	Vibro_coring	DATA_20130111171649984	11.01.2013	17:16:49	00:00:20	
600225_U864	Coring	Unidentified	DATA_20130111171736453	11.01.2013	17:17:36	00:09:14	
600225_U864	Coring	Vibro_coring	DATA_20130111172616484	11.01.2013	17:26:16	00:30:00	Recorded in PAL format

ID1 Project name	ID2 P-line	ID3 Description	Video File	Date	Time	Duration	Comments
600225_U864	NRK		DATA_20130111172836438	11.01.2013	17:28:36	00:15:00	
600225_U864	NRK		DATA_20130111174337015	11.01.2013	17:43:37	00:12:35	
600225_U864	UZO_Recovery		DATA_20130112063248562	12.01.2013	06:32:48	00:10:11	Recorded in PAL format
600225_U864	UZO_Recovery		DATA_20130112064311734	12.01.2013	06:43:11	00:24:11	Recorded in PAL format
600225_U864	UZO_Recovery		DATA_20130112070727328	12.01.2013	07:07:27	00:01:02	Recorded in PAL format
600225_U864	UZO_Recovery		DATA_20130112070837532	12.01.2013	07:08:37	00:30:02	Recorded in PAL format
600225_U864	UZO_Recovery		DATA_20130112073840500	12.01.2013	07:38:40	00:30:00	Recorded in PAL format
600225_U864	Coring	ROV coring / Soil sampling	DATA_20130112132527484	12.01.2013	13:25:27	00:30:00	Recorded in PAL format
600225_U864	Coring	ROV coring / Soil sampling	DATA_20130112135528812	12.01.2013	13:55:28	00:30:00	Recorded in PAL format
600225_U864	Coring	ROV coring / Soil sampling	DATA_20130112142521672	12.01.2013	14:25:21	00:30:01	Recorded in PAL format
600225_U864	Coring	ROV coring / Soil sampling	DATA_20130112145524000	12.01.2013	14:55:24	00:30:03	Recorded in PAL format
600225_U864	Coring	ROV coring / Soil sampling	DATA_20130112152531015	12.01.2013	15:25:31	00:30:00	Recorded in PAL format
600225_U864	Coring	ROV coring / Soil sampling	DATA_20130112155535781	12.01.2013	15:55:35	00:30:00	Recorded in PAL format
600225_U864	Coring	ROV coring / Soil sampling	DATA_20130112162536625	12.01.2013	16:25:36	00:29:59	Recorded in PAL format
600225_U864	Coring	ROV coring / Soil sampling	DATA_20130112165537218	12.01.2013	16:55:37	00:30:04	Recorded in PAL format
600225_U864	Coring	ROV coring / Soil sampling	DATA_20130112172538078	12.01.2013	17:25:38	00:30:00	Recorded in PAL format
600225_U864	Coring	ROV coring / Soil sampling	DATA_20130112175542875	12.01.2013	17:55:42	00:30:00	Recorded in PAL format
600225_U864	Coring	ROV coring / Soil sampling	DATA_20130112182543719	12.01.2013	18:25:43	00:30:03	Recorded in PAL format
600225_U864	Coring	ROV coring / Soil sampling	DATA_20130112185543985	12.01.2013	18:55:43	00:30:00	Recorded in PAL format

ID1 Project name	ID2 P-line	ID3 Description	Video File	Date	Time	Duration	Comments
600225_U864	Coring	ROV coring / Soil sampling	DATA_20130112192548719	12.01.2013	19:25:48	00:30:00	Recorded in PAL format
600225_U864	Coring	ROV coring / Soil sampling	DATA_20130112195549922	12.01.2013	19:55:49	00:30:00	Recorded in PAL format
600225_U864	Coring	ROV coring / Soil sampling	DATA_20130112202550672	12.01.2013	20:25:50	00:30:00	Recorded in PAL format
600225_U864	Coring	ROV coring / Soil sampling	DATA_20130112205551968	12.01.2013	20:55:51	00:29:59	Recorded in PAL format
600225_U864	Coring	ROV coring / Soil sampling	DATA_20130112212552781	12.01.2013	21:25:52	00:30:00	Recorded in PAL format
600225_U864	Coring	ROV coring / Soil sampling	DATA_20130112215553532	12.01.2013	21:55:53	00:30:00	Recorded in PAL format
600225_U864	Coring	ROV coring / Soil sampling	DATA_20130112222554766	12.01.2013	22:25:54	00:29:59	Recorded in PAL format
600225_U864	Coring	ROV coring / Soil sampling	DATA_20130112225555609	12.01.2013	22:55:55	00:30:00	Recorded in PAL format
600225_U864	Coring	ROV coring / Soil sampling	DATA_20130112232556813	12.01.2013	23:25:56	00:30:00	Recorded in PAL format
600225_U864	Coring	ROV coring / Soil sampling	DATA_20130112235557578	12.01.2013	23:55:57	00:30:00	Recorded in PAL format
600225_U864	Coring	ROV coring / Soil sampling	DATA_20130113002558734	13.01.2013	00:25:58	00:30:00	Recorded in PAL format
600225_U864	Coring	ROV coring / Soil sampling	DATA_20130113005559594	13.01.2013	00:55:59	00:30:00	Recorded in PAL format
600225_U864	Coring	ROV coring / Soil sampling	DATA_20130113012600813	13.01.2013	01:26:00	00:30:00	Recorded in PAL format
600225_U864	Coring	ROV coring / Soil sampling	DATA_20130113015601625	13.01.2013	01:56:01	00:30:00	Recorded in PAL format
600225_U864	Coring	ROV coring / Soil sampling	DATA_20130113022602813	13.01.2013	02:26:02	00:30:00	Recorded in PAL format
600225_U864	Coring	ROV coring / Soil sampling	DATA_20130113025603641	13.01.2013	02:56:03	00:30:00	Recorded in PAL format

6.5 DTM AND SOUNDINGS

6.5.1 DTM

DTM
600225_DTM_U864_2x2km_20cm_01.xyz
600225_DTM_U864_2x2km_20cm_02.xyz
600225_DTM_U864_2x2km_20cm_03.xyz
600225_DTM_U864_2x2km_20cm_04.xyz
600225_DTM_U864_2x2km_20cm_05.xyz
600225_DTM_U864_2x2km_20cm_06.xyz
600225_DTM_U864_2x2km_20cm_07.xyz
600225_DTM_U864_2x2km_20cm_08.xyz
600225_DTM_U864_2x2km_20cm_09.xyz
600225_DTM_U864_2x2km_20cm_10.xyz
600225_DTM_U864_2x2km_20cm_11.xyz
600225_DTM_U864_2x2km_20cm_12.xyz
600225_DTM_U864_2x2km_20cm_13.xyz
600225_DTM_U864_2x2km_20cm_14.xyz
600225_DTM_U864_2x2km_20cm_15.xyz
600225_DTM_U864_2x2km_20cm_16.xyz
600225_DTM_U864_2x2km_20cm_17.xyz
600225_DTM_U864_2x2km_20cm_18.xyz
600225_DTM_U864_2x2km_20cm_19.xyz
600225_DTM_U864_2x2km_20cm_20.xyz
600225_DTM_U864_2x2km_20cm_21.xyz
600225_DTM_U864_2x2km_20cm_22.xyz
600225_DTM_U864_2x2km_20cm_23.xyz
600225_DTM_U864_2x2km_20cm_24.xyz
600225_DTM_U864_2x2km_20cm_25.xyz
600225_DTM_U864_Wreck_20cm.xyz

6.5.2 Soundings

Soundings
600225_Soundings_U864_Wreck.xyz

6.6 NAVIMODEL SOFTWARE

NaviModel Projects
NaviModel_3.2.0_RC62.exe

6.7 NAVIMODEL PROJECT

NaviModel Projects
U864_Fedje_overview_2x2km.nmp
U864_Wreck.nmp

7 APPENDICIES

APPENDIX A: Task plans
APPENDIX B: Explanation of chart datum

7.2 APPENCIX A: TASK PLANS

Nine operational task plans were used during the project.

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Page 1 of 3

600225-SSKO-O02-001 Task Plan: HiPAP Cal Byfjorden.

Distribution Matrix

OM	x	Client	x	Bridge	x	Sen Sur	x	Online	x	ROV	x
Deck	x	Crane		Sur tech	x	Prod.Man		MAP		GEO/Video	

References:

DOF Subsea Procedure: DSN-SUR-O03-0003-06i USBL Calibration and Verification.pdf

Introduction

Prior to the Kystverket U864 Phase 3A survey operations, the APOS HiPAP system will be calibrated using the test site Bunnpunkt. There are 2 MPT transponders permanently deployed for this purpose.

Water depth is approx 230m.

Geodetic Parameters

Spheroid	:	WGS 84
UTM Zone	:	Zone 31° (CM3°)
Datum shift	:	None
Vertical datum	:	MSL

Survey Details

Required Logging	:	NP, APOS
KP runline	:	None
Displaylines	:	None
Waypoints	:	623983.3 E 6703442.4 N Zone 31

Gereral Preparations:

#	Description	Responsible
1.	Prepare XLX27 and conduct pre dive checks	Surv/ROV
2.	Deploy XLX27 to seabed – Log SVP	Surv/ROV
3.	CTD to be updated in APOS	Surv
4.	Recover XLX27	Surv/ROV
5.	Waypoints entered in Helmsman	Surv
6.	Prior to all activities, a full QC check of the online systems will be completed and documented	Surv

***NB If crane is unavailable the stern A frame winch can be used instead**

Operation:

1.	**Verification spin**	With the calculated sets of corrections entered into the USBL system, perform a 360° static spin 50m offset from the transponder position for both poles with corrections applied. If result acceptable move to step 5.
2.	**Static 360□ spin**	Hold the vessel static over the transponder position on each of 4 headings, record 200 updates on each heading. The headings can be oriented for weather.
3.	**Four Quadrant**	Place the vessel in turn at each of the four cardinal points at a distance of 180 metres from the transponder, with a fixed (northerly)

		heading. Log data one each pole for 200 updates at each cardinal point. Headings and 'Cardinal Points' can be oriented for weather.
4.	**Verification spin**	With the calculated sets of corrections entered into the USBL system, perform a 360° static spin 50m offset from the transponder position with corrections applied.
5.	**Verification lines**	Conduct two DP transit lines, West–East & South–North for each HiPAP system, with a vessel heading of 000°, over the transponder position. Each verification line to be 250 m long. Heading/transit lines may be oriented for weather.

Optional Tp Replacement

#	Description	Responsible
1.	Deploy replacement Tp and clump weight by crane	Cran/Deck
2.	Identify Tp to be replaced	Surv/ROV
3.	Remove old Tp from permanent clump weight using XLX27 and attach to crane clump weight	ROV
4.	Attach Replacement TP to permanent CW	ROV
5.	Recover XLX27 and old Tp to surface	ROV

Reporting

Calibration to be documented with relevant screen grabs.
Mobilisation report to be updated with results.

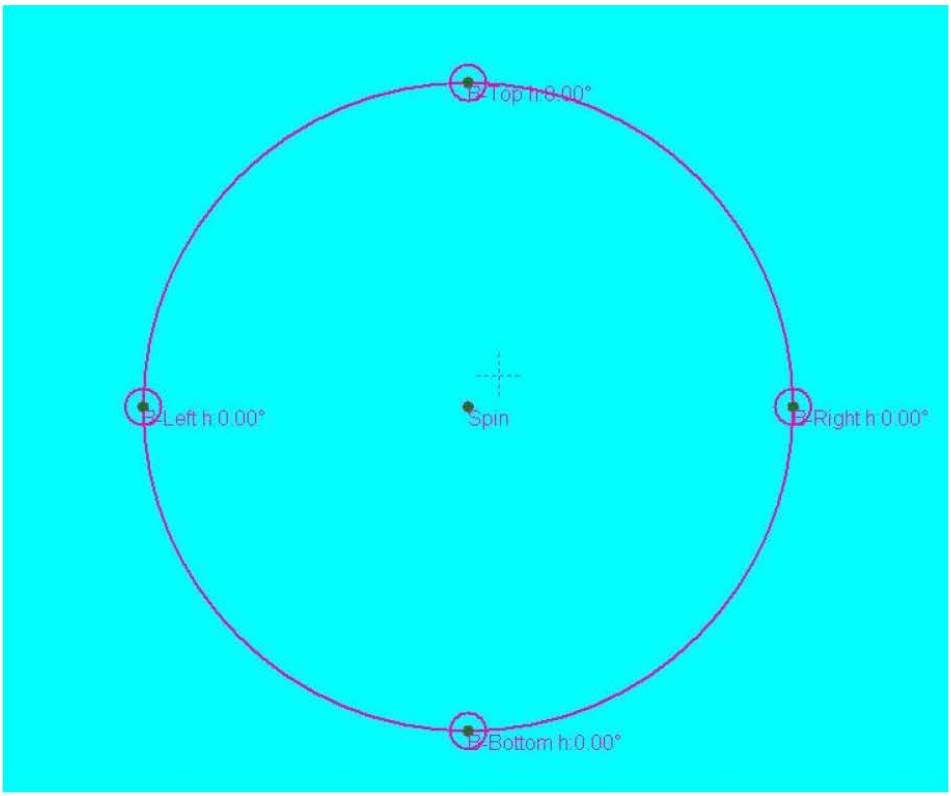

Figure 1 **Prelim HiPAP boxin at Bunnpunkt (Heading can change to suit weather)**

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600225-SSKO-O02-002 Task Plan: MBE Cal Byfjorden.

Distribution Matrix

OM	x	Client	x	Bridge	x	Sen Sur	x	Online	x	ROV	x
Deck		Crane		Sur tech	x	Prod.Man		MAP		GEO/Video	

References:

DOF Subsea Procedure: DSA-MP-ST-0001 - Rev. No: 1.02 - Date issued: 01/03/2012

Introduction

The purpose of this procedure is to verify the alignment of the multibeam sensor heads to the vehicle heading (gyro) and attitude (motion sensor). During installation it is not possible to align the sensors with sufficient accuracy so a procedure known as a patchtest is used to measure or verify these offsets once installation is complete.

The calibration will be conducted on the site of the wreck of the Nautilus submarine in Byfjorden. **Depth 340m**

Geodetic Parameters

Spheroid : WGS'84
UTM Zone : Zone 31° (CM3°)
Datum shift : None
Vertical datum : MSL

Survey Details

Required Logging : NP, HAIN, NS, **CODA**
Runline : Naut.rln
Displaylines : None
Waypoints :

Bow	624 732.0	6 702 076.5
Stern	624 682.3	6 702 089.8

MBE Settings : 40m, 20Hz, Pulse length 55µSec
Altitude : 10m -15m
Speed : As per individual line instructions

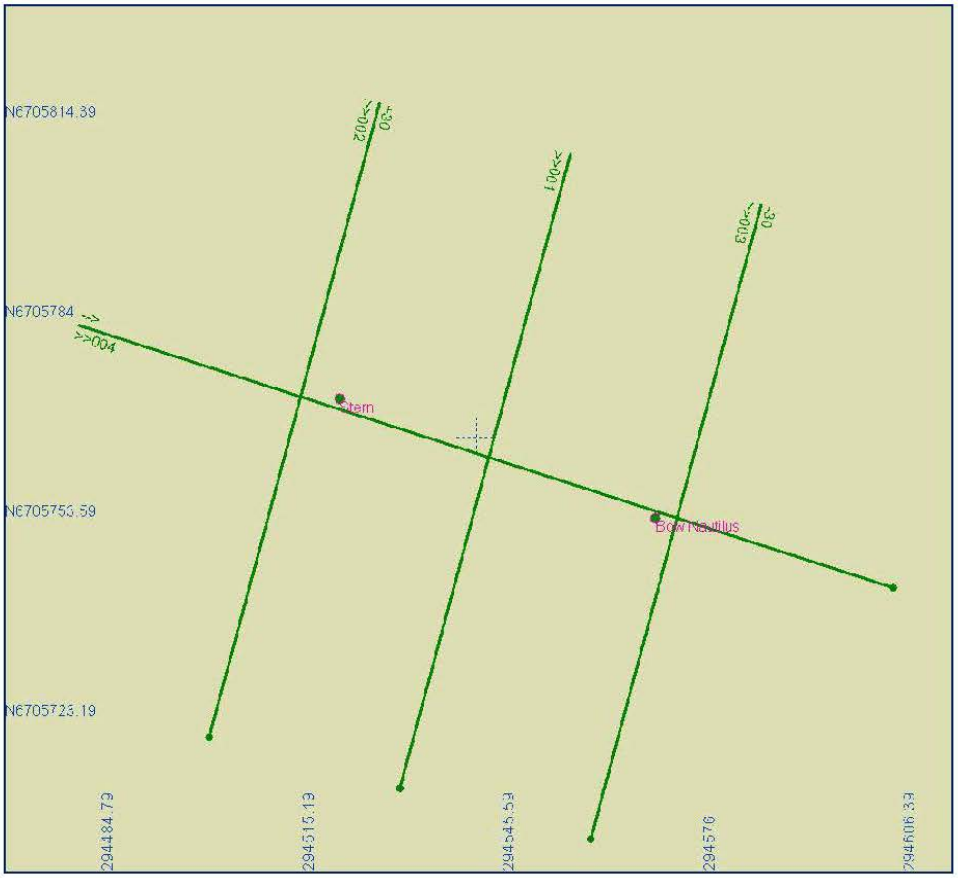
Gereral Preparations:

#	Description	Responsible
1.	Prior to all activities, a full QC check of the online systems will be completed and documented	
2.	Prepare XLX27 and conduct pre dive checks	Surv/ROV
3.	Deploy XLX27 to seabed – Log SVP	Surv/ROV
4.	CTD to be updated in APOS	Surv
5.	Conduct 2 min static bathy check (ROV **STATIONARY** on seabed)	Surv
6.	Move vehicle in square, circular or other random patterns to settle hain	

Operation:

1.	**DVL Calibration**	ROV to traverse a box, travelling forwards, backwards and laterally, at different speeds for approximately 30 minutes. Split HAIN logging before and after.
2.	**DVL Update**	Update DVL unit with settings received from Offline
3.	**DVL Verification**	Conduct "box traverse" for 15 minutes as verification of DVL settings
4.	**MBE Calibration**	Once DVL settings confirmed by offline conduct MBE calibration as detailed below. **Note: It is important to log only one file per survey line.** Log CODA SBP data simultaneously.

MBE Line Plan	
Line 1	North (15°) at 0.7kt, 10m altitude
Line 1	South (195°) at 0.7kt, 10m altitude
Line 1	North (15°) at 1.5kt, 10m altitude
Line 2	South (195°) 0.7kt, 15m altitude
Line 2	North (15°) 0.7kt, 15m altitude
Line 3	South (195°) 0.7kt, 15m altitude
Line 3	North (15°) 0.7kt, 15m altitude
Line 4	Verification line run across all the previous lines altitude 15m (115°)
Line 4	Verification line run in opposite direction to above with varying pitch, roll and altitude



Reporting

Calibration to be documented with relevant screen grabs.
Mobilisation report to be updated with results.

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600225-SSKO-O02-003 Task Plan: MBE Grid Survey U-864

Distribution Matrix

OM	x	Client	x	Bridge	x	Sen Sur	x	Online	x	ROV	x
Deck		Crane		Sur tech	x	Prod.Man		MAP	x	GEO/Video	x

References:

600225-PJ-O03-12-0003 Kystverket U-864 Phase 3A Operational Survey Procedure

Introduction

Operations on Phase 3A of the U-864 will commence with a high resolution MBE survey of a 2km x 2km area centred on the wreck of the U-864.

The purpose of the survey is to identify additional areas of debris and to extend the mapped area around thr wreck from previous surveys.

Depth on site 150m approx

Geodetic Parameters

Spheroid	:	WGS'84
UTM Zone	:	Zone 32° (CM9°)
Datum shift	:	None
Vertical datum	:	MSL

Survey Details

Required Logging	:	NP, NS (30min files), HAIN, **CODA**
Runline	:	2000m_2000m_Grid_40m_Spacing.rlx
Displaylines	:	864 Outline 2000.DWG
Waypoints	:	None
MBE Settings	:	40m, 20Hz, Pulse length 55µSec
Altitude	:	10m
Speed	:	0.8- 1.5kt (Achieve high quality data)

Gereral Preparations:

#	Description	Responsible
1.	Prior to all activities, a full QC check of the online systems will be completed and documented	
2.	Prepare XLX27 and conduct pre dive checks	Surv/ROV
3.	**South East Corner of survey area 200m before SOL** Deploy XLX27 to seabed – Log SVP	Surv/ROV
4.	CTD to be updated in APOS	Surv
5.	Conduct 2 min static bathy check (ROV **STATIONARY** on seabed)	Surv
6.	Move vehicle in square, circular or other random patterns to settle hain	ROV/Surv

Operation:

1.	**Setup ROV**	Tune systems and check all systems operating while HAIN settles
2.	**Start Run in**	During long (≈200m) run in further tune systems, ROV speed and ensure no interference between MBE/SBP
		Note: Ensure MBE logged on no less than 10m before SOL. SBP may continue to tune throughout the line as coverage only required over the wreck. **SBP will not be permitted to interfere with MBE operations**
3.	**Continue survey**	10m run in/ out on each subsequent line. Ensure ROV is stable before starting run in.
4.	**SVP**	Conduct SVP after 24 Hrs and at conclusion of survey

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600225-SSKO-O02-004 Task Plan: GVI Wreck Sections U-864

Distribution Matrix

OM	x	Client	x	Bridge	x	Sen Sur	x	Online	x	ROV	x
Deck		Crane		Sur tech	x	Prod.Man		MAP		GEO/Video	x

References:

600225-PJ-O03-12-0003 Kystverket U-864 Phase 3A Operational Survey Procedure

Introduction

Operations on Phase 3A of the U-864 project will continue with a HD GVI of the major wreck sections of U-864.

The purpose of the survey is to identify the extent of the missing mid section and to attempt to identify prominent features of this section in the surrounding debris.

The survey will be conducted under the direct supervision of the VR.

Depth on site 150m approx

Geodetic Parameters

Spheroid	:	WGS'84
UTM Zone	:	Zone 32° (CM9°)
Datum shift	:	None
Vertical datum	:	MSL

Survey Details

Required Logging	:	HAIN, DV
Runline	:	None
Displaylines	:	Debris Field outline 2000.DWG
Waypoints	:	None

Gereral Preparations:

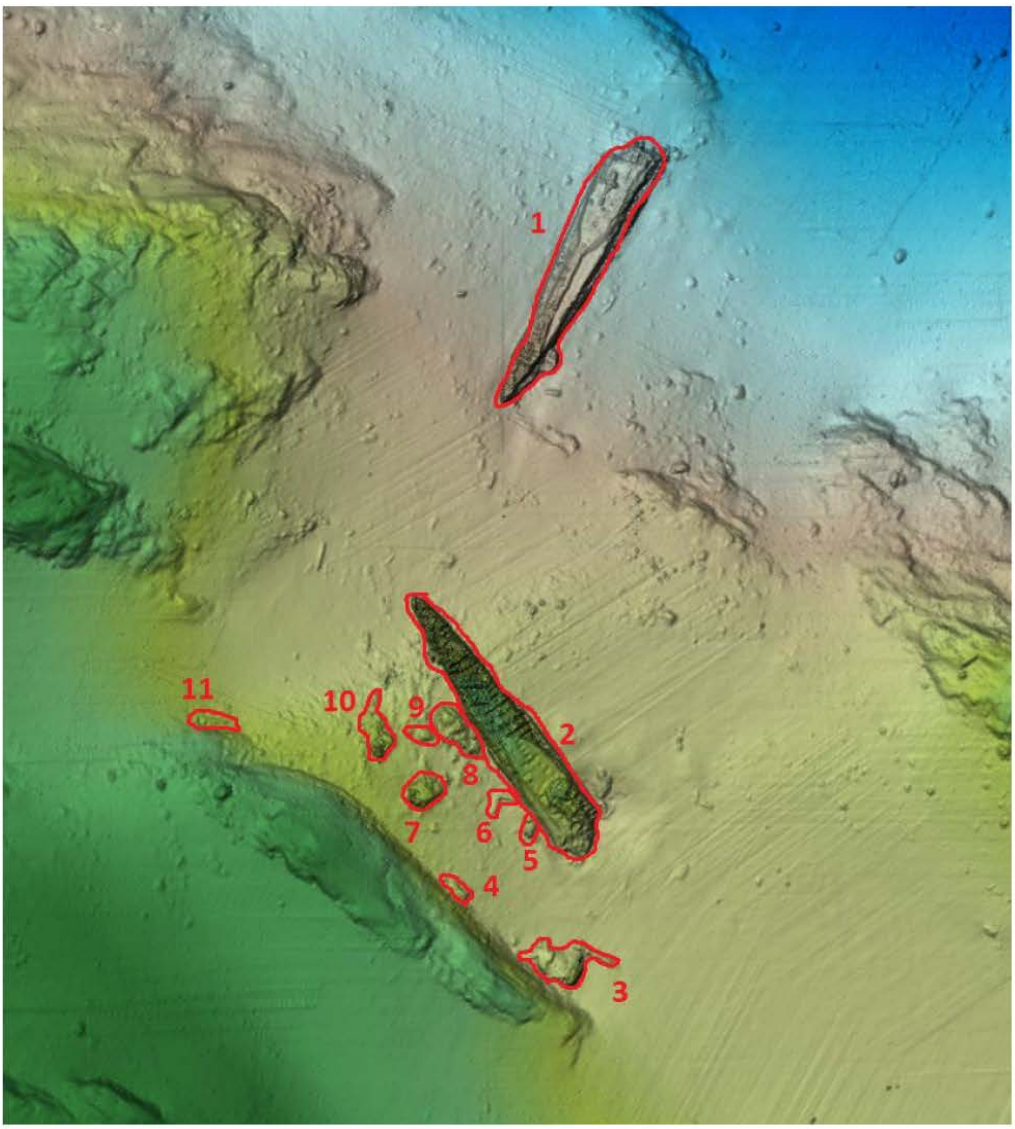
#	Description	Responsible
1.	Prior to all activities, a full QC check of the online systems will be completed and documented	
2.	Prepare XLX27 and conduct pre dive checks	Surv/ROV
3.	CTD to be updated in APOS	Surv
4.	Balance lighting, set up cameras and confirm suitable White Balance	ROV/GEO

All personnel to be aware that human remains will be present and the site shall be treated with the utmost respect. Live ammunition is also present on the wreck and caution should be exercised.

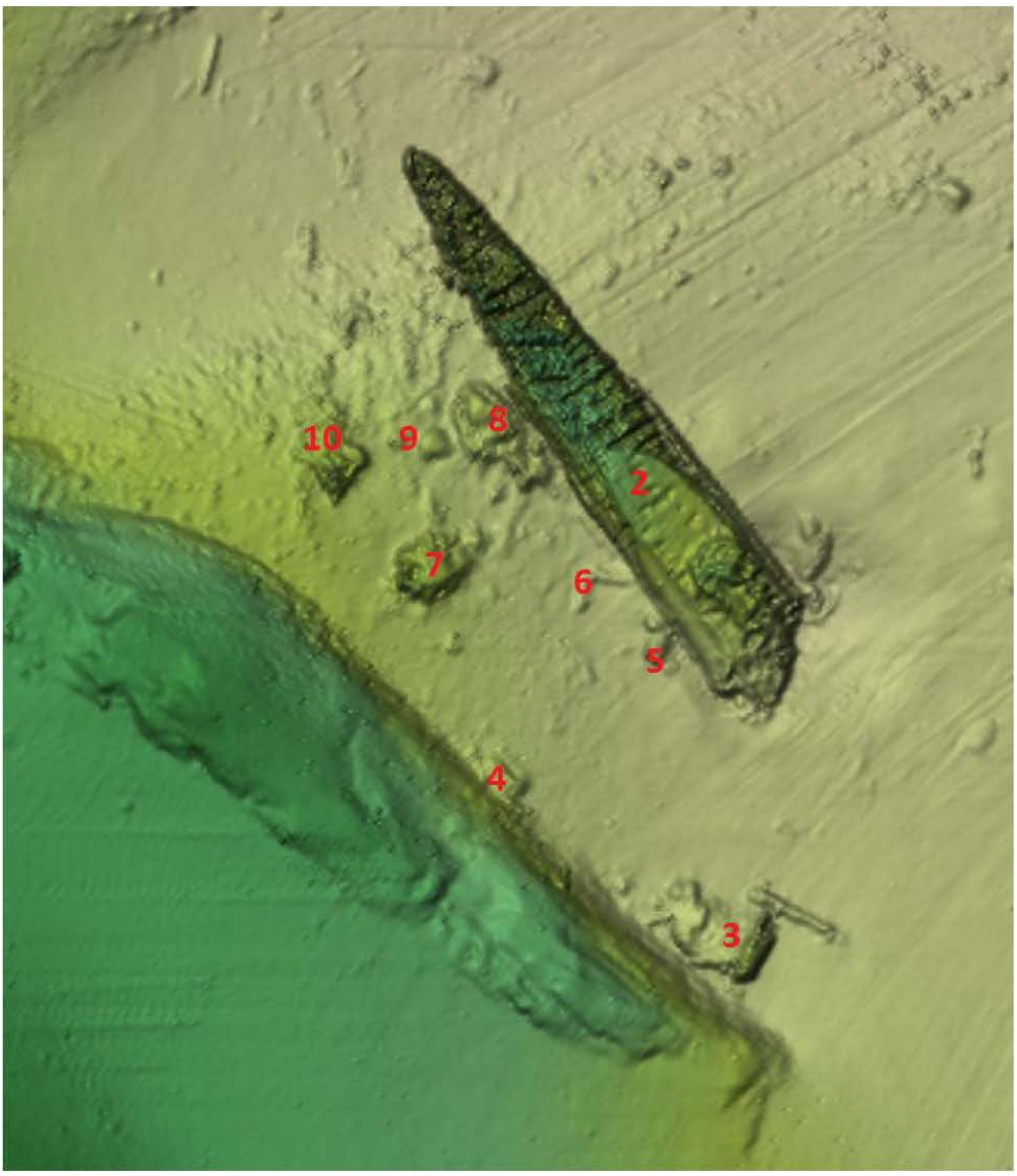
Any sighting, or possible sighting, of human remains, live ammunition, mercury containers or leaking oil should immediately be notified to the VR. Do not assume they have seen it!

Table 1 - Areas and 2005/2006 Target ID

Area	Target ID
3	78
4	
5	71/69
6	23
7	66
8	8
9	
10	15



1 Survey Areas Overview



2 Survey Area detail, stern section

Bilde 2.23 Kvikksølvbeholder før opptak

Bilde 2.24 Kvikksølvbeholder holdt av ROV

3 Mercury Container

Forged type:
Total height about 370 mm; external diameter about 140 mm

Welded type:
Height of 250 mm approximately, external diameter of about 130 mm

Ammunition

Ordnance			
Item	**Number / Weight**	**Storage**	**Conclusion**
Torpedoes	27	Assessed to be stored: Outside the pressure hull: 12 stored underneath the casing. Inside the pressure hull: 4 in the torpedo tubes fore, 6 in fore torpedo room, 2 in the torpedo tubes aft, 3 in the aft torpedo room.	**Salvage** When the submarine is raised towards the surface, the ambient pressure will be reduced. It is assessed only theoretically possible that this will cause a detonation of explosives. The possibility of a leakage from the pressurised air cylinder will increase during ascent (caused by reduction of the ambient pressure) and is assed to be remote. **Capping** The possibility of a detonation during capping, without a greater external influence, is assessed only to be theoretically possible. If a high pressure air cylinder starts leaking, due to corrosion, it is assessed that a rupture of the pressurised air cylinder is unlikely.
105 mm	202	Assessed to be stored: Outside the pressure hull: 32 by the 105 mm cannon. Inside the pressure hull: 170 divided in the two storage rooms below the central and the galley.	It is assessed that the risk concerning 105 mm ammunition is insignificant when salvaging or capping.
37 mm	1150	Assessed to be stored outside the pressure hull and in internal magazines. 60 projectiles under "winter-garden" (aft of tower).	May contain a tracer in base, which will self destruct the projectile if it burns out. **Salvage** Should be kept wet until they are removed from the wreck, and kept wet until moved to the deposit site. It is assessed that the risk concerning 37 mm ammunition is insignificant when salvaging. **Capping** It is assessed that the risk concerning 37 mm ammunition is insignificant when capping.
20 mm	3060	Assessed to be stored outside the pressure hull and in internal magazines.	**Salvage** Should be kept wet until they are removed from the wreck, and kept wet until moved to the deposit site. It is assessed that the risk concerning 20 mm ammunition is insignificant when salvaging. **Capping** It is assessed that the risk concerning 20 mm ammunition is insignificant when capping.

Demolition charges	500 kg TNT	Assessed to be stored in the ammunition magazines	**Salvage/capping** Demolition charges are safe to handle when salvaging or capping. It is assessed that the risk concerning demolition charges are insignificant when salvaging or capping.
Small arms ammunition	3000	Assessed to be stored throughout the submarine	**Salvage/capping** Small arms ammunition safe to handle when salvaging or capping. It is assessed that the risk concerning small arms ammunition is insignificant when salvaging or capping.
Hand grenades	30	Assessed to be stored throughout the submarine	Usually stored separately (stick and grenade). Explosives might be very sensitive, due to picric acid. **Salvage** If salvaged, avoid drying. The longer the submarine is stored in a dry environment, the more sensitive the grenade will be. It is assessed that the risk concerning stick grenades are insignificant when salvaging. **Capping** It is assessed that the risk concerning stick grenades are insignificant when capping.

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600225-SSKO-O02-005 Task Plan: MBE Survey U-864

Distribution Matrix

OM	x	Client	x	Bridge	x	Sen Sur	x	Online	x	ROV	x
Deck		Crane		Sur tech	x	Prod.Man		MAP	x	GEO/Video	x

References:

600225-PJ-O03-12-0003 Kystverket U-864 Phase 3A Operational Survey Procedure

Introduction

Operations on Phase 3A of the U-864 will continue with a high resolution MBE survey of the wreck of the U-864.

The purpose of the survey is to provide high data density DTMs of the wreck site to enable size estimates to be made of wreckage and debris.

Depth on site 150m approx

Geodetic Parameters

Spheroid	:	WGS'84
UTM Zone	:	Zone 32° (CM9°)
Datum shift	:	None
Vertical datum	:	MSL

Survey Details

Required Logging	:	NP, NS (30min files), HAIN
Runline	:	864 Lines.rlx
Displaylines	:	Debris Field Outline 2000.DWG
Waypoints	:	None
MBE Settings	:	20, 20Hz, Pulse length 55µSec
Altitude	:	5m
Speed	:	0. 5kt (Achieve high quality data)

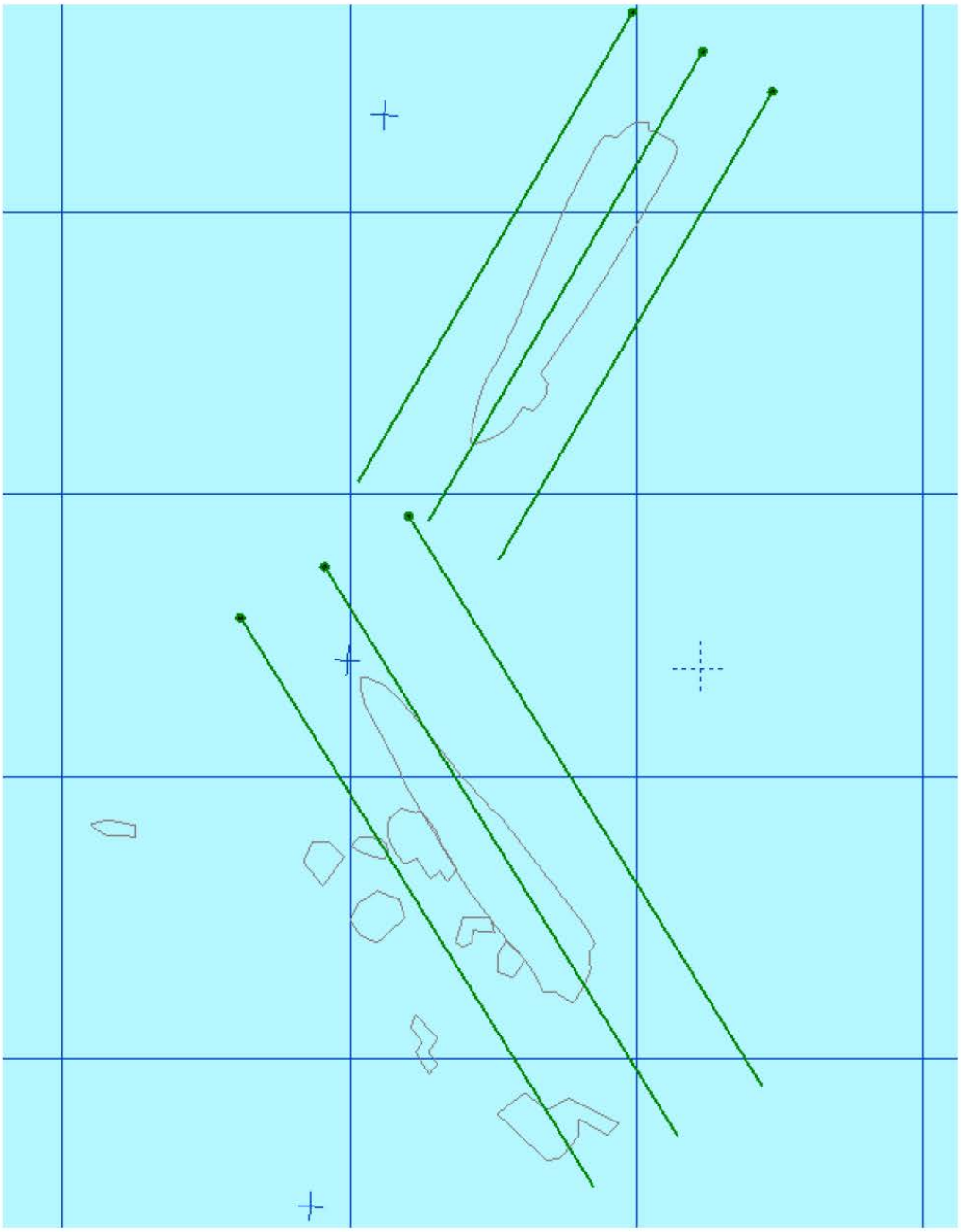
Consider reducing power over the wreck to prevent ringing

Gereral Preparations:

#	Description	Responsible
1.	Prior to all activities, a full QC check of the online systems will be completed and documented	
2.	Prepare XLX27 and conduct pre dive checks	Surv/ROV
3.	Deploy XLX27 to seabed – Log SVP. **Ensure deployment clear of all known wreckage**	Surv/ROV
4.	CTD to be updated in APOS	Surv
5.	Conduct 2 min static bathy check (ROV **STATIONARY** on seabed)	Surv
6.	Move vehicle in square, circular or other random patterns to settle hain	ROV/Surv

Operation:

1.	**Setup ROV**	Tune systems and check all systems operating while HAIN settles
3.	**Continue survey**	Conduct Survey pattern at the discretion of online surveyor



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600225-SSKO-O02-006 Task Plan: MBE Verification

Distribution Matrix

OM	x	Client	x	Bridge	x	Sen Sur	x	Online	x	ROV	x
Deck		Crane		Sur tech	x	Prod.Man		MAP	x	GEO/Video	x

References:

600225-PJ-O03-12-0003 Kystverket U-864 Phase 3A Operational Survey Procedure

Introduction

To achieve the best possible results it is necessary to conduct a verification of the MBE calibration data collected before the start of the project.

Depth on site 150m approx

Geodetic Parameters

Spheroid	:	WGS'84
UTM Zone	:	Zone 32° (CM9°)
Datum shift	:	None
Vertical datum	:	MSL

Survey Details

Required Logging	:	NP, NS (30min files), HAIN
Runline	:	Verify.rlx
Displaylines	:	Debris Field Outline 2000.DWG
Waypoints	:	None
MBE Settings	:	50m, 20Hz, Pulse length 55µSec
Altitude	:	According to line
Speed	:	According to line

Gereral Preparations:

#	Description	Responsible
1.	Task to be conducted immediately after the U-864 MBE survey.	

Operation:

1.	**Setup ROV**	Tune systems and check all systems operating while move to location from Wreck site.
2.	**Line 5**	E - W Cross line, 0.7kt
3.	**Line 4**	W - E Cross line, 0.7kt
4.	**Line 3**	N – S 0.7kt
5.	**Line 1**	S – N 0.7kt
6.	**Line 1**	N - S 0.7kt

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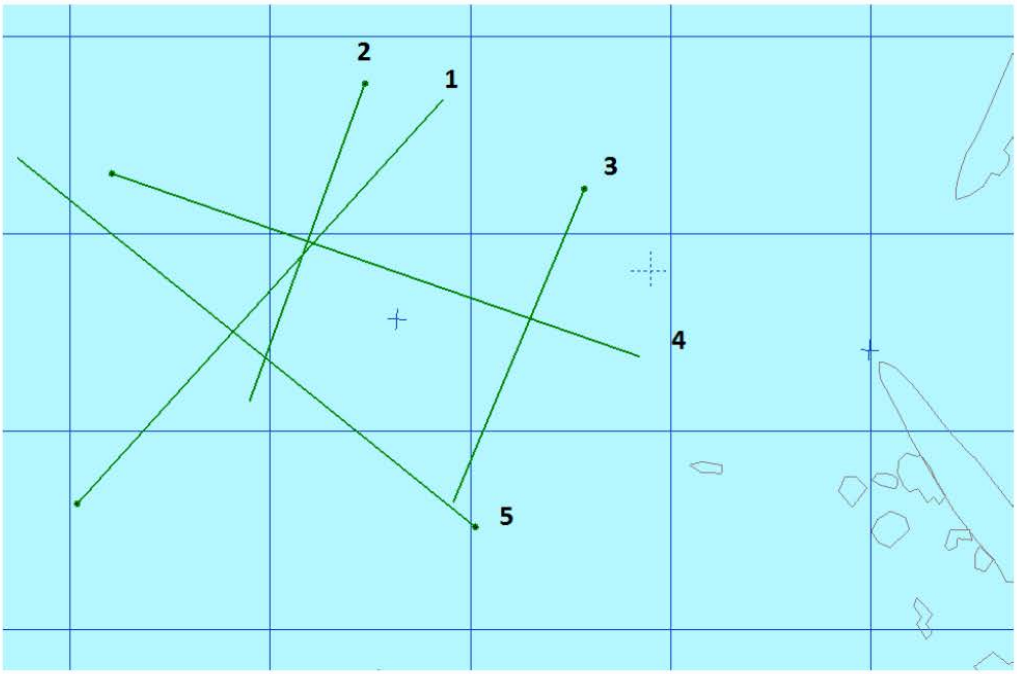
7.	**Line 1**	S – N 1.5kt (faster if possible)
8.	**Line 2**	N – S 0.7kt



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600225-SSKO-O02-007 Task Plan: Video Survey Clear Areas U-864

Distribution Matrix

OM	x	Client	x	Bridge	x	Sen Sur	x	Online	x	ROV	x
Deck		Crane		Sur tech	x	Prod.Man		MAP	x	GEO/Video	x

References:

600225-PJ-O03-12-0003 Kystverket U-864 Phase 3A Operational Survey Procedure

Introduction

Operations on Phase 3A of the U-864 will continue with a high resolution Video survey of the area to the West and South West of the U-864.

The purpose of the survey is to locate and identify any further debris outside the known debris field area and to provide information on the condition of known debris.

Depth on site 150m approx

Geodetic Parameters

Spheroid	:	WGS'84
UTM Zone	:	Zone 32° (CM9°)
Datum shift	:	None
Vertical datum	:	MSL

Survey Details

Required Logging	:	HD DV, HAIN
Runline	:	Video _Bow.rlx, Video_shelf.rlx, Video_Stern.rlx
Displaylines	:	Debris Field Outline 2000.DWG
Waypoints	:	None
Altitude	:	2m (ensure good video coverage)
Speed	:	0.5kt

DV Overlay

"Area Clearance Survey"

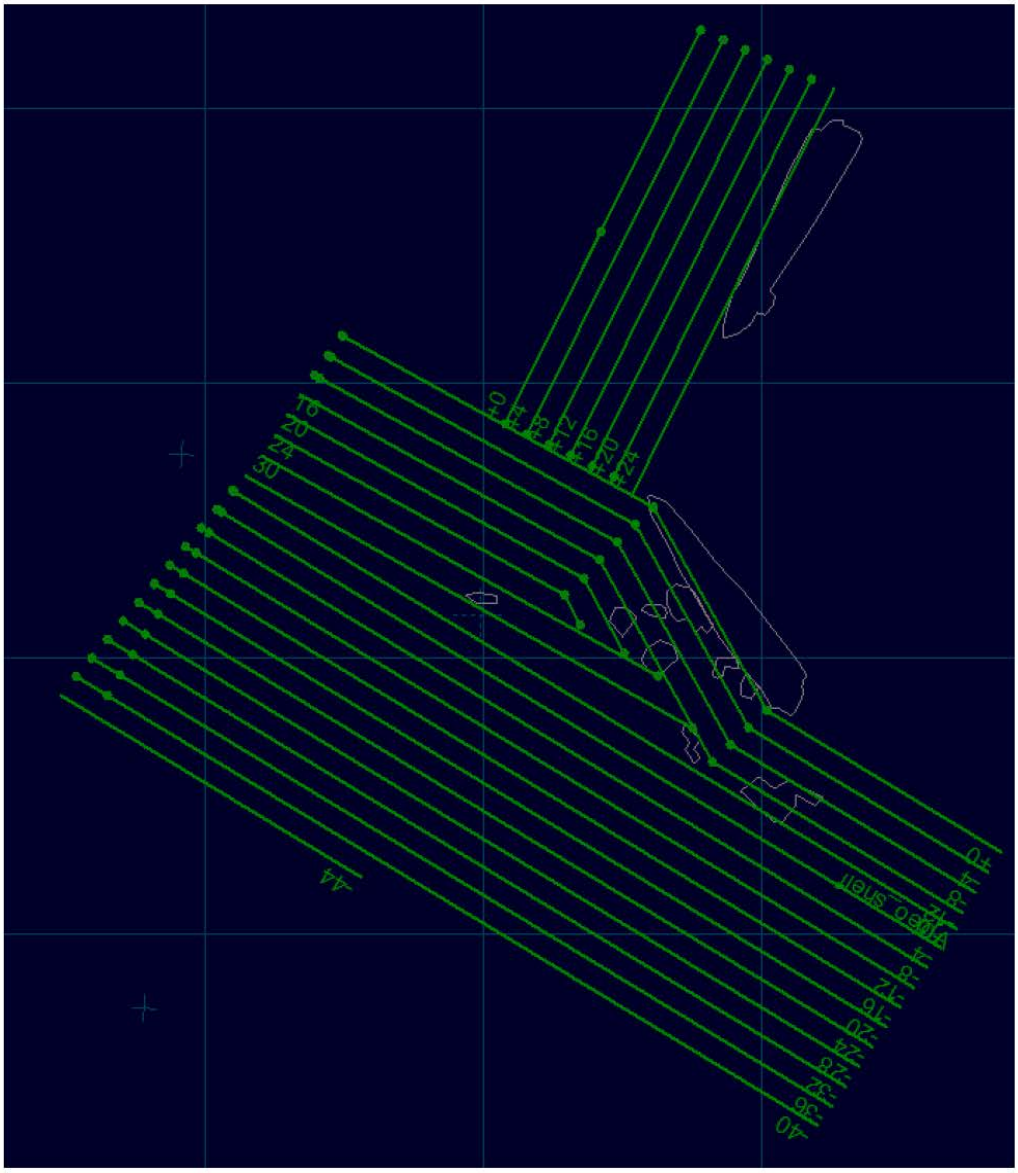
Gereral Preparations:

#	Description	Responsible
1.	Prior to all activities, a full QC check of the online systems will be completed and documented	
2.	Prepare XLX27 and conduct pre dive checks	Surv/ROV
3.	Deploy XLX27 to seabed – Log SVP. **Ensure deployment clear of all known wreckage**	Surv/ROV
4.	CTD to be updated in APOS	Surv
5.	Move vehicle in square, circular or other random patterns to settle hain	ROV/Surv

Operation:

1.	**Setup ROV**	HAIN settles
3.	**Continue survey**	Conduct Survey pattern at the discretion of online surveyor

Note; Do not stop survey at any targets identified, but notify VR immediately if Human remains, possible munitions, or Hg containers are suspected.



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600225-SSKO-O02-008 Task Plan: Geotechnical work for U-864 Rev 2

Distribution Matrix

OM	x	Client	x	Bridge	x	Sen Sur	x	Online	x	ROV	x
Deck		Crane		Sur tech	x	Prod.Man		MAP	x	GEO/Video	x

References:

600225-PJ-O03-12-0003 Kystverket U-864 Phase 3A Operational Survey Procedure
600225-PJ-O03-12-0004-03i Geotechnical operations

Introduction

For the Geotechnical stage of the project three different methods of sampling will take place:

- ROV Soil Sampling (this is to find extents of any pollution)
- Vibro coring and/or Gravity coring (to find depth of Hg contamination in soil)
- Seabed CPT (to Establish soil layering and soil strength)

Communication with deck and online will be of highest importance to establish which location each core is being taken.

Each location will be called by it's waypoint name and then a VC,GC,CPT added dependant on which method is being used. If additional attempts are to be carried out then an A,B,C…. will be added dependant on how many attempts. This information as well as time of sample will be logged in the Online log and the Coring spreadsheet.

Depth on site 150m approx

Geodetic Parameters

Spheroid	:	WGS'84
UTM Zone	:	Zone 32° (CM9°)
Datum shift	:	None
Vertical datum	:	MSL

Survey Details

Required Logging	:	NP, Position fixes
Waypoints	:	All waypoints in: P:\SSKO_Active\SSKO_600225\SSKO_SUR\SSKO_SUR_Online **Priority 1a_Re_Evaluated Areas** **Priority 1b_New_Areas** **Priority 2 Wreck Gravity Core Samples** **Priority 4 Soil Testing with CPTU**

Gereral Preparations:

#	Description	Responsible
1.	Prior to all activities, a full QC check of the online systems will be completed and documented	
2.	Prepare XLX27 and conduct pre dive checks	Surv/ROV
3.	Prepare coring tools for deployment	Deck
4.	Move vessel with specific launch point over the waypoint.	Surv

#	Description	Responsible
5.	Launch corer and lower to depth	ROV/Surv/Deck

Operation:

1.	**Launch**	Launch ROV and corer
2.	**Landing**	Under supervision of the ROV land corer in position Online to track corer beacon to ensure landing in correct position.
3.	**Pos fix**	Online to take position fix and relay the location and sample no. to deck.
4.	**Recover**	If required recover sampler to deck
5.	**Change location**	Once the deck has confirmed that the sample is good move to next location.

Note; Communication with deck and online will be of highest importance to establish which location each core is being taken and the sample name.

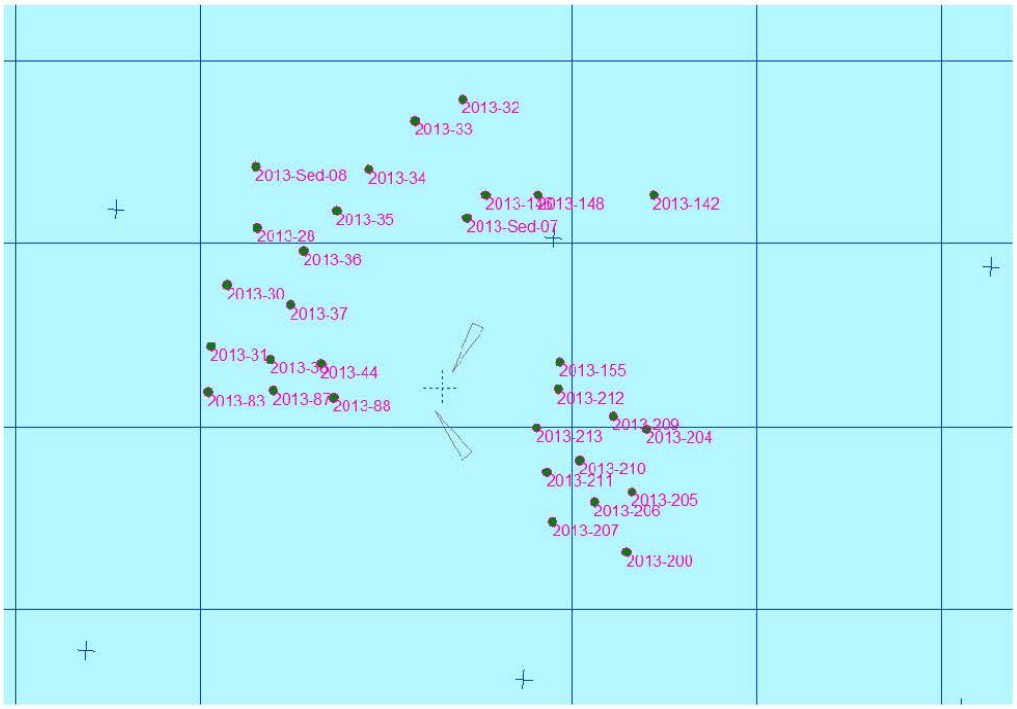
ROV Soils Sampling

Duplicates of previously sampled locations

Area	Easting	Northing	Waypoint
1	261 415.00	6745 227.00	2013-28
1	261 394.00	6745 187.00	2013-30
1	261 383.00	6745 144.00	2013-31
1	261 557.00	6745 317.00	2013-32
1	261 524.00	6745 302.00	2013-33
1	261 492.00	6745 268.00	2013-34
1	261 470.00	6745 239.00	2013-35
1	261 447.00	6745 211.00	2013-36
1	261 438.00	6745 173.00	2013-37
1	261 424.00	6745 135.00	2013-38
1	261 459.00	6745 132.00	2013-44
1	261 381.00	6745 112.00	2013-83
1	261 426.00	6745 113.00	2013-87
1	261 468.00	6745 108.00	2013-88
1	261 689.00	6745 250.00	2013-142
1	261 573.00	6745 250.00	2013-146
1	261 609.00	6745 250.00	2013-148
1	261 560.00	6745 234.00	2013-Sed-07
1	261 414.00	6745 270.00	2013-Sed-08
2	261 624.00	6745 133.00	2013-155
2	261 670.00	6745 000.00	2013-200
2	261 684.00	6745 086.00	2013-204
2	261 674.00	6745 042.00	2013-205
2	261 648.00	6745 035.00	2013-206
2	261 619.00	6745 021.00	2013-207
2	261 661.00	6745 095.00	2013-209

2	261 638.00	6745 064.00	2013-210
2	261 615.00	6745 056.00	2013-211
2	261 623.00	6745 114.00	2013-212
2	261 608.00	6745 087.00	2013-213

NOTE: All targets in yellow are if time allows

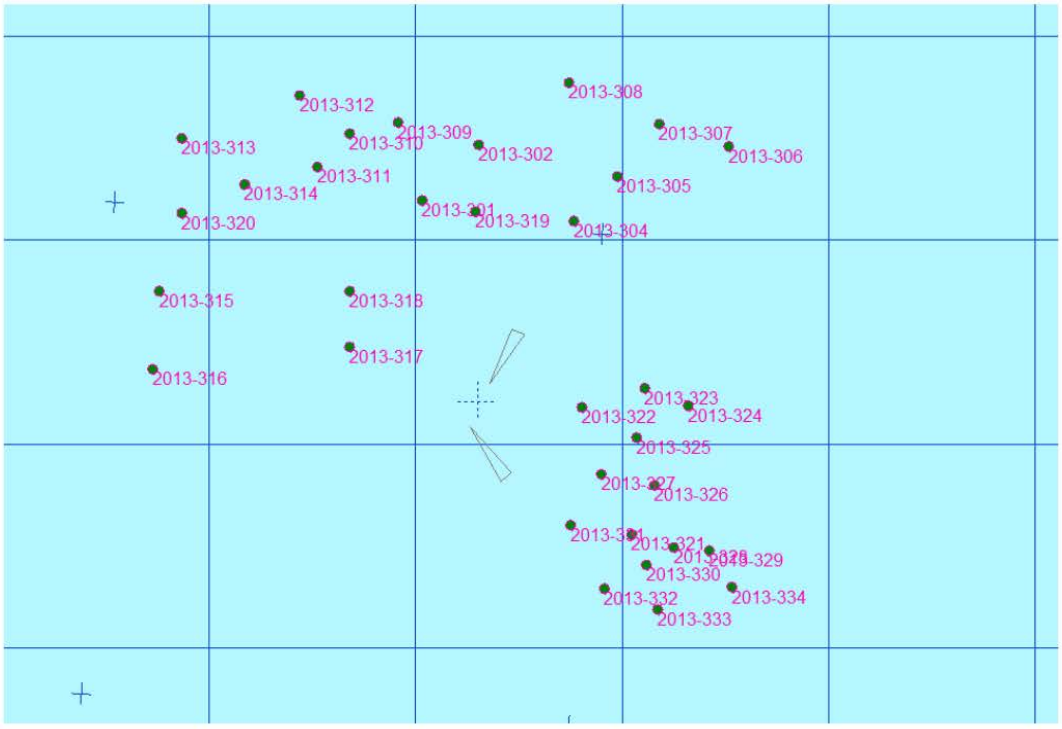


New locations

Area	Easting	Northing	Waypoint
1	261 508.00	6745 241.00	2013-301
1	261 543.00	6745 276.00	2013-302
1	261 602.00	6745 228.00	2013-304
1	261 629.00	6745 256.00	2013-305
1	261 698.00	6745 275.00	2013-306
1	261 655.00	6745 289.00	2013-307
1	261 599.00	6745 315.00	2013-308
1	261 493.00	6745 290.00	2013-309
1	261 463.00	6745 283.00	2013-310
1	261 443.00	6745 262.00	2013-311
1	261 432.00	6745 307.00	2013-312
1	261 359.00	6745 280.00	2013-313
1	261 398.00	6745 251.00	2013-314
1	261 345.00	6745 184.00	2013-315
1	261 341.00	6745 135.00	2013-316
1	261 463.00	6745 149.00	2013-317

1	261 463.00	6745 184.00	2013-318
1	261 541.00	6745 234.00	2013-319
1	261 359.00	6745 233.00	2013-320
2	261 638.00	6745 031.00	2013-321
2	261 607.00	6745 111.00	2013-322
2	261 646.00	6745 123.00	2013-323
2	261 673.00	6745 112.00	2013-324
2	261 641.00	6745 092.00	2013-325
2	261 652.00	6745 062.00	2013-326
2	261 619.00	6745 069.00	2013-327
2	261 664.00	6745 023.00	2013-328
2	261 686.00	6745 021.00	2013-329
2	261 647.00	6745 012.00	2013-330
2	261 600.00	6745 037.00	2013-331
2	261 621.00	6744 997.00	2013-332
2	261 654.00	6744 984.00	2013-333
2	261 700.00	6744 998.00	2013-334

NOTE: All targets in yellow are if time allows



Gravity coring

If all samples with Vibro corer are successful the gravity cores will be taken in the following CPT locations.

Area	Easting	Northing	Waypoint
Aft Wreck	261 628.00	6745 203.00	2013-509
Aft Wreck	261 652.00	6745 192.00	2013-512

Note that above positions are for guidance only. Ensure target location is between 2-5m away from the ACTUAL CPT location.

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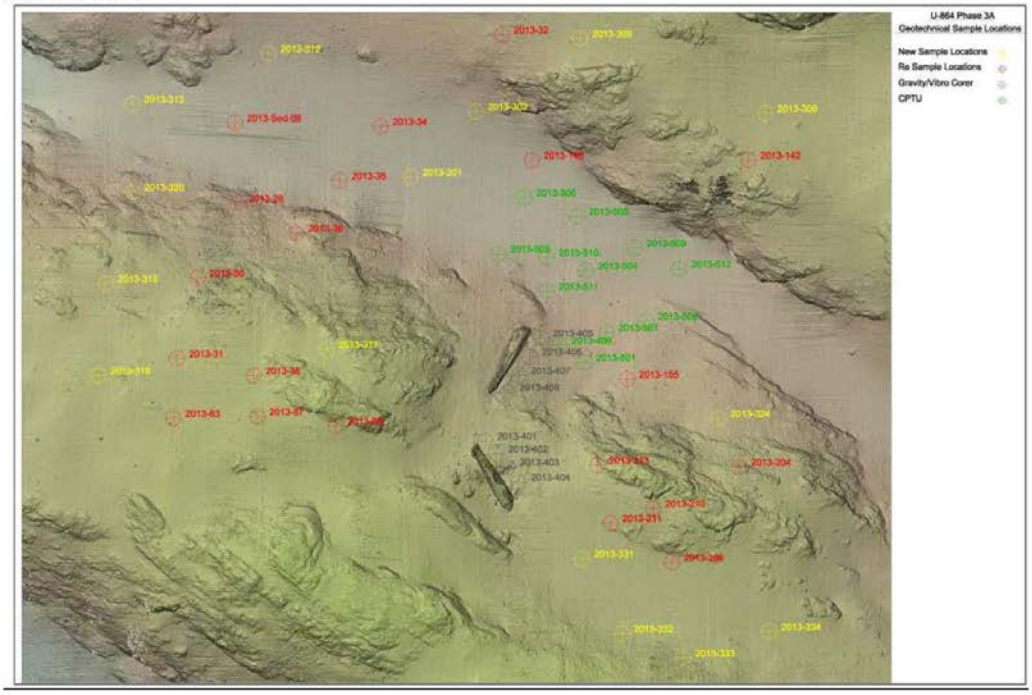
Coring Overview



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600225-SSKO-O02-009 Task Plan: SBP Survey

Distribution Matrix

OM	x	Client	x	Bridge	x	Sen Sur	x	Online	x	ROV	x
Deck		Crane		Sur tech	x	Prod.Man		MAP	x	GEO/Video	x

References:

600225-PJ-O03-12-0003 Kystverket U-864 Phase 3A Operational Survey Procedure

Introduction

Operations on Phase 3A of the U-864 will continue with a SBP survey on the Eastern side of both wreck parts.

The objective for the sub bottom profile survey is to identify any outcrops, large sub bottom rocks or other debris which could be a potential hazard to a later dredging campaign.

Depth on site 150m approx

Geodetic Parameters

Spheroid : WGS'84
UTM Zone : Zone 32° (CM9°)
Datum shift : None
Vertical datum : MSL

Survey Details

Required Logging : NP, NS (30min files), HAIN, **CODA**
Runline : **SBP lines.rlx** in P:\SSKO_Active\SSKO_600225\SSKO_SUR\SSKO_SUR_Online\Runlines
Displaylines : 864 Outline 2000.DWG
Waypoints : None

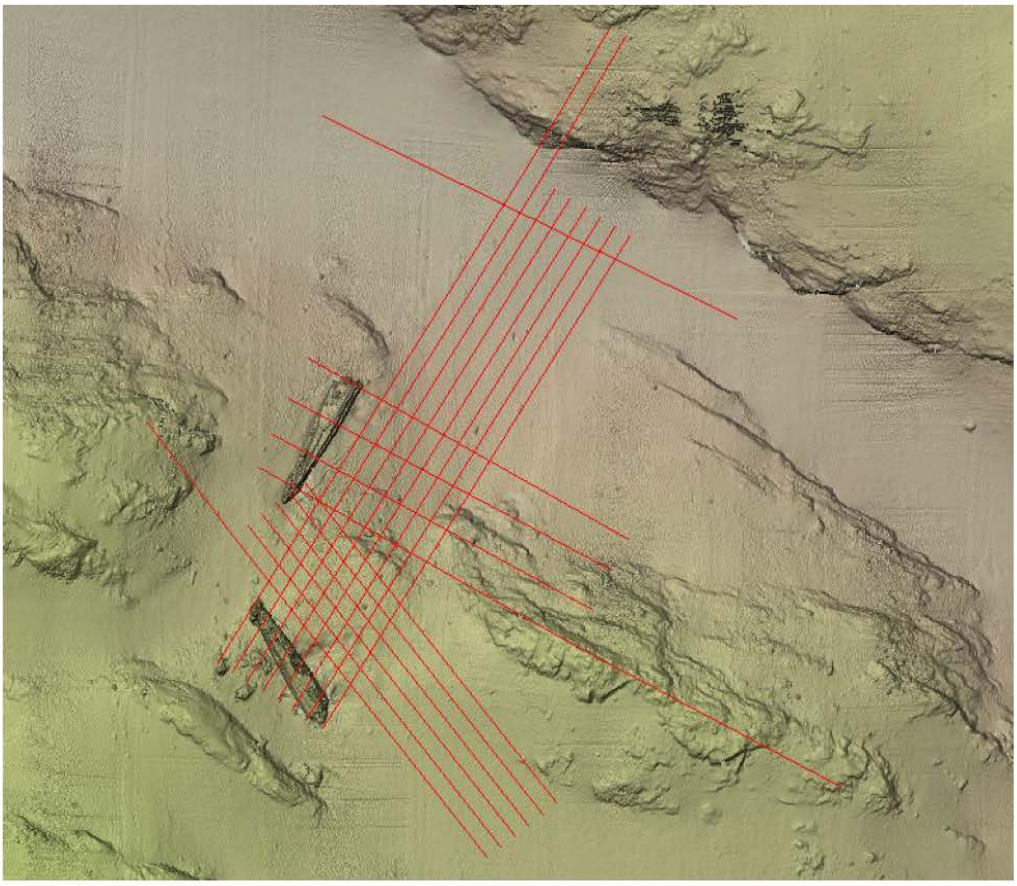
SBP Settings : To be optimised by Geo's
Altitude : 10m
Speed : 0.8- 1.5kt (Achieve high quality data)

Gereral Preparations:

#	Description	Responsible
1.	Prior to all activities, a full QC check of the online systems will be completed and documented	
2.	Prepare XLX27 and conduct pre dive checks	Surv/ROV
3.	Deploy XLX27 to seabed – Log SVP	Surv/ROV
4.	CTD to be updated in APOS	Surv
5.	Conduct 2 min static bathy check (ROV **STATIONARY** on seabed)	Surv
6.	Move vehicle in square, circular or other random patterns to settle hain	ROV/Surv

Operation:

1.	**Setup ROV**	Tune systems and check all systems operating while HAIN settles
2.	**Setup ROV**	Set up on Line "SBP lines start" at the northern end. This line will be used for setting up the system and although may not need the whole line for testing it may need to be run more than once.
3.	**Start Run in**	During long (≈100m) run in further tune systems, ROV speed and ensure good data from SBP
4.	**Continue survey**	After this line continue with each line in the most efficient manner.
5.	**Continue survey**	10m run in/ out on each subsequent line. Ensure ROV is stable before starting run in.
6.	**SVP**	Conduct SVP after 24 Hrs and at conclusion of survey



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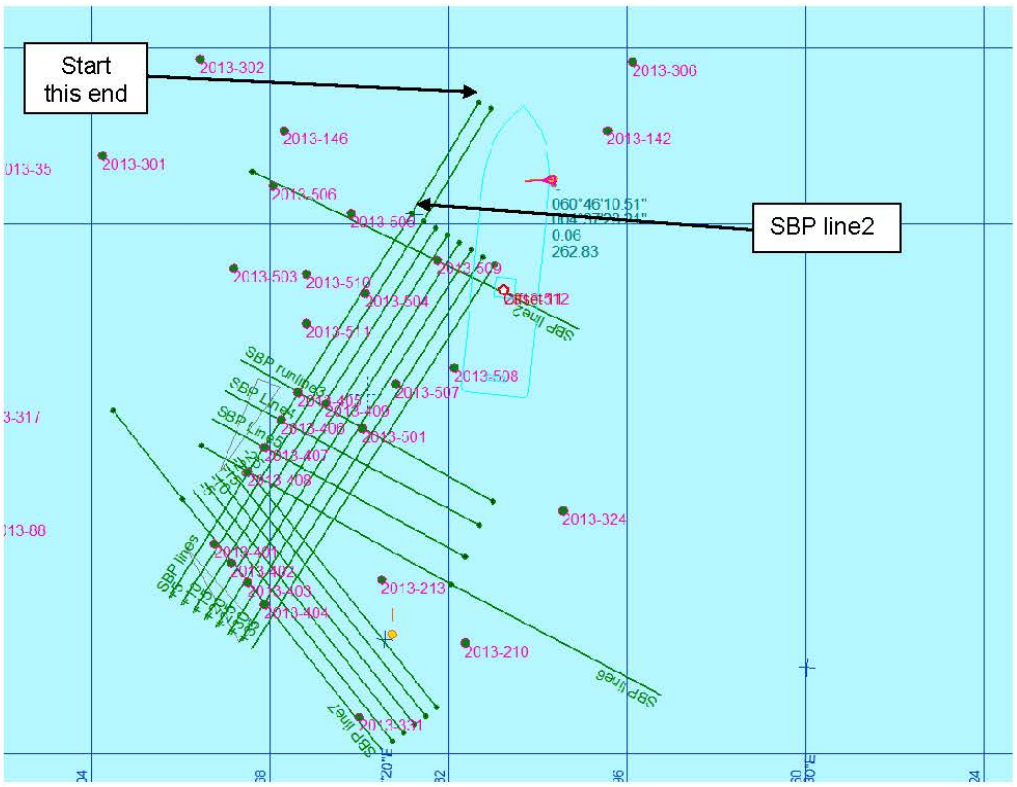


7.3 APPENDIX B: EXPLANATION OF CHART DATUM

Use of positions given by HMS Venturer on modern charts and navigation systems.

What follows is a brief explanation, in layman's terms, of the complications of using positions given by HMS Venturer in 1945 on modern charts and in modern GPS based navigation systems.

As the study of the planet increases in sophistication with modern technology, the shape of the earth is better understood. It is not a perfect sphere but has a 'flattened' top and bottom with a bulge around the equator; it also varies in curvature from place to place around the earth.

Mathematical models of the earth's shape used in navigation are called Spheroids or Ellipsoids. Different spheroids will fit different parts of the earth more accurately than others.

In addition to the spheroid another important aspect of positioning is the 'datum' in use. Many are familiar with the idea of coordinates or latitudes and longitudes, but few realise that these numbers are not absolute and without the correct datum these positions are meaningless. In its most simple form a datum may be thought of as a "zero point", telling the chart user where to start counting from to apply the numbers given as a position.

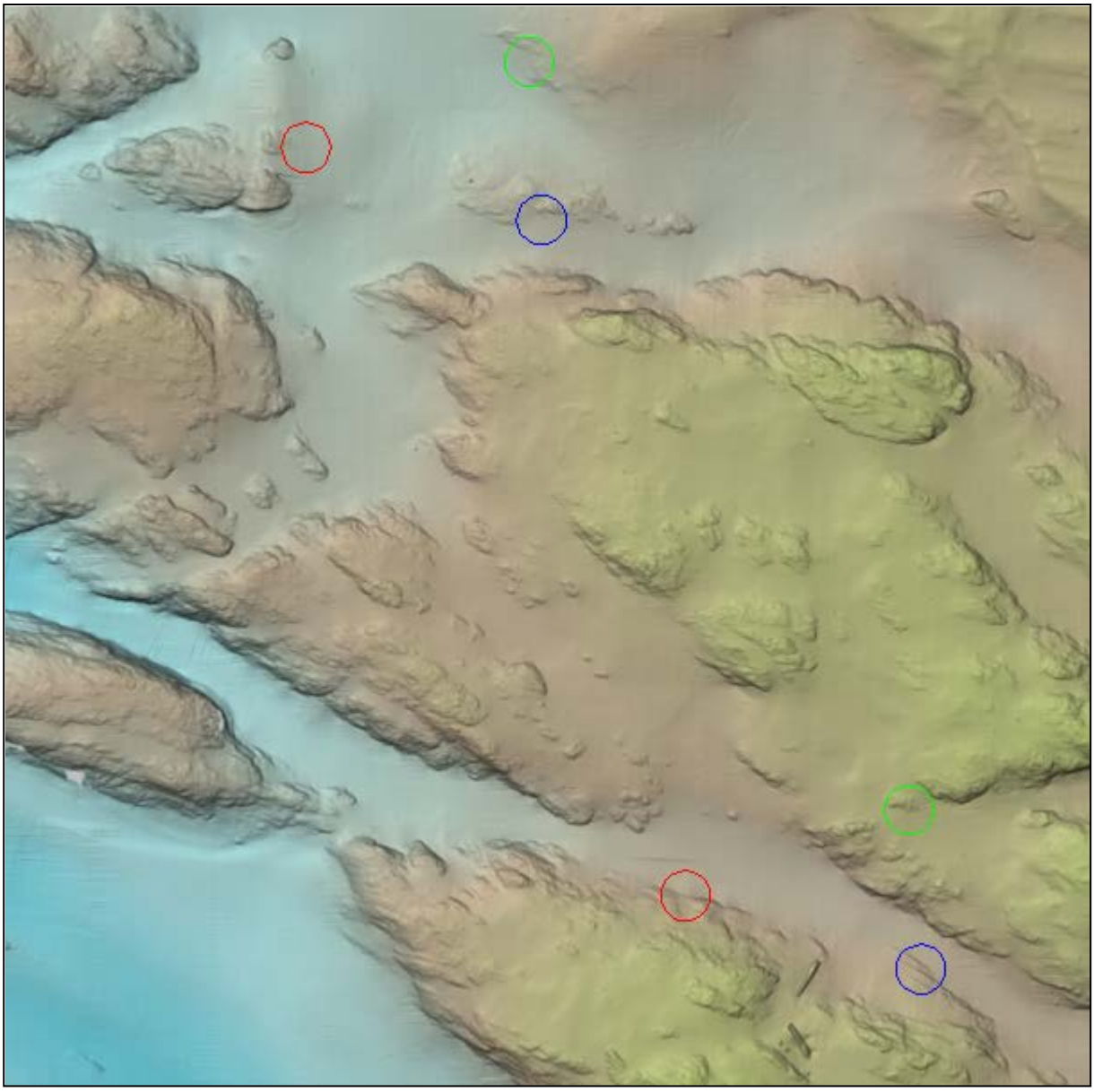
The datum used will vary from area to area (sometimes within the same country) and depends on the use for which the navigation system or chart is designed.

To further complicate matters, each spheroid may be used alone (in which case it is also the datum), or with a "datum shift", to produce multiple answers to the same question: "Where is the U864?"

In order to illustrate this we will compare three sets of "geodetic parameters".

Spheroid	Datum	Used By
WGS84	WGS84	Modern GPS Systems
International 1924	European Datum 1950	Modern Norwegian Charts
Bessel 1841	New Norwegian	Norwegain charts 1913-1956

Below can be seen the result of plotting the attack position and debris location from HMS Venturer's log straight into the three systems without carrying out any conversion between them. The act of converting coordinates from one datum to another is known as a 'transformation'.



1 Attack position (south) and debris surface position (North). WGS (Blue), ED50 (Green) and new Norwegian (Red)

It can be seen that with no transformation applied putting the same set of numbers into the three different systems gives three different answers. These answers are up to 250m apart.
In this case the correct position can only be established by using the same datum as that used in HMS Venturer's charts (or by transforming it from that datum into another and using the new latitude and longitude).

With the help of the UK Hydrographic office, it has been established that the most likely datum in use at the time was "New Norwegian" and although not definitive it is certainly incorrect to plot the position onto modern charts with no form of transformation and expect the positions to match exactly.

8 ATTACHMENTS

8.1 600225-SSKO-O15-13-0001

Kystverket U-864 Phase 3A: M/V Skandi Skolten Mobilisation and Calibration Report, **ref /1/**

8.2 REPORT ON THE SEARCH AND IDENTIFICATION OF U 864

Admiral Consulting, **ref /2/**

8.3 GEOTECHNICAL REPORT U-864 2013 SOIL SURVEY

NGI 20120738-01-R, **ref /3/**

8.4 INVESTIGATION OF MERCURY DURING A SURVEY NEAR SUBMARINE U-864 OUTSIDE FEDJE IN 2013

NIVA 6499-2013), **ref /4/**

8.5 COMPLETION REPORT OIL RECOVERY FOR THE SHIP WRECK OF U-864

FRAMO 616917/3A, **ref /5/**

8.6 600225-SSKO-O15-0001 FIELD MEMO VOR003

Identification of Oil Leak, and Position Verification of U864, **ref /6/**

Mobilisation and Calibration Report

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KYSTVERKET
KYSTDIREKTORATET

Document title

KYSTVERKET U-864 PHASE 3A: M/V SKANDI SKOLTEN MOBILISATION AND CALIBRATION REPORT

Document no.

600225-SSKO-O15-13-0001

Revision Description

Rev.	Date	Description	Originator	Checker	Approver
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01	09.01.2013	Issued for Internal Review	MRO	AJO	HKB
00	09.01.2013	Draft	MRO		

Signature Legend

	Name	Signature	Position
Originator	Michael Robinson		Senior Surveyor
Checker	Adrian Jones		Project Surveyor
Approver	Håvard K. Berge	pp.	Project Manager

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1. PURPOSE AND SCOPE

This report contains information regarding calibration and verification of the survey sensors and offset control measurements for the MV Skandi Skolten during the vessel's mobilisation for the Kystverket U-864 Phase 3A Project.

The DGPS health check was conducted alongside at Bergen on 3rd January 2013.

HIPAP and MBE calibration/verification were completed on the 04th and 05th January 2013 in Byfjorden near Bergen.

Other vessel sensors had been previously calibrated prior to the start of this project. Results are included here for completeness.

2. RESPONSIBILITY AND AUTHORITY

The Senior Surveyor and Project Surveyor are responsible for the preparation, checking and issuing of this document.

The Offshore Manager is responsible for the approval of this document.

3. DEFINITIONS

Abbreviation	Description
CRP	Common Reference Point
CTD	Conductivity, Temperature, Density
C-O	Calculated minus Observed
DGPS / GPS	Differential / Global Positioning System
DSNO	DOF Subsea Norway AS
DTM	Digital Terrain Model
DVL	Doppler Velocity Log
GIS	Geographical Information System
GNSS	Global Navigation Satellite System
HAIN	Hydroacoustic Aided Inertial Navigation
HiPAP	High Precision Acoustic Positioning
INS	Inertial Navigation System
KP	Kilometre Post / Kilometre Point
MBE	Multi Beam Echosounder
MRU	Motion Reference Unit
MSL	Mean Sea Level
PPS	Pulse per second
ROV	Remote Operated Vehicle
SOW	Scope of Work
SVP	Sound Velocity Profile
UNESCO	United Nations Educational, Scientific, and Cultural Organization
USBL	Ultra Short Baseline (acoustic positioning)
UTC	Coordinated Universal Time
UTM	Universal Transverse Mercator
WGS84	World Geodetic System 1984
ZDA	Date and Time (NMEA sentence)

4. REFERENCES

Table 4-1 Project SOW & Specifications

No.	Report / Proc / SOW	Title	Rev.	Date
1.	600225-PJ-O03-12-0002	Kystverket U-864 Phase 3A Skandi Skolten Survey Mobilisation and Calibration Procedure	03i	28.12.2012
2	600225-PJ-O03-12-0003	Kystverket U-864 Phase 3A Operational Survey Procedure	03i	28.12.2012

Table 4-2 DOF Subsea Norway AS Procedures / Reports

No.	Report / Proc / SOW	Title	Re	Date
1.	DG-PY-0002	Policy - Health, safety and working environment	01	26.11.2010
2.	DSA-SV-ST-0002	Global Standard - Dimensional Control Vessel and ROV	01	02.02.2011
3.	DSA-SV-GL-0002	Guideline - Motion Calibration System, Javad Navigation Systems (Javad/Vessel)	01	10.12.2009
4.	DSNO-SV-TMP-0005	Procedure - Heading Sensor Calibration, DSNO	02	14.07.2011
5.	DSNO-SV-PR-0001	Procedure - Doppler and HAIN system checks	01	10.01.2011
6.	DSNO-SV-PR-0002	Procedure - SAIV SD204 STD/CTD Operation	01	09.01.2012
7.	DSNO-SV-PR-0004	Procedure - Vessel Mobilisation	01	10.01.2012
8.	DSNO-SV-PR-0008	Survey Acceptance Test, DSNO	01	10.01.2012
9.	DSNO-SV-PR-0010	Procedure - DGPS Configuration	01	16.01.2012
10.	DSNO-SV-PR-0016	Procedure - Sound Velocity Sensor	01	16.01.2012
11.	DSNO-SV-PR-0017	Procedure - Transfer of Data and Information to Online Surveyor	01	16.01.2012
12.	DSNO-SV-PR-0021	Procedure - Paroscientific Digiquartz Depth Sensor Configuration and Operation	01	17.01.2012
13.	DSNO-SV-PR-0028	Procedure - DGPS Health Check	01	17.01.2012
14.	DSNO-SV-PR-0029	Procedure - Leica Builder R200m Total Station	01	17.01.2011
15.	DSNO-SV-PR-0032	Procedure - Motion Reference Sensor Calibration and Verification	02	14.07.2011
16.	DSNO-SV-PR-0033	Procedure - USBL Calibration and Verification	01	14.07.2009
17.	DSNO-SV-PR-0035	Procedure - Survey QA Checklists	01	02.07.2008
18.	DSNO-SV-PR-0036	Procedure - Collection of survey Data	01	02.07.2008
19.	DSNO-SV-PR-0037	Procedure - Control and Calibration of Total Stations	01	02.07.2008
20.	DSNO-SV-PR-0039	Procedure - Survey Process	01	03.07.2008
21.	DSNO-SV-PR-0044	Procedure - HiPAP Calibration using Kongsberg's APOS	01	01.07.2008
22.	DSNO-SV-PR-0045	Procedure - Multibeam Echo-sounder Calibration and Verification	01	02.07.2008
23.	DSNO-SV-PR-007	Procedure - Pressure Sensor for Draught Measurement	01	10.01.2012
24.	MGI-GEO-O03-0001	Process Management - Geology	04	07.07.2008
25.	MGI-GEO-O03-0003	Video Eventing Procedure	07	07.07.2008
26.	MGI-GEO-O03-0005	Visualworks Basics for ROV and Online	03	07.07.2008

No.	Report / Proc / SOW	Title	Re	Date
27.	MGI-MAP-O03-0001	Processing Procedure	06	02.02.2009
28.	MGI-MAP-O03-0002	Crew change and Project Start-up Procedure	03	06.02.2009
29.	MGI-MAP-O03-0003	Survey Data Corrections	06 i	05.02.2009
30.	MGI-MAP-O03-0004	Terrain Modelling Procedure	06	04.02.2009
31.	MGI-MAP-O03-0005	Presentation	03	05.02.2008
32.	MGI-MAP-O03-0006	Software QA Procedure	08	03.02.2009
33.	MGI-MAP-O03-0007	Data Security	03	05.02.2009
34.	MGI-MAP-O03-0009	Internal Reporting Procedure	06	04.02.2009
35.	MGI-MAP-O03-0010	Isopach Modelling	03	05.02.2009
36.	MGI-MAP-O03-0011	Hain Post Processing in Navlab	03	05.02.2009
37.	MGI-MAP-O04-0001	Collection and use of CTD/SVP Data	06	03.02.2009
38.	MGI-MAP-O04-0003	MBE Calibration	03	02.02.2009
39.	MGI-MAP-O04-0004	NaviEdit Manual	04	04.07.2008
40.	MGI-MAP-O04-0005	Imaging manual	03	05.02.2009
41.	MGI-MAP-O04-0007	Surfer Manual	06	01.02.2009
42.	MGI-MAP-O04-0008	CFloor Manual	05	05.02.2009
43.	MGI-MAP-O04-0009	Navimodel Manual	03	13.02.2009
44.	MGI-MAP-O04-0010	ArcGIS	04	04.02.2009
45.	MGI-MAP-O04-0012	Autochart Manual	05	04.01.2009
46.	MGI-MAP-O04-0013	Transferring Data from AutoCad to ARCGIS	04	04.02.2009
47.	MGI-MAP-O04-0015	Seabed Feature Interp Using MPOLYGONS	04	04.02.2009
48.	MGI-MAP-O04-0016	Isopach Modelling Manual	03	04.02.2009
49.	MGI-MAP-O04-0017	Pipeline Inspection Manual	03	04.02.2009
50.	MGI-MAP-O04-0022	Designing and Maintaining the AutoCad Production Line	08 i	05.02.2009
51.	DSL-SSKO-Q15-11-0002	MV Skandi Skolten Dimensional Control Survey Report	13 i	30.08.2011

5. GEODETIC PARAMETERS

5.1 Grid Co-ordinates System

All positioning will be referred to WGS84 Datum and UTM Projection.

The Datum and projection parameters are listed below.

Definition of Geographical Co-ordinate system (Work Site)

Geodetic datum name:	WGS84
Geographical co-ordinate system axes units:	metre
Ellipsoid name:	WGS84

Ellipsoid defining parameters:

Semi-major axis size	6378137
Semi-major axis units	metre
Inverse flattening value	298.2572235630
Units for ellipsoid height	metre

Definition of projection

Projection name	UTM zone 32(N)

Name of projection transformation method	Transverse Mercator
Projection parameters:	
Latitude of natural origin	0 degrees North
Longitude of central meridian	9 degrees East
Scale factor on CM	0.9996
False Easting, in grid units	500 000.00
False Northing, in grid units	0.00
Projected co-ordinate system axes units	metre

NB: Calibrations were conducted in WGS84, UTM zone 30 and 31. The system in use is specified in the relevant section

5.1.1 Definition of Vertical Datum

Vertical datum name:	MSL
Vertical co-ordinate system axis units:	metre

(N.B. All UTM coordinates, depths and linear dimensions quoted in this report are in metres, unless otherwise stated. Given KP figures are in kilometres).

5.2 Definition of Time

Times quoted are given in UTC unless otherwise defined in the text.

6. SURVEY SPREAD

6.1 MV SKANDI SKOLTEN EQUIPMENT FIT

The equipment listed below is used onboard the MV Skandi Skolten.

6.1.1 Surface Positioning System

- Fugro StarPack HP DGPS with StarFix HP. Corrections via Spotbeam
- Fugro SkyPack XP DGPS. Corrections via Spotbeam

6.1.2 Subsea Positioning Systems

- Kongsberg-Simrad HiPAP 500 USBL subsea positioning system including transponders/responders.

1.

6.1.3 Azimuth and Attitude Sensors

- Applanix Pos-MV heading and attitude sensor (including LN200 motion sensor)

6.1.4 On-line logging and QA system

- EIVA NaviPac Setup Software
- EIVA NaviPac navigation & data acquisition software
- EIVA NaviScan multibeam data acquisition software
- EIVA NaviScan setup software
- EIVA Navitag Recorder on-line 24hrs data acquisition logging software
- EIVA Timebox modules for all data acquisition interface
- CODA Geophysical acquisition system

6.1.5 Off-line Processing Equipment

- NaviEdit Data Editing software
- AutoCAD software for presentation/charting of acquired data.
- NavLAB for HAIN processing

- NaviModel, 3D processing
- Visual-Soft video review software
- Ixsea Delph

6.2 TRITON XLX27 EQUIPMENT FIT.

6.2.1 Doppler Log Unit

- T-RDI 300Khz Doppler velocity log

6.2.2 Camera systems

- Imenco HD-SDI 20X Zoom Camera

6.2.3 Depth sensor units

- 2x Paroscientific Digiquartz 2000

2.

6.2.4 Profiling Systems

- Reson 8125 Dual Head

6.2.5 Azimuth and Attitude Sensors

- CDL Mini RLG2

6.2.6 Sound Velocity Probes

- Saiv SD204 CTD-probe
- Valeport miniSVS

6.2.7 Positioning Systems

- 2 x Kongsberg transponders/responders (One responder, one transponder)
- Kongsberg HAIN integrated inertial navigation

6.2.8 Obstacle Avoidance Sonar (OAS)

- Kongsberg-Simrad Mesotech MS 1000

7. VESSEL SURVEY SENSORS

7.1 General

Survey sensors were calibrated according to DOF Subsea Norway AS procedures. Where calibrations were not possible, valid copies of the manufacturers' calibration/test sheets were obtained, and are held onboard. See Section 11.

As a general practice, verifications/comparisons of survey sensors are routinely analysed to confirm that sensors and equipment are operating to within specifications.

Sensors, which were calibrated/aligned and/or compared by the user, are:

- Surface positioning: Fugro Survey HP, Fugro Survey XP
- Subsea positioning systems: Kongsberg-Maritime HiPAP Dual USBL and HAIN
- Vessel heading sensors: Applanix Pos-MV
- Vessel motion reference system: Applanix LN200 in conjunction with Applanix Pos-MV
- ROV CDL Mini-RLG gyro with integral motion sensors
- ROV mounted dual Reson 8125 MBE

7.1.1 Calibration Alongside

ROV gyro and MRU calibrations were carried out 4th Januray 2013 alongside in bergen. Gyros were compared to the vessel heading sensors for an extended period and a C-O derived. A digital protractor was used to establish roll and pitch of the vehicles to establish a C-O for the MRU. See Section 8.1
Offsets for the instrumentation on the ROV was established using land survey techniques alongside in Bergen.
The vessel heading, pitch and roll sensors were calibrated using the JAVAD heading and motion sensor calibration system alongside in Tananger, Stavanger on 23rd July 2012 as part of a previous project.

7.1.2 Field Calibrations and Verifications

The HIPAP calibration was carried out in Byfjorden on the 04th of January 2013. See Section 7.4

MBE calibration and position verification were conducted at the wreck of the Nautilus in Byfjorden . See Section 8

7.2 Differential Global Positioning systems (DGPS)

7.2.1 General Description

MV Skandi Skolten is fitted with two DGPS systems for surface positioning.

- Fugro StarPack XP DGPS
- Fugro StarPack HP DGPS

Reference is made to DOF Subsea Norway AS document DSNO-SV-PR-0010 DGPS Configuration Procedure and DSNO-SV-PR-0028 DGPS Health Check Procedure.

7.2.2 DGPS Confidence Check

The vessels DGPS positioning was checked whilst alongside in Bergen by using a total station set up over a known coordinate then making observations to a prism mounted on the underside of the mounting bracket of the respective GPS antennae.
GPS antenna positions (HP, XP) were logged at the same time as the total station measurements. The total station calculated coordinates were then compared to the co-ordinates logged by Navipac (observations). This check was conducted in WGS84, UTM 32N. The results are listed below:

Table 7-1 HP Health Check Observations, Bergen 03rd January 2013

Setup	L6	R.O. :	D4	Target offset	ANTENNA :	HP	CLIENT : Kystverket
Easting	296627.869	Grid Brg to RO. :	223.8504	X: 0	SPHEROID :	WGS84	VESSEL: Skandi Skolten
Northing	6700367.853	Convergence	0	Y: 0	PROJECTION :	UTM32N	LOCATION: Dokken
Scale Factor	0.999600	Vessel Heading	0		C.M. :	9°	DATE: 03/01/2013

OBS	TIME	GRID			HORIZ DIST		BEARING	Target		Calculated		Observed		C - O	
No.	UTC	BEARING			TRUE	GRID	(decimal)	EASTING	NORTHING	EASTING	NORTHING	EASTING	NORTHING	EASTING	NORTHING
1	12:45:00	311	53	42	57.59	57.567	175.7454	296632.14	6700310.44	296632.14	6700310.44	296632.36	6700310.42	-0.22	0.03
2	12:45:30	311	48	27	57.57	57.547	175.6579	296632.23	6700310.47	296632.23	6700310.47	296632.38	6700310.46	-0.16	0.01
3	12:46:00	311	50	30	57.59	57.567	175.6920667	296632.19	6700310.45	296632.19	6700310.45	296632.32	6700310.43	-0.13	0.02
4	12:46:30	311	51	43	57.58	57.557	175.7123444	296632.17	6700310.46	296632.17	6700310.46	296632.31	6700310.47	-0.14	-0.01
5	12:47:00	311	54	42	57.6	57.577	175.7620667	296632.12	6700310.43	296632.12	6700310.43	296632.25	6700310.47	-0.12	-0.03
6	12:48:00	311	35	42	57.36	57.337	175.4454	296632.42	6700310.70	296632.42	6700310.70	296632.61	6700310.72	-0.19	-0.02
7	12:49:00	311	51	48	57.59	57.567	175.7137333	296632.17	6700310.45	296632.17	6700310.45	296632.34	6700310.42	-0.17	0.03
8	12:49:30	311	50	42	57.63	57.607	175.6954	296632.19	6700310.41	296632.19	6700310.41	296632.34	6700310.44	-0.14	-0.03
9	12:50:30	311	12	55	57.09	57.067	175.0656778	296632.78	6700311.00	296632.78	6700311.00	296632.91	6700310.96	-0.13	0.04
10	12:52:00	311	36	42	57.39	57.367	175.4620667	296632.41	6700310.67	296632.41	6700310.67	296632.57	6700310.66	-0.16	0.01
11	12:52:30	311	32	31	57.33	57.307	175.3923444	296632.47	6700310.73	296632.47	6700310.73	296632.60	6700310.71	-0.13	0.03
12	12:54:00	311	15	56	57.15	57.127	175.1159556	296632.73	6700310.93	296632.73	6700310.93	296632.88	6700310.93	-0.15	0.00
13	12:54:30	311	16	22	57.14	57.117	175.1231778	296632.72	6700310.94	296632.72	6700310.94	296632.88	6700310.92	-0.15	0.02
14	12:55:00	311	32	43	57.38	57.357	175.3956778	296632.47	6700310.68	296632.47	6700310.68	296632.72	6700310.70	-0.25	-0.02
15	12:55:30	311	34	10	57.37	57.347	175.4198444	296632.45	6700310.69	296632.45	6700310.69	296632.65	6700310.65	-0.20	0.04
16	12:56:00	311	40	4	57.42	57.397	175.5181778	296632.35	6700310.63	296632.35	6700310.63	296632.50	6700310.60	-0.15	0.03
17	12:57:00	311	53	18	57.58	57.557	175.7387333	296632.15	6700310.46	296632.15	6700310.46	296632.30	6700310.47	-0.15	-0.02
18	12:57:30	311	53	46	57.59	57.567	175.7465111	296632.14	6700310.44	296632.14	6700310.44	296632.28	6700310.43	-0.14	0.02
19	12:58:00	311	56	30	57.59	57.567	175.7920667	296632.09	6700310.44	296632.09	6700310.44	296632.28	6700310.42	-0.18	0.02
20	12:58:30	311	59	43	57.63	57.607	175.8456778	296632.04	6700310.40	296632.04	6700310.40	296632.24	6700310.35	-0.20	0.04
21	12:59:00	312	1	49	57.66	57.637	175.8806778	296632.01	6700310.36	296632.01	6700310.36	296632.19	6700310.33	-0.18	0.03
22	13:00:00	311	55	44	57.61	57.587	175.7792889	296632.11	6700310.42	296632.11	6700310.42	296632.27	6700310.41	-0.17	0.01
23	13:00:30	311	54	31	57.6	57.577	175.7590111	296632.13	6700310.43	296632.13	6700310.43	296632.24	6700310.36	-0.11	0.07
24	13:01:30	311	55	30	57.6	57.577	175.7754	296632.11	6700310.43	296632.11	6700310.43	296632.27	6700310.42	-0.16	0.01
25	13:02:00	311	55	32	57.59	57.567	175.7759556	296632.11	6700310.44	296632.11	6700310.44	296632.28	6700310.43	-0.17	0.01
26	13:03:00	312	0	39	57.64	57.617	175.8612333	296632.03	6700310.39	296632.03	6700310.39	296632.21	6700310.38	-0.18	0.01
27	13:03:30	311	53	24	57.57	57.547	175.7404	296632.14	6700310.46	296632.14	6700310.46	296632.30	6700310.45	-0.16	0.01
28	13:05:00	312	30	37	58.03	58.007	176.3606778	296631.55	6700309.96	296631.55	6700309.96	296631.72	6700309.91	-0.16	0.06
29	13:05:30	312	31	41	58.04	58.017	176.3784556	296631.53	6700309.95	296631.53	6700309.95	296631.72	6700309.94	-0.18	0.01
30	13:06:00	312	32	29	58.04	58.017	176.3917889	296631.52	6700309.95	296631.52	6700309.95	296631.68	6700309.92	-0.16	0.03
31	13:06:30	312	33	13	58.05	58.027	176.4040111	296631.51	6700309.94	296631.51	6700309.94	296631.66	6700309.89	-0.15	0.05
32	13:07:00	312	33	3	58.03	58.007	176.4012333	296631.51	6700309.96	296631.51	6700309.96	296631.70	6700309.97	-0.19	-0.01
		MEAN						296632.15	6700310.45	296632.15	6700310.45	296632.31	6700310.44	**-0.16m**	**0.02m**
		S.D.						0.33	0.27	0.33	0.27	0.33	0.28	**0.03**	**0.02**

Table 7-2 XP Health Check Observations, Bergen 03rd January 2013

Setup	L6	R.O. :	D4	Target offset	ANTENNA :	XP	CLIENT : Kystverket
Easting	296627.869	Grid Brg to RO. :	223.8504	X: 0	SPHEROID :	WGS84	VESSEL: Skandi Skolten
Northing	6700367.853	Convergence	0	Y: 0	PROJECTION :	UTM32N	LOCATION: Dokken
Scale Factor	0.999600	Vessel Heading	0		C.M. :	9°	DATE: 03/01/2013

OBS No.	TIME UTC	GRID BEARING			HORIZ DIST TRUE	Target EASTING	Target NORTHING	Calculated EASTING	Calculated NORTHING	Observed EASTING	Observed NORTHING	C - O EASTING	C - O NORTHING	OUTL C-O Magnitude (m)
1	10:55:00	313	23	9	56.86	296630.61	6700311.08	296630.61	6700311.08	296630.73	6700311.01	-0.12	0.07	0.139
2	10:55:30	313	25	32	56.9	296630.57	6700311.04	296630.57	6700311.04	296630.70	6700311.01	-0.13	0.03	0.130
3	10:56:00	313	24	25	56.91	296630.59	6700311.03	296630.59	6700311.03	296630.67	6700310.96	-0.08	0.07	0.110
4	10:56:30	313	29	1	56.94	296630.52	6700311.00	296630.52	6700311.00	296630.65	6700310.93	-0.13	0.06	0.148
5	10:57:00	313	26	32	56.9	296630.56	6700311.04	296630.56	6700311.04	296630.69	6700310.96	-0.13	0.08	0.153
6	10:57:30	313	25	46	56.88	296630.57	6700311.06	296630.57	6700311.06	296630.69	6700310.97	-0.13	0.09	0.155
7	10:58:00	313	30	11	56.94	296630.50	6700311.00	296630.50	6700311.00	296630.64	6700310.90	-0.15	0.09	0.174
8	10:58:30	313	19	36	56.83	296630.67	6700311.11	296630.67	6700311.11	296630.75	6700311.00	-0.08	0.11	0.137
9	10:59:00	313	23	27	56.81	296630.60	6700311.13	296630.60	6700311.13	296630.79	6700311.04	-0.19	0.09	0.206
10	10:59:30	313	27	12	56.91	296630.55	6700311.03	296630.55	6700311.03	296630.68	6700310.94	-0.13	0.09	0.160
11	11:00:00	313	18	59	56.78	296630.67	6700311.17	296630.67	6700311.17	296630.81	6700311.06	-0.13	0.11	0.170
12	11:01:00	313	32	28	56.96	296630.46	6700310.97	296630.46	6700310.97	296630.65	6700310.92	-0.19	0.05	0.198
13	11:01:30	313	27	51	56.91	296630.53	6700311.03	296630.53	6700311.03	296630.66	6700310.93	-0.12	0.10	0.162
14	11:02:00	313	28	16	56.96	296630.53	6700310.98	296630.53	6700310.98	296630.61	6700310.87	-0.08	0.11	0.134
15	11:02:30	313	27	18	56.9	296630.54	6700311.04	296630.54	6700311.04	296630.70	6700310.97	-0.16	0.06	0.172
16	11:03:00	313	26	24	56.88	296630.56	6700311.06	296630.56	6700311.06	296630.70	6700310.96	-0.15	0.10	0.178
17	11:03:30	313	29	11	56.96	296630.51	6700310.98	296630.51	6700310.98	296630.65	6700310.90	-0.13	0.08	0.155
18	11:04:00	313	28	36	56.98	296630.53	6700310.96	296630.53	6700310.96	296630.62	6700310.87	-0.09	0.09	0.131
20	11:05:00	313	26	54	56.91	296630.55	6700311.03	296630.55	6700311.03	296630.68	6700310.95	-0.13	0.08	0.146
21	11:05:30	313	30	8	56.94	296630.50	6700311.00	296630.50	6700311.00	296630.64	6700310.91	-0.14	0.09	0.166
22	11:06:00	313	26	5	56.85	296630.56	6700311.09	296630.56	6700311.09	296630.74	6700311.03	-0.18	0.06	0.193
23	11:06:30	313	37	11	56.98	296630.38	6700310.95	296630.38	6700310.95	296630.53	6700310.85	-0.15	0.10	0.179
24	11:07:00	313	30	34	56.92	296630.49	6700311.02	296630.49	6700311.02	296630.59	6700310.94	-0.10	0.08	0.129
25	11:07:30	313	27	13	56.85	296630.54	6700311.09	296630.54	6700311.09	296630.71	6700311.02	-0.17	0.07	0.184
26	11:08:00	313	31	14	56.95	296630.48	6700310.99	296630.48	6700310.99	296630.62	6700310.92	-0.14	0.06	0.151
27	11:08:30	313	32	11	56.95	296630.46	6700310.98	296630.46	6700310.98	296630.63	6700310.94	-0.17	0.05	0.174
28	11:09:00	313	29	57	56.94	296630.50	6700311.00	296630.50	6700311.00	296630.61	6700310.94	-0.11	0.06	0.124
29	11:09:30	313	26	19	56.86	296630.56	6700311.08	296630.56	6700311.08	296630.68	6700311.01	-0.12	0.07	0.140
30	11:10:00	313	24	20	56.85	296630.59	6700311.09	296630.59	6700311.09	296630.70	6700311.01	-0.12	0.08	0.139
31	11:10:30	313	30	50	56.94	296630.49	6700311.00	296630.49	6700311.00	296630.70	6700310.99	-0.21	0.01	0.212
		MEAN				296630.54	6700311.03	296630.54	6700311.03	296630.67	6700310.96	**-0.14m**	**0.08m**	0.158
		S.D.				0.06	0.05	0.06	0.05	0.06	0.05	**0.03**	**0.02**	

7.2.3 DGPS Comparison

A comparison between the survey navigation systems, Fugro XP/HP was carried out during the vessel mobilisation on 3rd January 2013.

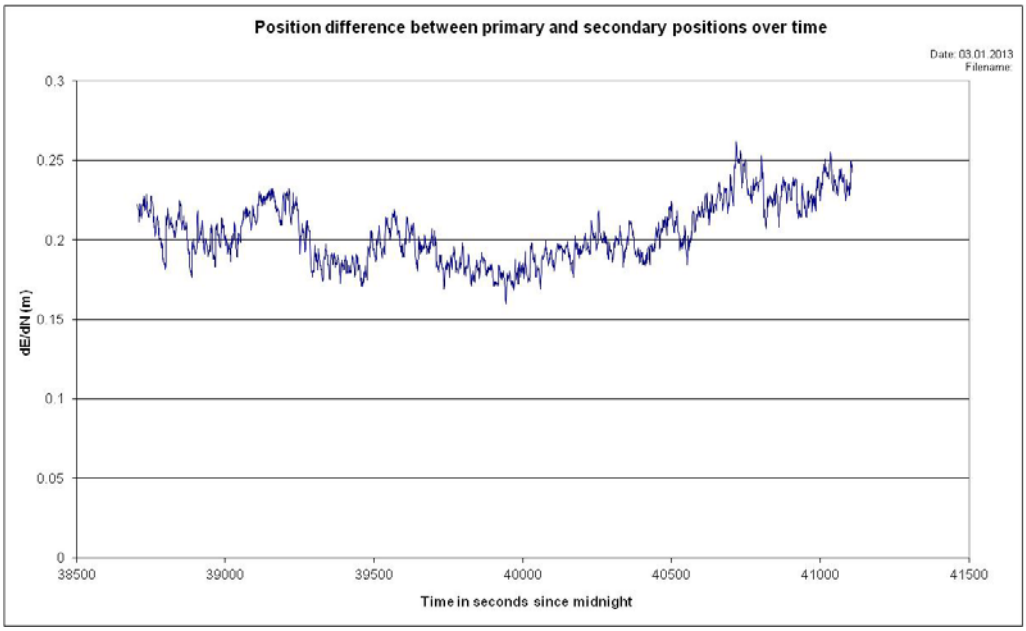


Figure 7-1 Position difference between HP and XP systems, 3rd January 2013

7.3 Heading and Motion Sensors

7.3.1 General Description

MV Skandi Skolten is fitted with a Applanix Pos-MV GPS based heading, pitch and roll system. Calibration of this system was conducted on 23rd July 2012 alongside in Tanager, Stavanger.

The JAVAD motion and heading calibration system was used during the calibration One hour of data was collected for heading, roll and pitch. These results were directly compared to that of the Pos-MV logged over the same period.

Table 7-3 Calibration Results for POS-MV System

Measurement	C-O (°)	Std. Dev (°)	Number of measurements
Heading	0.008	0.061	82183
Pitch	-1.551	0.030	82183
Roll	-0.448	0.022	82183

Table 7-4 Calibration Verification Results for the POS-MV System

Measurement	C-O (°)	Std. Dev (°)	Number of measurements
Heading	-0.008	0.013	9509
Pitch	-0.027	0.026	9509
Roll	0.029	0.016	9509

7.4 HiPAP Calibration

7.4.1 General Description

MV Skandi Skolten's Kongsberg-Maritime HiPAP system was calibrated for deep water on the 23rd July 2012 at a site near Stavanger. A verification of the calibration was carried out in Byfjorden on the 4th January 2013.

The Fugro StarFix HP DGPS was used as primary surface navigation reference for the calibration, conducted in accordance with DOF Subsea Norway AS document No DSNO-SV-PR-033 USBL Calibration and Verification Procedure.

A sound-velocity profile was taken before the calibrations, and the profile was loaded into the HiPAP system prior to the start of the calibration.

The verification was conducted using the NaviPac routine for USBL calibrations. Data was checked using in house DSNO systems.

1.	Verification spin	A static 360° spin was performed, 50m offset from the transponder with corrections applied.
2.	Verification lines	With the existing corrections entered into the USBL system, two DP transit lines 340m in length were run, forward/aft & port/stbd with a constant vessel heading of North, over the transponder position.

Applanix POS-MV, Heading and Motion (pitch/roll), data was used as primary input to the HiPAP system during the verification.

7.4.2 HiPAP Verification Results

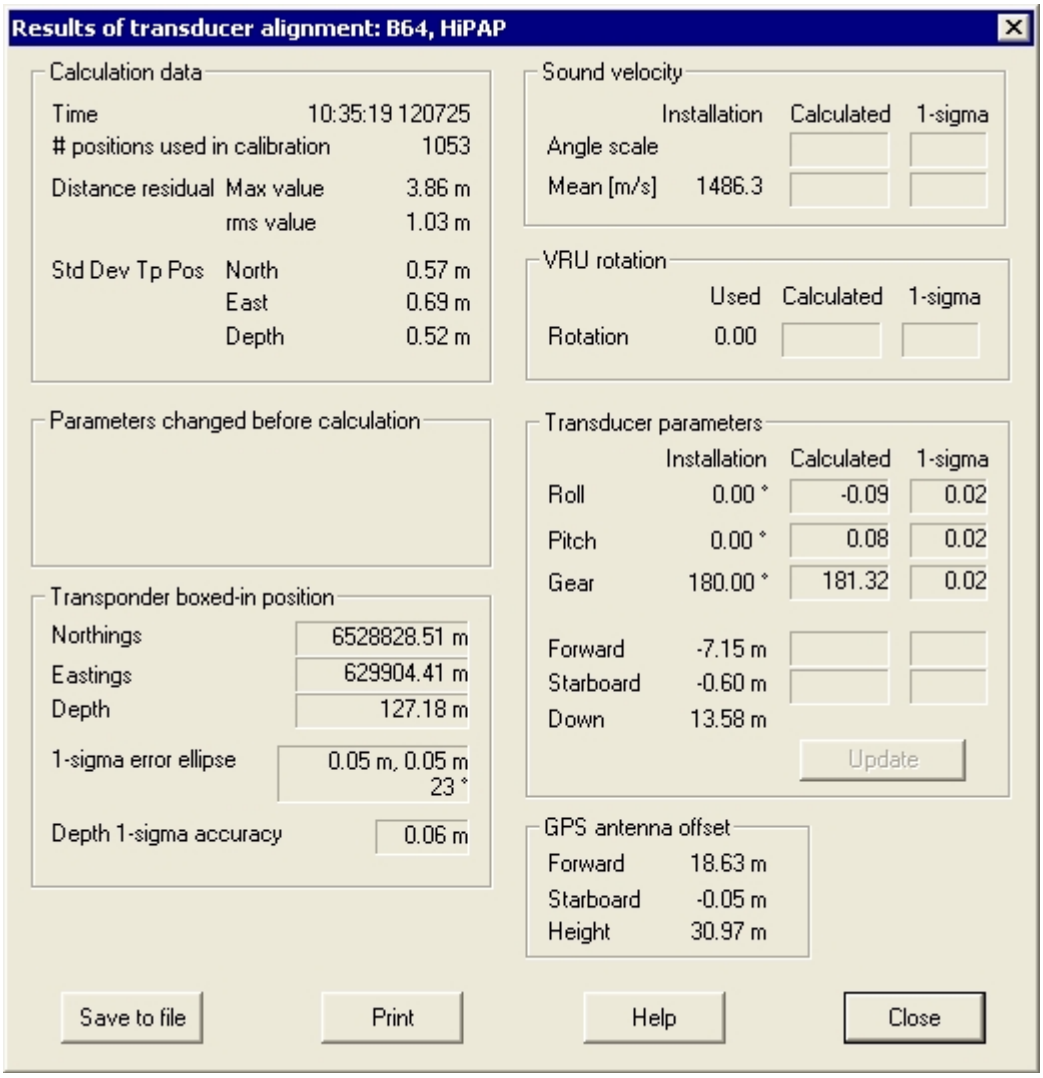


Figure 7-2 HiPAP Calibration results: 23rd July 2012 (existing settings)

7.4.3 HiPAP Verification Observations

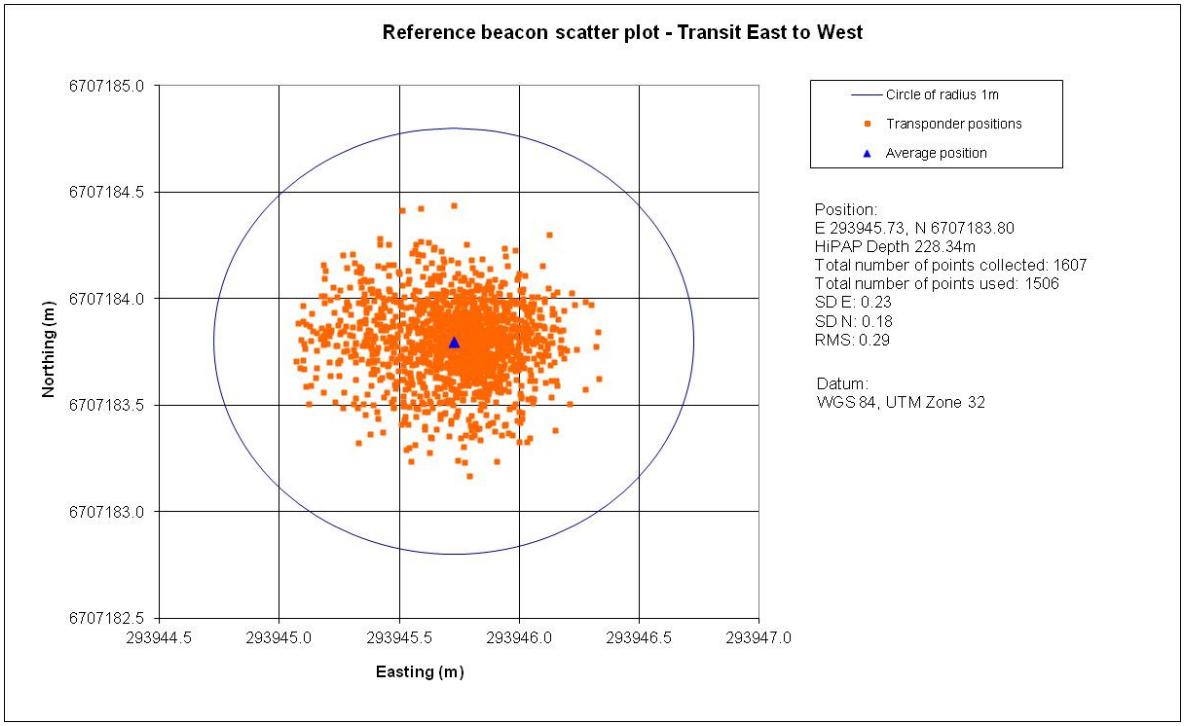


Figure 7-3 HiPAP - Position plot, lateral verification East to West, 4th January 2013

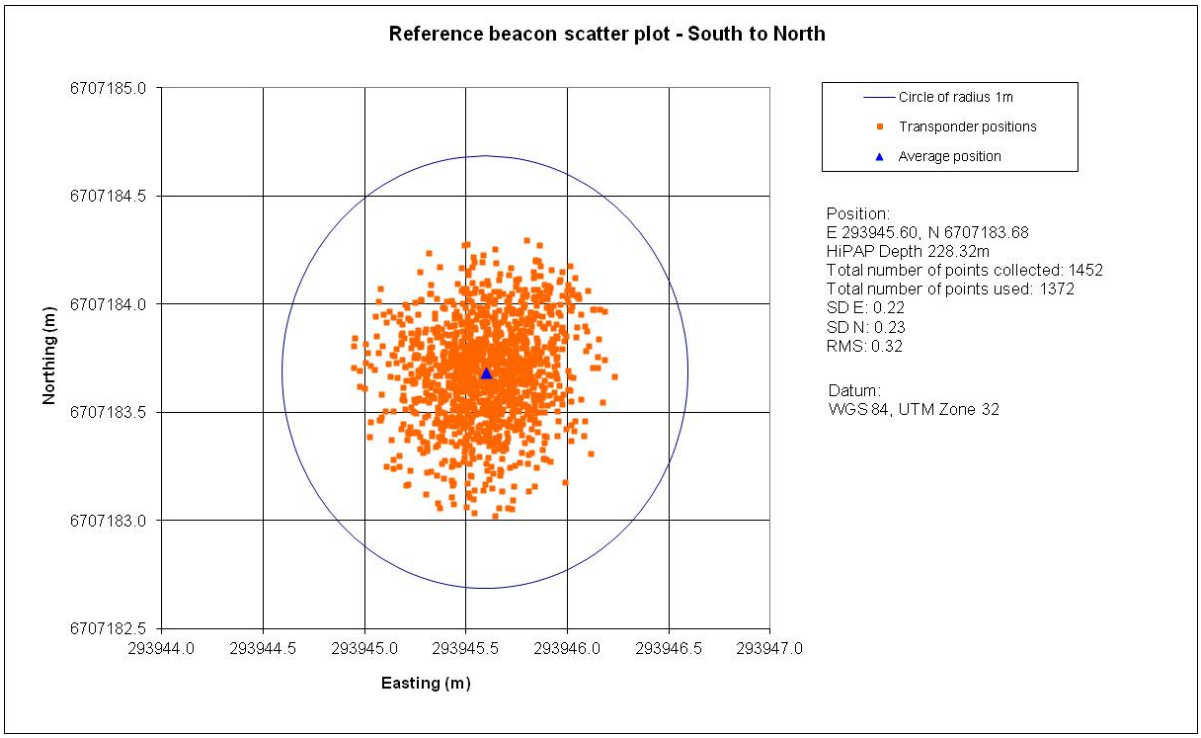


Figure 7-4 HiPAP - Position plot, forward verification South to North, 4th January 2013

7.4.4 Sound Velocity Profiles

The speed of sound profile used during the HiPAP calibration is shown below in Figure 7.19

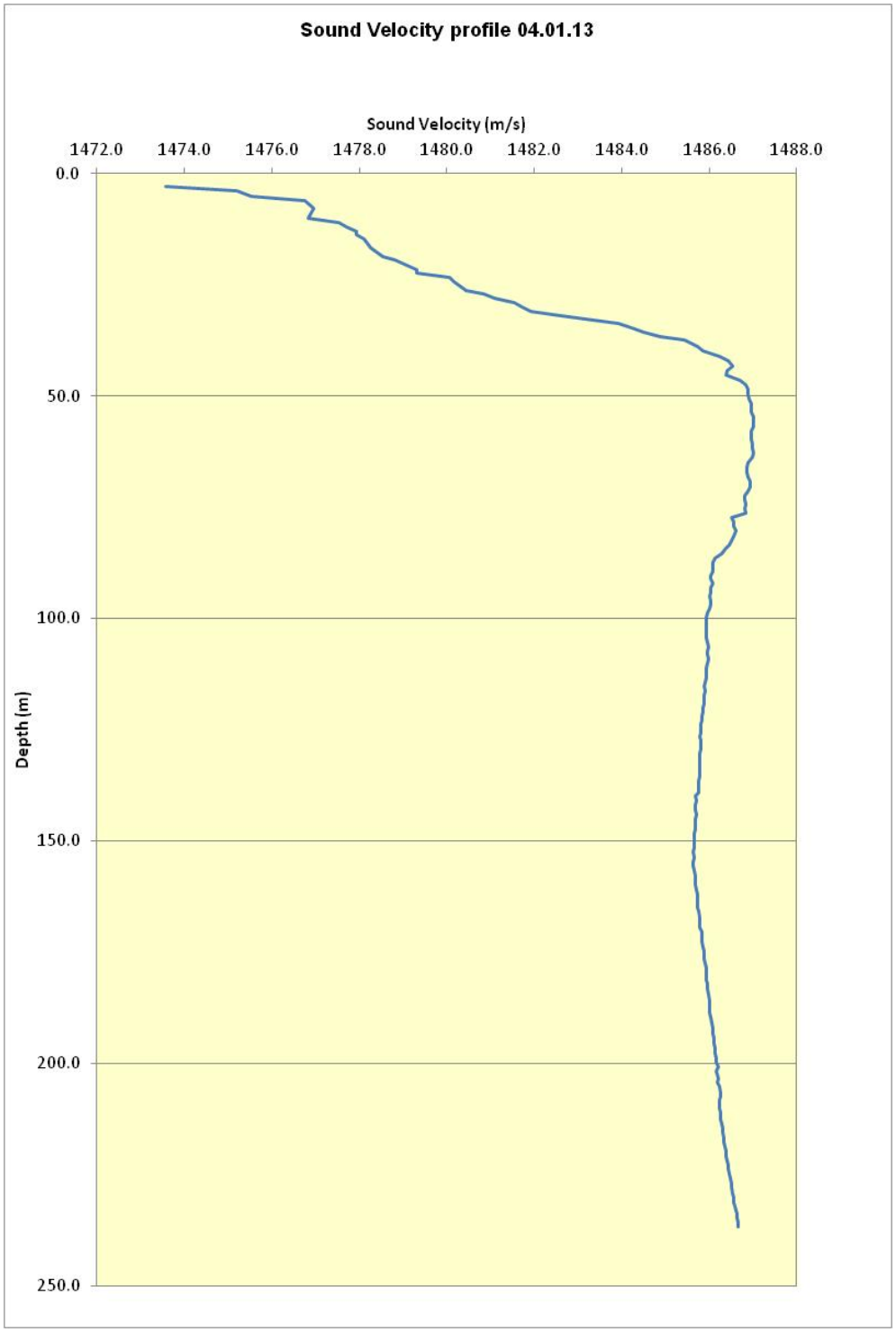


Figure 7-5 Speed of sound profile measured before HiPAP verification 4th January 2013

7.5 Air pressure sensor

The Aanderaa air pressure sensor was used to log air pressure in NaviPac. This data was used to correct depths measured by subsea pressure sensors.

During the mobilisation the air pressure sensor was compared against reading acquired from Bergen airport. The vessel was alongside at Dokken, Bergen which is approximately 12km away.

Table 7-5 Air pressure sensor verification 13:00hrs UTC on the 4th January 2013

Date	Measured onboard (mb)	Check value (mb)	Observed data source
04.01.2013	1018.8	1018	WorldWeatherOnline (Bergen Airport)

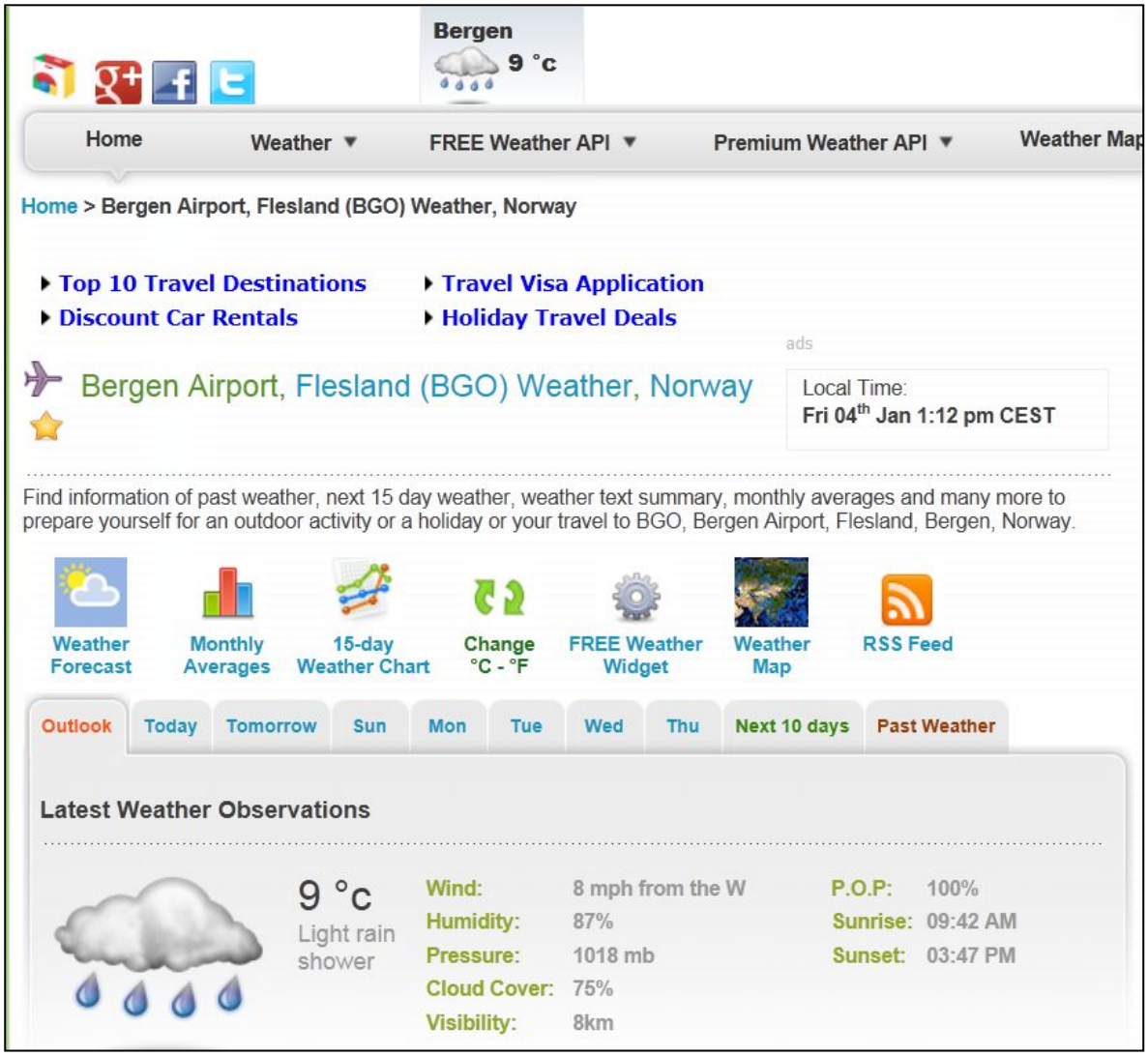


Figure 7-6 Image from World Weather website for Bergen airport.

8. CALIBRATION / VERIFICATION ROV EQUIPMENT

8.1 Heading and Motion Sensors

8.1.1 General Description

The survey XLX ROV on board MV Skandi Skolten is fitted with a Mini RLG 2 Gyro for this project providing heading, roll and pitch measurements.

8.1.2 ROV Heading Sensor Calibration and Verification Procedure

The ROV Gyro was compared to the vessel gyro over a period of 30 minutes. The results were tabulated and C-Os derived.

Table 8-1 Results from ROV Heading calibration XLX27

Vessel POSMV Hdg° (C)	CDL RLG2 Hdg° (O)	C-O (º)	SD
220.235	219.431	0.803	0.037

Table 8-2 Results from ROV Pitch calibration XLX27

Measured average Pitch from inclinometer° (C)	CDL RLG2 Pitch° (O)	C-O (º)	SD
-0.19	0.23	0.42	0.045

Table 8-3 Results from ROV Roll calibration XLX27

Measured average Roll from inclinometer° (C)	CDL RLG2 Roll° (O)	C-O (º)	SD
-0.25	-0.08	0.17	0.060

8.2 Depth System Checks

8.2.1 Setup of Digiquartz Units

XLX27 has two Paroscientific Digiquartz units rated to 2000m. One located on the ROV frame and one in a bracket for “Hand held” operations. The installation was performed in accordance with DOF Subsea Norway AS document No DSNO-SV-PR-0021.

Comparisons between these instruments with the ROV static on the seabed agreed very well once the difference in position on the ROV was taken into consideration. CTD data from a ROV mounted sensor was used in UNESCO density calculations for these tests.

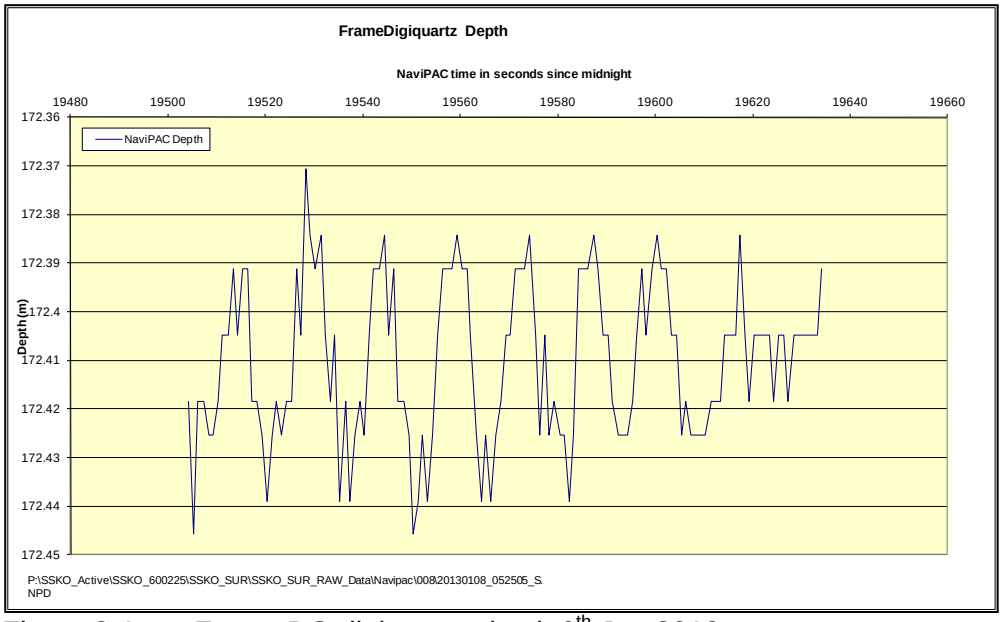


Figure 8-1 Frame DQ digiquartz check 6th Jan 2013

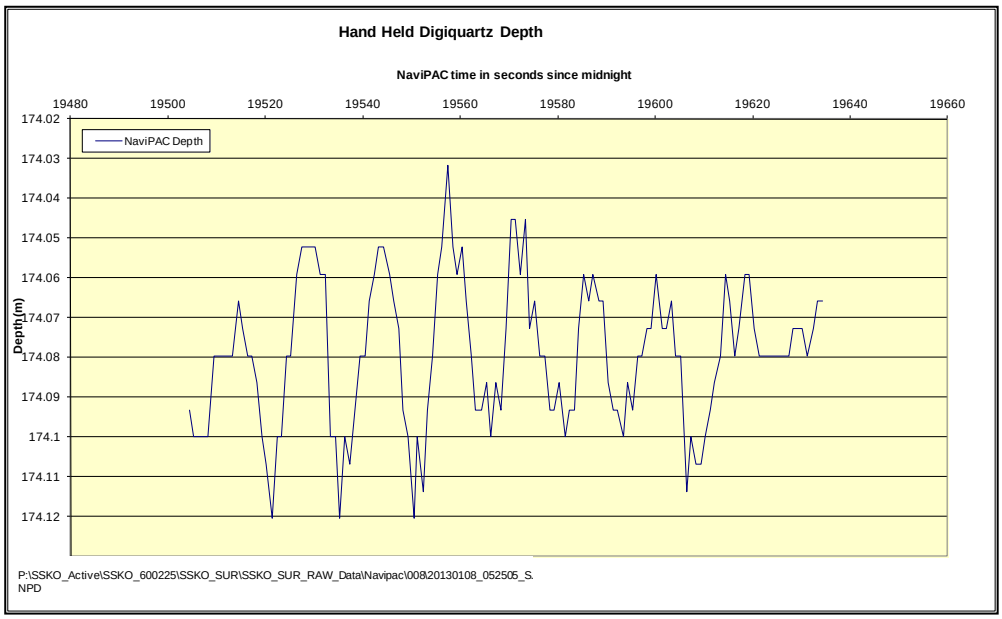


Figure 8-2 Hand Held DQ digiquartz check 6th Jan 2013

8.3 Doppler Velocity Log

XLX27 is equipped with a 300kHz Navigator DVL for survey purposes. The calibration was carried out in accordance with DOF Subsea procedure DSNO-SV-PR-0011 Doppler Velocity Log Alignment Procedure.

On the 05th January 2013 a Doppler alignment calibration was conducted in Byfjorden. It was found that there was a problem with the mounting position of the DVL and so a second calibration was undertaken near Fedje before the start of the survey.
The alignment angle, pitch and roll were all set to zero at the start of the calibration. To determine the alignment value correction, the Doppler data was post processed using Navlab software. Results of the calibration can be seen in Figure 8.1. The heading, pitch and roll values were then updated to match those in Figure 8.1.

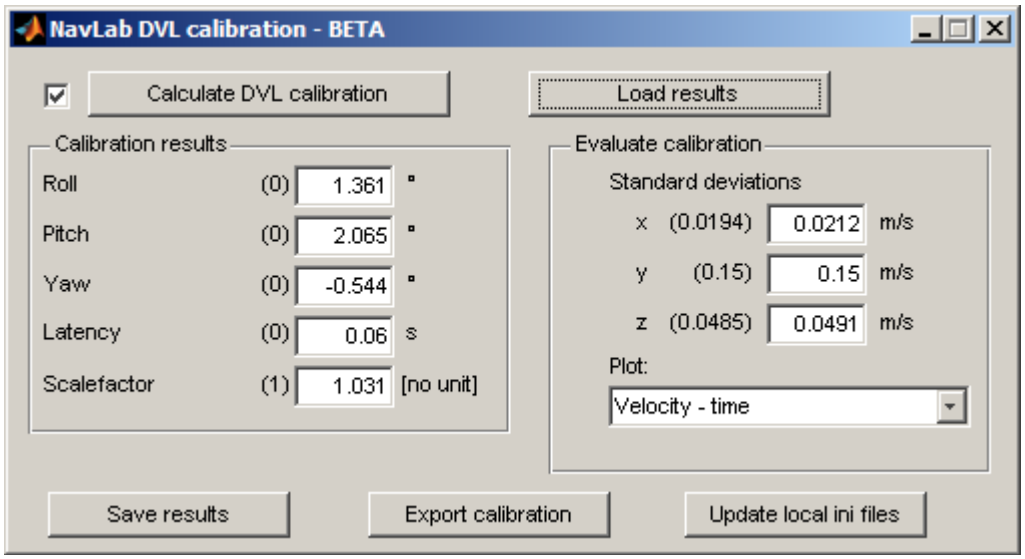


Figure 8-3 DVL calibration results from Navlab DVL Calibration

8.4 Inertial Navigation sensor

The Kongsberg-Maritime HAIN system was installed and interfaced to XLX27's subsea sensors and all offsets in the HAIN setup within APOS were recorded and checked. The installation and system performance was conducted in accordance with DOF Subsea Norway AS document No DSNO-SV-PR-0001.

This system is interfaced to a CDL Mini RLG2 Gyro on the ROV which provides inertial data together with gyro, pitch & roll. It also receives data from the 300 kHz survey Doppler log and a Digiquartz pressure sensor. Hydro acoustic position aiding comes from the responder mounted on the vehicle.

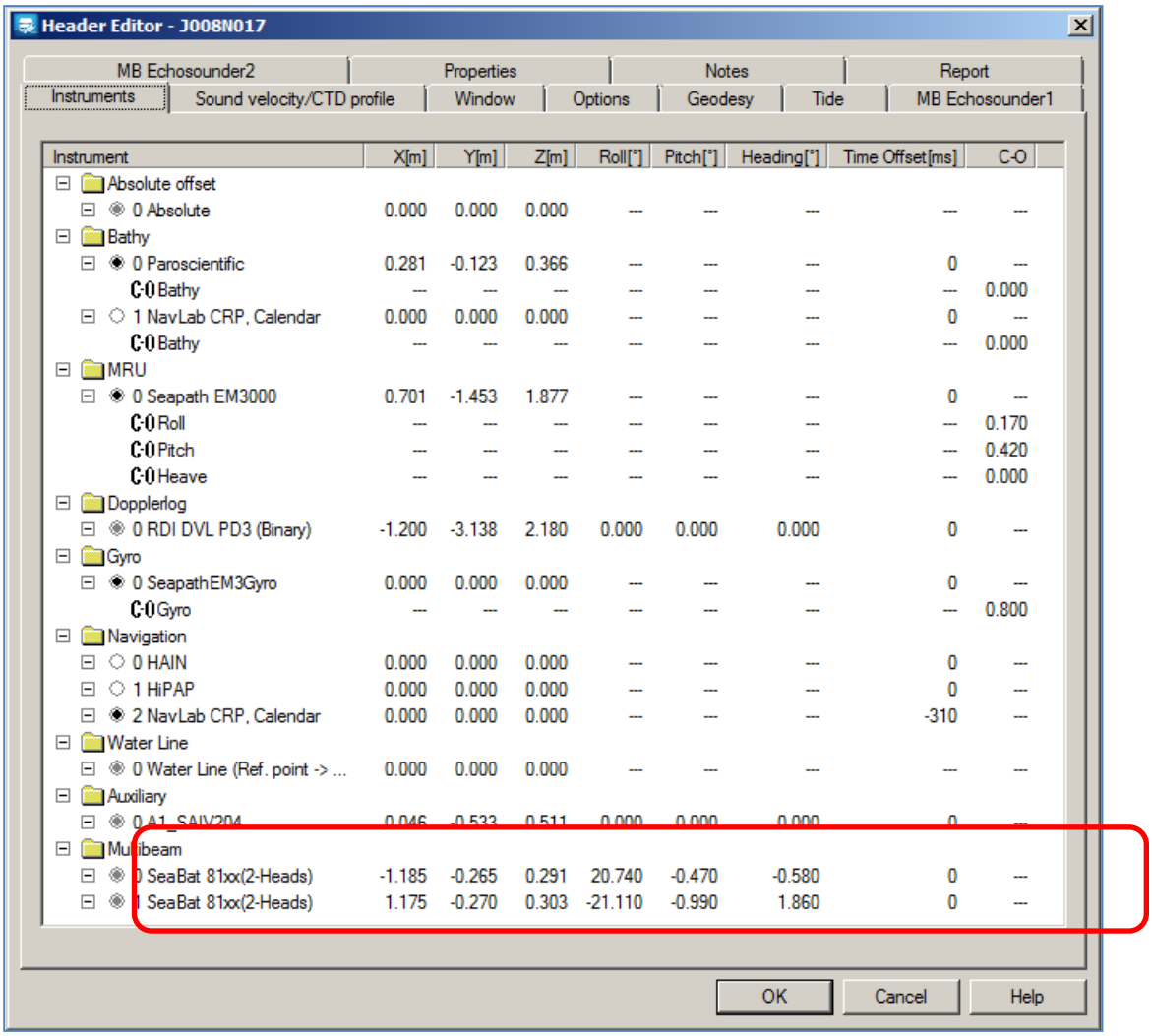
```
#
# Arms.ini, defines the lever arms for the sensors.
# --------  The lever arm is the vector from the ROV / Vessel reference point to the sensor.
#           x is Forward, y is starboard and z is down.
#           x=-0.47 means that the sensor is aft of the reference point.
#
[IMU]
x=-1.453   # m
y= 0.701   # m
z= 1.877   # m

[DVL]
x=-3.138   # m
y=-1.200   # m
z= 2.180   # m

[Pressure]
x=-0.123   # m
y= 0.281   # m
z= 0.300   # m

[HiPAP]
x=-0.190   # m
y= 0.135   # m
z= 0.065   # m
```

Figure 8-4 HAIN lever arms settings

8.5 Dual Head MBE calibration

The Survey ROV, XLX27 conducted a multibeam calibration on the 5th January 2013, over the wreck site of the Nautilus submarine in Byfjorden . The calibration was carried out in accordance with DOF Subsea procedure MGI-MAP-O04-0003 MBE Calibration. A series of lines were run over the pipeline in order to determine pitch, roll and heading misalignments for each head.

Vessel:	MSV Skandi Skolten
ROV:	XLX27
Echosounder 1:	Reson 8125
Echosounder 2:	Reson 8125
Survey date:	05.01.2013
Location:	Nautilus, Byfjorden



Instrument	X[m]	Y[m]	Z[m]	Roll[°]	Pitch[°]	Heading[°]	Time Offset[ms]	C-O
Absolute offset								
0 Absolute	0.000	0.000	0.000	---	---	---	---	---
Bathy								
0 Paroscientific	0.281	-0.123	0.366	---	---	---	0	---
C-O Bathy	---	---	---	---	---	---	---	0.000
1 NavLab CRP, Calendar	0.000	0.000	0.000	---	---	---	0	---
C-O Bathy	---	---	---	---	---	---	---	0.000
MRU								
0 Seapath EM3000	0.701	-1.453	1.877	---	---	---	0	---
C-O Roll	---	---	---	---	---	---	---	0.170
C-O Pitch	---	---	---	---	---	---	---	0.420
C-O Heave	---	---	---	---	---	---	---	0.000
Dopplerlog								
0 RDI DVL PD3 (Binary)	-1.200	-3.138	2.180	0.000	0.000	0.000	0	---
Gyro								
0 SeapathEM3Gyro	0.000	0.000	0.000	---	---	---	0	---
C-O Gyro	---	---	---	---	---	---	---	0.800
Navigation								
0 HAIN	0.000	0.000	0.000	---	---	---	0	---
1 HiPAP	0.000	0.000	0.000	---	---	---	0	---
2 NavLab CRP, Calendar	0.000	0.000	0.000	---	---	---	-310	---
Water Line								
0 Water Line (Ref. point -> ...	0.000	0.000	0.000	---	---	---	---	---
Auxiliary								
0 A1_SAIV204	0.046	-0.533	0.511	0.000	0.000	0.000	0	---
Multibeam								
0 SeaBat 81xx(2-Heads)	-1.185	-0.265	0.291	20.740	-0.470	-0.580	0	---
1 SeaBat 81xx(2-Heads)	1.175	-0.270	0.303	-21.110	-0.990	1.860	0	---

Figure 8-5 MBE mounting values after calibration

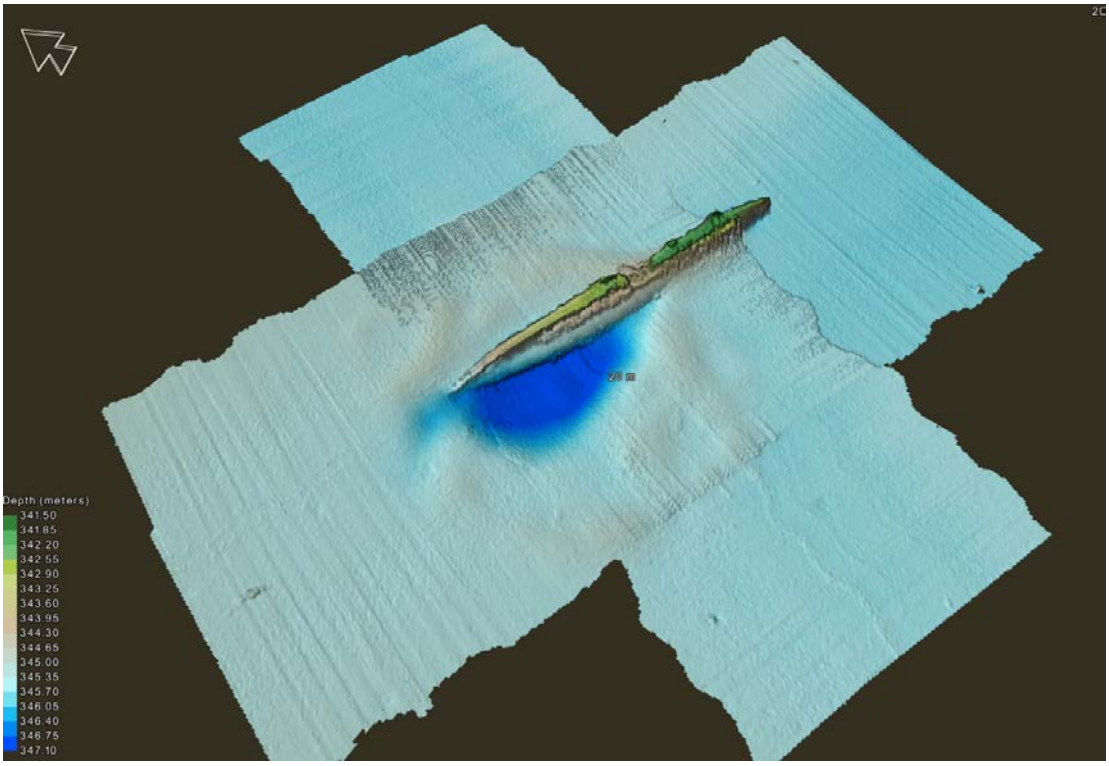


Figure 8-6 DTM before calibration

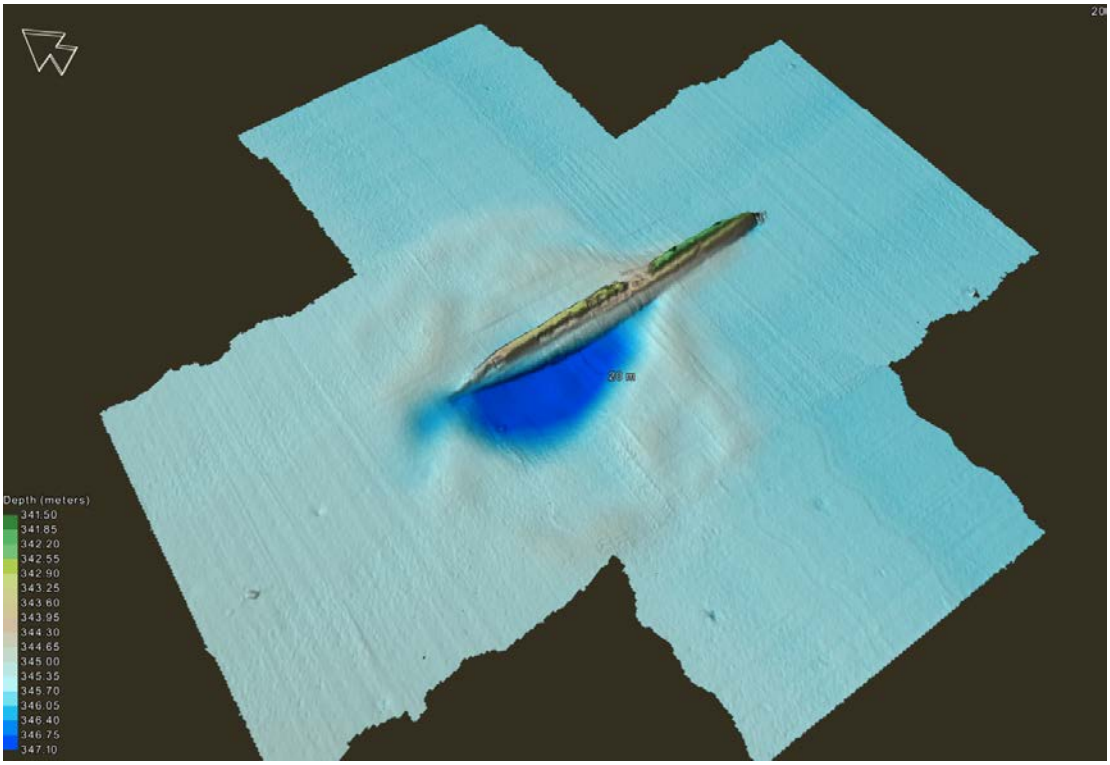


Figure 8-7 DTM after calibration

9. OFFSETS

9.1 Vessel Offsets

Vessel offsets were established during a dimensional control survey conducted during August 2011.

All offset positions, including MRUs and HiPAP head in deployed position were either determined during the dimensional control survey, or at a later date by measuring from known points established during it.

Table 9-1 Antenna Offsets

Skandi Skolten Antenna Offsets				
	X (m)	Y(m)	Z(m)	Description
L2 Antenna Ref Point	-0.054	18.388	30.958	HP
L2 Antenna Ref Point	-0.816	20.129	30.767	XP
L2 Antenna Ref Point	-3.926	20.835	31.516	PosMV Port
L2 Antenna Ref Point	3.850	20.760	31.510	PosMV Stbd

Table 9-2 HiPAP Pole Offsets

Skandi Skolten HiPAP Offsets			
X (m)	Y(m)	Z(m)	Description
-0.604	-7.153	-13.582	HiPAP Pole fully deployed – Centre of Head

Table 9-3 MRU Offsets and Heading alignment

Skandi Skolten MRU Offsets				
	X (m)	Y(m)	Z(m)	Description
Applanix LN200	-4.165	22.238	2.779	Ref Point on Top of unit

9.2 ROV Offsets

XLX27 had the offsets established for the survey sensors on the 03rd of January 2013 alongside in Bergen.

The CRP is situated on the front of the upper ROV frame and is marked by a punch mark in the aluminium.

The offset sheet below (Table 9.4) was used for inputting and checking the ROV offsets entered into Navipac and Naviscan.

Table 9-4 XLX27 Offsets – 04th of January 2013

XLX27 Instrument Offsets			
Instrument	X(m)	Y(m)	Z(m)
CRP	0.000	0.000	0.000
SVS	0.376	-0.033	-0.296
Rx	0.135	-0.190	0.065
DVL	-1.200	-3.138	-2.180
CDL Gyro	0.701	-1.453	-1.877
SAIV	0.046	-0.533	-0.511
Digiquartz	0.281	-0.123	-0.366

10. TIME SYNCHRONISATION

Time synchronisation was achieved by the use of pps and UTC time, with pps and ZDA signals from the XP system being sent via a 1PPS / ZDA distribution box to all sensors capable of utilising these signals. NaviPac, APOS, Time boxes computers were all synchronised in this manner and the Reson 8125 synchronised with PPS and a UTC string.

The EIVA ATTU “Timebox” system was utilised for time stamping all incoming data into the EIVA computers. The VisualSoft suite was synchronised using a timing string from the Navipac system to the master PC and then via network to the slave DVR units.

11. FACTORY CALIBRATION CERTIFICATES AND CONFIG FILES

11.1 SAIV SD204 CTD Sensors

11.1.1 Statement from Manufacturer

“From the experience over more than 10 years with the model SD204 and TD301/303, the long term stability prove to be so good that we today dare to say; "*Calibrated for life time*".

However, as we know that the instruments may be exposed to various kind of handling in the field, we suggest a check-up/verification yearly or every second year, depending on how extensive the use is. It may be practical to combine this with replacement of battery.”

11.1.2 SAIV SD204 - (SN884)

MINI STD/CTD Calibration Certificate

Certificate no: 2698

Instrument model: ***SD204*** Serial number: 884 Owner: DOF

Calibrated date: 2012-06-30 Certificate issued date: 2012-06-30 Env. temp (degr. C): 19

Calibrated by: Sensordata a.s and *SAIV A/S* Bergen Norway

Calibration procedure:
Conductivity and temperature are calibrated by setting the MINI STD/CTD instrument in raw data mode and keeping it in three 200 l stirred, temperature stabilised calibration baths. Raw conductivity and temperature data are recorded with bath temperature and bath conductivity as measured by reference temperature* and conductivity** instruments. Calibration coefficients A1, B1, C1 for temperature and A3, B3, C3, D3 for conductivity are calculated from least square equations included in the MINISOFT software packet. Output temperature and conductivity from calibrated instrument must correspond with reference readings within +/- 1/100 degr. C and +/- 1/100 mmho/cm. Pressure is calibrated by connecting to a reference DWT*** and successively generate 6 pressures from 1 bar to FS. Pressure coefficients A2, B2, C2, D2 are calculated from least squares equations included in the instruments software. Output CTD data must correspond to data from reference instruments within specified accuracy.

TEMPERATURE degr. C			CONDUCTIVITY mmho/cm			PRESSURE dbar		
Bef. cal.	After cal.	Reference	Bef. cal.	After cal.	Reference	Bef. cal.	After cal.	Reference
19,15	19,15	19.152	7.64	7.65	7.650	10.00	NO CHANGE	10.01
12,17	12.17	12.173	35.18	35.17	35,172	100,12		100,13
0,84	0,84	0,841	51,08	51.10	51.104	400.54		400.52
						600,79		600.78
						1001.30		1001,30
						2002.62		2002.60

All calibration coefficients are shown on attached calibration sheet

Working references:
Temperature* Falmouth Scientific Model OTM S-112 S/N 1377-09JUL96 Accuracy +/- 2/1000 deg.C
Conductivity** Falmouth Scientific Model OCM S-112 S/N 1354-09JUL96 Accuracy +/- 2/1000 mmho/cm
Pressure*** Budenberg DWT Model 280L S/N 9050 Accuracy 0.01% FS (150 bar)

Traceable references:
Temperature:
Subreference 1:
General Oceanics ATB 1250 temp. bridge serial no 1235
(Working ref. is controlled by subref.1 four times per year)
(Subref.1 is controlled by subref.2 twice per year)

Subreference 2:
Destilled water tripple point cell at +0.010 degr.C
Phenoxybenzene tripple point cell at +26.868 degr.C

Conductivity:
Subreference 1:
Neil Brown Cond./Temp. transfer standard mod. CT-2 serial no.3
(Working reference is controlled by subref.1 four times per year)
(Subref.1 is controlled by subref.2 four times per year)
(Subref.2 is controlled by subref.3 four times per year)

Subreference 2:
Guildline Portasal 8410 Portable Salinometer serial no.59

Subreference 3:
Ocean Scientific International Standard Seawater

Pressure:

11.2 Paroscientific Digiquartz

11.2.1 Statement from Supplier

"If no change of instrument performance 6 months after delivery we would recommend you to have a recalibration every 12 months. After 2 or 3 recalibration you do have a track record which can be of help to you to verify if you can extend the calibration interval beyond each 12 months."

11.2.2 Digiquartz - (SN 99954)

DPS OFFSHORE

CERTIFICATE OF CALIBRATION

INSTRUMENT:	PAROSCIENTIFIC DQ
MODEL:	8CB2000-I-005
SERIAL No.:	99954

CERTIFICATE No.:	2012C044

ISSUED BY DPS ABERDEEN

CALIBRATED BY:	N.Taylor
DATE:	17/04/2012
SIGNED:	Nat Taylor

DPS OFFSHORE Calibration Laboratory, Unit 2 Denmore Place, Bridge of Don, Aberdeen AB23 8JS.
Tel.: +44 (0)1224 226850 Fax : +44 (0)1224 226851

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11.2.3 Digiquartz - (SN 99951)

DPS OFFSHORE

CERTIFICATE OF CALIBRATION

INSTRUMENT:	PAROSCIENTIFIC DQ
MODEL:	8CB2000-I-005
SERIAL No.:	99951

CERTIFICATE No.:	2012C045

ISSUED BY DPS ABERDEEN

CALIBRATED BY:	N.Taylor
DATE:	17/04/2012
SIGNED:	Nat Taylor

DPS OFFSHORE Calibration Laboratory, Unit 2 Denmore Place, Bridge of Don, Aberdeen AB23 8JS.
Tel.: +44 (0)1224 226850 Fax : +44 (0)1224 226851

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11.3 Valeport Sound Velocity Sensors

11.3.1 Statement from Manufacturer

"It is a fact that several companies ensure their equipment is calibrated and serviced annually but that is governed by their own set practices. What we find at Valeport is that the vast majority of instruments that are returned after one year are still within specification. Those instruments that do not fall within specification do so usually because of a fault or a lack of basic maintenance to the instrument.

As such, Valeport would be happy to see a probe returned for calibration once every two years. This assumes that the instrument is well maintained and used correctly."

11.3.2 Valeport mini SVS - (SN37529)

VALEPORT

Calibration Certificate Number: **29380**

This document certifies that the instrument detailed below has been calibrated according to Valeport Limited's Standard Procedures, using equipment with calibrations traceable to NAMAS or National Standards.

Instrument Type:	miniSVS - SV only
Instrument Serial Number:	37529
Calibrated By:	L.Bicknell
Date:	02/11/2011
Signed:	

Full details of the results from the calibration procedure applied to each fitted sensor are available in separate documents. This summary certificate should be kept with the instrument.

Valeport Limited, St. Peter's Quay, Totnes, Devon, TQ9 5EW. U.K.
Tel: +44 (0)1803 869292 Fax: +44 (0)1803 869293
E-mail: sales:valeport.co.uk Web: www.valeport.co.uk

11.4 Applanix LN200

11.4.1 Statement from Manufacturer

POS MV is a tightly coupled Kalman filter based GNSS aided INS. In dynamics, the Kalman filter uses GNSS observations to estimate the error model for each inertial sensor. If and when an inertial sensor performs outside of its specified limits, the inbuilt FDIR (Fault Detection Isolation and Reconfiguration) will manage the issue and a warning will be flagged to the user via POSView. Sensor performance usually degrades very slowly with time. In such cases, the warning message in POSView provides advance notice to the user to get the POS MV data checked by Applanix whilst the degradation in POS MV performance remains minimal.

Hence, unlike most standalone inertial devices, there is no requirement to return a POS MV to Applanix for routine recalibration to confirm the IMU performance is within specification.

applanix
A TRIMBLE COMPANY

Certificate of Compliance

This document certifies that the system below meets the stated requirements.

Product: **POS MV V4**

Model: **320**

Sales Order No: **SO-005710**

Hardware Item	Part No	Serial No
PCS unit	PCS-29	3067
IMU top hat	10001506-4	751_411820

Software Item	Part No	Version
Firmware	10003369	3.42

Requirement: **mPOS System Acceptance Test #PRO-WI-000084**

Result: **Passed**

Authorised signature: K. Dallaire

Date: Mar. 19, 2008

85 Leek Crescent Richmond Hill, Ontario Canada L4B 3B3
Tel: (905) 709-4600 **Fax:** (905) 709-6027 **Web:** www.applanix.com

11.5 CDL RLG2 Gyro

11.5.1 CDL RLG2 Gyro – (SN MP2-089)

CDL
WATER ENGINEERING

Silverfield House
Claymore Drive, Aberdeen
UK, AB23 8GD

Tel: 01224 706655
Fax: 01224 709840

email: info@cdltd.net
Web: www.cdltd.net

GYRO CALIBRATION CERTIFICATE

Company: DOF Subsea

Gyro Type: RLG2

Serial Number: MP2089

Firmware: 3.12

Date: 26/11/2012

4 Quadrant Check

Run	Test Heading	Heading	Error	Status
1	2.07	2.25	-0.18	
2	91.79	92.25	-0.46	
3	182.21	182.25	-0.04	
4	272.36	272.25	0.11	
mean			-0.1425	
max diviation			0.3175	
Spec: max diviation <	0.32			Pass

12 Hour Calibration Check

	Minimum	Maximum	Spread	Average	Sigma	In Spec
Heading	272.22°	272.36°	0.14°	272.300°	0.0392°	Pass
Pitch	0.17°	0.192°	0.02°	0.178°	0.0038°	Pass
Roll	0.065°	0.076°	0.01°	0.071°	0.0022°	Pass

See page 2 for full 12 Hour heading calibration graph

11.6 Navigation Software Setup

END OF DOCUMENT

Identification of oil leak and position verification of U-864

DOF subsea
delivering solutions at any depth

KYSTVERKET
KYSTDIREKTORATET

Kystverket – U864

02i	-	25.03.13	Issued for Construction	TOls	ÅR	AMS
01	-		Issued for Internal Document Control	TOls		
Revision DSN	*Revision Company*	*Date*	*Reason for Issue*	*Originator*	*Checked*	*Approved*

	Organisation Unit	*Person*	*Title*	*Signature*	*Date*
Originator	DOF Subsea Norway AS	Trond Olsen	Offshore Manager	T. Olsen	25.03.2013
Checked	DOF Subsea Norway AS	Åse Røssland	Proj. Doc. Controller	Å. Røssland	25.03.2013
Approved	DOF Subsea Norway AS	Agnete Marie Strømme	Ass. Project Manager	A. Strømme	25.03.2013

VOR-003

Identification of Oil Leak, and Position Verification of U864

Responsible Party:

No of Sheets:
10

DOF Subsea Norway AS Project No.
600225-111_VOR-003

Doc. Type Code:	*Area Code:*	Company Document Number:	
DOF Subsea Norway AS Document Number: **600225-SSKO-O15-0001**			**02i**

Contract Number:	*System:*	*Project No.*	*Orig. Code*	*Area / System*	*Disc. Code*	*Doc. Type*	*Seq. No.*	*Rev.*
2012/2998								

Company : Kystverket *Ref No.:* ***L003-T12-039-VOR02***

Attn. : hans.petter.laahne.mortensholm@kystverket.no

Copied to : Havard Berge, Agnete Strømme

From : Offshore Manager Skandi Skolten

Subject : Identification of Oil Leak, and Position Verification of U864

Revision Record Sheet:

DSN Rev.	Date	Description
01	22.03.2013	Issued for IDC
02i	25.03.2013	Issued for Construction

INDEX

1. General
2. Results
3. Screen Grabs
4. Conclusions

1 GENERAL

Skandi Skolten was requested by Kystverket to investigate Oil Leak coming from U-864 outside Fedje. Skandi Skolten was alongside Dokken performing maintenance on auxiliary engines at the time of request, and started immediately to prepare the vessel and ROV. 2 hrs later, Skandi Skolten left Dokken heading for U-864.

Kystverket wanted to verify two things.

1. ROV inspection to identify Oil Leak.
2. Investigate if U-864 has moved compared to “As Left” Sunday 17th Mars 2013.

Tools used to perform these tasks were: XLX-27, a “home made” measurement stick to measure gap at mud line, and a “Oil Collector” to measure leak rate.
Measurement stick was left at location for later references’.

Upon arriving location for U-864, no oil was visible from bridge.

Hans Petter Mortensholm from Kystverket was “online” by phone during the whole session.

2 RESULTS

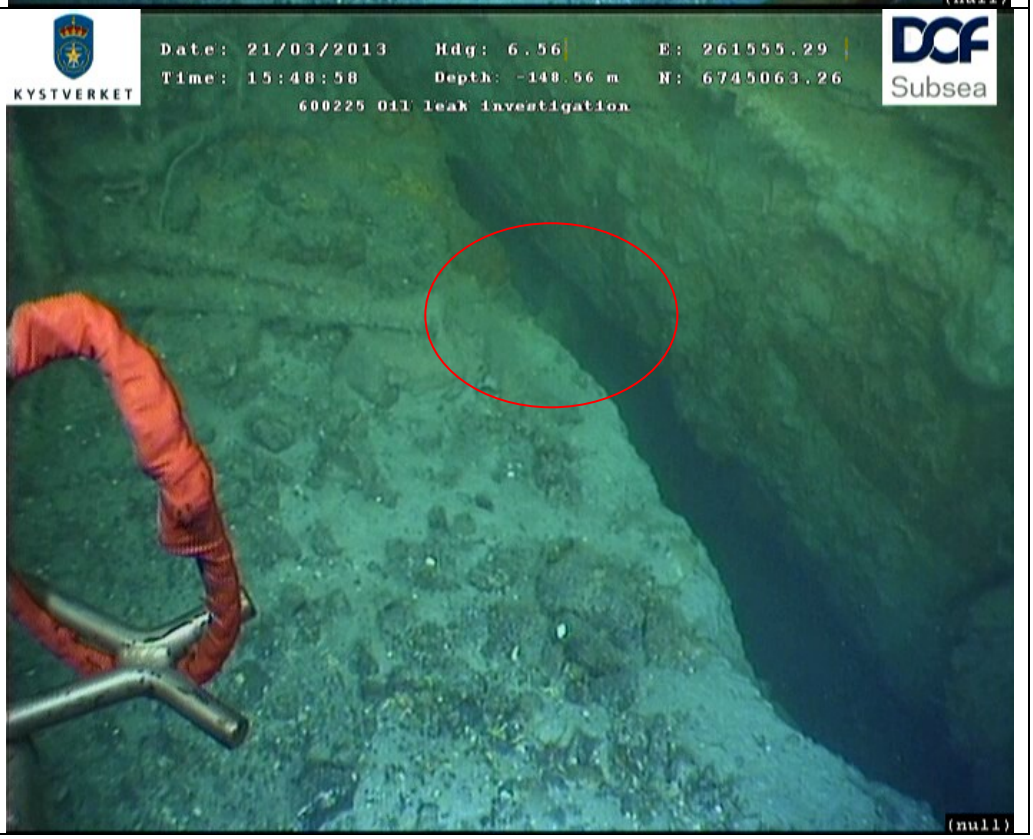
Oil leak was found to come from where we did the first cut to release air at aft section #1. Oil was also spotted coming out from several cracks in the outer fuel tanks.
Leak rate was measured and recorded on DVR over a period of 60 minutes. Approximately 3 dl of oil was captured during this period.

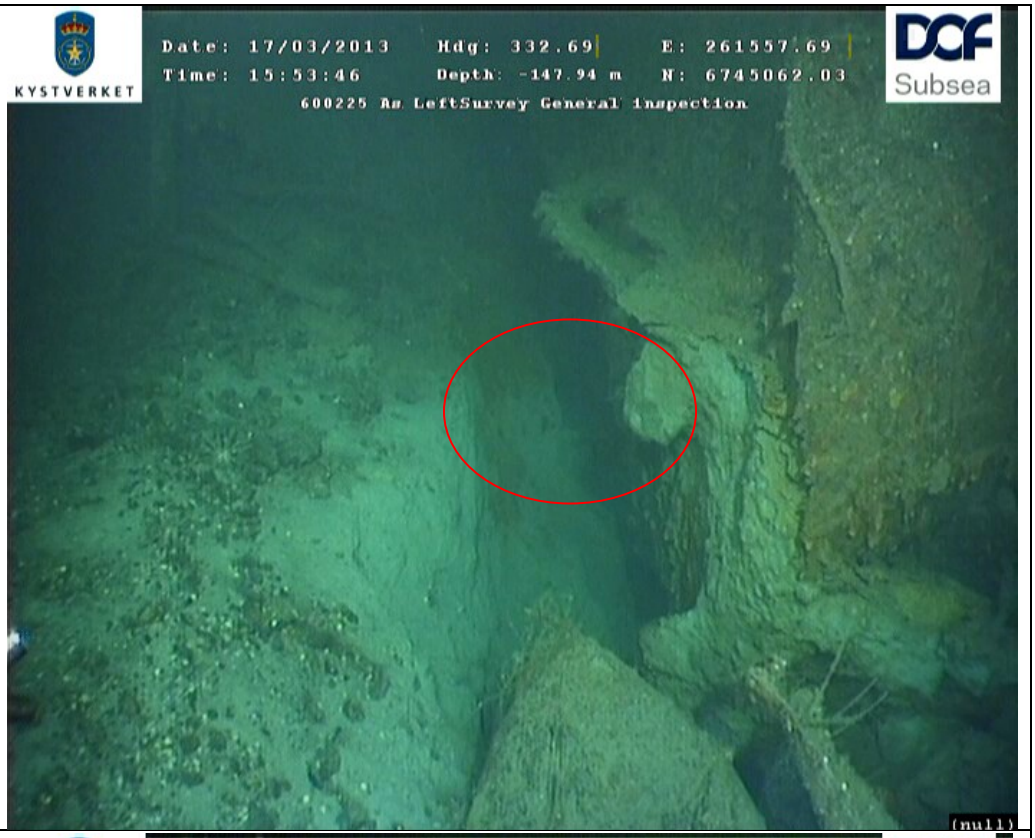
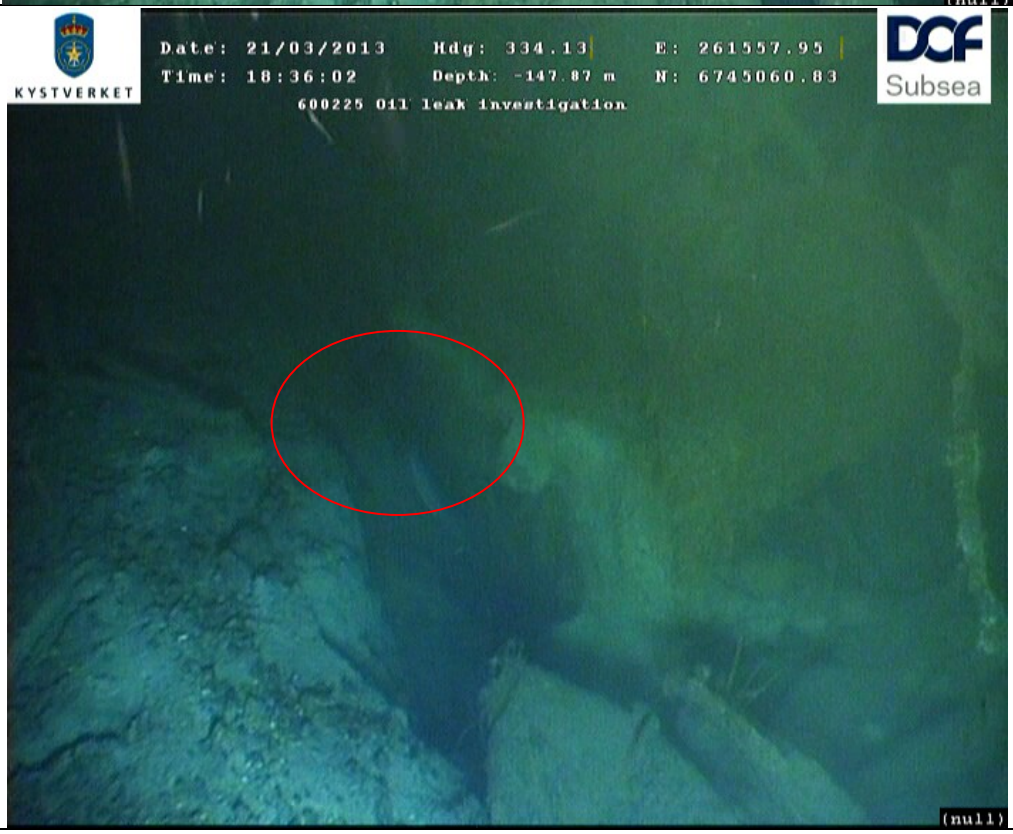
To identify if U-864 has moved since “As-Left”, a 1,5m aluminium measurement stick was used.

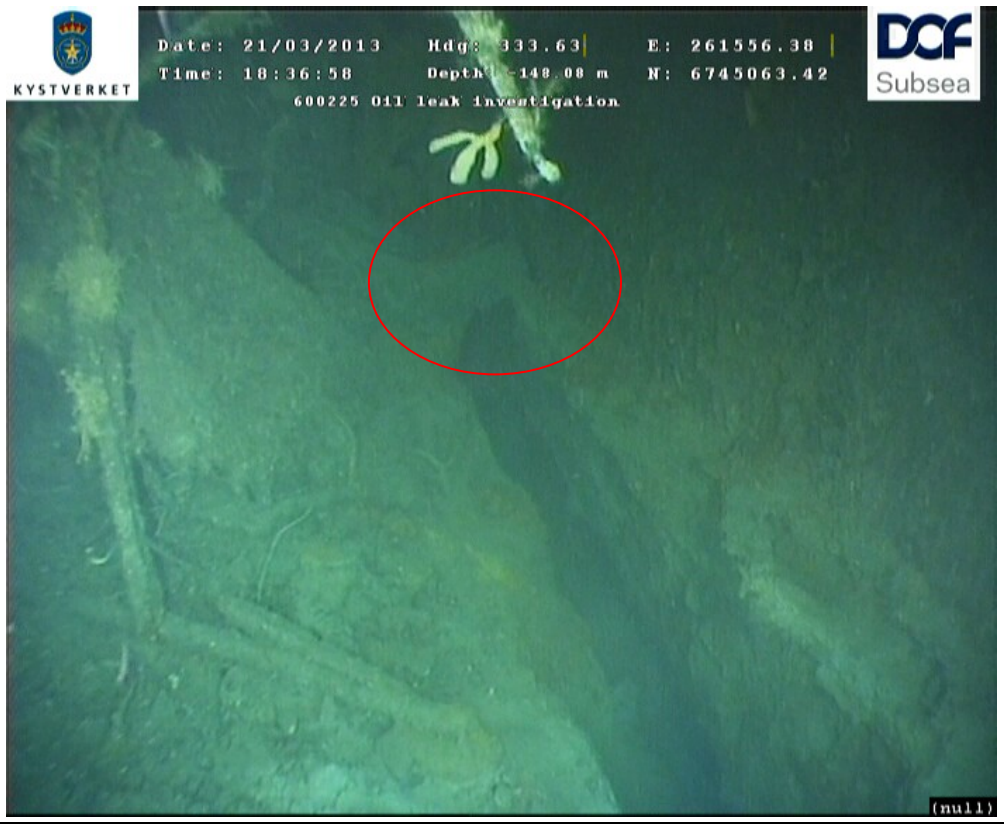
Measurement was only taken at one location due to limited access along mud line. Gap was at the selected spot measured to approximately 1,1 metre.

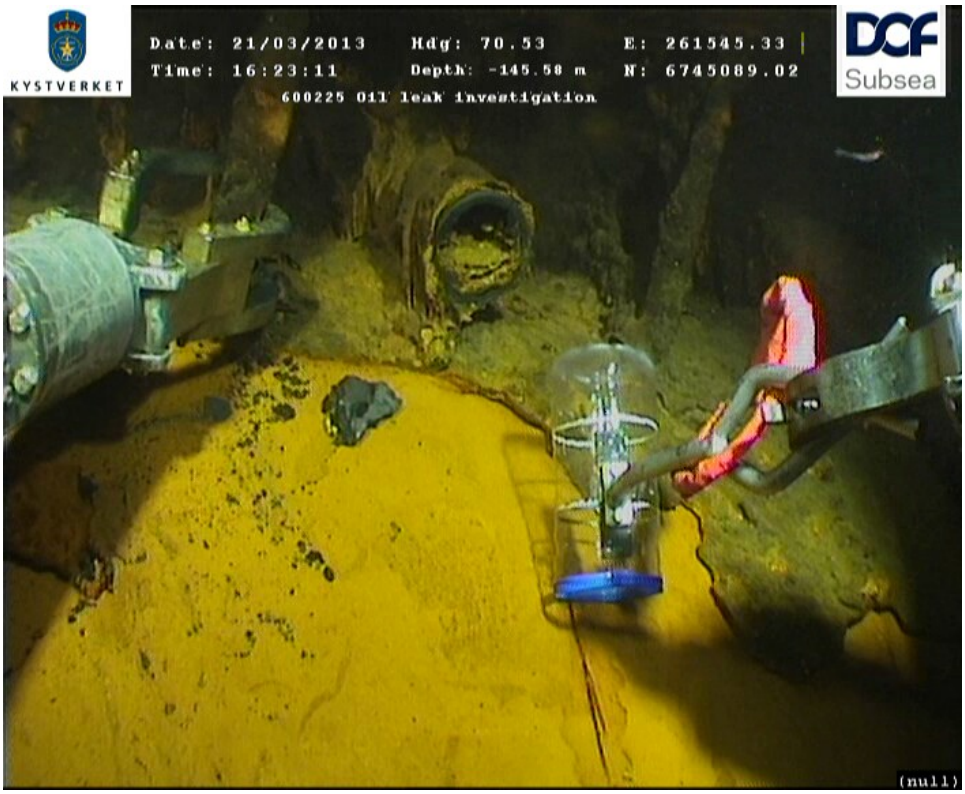
3 SCREEN GRABS

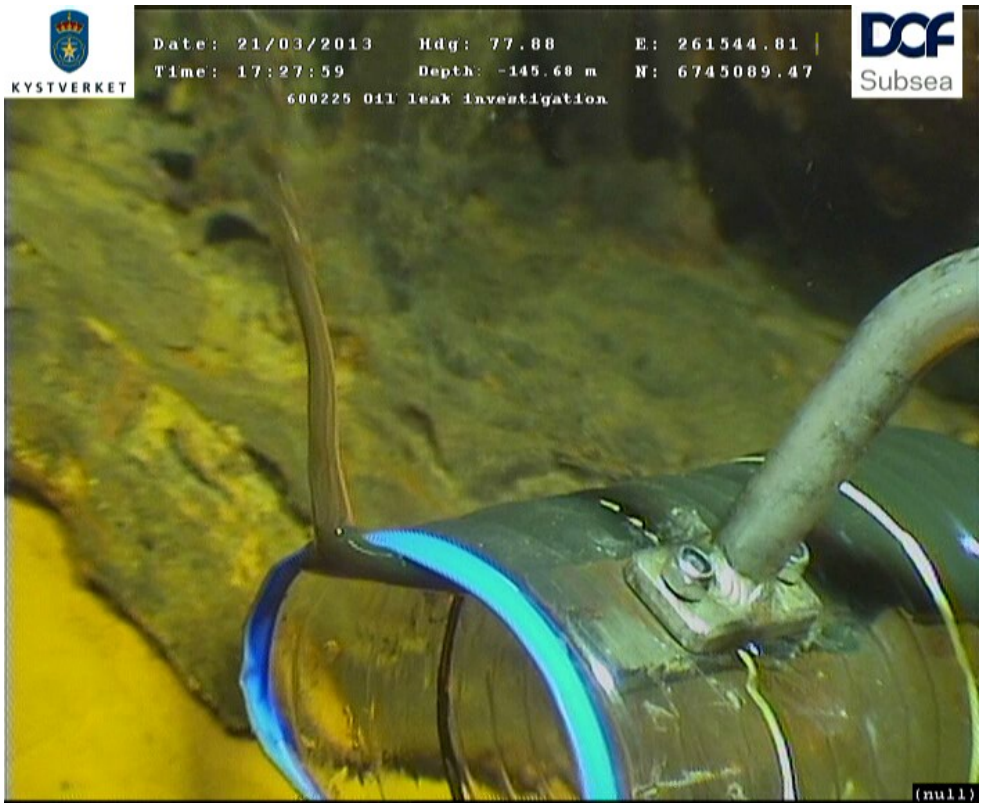
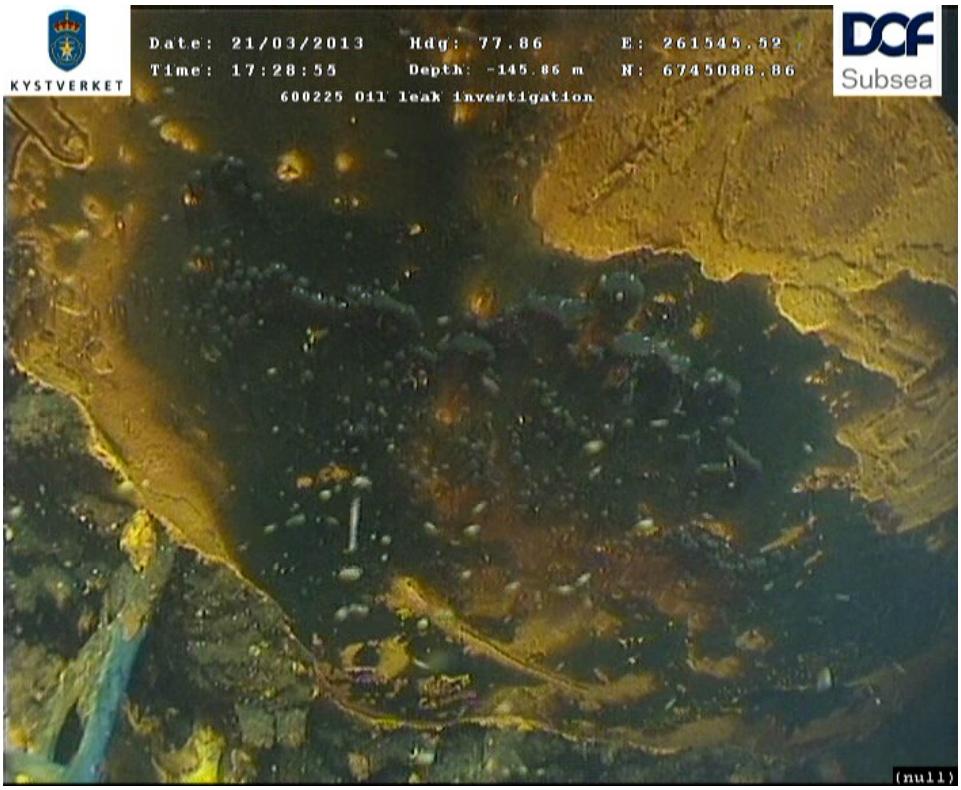
1. Debris resting towards U-864. 17.03.2013
2. Debris resting towards U-864. 21.03.2013
3. Mud gap. 17.03.2013
4. Mud gap. 21.03.2013
5. Debris resting towards U-864. 17.03.2013
6. Debris resting towards U-864. 21.03.2013
7. Start of Oil Leak Rate test. Yellow rings on each 0,5 litre.
8. End of Oil Leak Rate Test. Approx 0.3 litre inside bottle
9. Close up of Oil
10. Oil trapped in wreck
11. Measurement stick. Readings approx 1.1 metre
12. Measurement stick. Readings approx 1.1 metre

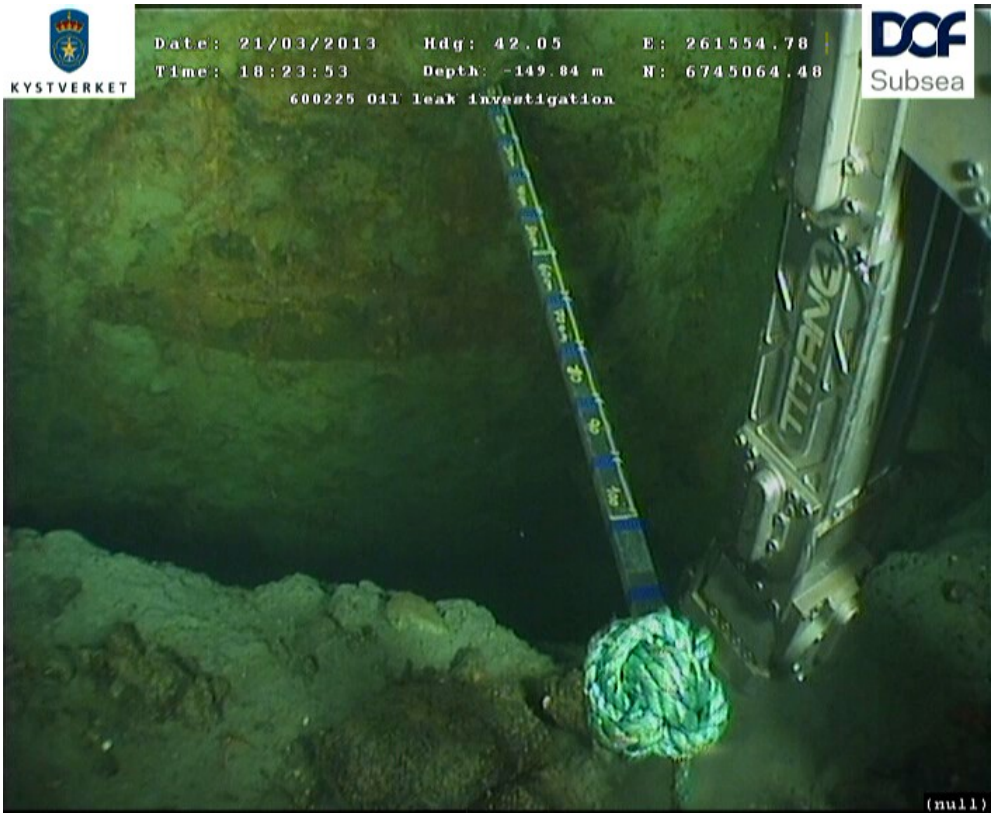
1	KYSTVERKET Date: 17/03/2013 Hdg: 6.77 E: 261554.65 Time: 15:04:36 Depth: -147.55 m N: 6745062.37 600225 Aw LeftSurvey Stbd - Mud Line DOF Subsea (null)
2	 KYSTVERKET Date: 21/03/2013 Hdg: 6.56 E: 261555.29 Time: 15:48:58 Depth: -148.56 m N: 6745063.26 600225 Oil leak investigation DOF Subsea (null)

3	 KYSTVERKET Date: 17/03/2013 Hdg: 332.69 E: 261557.69 Time: 15:53:46 Depth: -147.94 m N: 6745062.03 600225 Rø LeftSurvey General inspection DOF Subsea (null)
4	 KYSTVERKET Date: 21/03/2013 Hdg: 334.13 E: 261557.95 Time: 18:36:02 Depth: -147.87 m N: 6745060.83 600225 Oil leak investigation DOF Subsea (null)

5	KYSTVERKET Date: 17/03/2013 Hdg: 326.73 E: 261557.20 Time: 15:54:19 Depth: -146.99 m N: 6745062.11 600225 Au LeftSurvey General inspection DOF Subsea (null)
6	 KYSTVERKET Date: 21/03/2013 Hdg: 333.63 E: 261556.38 Time: 18:36:58 Depth: -148.08 m N: 6745063.42 600225 Oil leak investigation DOF Subsea (null)

7	 KYSTVERKET Date: 21/03/2013 Hdg: 70.53 E: 261545.33 Time: 16:23:11 Depth: -145.58 m N: 6745089.02 600225 Oil leak investigation DOF Subsea (null)
8	KYSTVERKET Date: 21/03/2013 Hdg: 77.90 E: 261544.98 Time: 17:24:13 Depth: -145.91 m N: 6745089.48 600225 Oil leak investigation DOF Subsea (null)

9	 KYSTVERKET Date: 21/03/2013 Hdg: 77.88 E: 261544.81 Time: 17:27:59 Depth: -145.68 m N: 6745089.47 600225 Oil leak investigation DOF Subsea (null)
10	 KYSTVERKET Date: 21/03/2013 Hdg: 77.86 E: 261545.52 Time: 17:28:55 Depth: -145.86 m N: 6745088.86 600225 Oil leak investigation DOF Subsea (null)

11	KYSTVERKET Date: 21/03/2013 Hdg: 42.07 E: 261555.25 Time: 18:23:16 Depth: -149.85 m N: 6745064.19 600225 Oil leak investigation DOF Subsea (null)
12	 KYSTVERKET Date: 21/03/2013 Hdg: 42.05 E: 261554.78 Time: 18:23:53 Depth: -149.84 m N: 6745064.48 600225 Oil leak investigation DOF Subsea (null)

4 CONCLUSIONS

As seen on the screen grabs where debris is resting towards the wreck, it appears that there has not been any or very little movement on the wreck since the “As Left “survey on the 17th Mars 2013.

We will recommend doing a full MBE survey of the U-864 to get exact position data’s.

We had a close up GVI on most of the stern section, and the oil leak was located to where we did a cut to release air. Oil was spotted coming out of cracks around the stern section, but this is most likely oil trapped inside or under the fuel tank plates. Screen grab “10” shows oil trapped under a plate.

Oil leak level was measured to be approx 0.3L in 60 minutes. Upon arriving location, no oil was visible on surface from bridge level. It was no wind and calm sea.

A GVI of the front section was also performed, and no sign of movement or oil leaks was spotted there.

U-864 2013 Soil servey

Tilsvarende som Vedlegg V0.04, derfor ikke lagt til her.

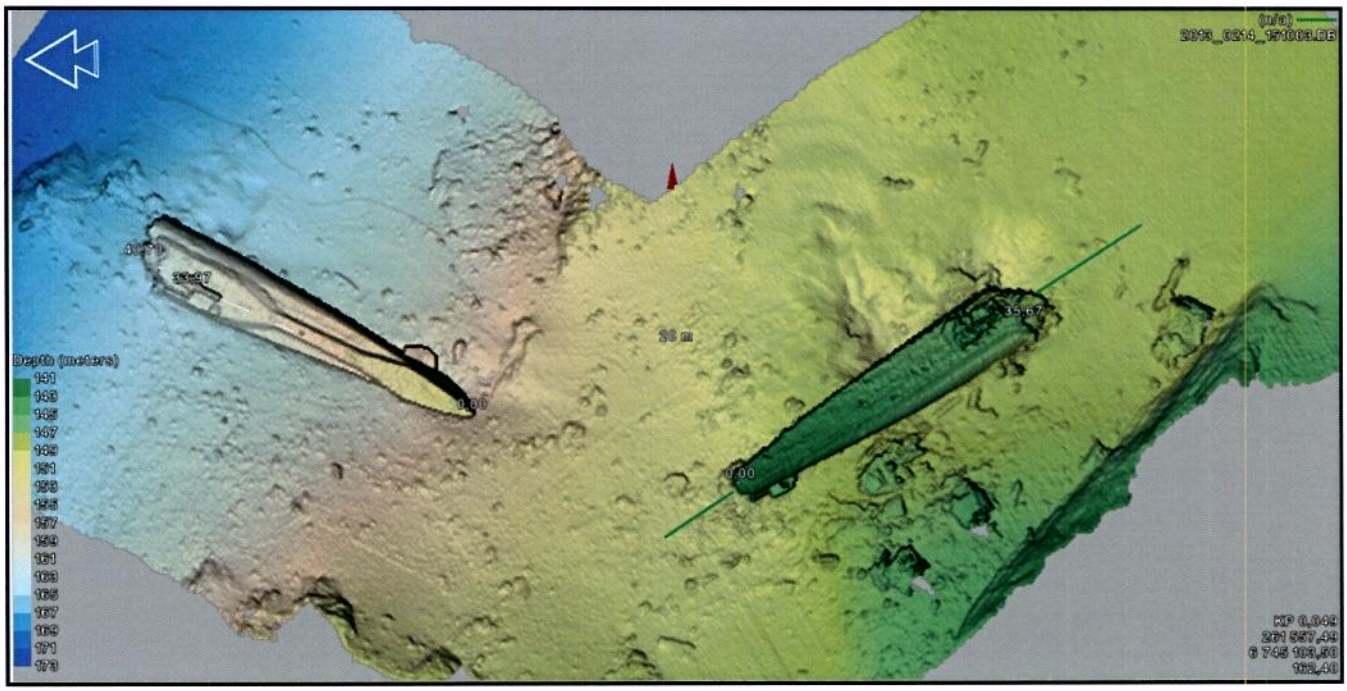
Oil recovery for the ship wreck of U-864

FRAMO

COMPLETION REPORT

Oil Recovery for the ship wreck of

"U-864"



Date	: 11.03.13
Project number	: 616917/3A
Number of pages	: 15
Customer	: DOF Subsea Norway AS
Client	: Kystverket (NCA)
Report generated by	: Arne Thilesen / John Magne Oppedal

FRAMO

1. Summary

- This document is the verification for the completion of FRAMO Oil Recovery Operation for mentioned wreck.
- HSE related issues are summarized hereunder
- Enclosed are proof of evidence by photographs of collected oil samples in addition to pictures taken of hull plates installed to the wreck
- Conclusion with course of action

2. Health, Safety & Environmental issues (HSE)

- Confirmation is given that the removal of cargo from the wreck of "U-864" did not inflict any environmental pollution.
- The operation has been carried out in accordance to Client and Framo HSE standards and procedures and obligations within the requirements stated in the contract
- The work was carried out with good safety standards and all Framo personnel involved in the operation have showed excellent grade of cooperative workmanship and respect for HSE code of conduct.

3. Proof of completion

- Enclosed are pictures from confirmation survey after cleaning and pictures taken of collected samples from tanks attempted emptied during oil recovery. There were recovered a minor quantity of oil from tank 4A. Tank 2 was found without oil residuals, and only minor oil fumes were detected from the recovered water. Tank 3A was found with colored water, and here as well there were noted fumes from oil.

Picture 1: Samples from tank 2

Picture 2: Sample from tank 4A

Picture 3: Sample taken from tank 3A

Picture 4: Hull plates for tank 2 Stb

Picture 5: Hull plate installed for tank 4A

Picture 6: Hull plate installed for tank 3A

- In addition to pictures of collected samples and installed hull plates, there are made video recording from the installation of hull plates, pumping sequences and final survey to confirm the completion of work in accordance to contract.

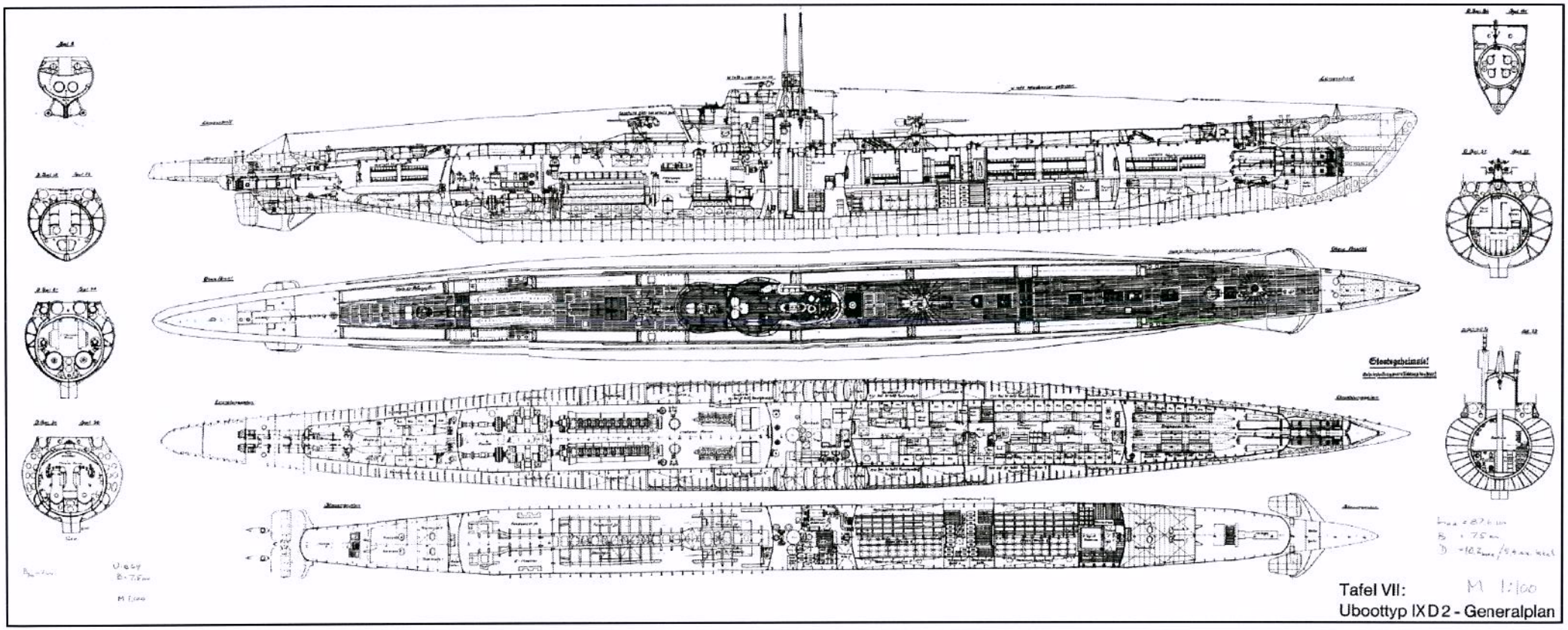


Figure 1 - General arrangement U-864

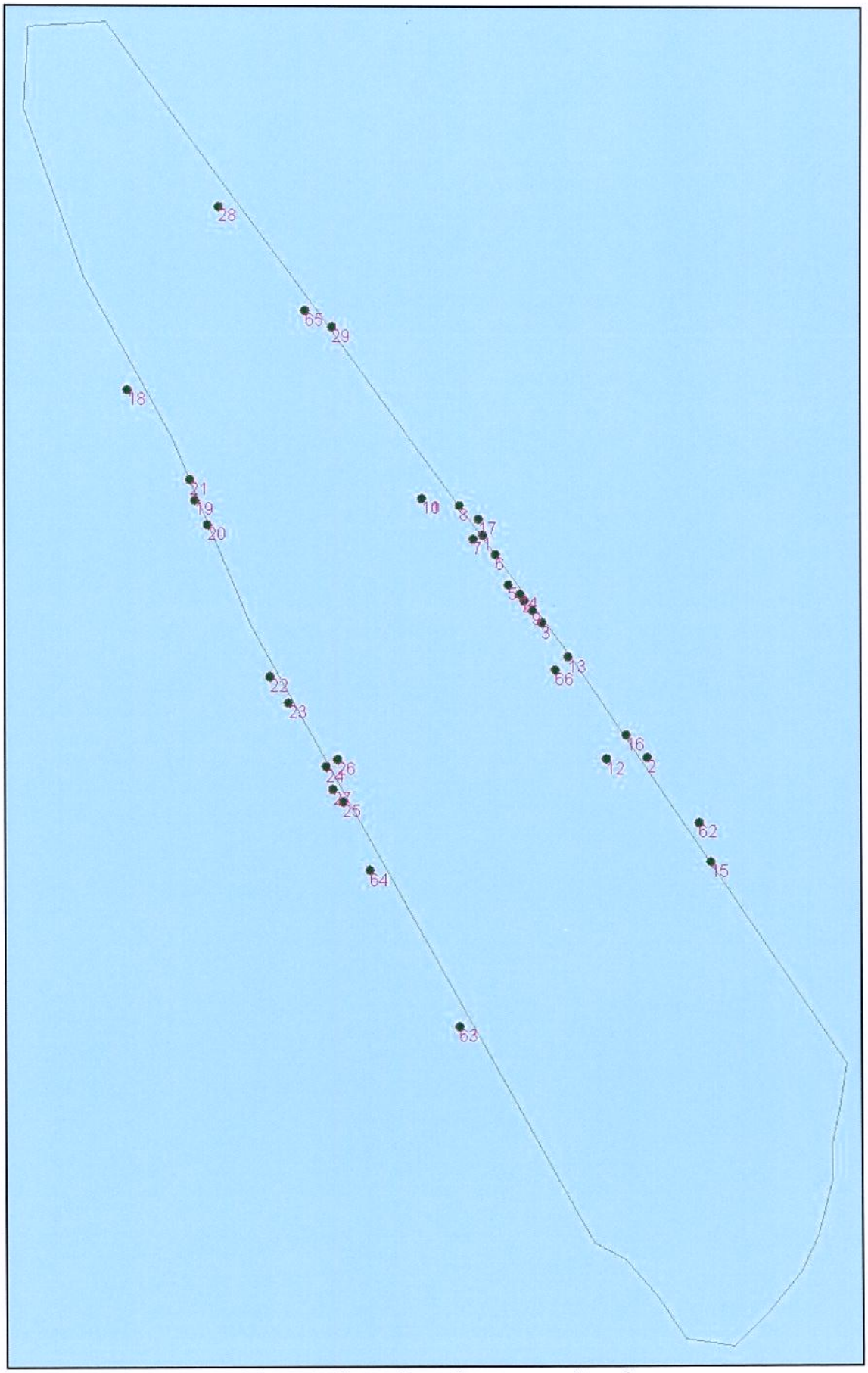


Figure 2 - Screenshot reference map aft section

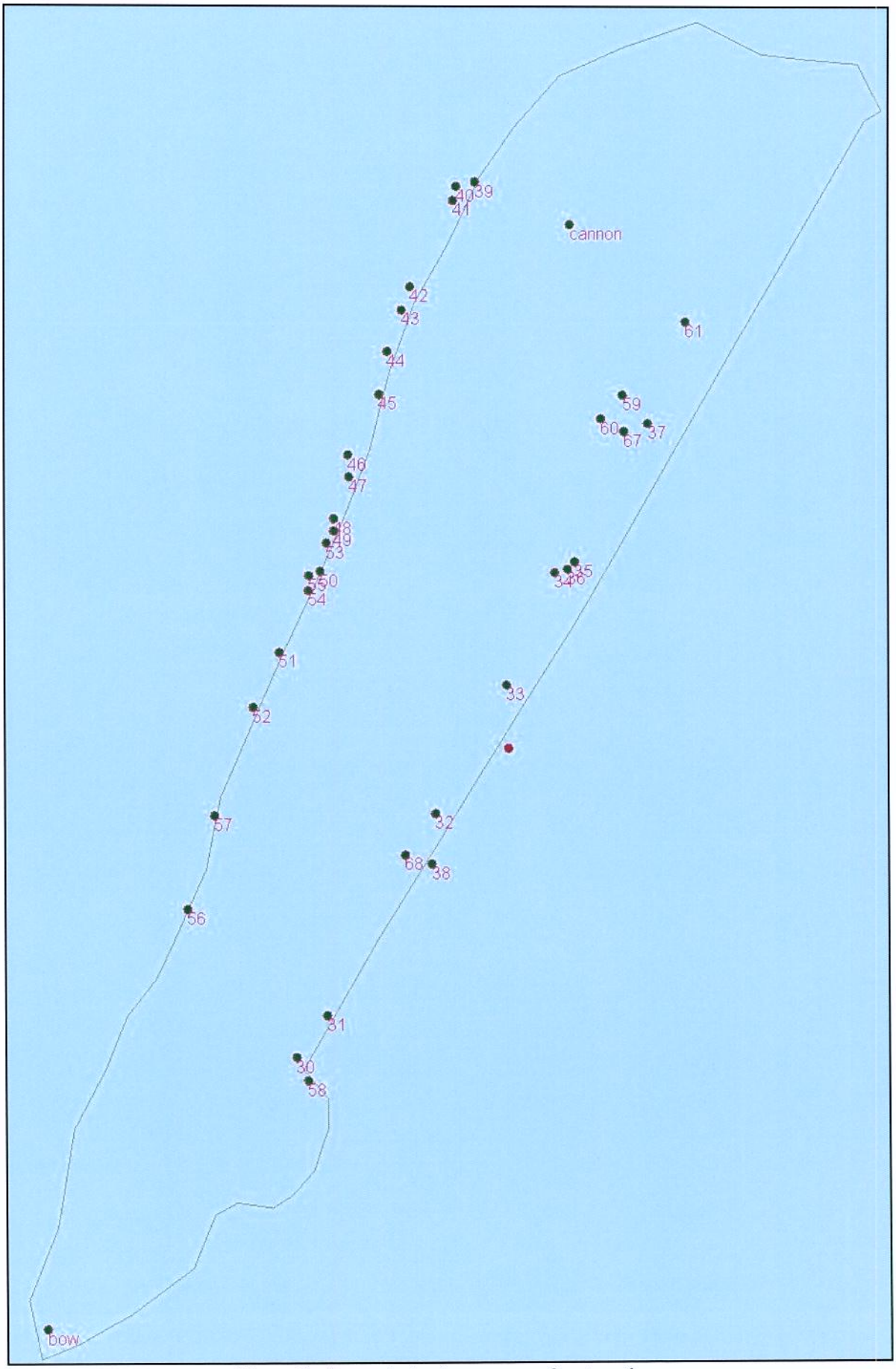


Figure 3 - Screenshot reference map front section

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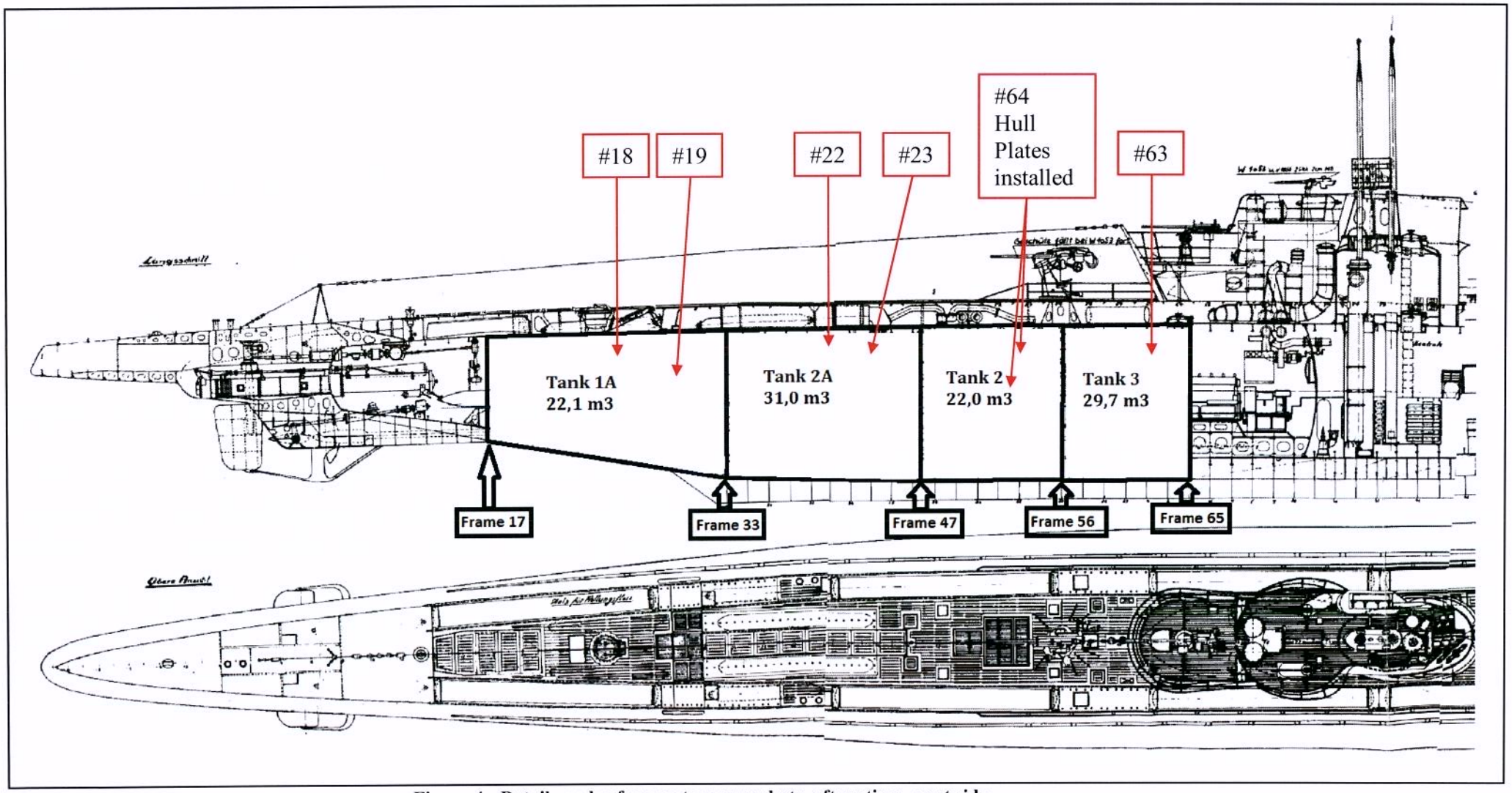

Figure 4 - Details and reference to screen shots, aft section - port side

FRAMO

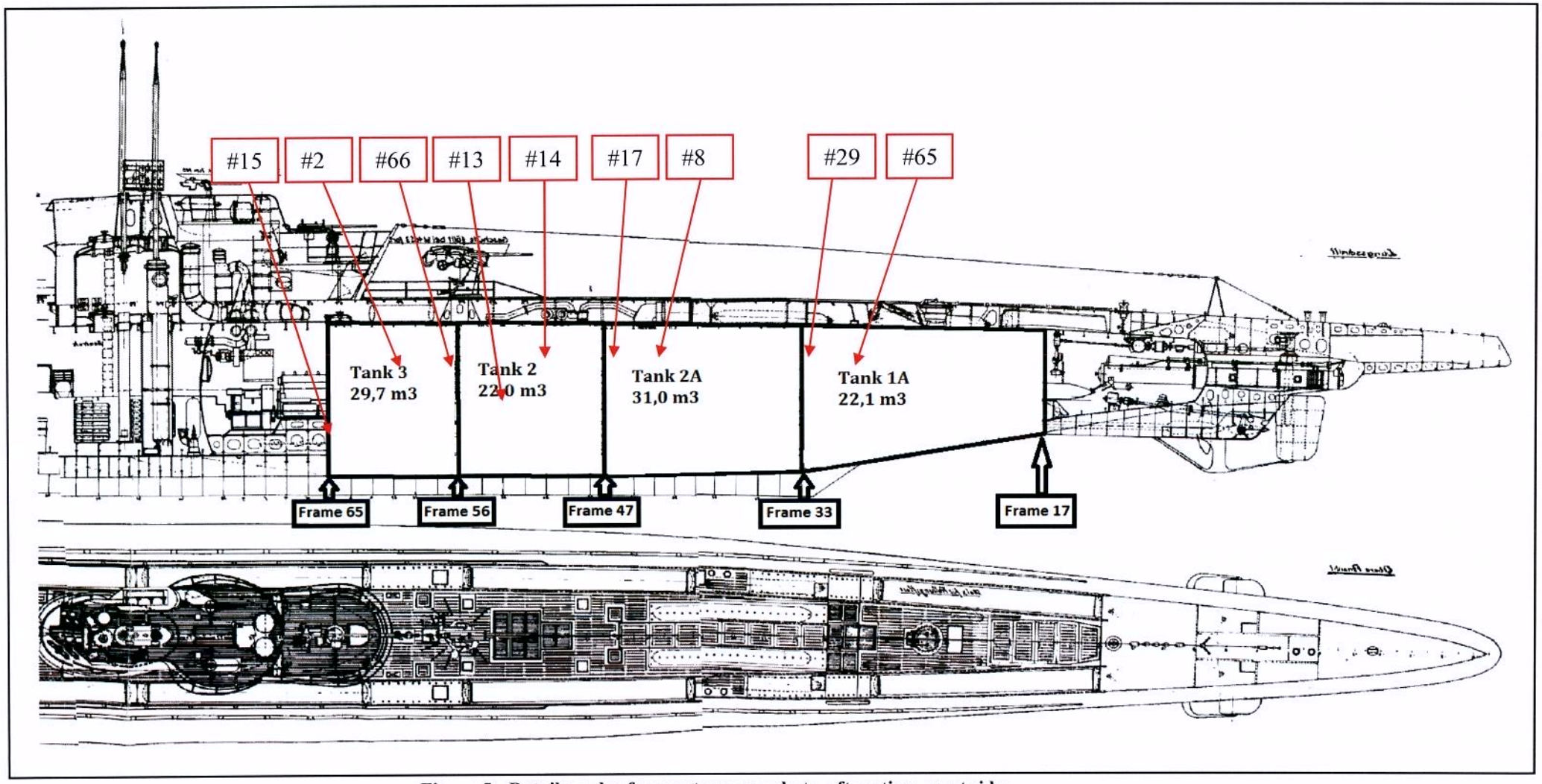

Figure 5 - Details and reference to screen shots, aft section - port side

FRAMO

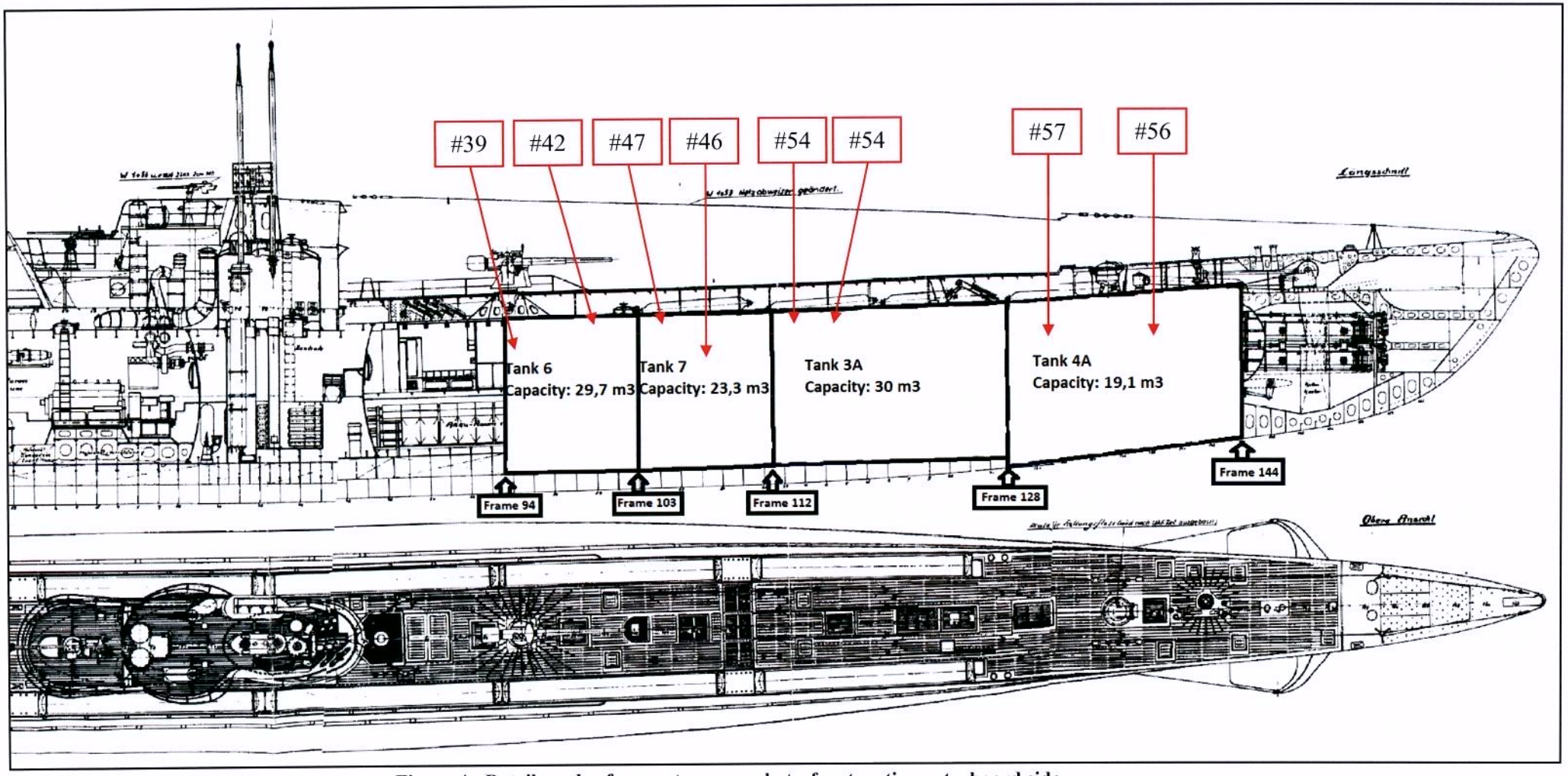

Figure 4 - Details and reference to screen shots, front section - starboard side

FRAMO

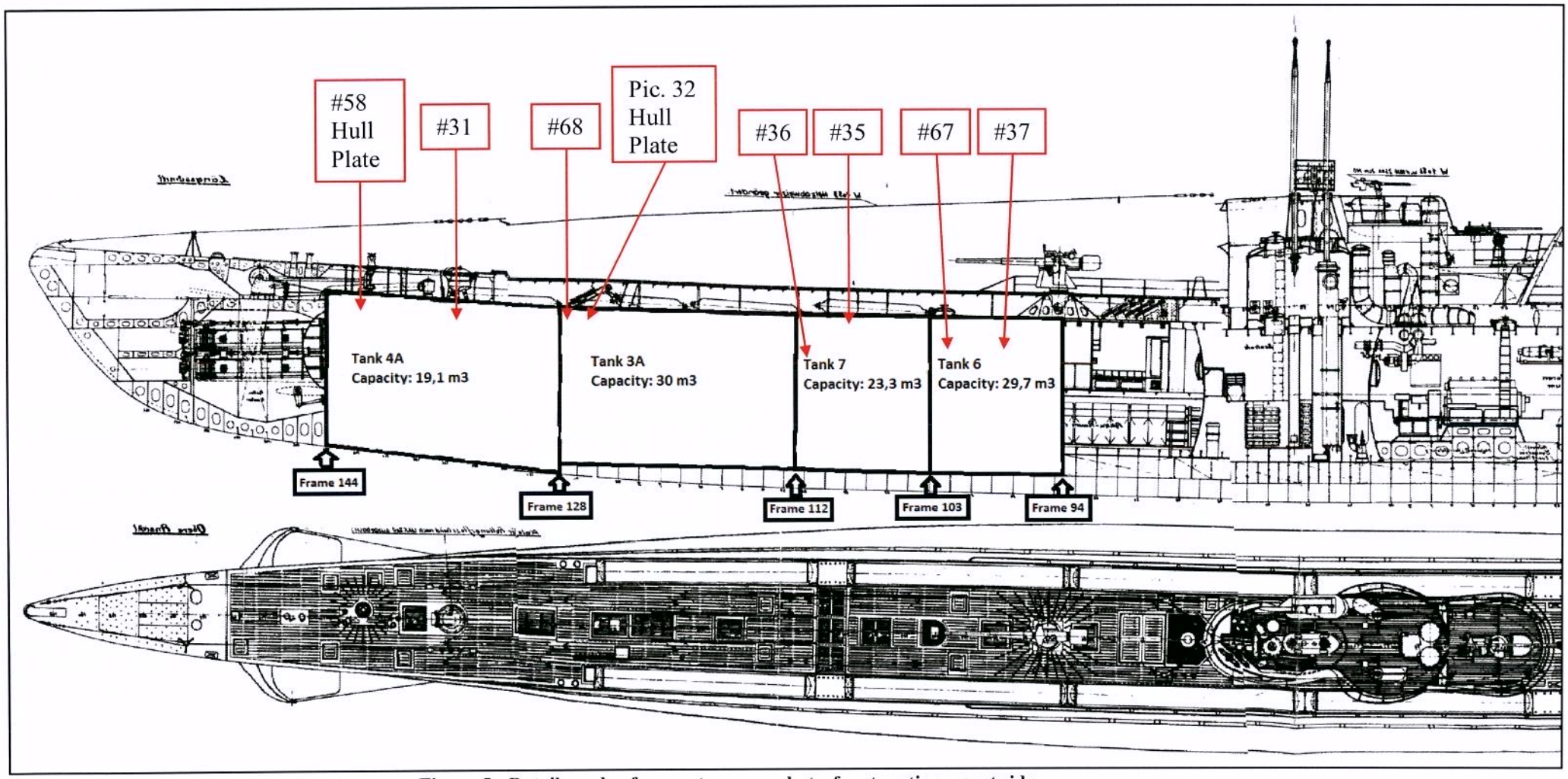

Figure 5 - Details and reference to screen shots, front section - port side

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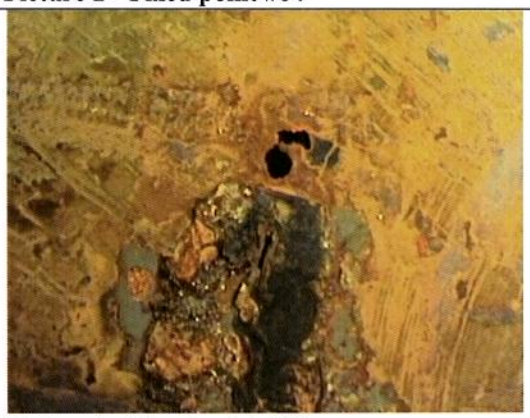
Picture 1 - Fixed point #63

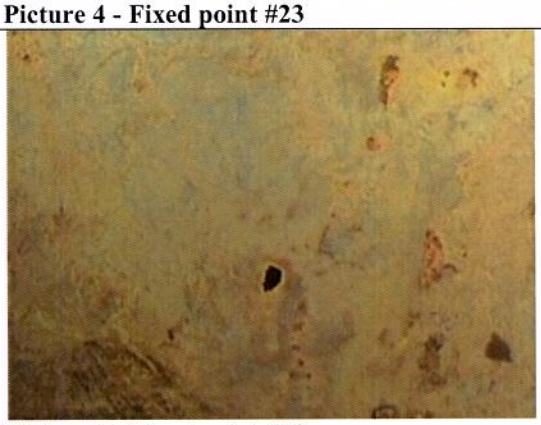
Picture 2 - Fixed point #64

Picture 3 - Fixed point #22

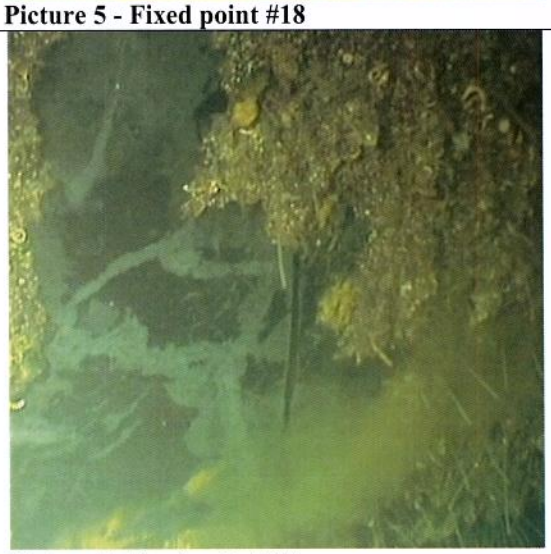


Picture 4 - Fixed point #23

Picture 5 - Fixed point #18



Picture 6 - Fixed point #19



Picture 7 -Fixed point #29

Picture 8 - Fixed point #65

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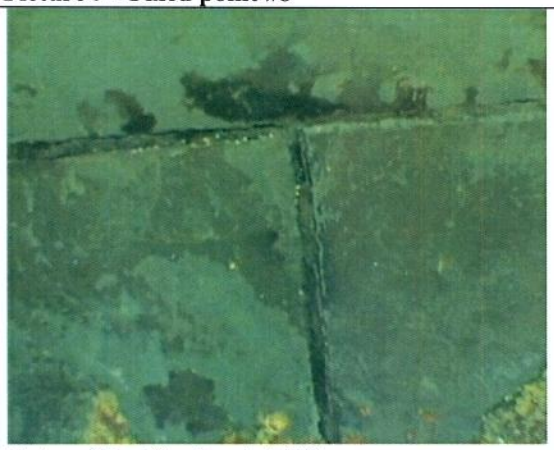
Picture 9 - Fixed point #8

Picture 10 - Fixed point #17



Picture 11 - Fixed point #13

Picture 12 - Fixed point #14

Picture 13 - Fixed point #66

Picture 14 - Fixed point #15

Picture 15 - Fixed point #2

Picture 16 - Fixed point #29

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Picture 17 - Fixed point #56

Picture 18 - Fixed point #57

Picture 19 - Fixed point #54

Picture 20 - Fixed point #55

Picture 21 - Fixed point #46

Picture 22 - Fixed point #47

Picture 23 - Fixed point #42

Picture 24 - Fixed point #39

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Picture 25 - Fixed point #58 , Hull Plate

Picture 26 - Fixed point #31

Picture 27 - Fixed point #68

Picture 28 - Fixed point #35

Picture 29 - Fixed point #36

Picture 30 - Fixed point #37

Picture 31 - Fixed point #67

Picture 32 - Hull plate for tank 3A

FRAMO

4. Conclusion and course of action

- The cargo recovery from the wreck of "U864" is completed and documented with this report, collected oil samples from recovery, and video recording from final surveys. There were found no further recoverable residual liquids at completion of the recovery work, and no leakages were spotted at final survey.
- As seen from pictures above enclosed in this report, the condition of weld seems are found in a poor condition for most of the outer shell plates for the fuel tanks. As brushing revealed such a poor condition, the focus was changed from oil recovery to verification survey for most of the fuel tanks. If there were any uncertainty, oil recovery was commenced to ensure that the actual tank was empty. Oil recovery was made for totally 3 out of 16 tanks, and only minor quantities of oil was recovered
- Based on documentation above and agreement within the participating companies, the conclusion is made that no further action are recommended.

Radøy, 12th of March 2013

John Magne Oppedal	Knut Arnhus	Tony Collins
Framo Representative	NCA representative	DSNO representative

Report on the search and identification of U 864

ADMIRAL CONSULTING, HOP 5307 ASK

Report on the search and identification of U 864

The search and identification of debris from the WW2 submarine wreck of U 864 off the island of Fedje in Norway

Rear Admiral Ret'd Jan Jæger
22.02.2013

This report is a summary of a mission carried out in order to prove that the wreck of the WW2 submarine U 864 has been located in an area approximately 2 nautical miles west of the island Fedje north of Bergen Norway. The forward part and the rear part of the submarine are the dominant parts of the wreck. In addition, debris is located near the rear part of the submarine. The debris has been identified positively to be parts of the missing mid section of the submarine. This report proves that the two main parts of the submarine and the debris comprise the complete wreck of the WW2 submarine U 864. No parts are missing.

Search and identification of debris from the WW2 submarine wreck from U 864 off the island of Fedje in Norway

Background

The Nazi-German submarine U 864 was sunk by the HMS Venturer on the 9th of February 1945 (Figure 1). All the crew and passengers perished.

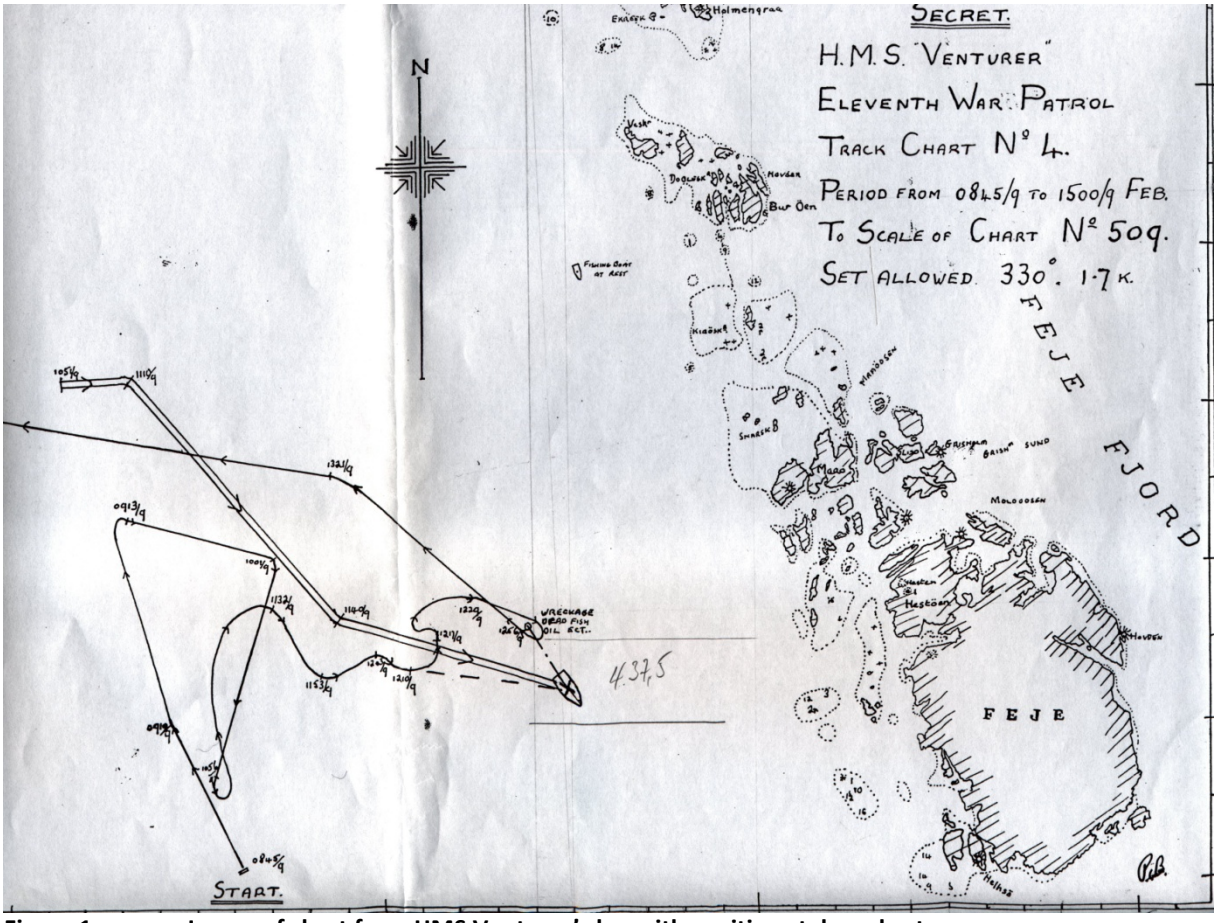

Figure 1 **Image of chart from HMS Venturer's log with positions taken chart**

The U 864 was en route Japan with personnel possessed with great technical skill and knowledge of the state of the art war material related to the development of new aircraft propulsion systems and other advanced weapons and sensors. A significant amount of mercury was carried in the keel of the submarine for delivery in Japan. The submarine was located by the Royal Norwegian Navy in Mars 2003 on 150m water depth about two nautical miles west of the island of Fedje North of Bergen.

Forward and aft section located

Two main bodies and several smaller parts and debris were found on the seabed. The forward and the rear section comprise most of the submarine and the minor parts and debris comprise the rest of the missing part of the hull.

There has been a discussion if the debris and the minor parts together represent the missing section, or if there is an independent third section not yet found in the immediate vicinity of the wreckages. Since one of the alternatives for the Norwegian Government in the process to secure the wreck, is to cover the submarine with a special mix of concrete, it is of significant importance to identify the complete submarine and all debris in order to have accurate information on what will be covered by the concrete. The search and identification process carried out in 2005 and 2006 did not conclude satisfactory on this question. Therefore it was decided to carry out a new search in 2013. The search area was extended to 2000 x 2000 meters with the two submarine sections in the middle of the area. New and improved multi beam sensors and HD quality cameras and LED light were to be used.

Subcontractor award

Admiral consulting was awarded a subcontract to DOF Subsea Norway AS (DSNO) on professional support and interpretation of the multi beam echo sounder and the video data on the 14th of November 2012.

Scope of work

DSNO was tasked by the Norwegian Coast Administration to provide an extended search in the area by multi beam sonar and by video cameras, in order to find and identify the missing part of the submarine. In a later phase, the bodies will be emptied for fuel oil and new sediment samples will be taken in the same general areas as before. The process of emptying the main sections for fuel oil and the sediment samples collection will not be covered by this report.

The discrepancy of the wreck position and the position given by HMS Venturer

The already established area limited to 1000 x 1000 meters with the forward and aft sections in the center was extended to an area 2000 x 2000 meters. This was done in order to cover the position 60 degrees 46’6 North, 04 degrees 36’9 East which was the position Lieutenant J.S. Launders, the Commanding officer of HMS Venturer, reported U 864 to be attacked in. This position is not in accordance with the actual position where the two main bodies and the debris of U 864 is located on the seabed, which is about 0.5 nautical mile SSE of the position given by HMS Venturer.

There are several reasons for the discrepancy between the two positions, such as time difference between the actual torpedo hit and the observation of the oil on the surface, tide setting calculations, the accuracy of the WW2 - Admiralty charts compared with the charts of today, navigation error in a stressed combat situation, and the fact that the plotting table used by the WW2-submarines for the generation of track charts, might be exposed to technical and operational errors. However, there should be no doubt about the position of the submarine today, as this operation has proved that the two main bodies and the debris comprise the complete submarine U 864.

The search and mapping of the extended area 2000 x 2000 meters started on the 4th of January. A clear zone grid survey was carried out throughout the area which confirmed the findings from 2005 and 2006. No other major debris was found during the new scanning. The state of the art multi beam equipment was tailored to the clear zone grid survey requirements and gave excellent recordings for the more detailed video search and the debris identification process. There were no indications that a third section could be located on the seabed within the extended area of 2000x 2000 meters. Consequently the missing parts of the submarine were to be found among the major debris near the rear part of the wreck (Figure 2).

In the next phase, the keel of the two submarine bodies was thoroughly investigated by video cameras.

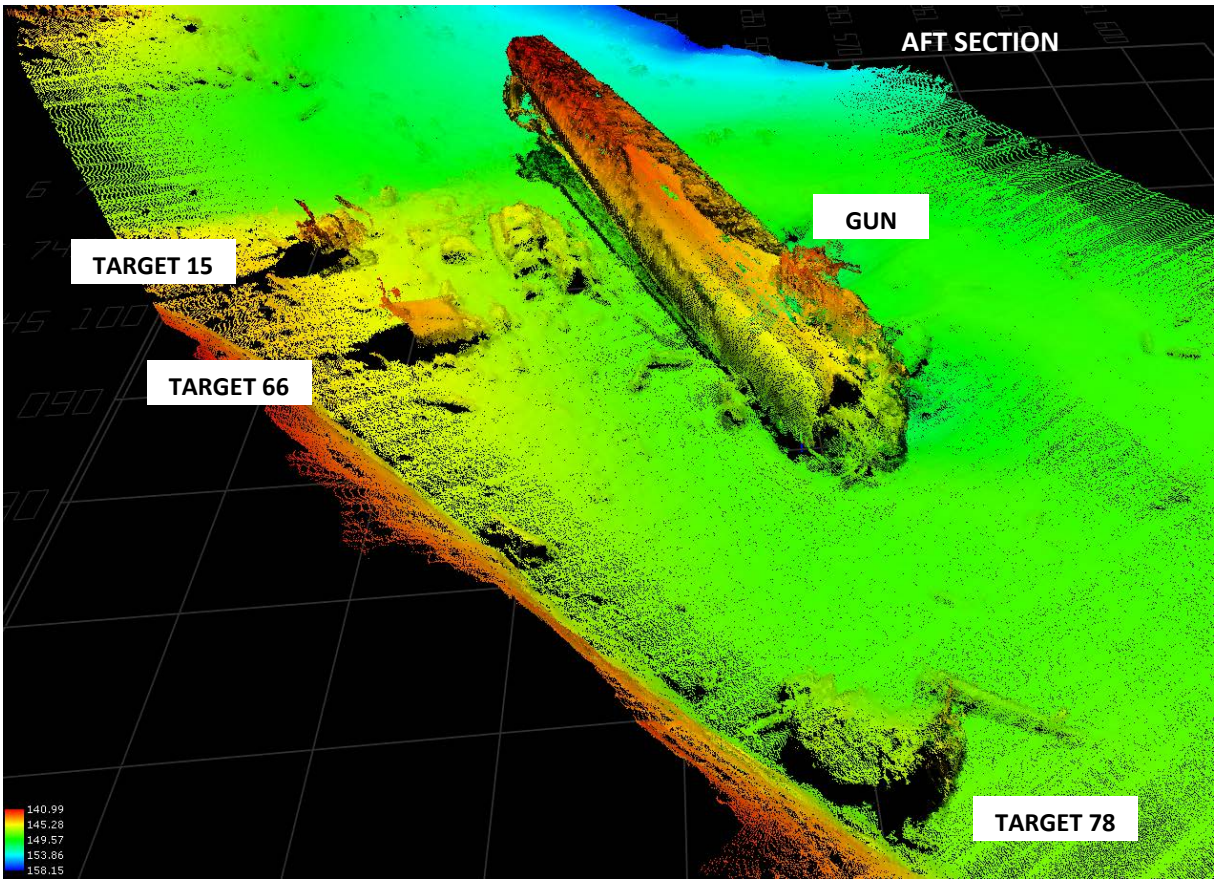

Figure 2 **The Aft section of U 864 with target 15, 66 and 88**

The debris identification process

The ROV operators as well as the multi beam scanning data handling personal were briefed about the U 864, the debris and what to look for. Significant parts as periscopes, snort mast, the conning tower, “winter garden”, guns, ladders and mercury canister were highlighted and pictures / drawings were handed out, in order to ease the recognition and identification for the personnel involved. The strategy was to identify all the above mentioned significant parts of the submarine and link them to specific mid-section debris on the seabed to prove that the complete submarine was located in one confined area.

The strategy for how to prove that the whole submarine is located in one general area, close to the two main wreck sections, is to find and to identify the periscopes, the small caliber guns, the snort mast and parts of the conning tower. Most of the debris was located on the starboard side of the aft section. The likelihood that the rest of the submarine could be identified among the debris was estimated to be high.

The guns

It was possible to identify the missing small caliber gun (or guns) on the aft part of the bridge deck, on top of the conning tower. The small caliber guns appeared in two variants, single barrel or twin guns. This could vary from submarine to submarine. The small caliber gun on U 864 has been positively identified as single barreled guns, one on each side of the conning tower (Figure 3 to 5). This was the case on the day the submarine was commissioned.

Figure 3 **one of the two single barreled guns (red arrow), from the conning tower**

Only one gun can be positively identified among the debris. However it is likely to believe that the other one can be found among the numerous wreckages in the same general area, but not visible

without lifting up other pieces to ease the identification. One gun is sufficient evidence for the identification of the rear section of the bridge area.

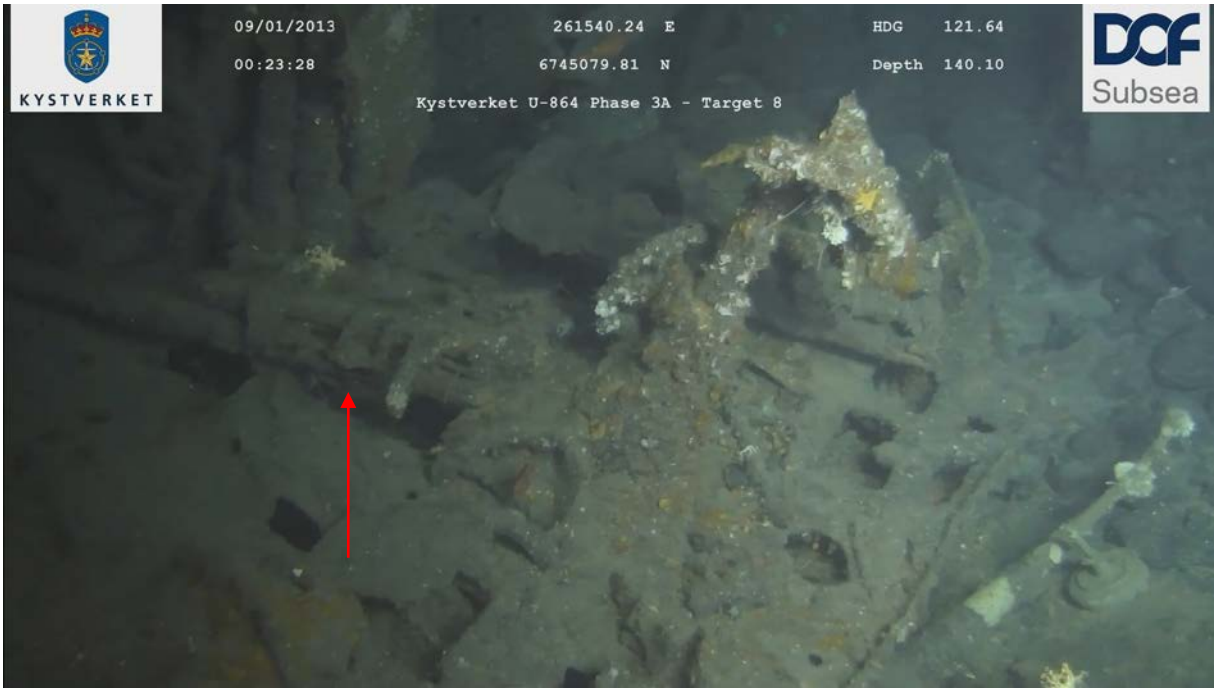

Figure 4 **One of the two Single barreled guns (red arrow), from the conning tower**

As the main gun is clearly visible on the forward casing, and the aft gun is located on the aft part of the "winter garden" (Figure 3 to 5), the conclusion is that two of the guns have been identified on the wreck and the last one on the adjacent debris. This is an important finding as it proves that all major parts of the top of the superstructure have been located.

Figure 5 **One of the two Single barreled guns (red arrow), from the conning tower**

The periscopes

U 864 was equipped with two periscopes, one attack periscope and one observation periscope. The diameter of the periscope masts were identical for both types, however the upper part of the attack periscope was slim, in order to avoid visual or radar detection when the periscope was exposed.

The observation periscope was thicker and more exposed for detection from ships and aircraft. The location and the identification of the attack periscope is a 100% verification that major parts of the mid section are among the debris. See the attack periscope in the middle of the Figure 6.

Figure 6 **The U 864 attack periscope (red arrow)**

Parts of the observation periscope have been located and are visible on several pictures.

To get an absolutely positive documentation of the search periscope, parts among the debris have to be lifted or recovered and put together as one unit.

For the purpose of this operation however, it is not mandatory to identify both periscopes as they are mounted onboard in a common structure of the hull. The metal tube on the Figure 7 shows a part of what is likely to be the observation periscope. The Figure 8 is taken from the top of the same section, shows what is believed to be the top of the observation periscope. Both periscopes are penetrating a solid support construction on the top of the conning tower with the mission to prevent vibrations in the periscopes when the submarine is operating on periscope depth at speeds in access of 4-5 knots.

Figure 7 **Part of the observation periscope (red arrow)**

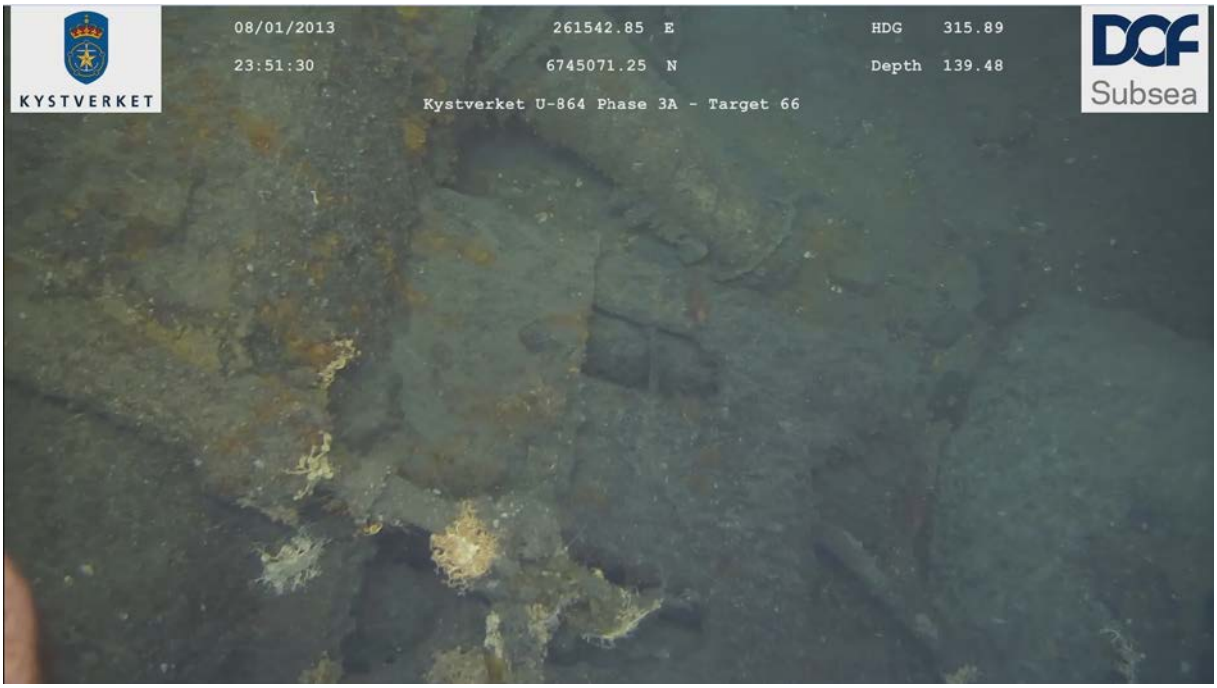

Figure 8 **Top of the periscope on the top of the conning tower**

The pictures of the periscopes were registered on the search in 2005 / 2006, but at that time it was not possible to classify them due to reduced video quality of the recordings.

The snort mast

The snort mast was not fitted onboard when the U 864 was commissioned in December 1942. During the preparations for the long transit to Japan due to take place in 1945, a snort mast was mounted onboard in 1944, on the starboard side of the submarine. The location of the snort mast on the seabed in vicinity of the other debris indicates that another significant part of the submarine supports the thesis that the debris belongs to the midsection. As a new introduction, the snort mast technique was not fully reliable. Problems with the snort mast were some of the reasons why the submarine had to return to Bergen for repair.

Figure 9 Top of the snort mask

The picture in Figure 9 shows the top of the snort mast, covered with a material with the purpose of reducing the radar cross section of the snort mast, using a radar radiation absorbing material. The snort mast is located near target 78, where also the unit connecting the snort mast to the fixed air inlet on the submarine is located.

Figure 9 is another example of how improved video equipment with the HD quality and LED lightning makes it possible to get a clear interpretation of what we see. This object has been registered several times during the previous investigations in 2005 / 2006, but impossible to classify due to reduced video quality.

The conning tower

The conning tower is a major part of the submarine superstructure and a central part of vital and significant equipment for the identification of the centre part of the U 864. By the localization and identification of this rather large debris, it is possible to link the findings of the two periscopes, the snort mast, the small caliber arms and hatches between the bridge and the submerged operational facilities to the submarine. No major parts or significant equipment is missing. The debris with all the above mentioned items can be seen on the scanned profiles as target 66.

The bridge bearing repeater construction

The bearing repeater arrangement on the bridge was mounted on top of a conical construction (uzo), see Figure 10. This devise was deliberately removed by the ROV and later recovered by Skandi Skolten. This is another vital documentation of the presence of the mid section of the submarine among the debris.

Figure 10 **Conical construction (red arrow) for the bearing repeater (uzo)**

Summary

A thorough and successful clear zone grid survey, followed by the identification of significant debris from U 864 was carried out in January 2013. No new debris parts from the middle section were found. Distinguished parts of the submarine was identified on or near the debris, such as the attack periscope, the observation periscope, the bearing repeater on the bridge, the small caliber gun, the snort mast and a significant part of the conning tower.

Conclusion

The multi beam echo sounder survey of the extended area have registered the main debris from the submarine U 864 in the immediate vicinity of the two main bodies, the forward ship and the aft section. The search was carried out by the multipurpose Construction Anchor Handling Vessel Skandi Skolten in the period 4th of January to the 9th of January 2013. The debris found adjacent to the submarine wreck were identified and is classified to be parts of the missing mid section of the submarine.

The effect of the warhead of the MK 8 torpedo has caused severe damage. The deformation of the conning tower indicates that the torpedo hit higher up than previously anticipated. The mid section is torn to pieces and the keel section is most probably less damaged than previously anticipated.

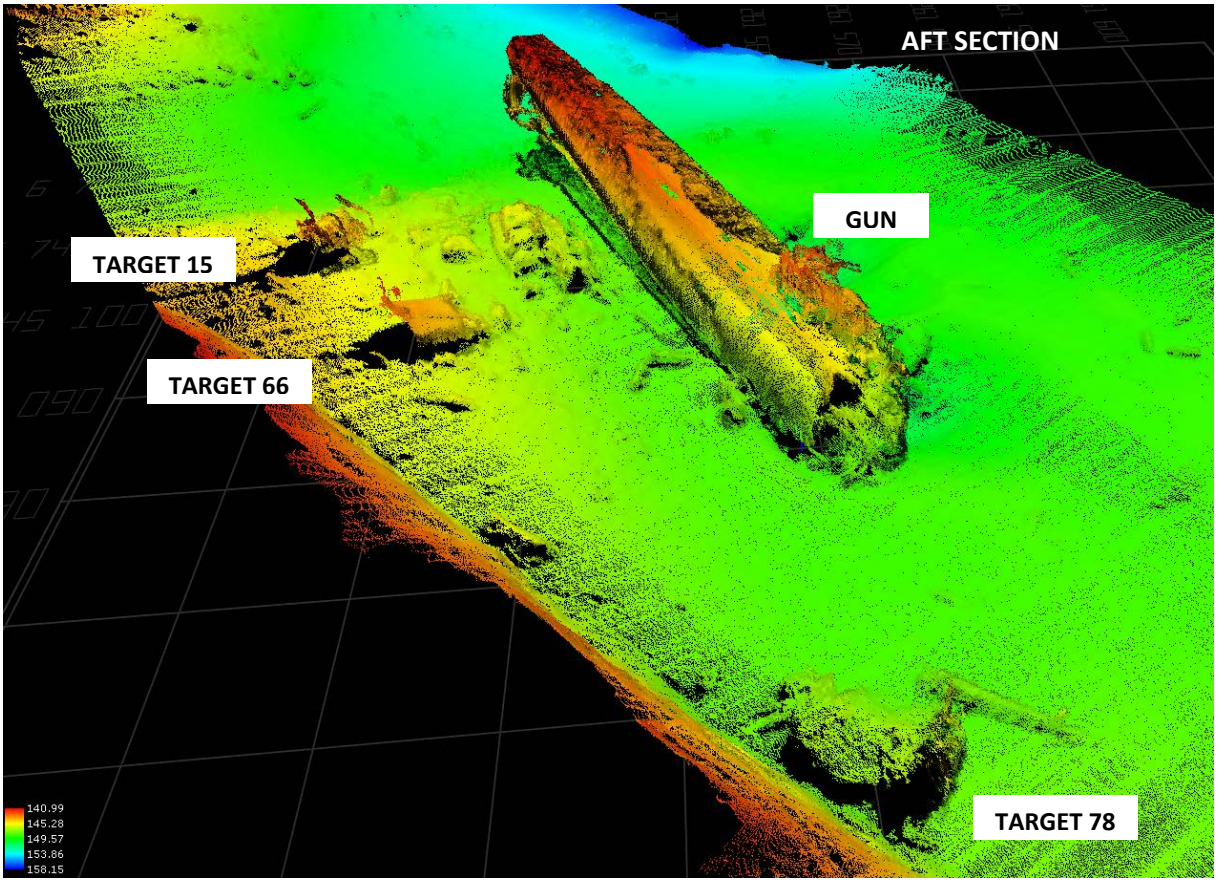

Figure 11 **The Aft section of U 864 with target 15, 66 and 88**

The identification of the significant parts attached to the mid section has mainly been done on or near the targets 66 and 78 (see Figure 11). Here we find the periscopes, the top bridge with navigation equipment, the conning tower, the snort mast and the small caliber gun from the aft part of the bridge.

New measurements of the main wreckages and the major debris will indicate that the keel is more complete and the main sections longer. This means that less mercury bottles may have dropped out of the storage than previously anticipated.

Investigations of mercury during a survey near submarine U-864 outside Fedje in 2013

REPORT SNO 6499-2013

Investigations of mercury during a survey near submarine U-864 outside Fedje in 2013

Norwegian Institute for Water Research
– an institute in the Environmental Research Alliance of Norway

REPORT

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Abstract

During a survey in January 2013 sediment samples were taken from the area near the wreck of submarine U-864 outside Fedje. The submarine is assumed to have had 67 tons of liquid mercury onboard, stored in carbon steel cans. When torpedoed, the mid-section of the submarine was blown up, and an unknown number of the stored mercury cans were destroyed and have polluted the seabed below. NIVA has analysed sediment samples for mercury in order to provide updated information about the area around the wreck that is polluted with mercury. Measurements for mercury vapour were done for safety reasons on deck and near sampling equipment during the survey. No high concentrations of mercury vapour were found.

4 keywords, Norwegian	4 keywords, English
1. Ubåt U-864	1. Submarine U-864
2. Fedje	2. Fedje
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Investigation of mercury during a survey near submarine U-864 outside Fedje in 2013

Preface

On request from DOF Subsea, NIVA has analysed mercury in sediment samples taken from the area around submarine U-864 outside Fedje. The survey was done in January 2013 on the anchor handling vessel Skandi Skolten from DOF Subsea. Analysis of mercury and reporting was done by Sigurd Øxnevad and Bjørnar Beylich. Agnete Strømme from DOF Subsea was our contact person during the project.

Oslo, 2.4.2013

Sigurd Øxnevad

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Summary

During a survey in January 2013 sediment samples were taken from the area near the wreck of submarine U-864 outside Fedje. The submarine is assumed to have had 67 tons of liquid mercury onboard, stored in carbon steel cans. When torpedoed, the mid-section of the submarine was blown up. During the event, an unknown number of the steel cans were destroyed which resulted in severe mercury pollution of the seabed around the wreck.

Pollution of mercury in the sediments around U-864 has been investigated on surveys in 2003, 2005 and 2006. During the cruise in January 2013 NIVA analysed sediment samples for mercury in order to provide updated information on pollution status in the area around the wreck. Some sediment stations north and west of the submarine were slightly more polluted with mercury than they were in 2006. Sediment stations east and southeast of the submarine had low concentrations of mercury and had not increased during the period 2006-2013.

Measurements for mercury vapour were done for safety reasons on deck and near sampling equipment during the survey. No high concentrations of mercury vapour were detected. All concentrations were lower than the administrative norm of 0.02 mg/m^3.

Sammendrag

På et tokt i januar 2013 ble det tatt sedimentprøver i området rundt vraket av ubåt U-864 utenfor Fedje. Det antas at ubåten hadde en last på 67 tonn kvikksølv om bord, og disse var lagret i beholdere av stål. Da ubåten ble torpedert ble midtseksjonen sprengt, og et ukjent antall kvikksølvbeholdere ble ødelagt. Det førte til at kvikksølv lakk ut og forurenset sjøbunnen.

Det har blitt utført undersøkelser av kvikksølvforurensning ved ubåten i 2003, 2005 og 2006. NIVA har i januar 2013 analysert kvikksølv i sedimentprøver fra området rundt ubåten for å få et oppdatert bilde av hvor stort område som er forurenset av kvikksølv. Noen stasjoner nord og vest for ubåtvraket var noe mer forurenset av kvikksølv enn ved forrige undersøkelse i 2006. Sedimentstasjoner øst og sørøst for ubåten var lite forurenset av kvikksølv og hadde ikke økt i konsentrasjon i perioden 2006-2013.

Av sikkerhetshensyn ble det målt for kvikksølvdamp på dekk og ved prøvetakingsutstyr. Det ble ikke funnet høye konsentrasjoner av kvikksølvdamp. Alle de målte konsentrasjonene var lavere enn administrativ norm på 0,02 mg Hg/m^3.

1. Background

In February 1945 the German submarine U-864 was sunk outside Fedje, on the south western coast of Norway. The submarine was torpedoed midship, broke in two and sank, and is located at 150 m depth. U-864 is assumed to have had 67 tons of liquid mercury onboard, stored in 1857 carbon steel cans in compartments inside the keel. When torpedoed, the mid-section of the submarine was blown up, and an unknown number of the steel cans were destroyed and mercury was spread to pollute the surrounding seabed. Mercury cans may also have corroded during the decades that have passed since the torpedition event and started to leak mercury to the seabed.
The authorities have decided to further evaluate two different methods of pollution abatement:

- Seal-in the polluted area, utilizing sand with special characteristics
- Retrieve the mercury cans from the keel section and seal-in the polluted area

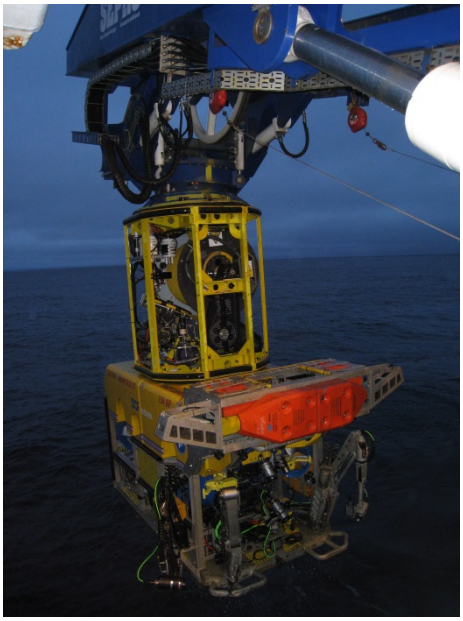
In January 2013 a final data collecting campaign was performed in order to obtain additional information regarding the two alternatives.

During the survey in January 2013 sediment samples were collected from the area around the submarine in order to provide updated information about the area around the wreck that is polluted with mercury.

2. Materials and methods

2.1 Sediment sampling

Surface sediment samples were taken from a total of 35 stations. 16 of the stations were taken at the same stations as in 2006. However, sediment from stations 12 and 30B were taken respectively 14 and 28 meters away from the original positions. The surface sediment was sampled by operators from DOF Subsea using a ROV. The top 0-2 cm of the sediment was to be analysed for mercury. Long sediment cores were sampled using a Vibro corer. Sediment cores were cut into sections by personnel from Franzefoss and passed on to NGI and NIVA for further handling and analysis.

A  **B**

Picture A and B. The ROV (A) and the Vibro corer (B) used for taking the sediment samples near U-864 at Fedje (Photos: Sigurd Øxnevad).

2.2 Measurements for mercury in air as part of HSE procedures

For safety reasons, equipment that had been used on the seabed or near the seabed was checked for mercury pollution when it was placed on deck. A Lumex RA-915+ Mercury Analyzer was used to check for mercury vapour. Survey equipment, the lab container and deck area was checked for mercury vapour during the survey operations and during and after the demobilization. The detection limit was 2 ng/m^3 in air. Administrative norm for mercury vapour is 0.02 mg/m^3 (20 000 ng/m^3) (http://www.arbeidstilsynet.no/artikkel.html?tid=78880). For a 12 hours shift the norm is 0.014 mg/m^3 (http://www.norskoljeoggass.no/no/Publikasjoner/Retningslinjer/Helse-arbeidsmiljo-og-sikkerhetHealth-working-environment-safety/Arbeidsmiljo/130-OLF-anbefalte-retningslinjer-for-helseovervaking-av-kjemikalieeksponerte-arbeidstakere/).

2.3 Preparations of sediment samples

Sediment samples were split into subsamples for analysis by NGI and NIVA. Sediment samples were put in 55 ml boxes, and subsamples of a few grams were then dried in a Termaks laboratory drying oven (60° C for approximately 30 minutes).

2.4 Analysis of mercury in sediment samples

Sediment samples were analysed roughly on board, and more accurately in the NIVA laboratory after the cruise. A Lumex RA-915+ Mercury Analyzer with pyrolyzer PYRO-915+ was used for the analysis (picture C).

Picture C. The Lumex Mercury Analyzer with pyrolyzer unit (Photo: Sigurd Øxnevad).

The RA-915+ Mercury Analyzer is a portable multifunctional atomic absorption spectrometer with Zeeman background correction, which eliminates the effect of interfering impurities. It does not require gold amalgam pre-concentration and subsequent regeneration steps. This enables the user to conduct real time monitoring and detection of a mercury vapour. Combined with a two-chamber atomizer (PYRO-915+), the instrument can determine mercury content in solid samples such as sediment. The detection limit is 1.0 µg/kg in solid samples. A certified marine sediment reference material (MESS-3) was used as standard for the analysis of sediment samples.
The results were classified according to the classification system of the Norwegian Climate and Pollution Agency for classification of environmental quality in fjords and coastal water (Table 1) (Bakke et al. 2007).

Table 1. Classification system for concentration of mercury in marine sediments (from Bakke et al. 2007).

	Class I Background	Class II Good	Class III Moderately polluted	Class IV Bad	Class V Very bad
Mercury (mg/kg) dry weight	**<0.15**	**0.15 – 0.63**	**0.63 – 0.86**	**0.86 – 1.6**	**>1.6**

3. Results

3.1 Measurements for mercury vapour

Measurements of mercury in air are presented in Table 2. No high concentrations of mercury were detected in air near any equipment that was landed on deck. Quite high concentrations of mercury in air were detected in the lab container when some of the sediment samples were dried in the laboratory drying oven. The highest measurement (January 11th 22.00) was taken in the lab container after a longer period where the door had been shut. No personnel were in the container in that period.
The highest measurement was below the administrative norm for work environment. However protective masks with air filters were used in the laboratory container when the concentration was higher than 500 ng/m^3 and when working with the highly contaminated samples.

Table 2. Concentrations of mercury detected in air during the survey.

Date	Time	Location for Hg measurement	Hg (ng/m^3)
January 5.	09.50	In ROV hangar, before deployment	20 -30
January 7.	12.35	In ROV hangar	15 - 25
January 8.	00.10	In ROV hangar	0
January 8.	16.05	In ROV hangar	4
January 9.	04.00	In ROV hangar	4
January 9.	20.50	Inside lab container	10
January 9.	21.50	In the area outside the lab container and by the vibro corer	0
January 10.	01.00	By vibro corer	0 - 8
January 10.	03.20	By vibro corer	0 - 10
January 10.	04.30	By vibro corer	0 - 9
January 10.	14.30	Inside lab container	0 - 22
January 11.		In ROV hangar	3 - 5
January 11.	07.50	By CPD	10
January 11.	09.30	By vibro corer	6
January 11.	16.10	By vibro corer	5
January 11.	16.20	Inside lab container	5500
January 11.	17.15	By vibro corer	8
January 11.	17.45	Inside lab container	700 – 1900
January 11.	18.10	By vibro corer	10
January 11.	18.15	Inside lab container	800 – 1800
January 11.	20.00	Inside lab container	700 – 2500
January 11.	22.00	Inside lab container	10000
January 12.	06.15	Inside lab container	480
January 12.	11.45	Inside lab container	120
January 12.		By gravity corer	4
January 12.	12.55	By gravity corer	6
January 12.	16.45	Inside lab container, after removal of sediment samples from drying oven	1 -13
January 12.	17.00	By ROV basket	0
January 12.	17.45	By Uzo retrieved from the submarine	0 - 5
January 13.	07.	Inside lab container	0 - 5
January 13.		On deck, and by equipment on deck	0 - 10

3.2 Mercury in the sediment surface

Results of the mercury analysis performed after the survey are presented in Table 3, Figure 1 and Figure 2. Some sediment stations north and west of the submarine were slightly more polluted with mercury than in 2006. This is in accordance with the direction of the water current which has been found to go in a north western direction (Uriansrud et al. 2006). On station 146 the concentration of mercury was substantially higher (Class V) compared to 2006 (Class II). The new samples taken south and west of the submarine were in Class I and II and had not increased since 2006. The results of mercury measurements for all years are shown in Figure 2. Data from earlier investigations have been taken from Skei (2003), Uriansrud et al (2005) and Uriansrud et al (2006). This gives an updated picture of the polluted area around the wreck of U-864.

Table 3. Concentrations of mercury in surface sediment (0-2 cm) on 35 stations around submarine U-864. Measurements from samples taken in 2006 are also presented. The results are presented in mg/kg dry weight and are classified according to the classification system of the Norwegian Climate and Pollution Agency (Bakke et al. 2007).

Station	Hg (mg/kg) 2013	Hg (mg/kg) 2006
28	0,28	0,44
31	0,05	-
32	0,11	0,07
34	0,26	0,22
35	1,23	1,30
36	0,33	-
38	0,41	0,07
83	0,04	-
87	0,33	0,07
88	0,89	0,35
142	0,07	0,02
146	1,62	0,20
155	0,03	-
204	0,07	0,04
206	0,08	0,04
210	0,03	0,03
211	0,06	0,20
213	0,12	0,25
301	0,89	-
302	0,60	-
306	0,04	-
308	0,07	-
312	0,70	-
313	0,06	-
315	0,11	-
316	0,09	-
317	0,58	-
320	0,08	-
324	0,11	-
331	0,18	-
332	0,08	-
333	0,15	-
334	0,05	-
30B	0,08	0,15
Sed-8	0,25	0,02

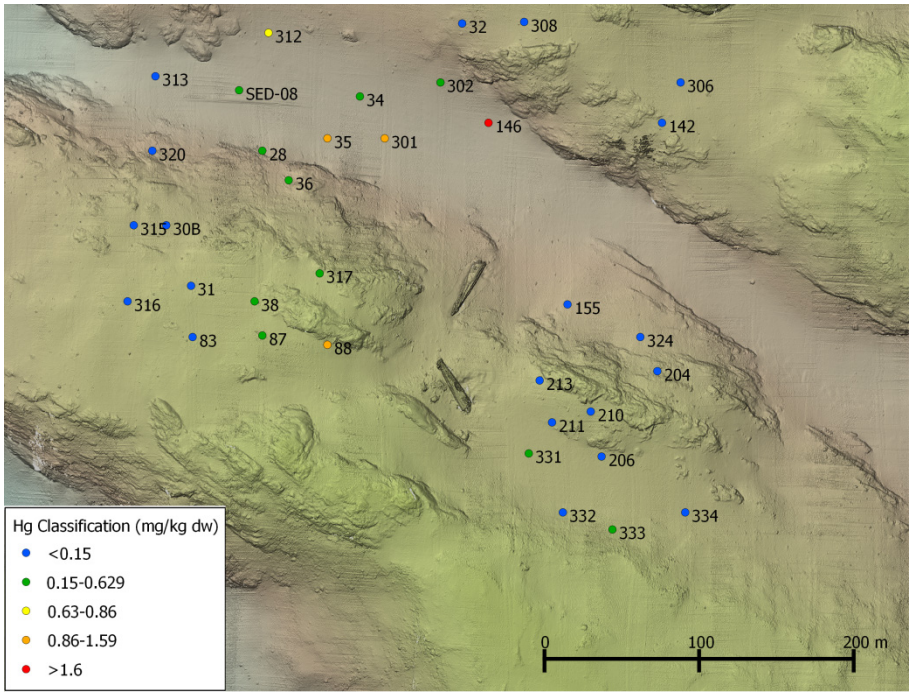


Figure 1. Concentrations of mercury in the surface sediment (0-2 cm) near the wreck of U-864 outside Fedje. The samples were taken in January 2013. The results are classified according to the classification system of the Norwegian Climate and Pollution Agency (Bakke et al. 2007).

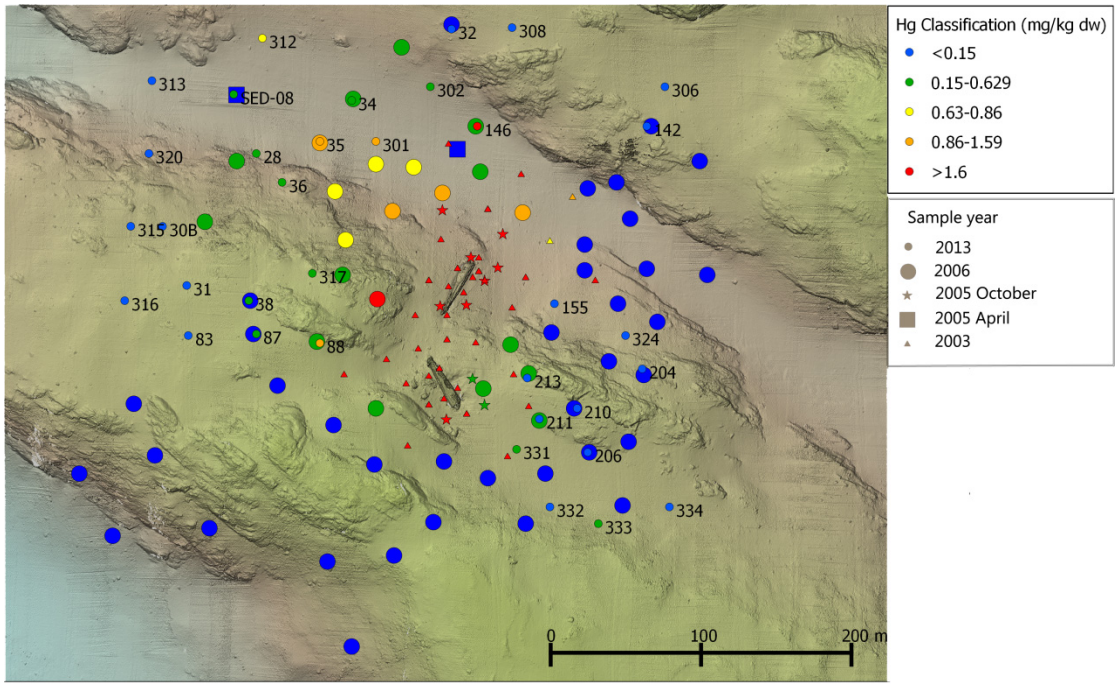


Figure 2. Concentrations of mercury in the sediment around U-864 outside Fedje. Results for all years are presented on the map. The results are classified according to the classification system of the Norwegian Climate and Pollution Agency (Bakke et al.2007). Because of the revision of the classification system, some of the observations may have been classified one class higher (worse) than they were in previous reports.

3.3 Mercury in the sediment cores

The core samples were all taken just a few meters from the wreck. In general they show a high surface concentration, with decreasing concentrations down in the sediment. The area around station 403 and 404 was dredged in 2006, removing the surface sediment. This could explain the low concentrations seen at these two stations. Station 402 is just a few meters from the dredged area.

In cores 406 and 407 liquid mercury were found (picture D). Sections of the sediment cores with visible liquid mercury were not analysed for mercury. In the cores from station 405 and 407 mercury was found down to the end of the core at respectively 3.2 and 2.2 meters. However the lack of mercury from 1.0 to 3.1 meters in the core from station 405 indicates that the deep samples might have been polluted with mercury from the top part of the core. This could also be the case for the core from station 406, but no samples between 0.2 and 2.1 meters have been analysed. It is our guess that the potential contamination of the deep samples could have occurred during cutting of the core or by the core catcher (a metal structure inside the core liner that keeps the sediment in the core from falling out). The results are shown in table 4.

Picture D. Sediment sample with liquid mercury (photo: Sigurd Øxnevad).

Table 4. Concentrations of mercury in core samples close to submarine U-864.

Station	sample	Hg mg/kg dry weight
402	0-10 cm	1,490
402	10-20 cm	0,018
402	50-60 cm	0,120
402	100-110 cm	0,092
402	110-120 cm	0,030
402	200-210 cm	0,039
402	210-220 cm	0,012
401	0-10 cm	3,6
401	10-20 cm	0,406
401	50-60 cm	0,365
401	100-110 cm	0,153
401	110-120 cm	0,103
401	200-210 cm	0,057
401	210-220 cm	0,137
403	0-10 cm	0,067
403	10-20 cm	0,014
403	50-60 cm	0,006
403	100-110 cm	0,012
403	110-120 cm	0,036
404	0-10 cm	0,205
404	10-20 cm	0,209
404	80-90 cm	0,013
404	90-100 cm	0,002
405	0-10 cm	87,6
405	50-60 cm	0,837
405	100-110 cm	0,128
405	110-120 cm	0,132
405	200-210 cm	0,075
405	210-220 cm	0,131
405	300-310 cm	0,060
405	310-320 cm	8,2
407	0-10 cm	37,4
407	10-20 cm	18,4
407	50-60 cm	1,8
406	0-10 cm	3,0
406	10-20 cm	34,0
406	210-220 cm	23,8

4. Main conclusions

Some sediment stations north and west of the submarine were slightly more polluted with mercury than in 2006. This is in accordance with the direction of the water current which has been found to go in a north western direction (Uriansrud et al. 2006). On station 146 the concentration of mercury was substantially higher (Class V) compared to 2006 (Class II). The new samples taken south and west of the submarine were in Class I and II and had not increased since 2006.

Core samples were taken just a few meters away from the wreck. In two of the cores mercury was found down to the end of the core at 2.2 and 3.2 meters. Liquid mercury was found in two of the sediment cores.

Measurements for mercury vapour were done for safety reasons on deck and near sampling equipment during the survey. No high concentrations of mercury vapour were detected. All concentrations were lower than the administrative norm of 0.02 mg/m3.

5. References

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Appendix A. Hg measured in the sediment surface in 2013

Station	Sediment	Hg ng pr gram	Hg mg pr kg	Hg mg pr kg dry weight - average
317	Surface 0-2 cm	663	0,663	0,580
317	Surface 0-2 cm	553	0,553	
317	Surface 0-2 cm	525	0,525	
313	Surface 0-2 cm	52	0,052	0,059
313	Surface 0-2 cm	45	0,045	
313	Surface 0-2 cm	81	0,081	
204	Surface 0-2 cm	78	0,078	0,073
204	Surface 0-2 cm	67	0,067	
204	Surface 0-2 cm	73	0,073	
213	Surface 0-2 cm	129	0,129	0,119
213	Surface 0-2 cm	110	0,11	
213	Surface 0-2 cm	117	0,117	
210	Surface 0-2 cm	36	0,036	0,033
210	Surface 0-2 cm	38	0,038	
210	Surface 0-2 cm	24	0,024	
206	Surface 0-2 cm	87	0,087	0,076
206	Surface 0-2 cm	66	0,066	
206	Surface 0-2 cm	74	0,074	
142	Surface 0-2 cm	66	0,066	0,066
142	Surface 0-2 cm	88	0,088	
142	Surface 0-2 cm	43	0,043	
31	Surface 0-2 cm	54	0,054	0,052
31	Surface 0-2 cm	49	0,049	
31	Surface 0-2 cm	52	0,052	
87	Surface 0-2 cm	323	0,323	0,327
87	Surface 0-2 cm	329	0,329	
87	Surface 0-2 cm	328	0,328	
88	Surface 0-2 cm	869	0,869	0,886
88	Surface 0-2 cm	898	0,898	
88	Surface 0-2 cm	890	0,89	
334	Surface 0-2 cm	57	0,057	0,053
334	Surface 0-2 cm	44	0,044	
334	Surface 0-2 cm	58	0,058	
308	Surface 0-2 cm	71	0,071	0,067
308	Surface 0-2 cm	72	0,072	

Station	Sediment	Hg ng pr gram	Hg mg pr kg	Hg mg pr kg dry weight - average
308	Surface 0-2 cm	59	0,059	
32	Surface 0-2 cm	63	0,063	0,107
32	Surface 0-2 cm	224	0,224	
32	Surface 0-2 cm	80	0,08	
32	Surface 0-2 cm	62	0,062	
331	Surface 0-2 cm	179	0,179	0,184
331	Surface 0-2 cm	228	0,228	
331	Surface 0-2 cm	153	0,153	
331	Surface 0-2 cm	177	0,177	
83	Surface 0-2 cm	37	0,037	0,040
83	Surface 0-2 cm	42	0,042	
83	Surface 0-2 cm	42	0,042	
306	Surface 0-2 cm	46	0,046	0,044
306	Surface 0-2 cm	43	0,043	
306	Surface 0-2 cm	44	0,044	
302	Surface 0-2 cm	611	0,611	0,596
302	Surface 0-2 cm	568	0,568	
302	Surface 0-2 cm	609	0,609	
155	Surface 0-2 cm	36	0,036	0,030
155	Surface 0-2 cm	28	0,028	
155	Surface 0-2 cm	26	0,026	
315	Surface 0-2 cm	101	0,101	0,111
315	Surface 0-2 cm	120	0,12	
315	Surface 0-2 cm	112	0,112	
324	Surface 0-2 cm	122	0,122	0,113
324	Surface 0-2 cm	109	0,109	
324	Surface 0-2 cm	108	0,108	
34	Surface 0-2 cm	401	0,401	0,264
34	Surface 0-2 cm	208	0,208	
34	Surface 0-2 cm	231	0,231	
34	Surface 0-2 cm	217	0,217	
146	Surface 0-2 cm	1720	1,72	1,623
146	Surface 0-2 cm	1500	1,5	
146	Surface 0-2 cm	1650	1,65	
35	Surface 0-2 cm	1210	1,21	1,225
35	Surface 0-2 cm	1180	1,18	
35	Surface 0-2 cm	1370	1,37	
35	Surface 0-2 cm	1140	1,14	
30B	Surface 0-2 cm	78	0,078	0,077
30B	Surface 0-2 cm	86	0,086	

Station	Sediment	Hg ng pr gram	Hg mg pr kg	Hg mg pr kg dry weight - average
30B	Surface 0-2 cm	68	0,068	
38	Surface 0-2 cm	422	0,422	0,408
38	Surface 0-2 cm	431	0,431	
38	Surface 0-2 cm	372	0,372	
312	Surface 0-2 cm	817	0,817	0,705
312	Surface 0-2 cm	594	0,594	
312	Surface 0-2 cm	680	0,68	
312	Surface 0-2 cm	728	0,728	
36	Surface 0-2 cm	376	0,376	0,330
36	Surface 0-2 cm	351	0,351	
36	Surface 0-2 cm	262	0,262	
320	Surface 0-2 cm	61	0,061	0,076
320	Surface 0-2 cm	55	0,055	
320	Surface 0-2 cm	95	0,095	
320	Surface 0-2 cm	93	0,093	
316	Surface 0-2 cm	155	0,155	0,092
316	Surface 0-2 cm	70	0,07	
316	Surface 0-2 cm	74	0,074	
316	Surface 0-2 cm	68	0,068	
28	Surface 0-2 cm	267	0,267	0,277
28	Surface 0-2 cm	198	0,198	
28	Surface 0-2 cm	367	0,367	
28	Surface 0-2 cm	277	0,277	
211	Surface 0-2 cm	68	0,068	0,063
211	Surface 0-2 cm	61	0,061	
211	Surface 0-2 cm	59	0,059	
332	Surface 0-2 cm	62	0,062	0,085
332	Surface 0-2 cm	46	0,046	
332	Surface 0-2 cm	169	0,169	
332	Surface 0-2 cm	61	0,061	
301	Surface 0-2 cm	976	0,976	0,894
301	Surface 0-2 cm	952	0,952	
301	Surface 0-2 cm	753	0,753	
SED8	Surface 0-2 cm	222	0,222	0,250
SED8	Surface 0-2 cm	234	0,234	
SED8	Surface 0-2 cm	295	0,295	
333	Surface 0-2 cm	163	0,163	0,145
333	Surface 0-2 cm	119	0,119	
333	Surface 0-2 cm	144	0,144	
333	Surface 0-2 cm	155	0,155	

Appendix B. Hg in surface sediment, 2003 - 2013

station	year	UTMZone	E	N	Hg mg/kg dry weight
28	2013	32North	261428	6745232	0,28
31	2013	32North	261382	6745145	0,05
32	2013	32North	261557	6745314	0,11
34	2013	32North	261491	6745267	0,26
35	2013	32North	261470	6745240	1,23
36	2013	32North	261445	6745213	0,33
38	2013	32North	261423	6745135	0,41
83	2013	32North	261383	6745112	0,04
87	2013	32North	261428	6745113	0,33
88	2013	32North	261470	6745107	0,89
142	2013	32North	261686	6745250	0,07
146	2013	32North	261574	6745250	1,62
155	2013	32North	261625	6745133	0,03
204	2013	32North	261683	6745090	0,07
206	2013	32North	261647	6745035	0,08
210	2013	32North	261640	6745064	0,03
211	2013	32North	261615	6745057	0,06
213	2013	32North	261607	6745084	0,12
301	2013	32North	261507	6745240	0,89
302	2013	32North	261543	6745276	0,60
306	2013	32North	261698	6745276	0,04
308	2013	32North	261597	6745315	0,07
312	2013	32North	261432	6745308	0,70
313	2013	32North	261359	6745280	0,06
315	2013	32North	261345	6745184	0,11
316	2013	32North	261341	6745135	0,09
317	2013	32North	261465	6745153	0,58
320	2013	32North	261357	6745232	0,08
324	2013	32North	261672	6745112	0,11
331	2013	32North	261600	6745037	0,18
332	2013	32North	261622	6744999	0,08
333	2013	32North	261654	6744988	0,15
334	2013	32North	261701	6744999	0,05
30B	2013	32North	261366	6745184	0,08
Sed-8	2013	32North	261413	6745271	0,25
28	2006	32North	261415	6745227	0,44
30	2006	32North	261394	6745187	0,15
31	2006	32North	261383	6745144	
32	2006	32North	261557	6745317	0,07

station	year	UTMZone	E	N	Hg mg/kg dry weight
33	2006	32North	261524	6745302	0,23
34	2006	32North	261492	6745268	0,22
35	2006	32North	261470	6745239	1,3
36	2006	32North	261447	6745211	
37	2006	32North	261438	6745173	
38	2006	32North	261424	6745135	0,07
41	2006	32North	261507	6745225	0,7
42	2006	32North	261480	6745207	0,7
43	2006	32North	261485	6745152	0,6
44	2006	32North	261459	6745132	
45	2006	32North	261551	6745206	1
46	2006	32North	261532	6745223	0,8
47	2006	32North	261518	6745194	1,5
48	2006	32North	261487	6745175	0,8
49	2006	32North	261508	6745136	2,5
68	2006	32North	261311	6745021	0,05
69	2006	32North	261333	6744980	0,02
70	2006	32North	261365	6744939	
71	2006	32North	261405	6744902	
72	2006	32North	261444	6744878	0,01
73	2006	32North	261492	6744855	
74	2006	32North	261540	6744846	0,04
76	2006	32North	261347	6745067	0,04
77	2006	32North	261361	6745033	0,02
78	2006	32North	261397	6744985	0,03
79	2006	32North	261419	6744962	
80	2006	32North	261456	6744933	
81	2006	32North	261491	6744907	0,07
82	2006	32North	261540	6744882	0,04
83	2006	32North	261381	6745112	
84	2006	32North	261395	6745079	
85	2006	32North	261418	6745039	
86	2006	32North	261442	6745079	0,08
87	2006	32North	261426	6745113	0,07
88	2006	32North	261468	6745108	0,35
90	2006	32North	261475	6744963	0,03
92	2006	32North	261552	6745029	0,08
93	2006	32North	261507	6745064	0,21
94	2006	32North	261479	6745053	0,08
95	2006	32North	261506	6745027	0,02
96	2006	32North	261469	6745051	
97	2006	32North	261480	6745020	

station	year	UTMZone	E	N	Hg mg/kg dry weight
98	2006	32North	261514	6744992	
99	2006	32North	261545	6744989	0,06
100	2006	32North	261519	6744967	0,04
142	2006	32North	261689	6745250	0,02
143	2006	32North	261721	6745227	0,04
144	2006	32North	261721	6745188	
145	2006	32North	261726	6745152	0,05
146	2006	32North	261573	6745250	0,2
147	2006	32North	261576	6745220	0,5
148	2006	32North	261609	6745250	
149	2006	32North	261647	6745209	0,05
150	2006	32North	261666	6745213	0,1
151	2006	32North	261675	6745189	0,04
152	2006	32North	261686	6745156	0,1
153	2006	32North	261645	6745172	0,1
154	2006	32North	261604	6745193	0,9
155	2006	32North	261624	6745133	
156	2006	32North	261667	6745133	0,05
157	2006	32North	261645	6745155	0,06
200	2006	32North	261670	6745000	0,05
201	2006	32North	261638	6744989	
202	2006	32North	261606	6744988	0,05
203	2006	32North	261693	6745121	0,025
204	2006	32North	261684	6745086	0,04
205	2006	32North	261674	6745042	0,02
206	2006	32North	261648	6745035	0,04
207	2006	32North	261619	6745021	0,07
208	2006	32North	261581	6745018	0,04
209	2006	32North	261661	6745095	0,05
210	2006	32North	261638	6745064	0,03
211	2006	32North	261615	6745056	0,2
212	2006	32North	261623	6745114	0,01
213	2006	32North	261608	6745087	0,25
214	2006	32North	261596	6745106	0,22
215	2006	32North	261578	6745077	0,4
01 FS	2005	32North	261594	6745032	134,5
02 FS	2005	32North	261608	6745065	13,6
03 FS	2005	32North	261573	6745107	33,3
04 FS	2005	32North	261597	6745130	66,5
05 FS	2005	32North	261652	6745148	14
06 FS	2005	32North	261606	6745150	49,7
07 FS	2005	32North	261622	6745174	0,72

station	year	UTMZone	E	N	Hg mg/kg dry weight
08 FS	2005	32North	261637	6745203	0,9
09 FS	2005	32North	261581	6745195	4,32
10 FS	2005	32North	261528	6745039	7,25
11 FS	2005	32North	261555	6745238	2,61
12 FS	2005	32North	261550	6745175	5,75
13 FS	2005	32North	261603	6745218	4,78
14 FS	2005	32North	261561	6745156	58
15 FS	2005	32North	261571	6745150	185,5
16 FS	2005	32North	261565	6745140	194
16 FS	2005	32North	261565	6745140	181
17 FS	2005	32North	261555	6745144	28,3
18 FS	2005	32North	261542	6745148	21,3
19 FS	2005	32North	261533	6745125	21,8
20 FS	2005	32North	261598	6745086	1,76
21 FS	2005	32North	261535	6745103	29,4
22 FS	2005	32North	261514	6745096	21,1
23 FS	2005	32North	261554	6745109	24
24 FS	2005	32North	261527	6745080	60,7
25 FS	2005	32North	261542	6745085	107800
26 FS	2005	32North	261549	6745090	17,7
27 FS	2005	32North	261561	6745077	8,05
28 FS	2005	32North	261552	6745070	62,3
29 FS	2005	32North	261542	6745066	134,4
30 FS	2005	32North	261567	6745060	25,2
31 FS	2005	32North	261486	6745086	7,65
32 FS	2005	32North	261575	6745163	268,6
33 FS	2005	32North	261579	6745148	949,5
34 FS	2005	32North	261554	6745125	130,1
35 FS	2005	32North	261575	6745154	89,2
Sed-1	2005	32North	261898	6745027	0,023
Sed-2	2005	32North	262195	6745450	0,026
Sed-3	2005	32North	261745	6745836	0,017
Sed-4	2005	32North	260770	6745128	0,016
Sed-5	2005	32North	261101	6744903	0,015
Sed-6	2005	32North	261473	6744569	0,016
Sed-7	2005	32North	261561	6745235	0,034
Sed-8	2005	32North	261415	6745271	0,022
Sed-9	2005	32North	262375	6744587	0,019
Sed-10	2005	32North	262873	6744314	0,025
Sed-11	2005	32North	263075	6745708	0,026
Sed-12	2005	32North	262848	6746246	0,034
Sed-13	2005	32North	261688	6746858	0,038

station	year	UTMZone	E	N	Hg mg/kg dry weight
Sed-14	2005	32North	260921	6746319	0,023
Sed-15	2005	32North	260966	6745424	0,097
Sed-16	2005	32North	260229	6745677	0,02
Sed-17	2005	32North	260502	6744727	0,018
Sed-18	2005	32North	261047	6744367	0,013
Sed-19	2005	32North	261621	6744053	0,015
Sed-20	2005	32North	263627	6743549	0,037
Sed-21	2005	32North	264065	6744914	0,029
Sed-22	2005	32North	264525	6745163	0,017
Sed-23	2005	32North	263962	6745644	0,025
Sed-24	2005	32North	263500	6747069	0,017
Sed-25	2005	32North	262624	6747553	0,032
Sed-26	2005	32North	261598	6747469	0,019
Sed-27	2005	32North	261250	6748202	0,024
Sed-28	2005	32North	259877	6746722	0,026
Sed-29	2005	32North	258601	6745399	0,027
Sed-30	2005	32North	260135	6743780	0,019
1	2003	32North	261554	6745057	1,94
2	2003	32North	261571	6745084	0,56
3	2003	32North	261579	6745067	0,41
4	2003	32North	261567	6745133	96,5
5	2003	32North	261579	6745149	1653
6	2003	32North	261588	6745157	139
7	2003	32North	261591	6745179	10,2
8	2003	32North	261570	6745164	3,23
9	2003	32North	261549	6745132	2,96
10	2003	32North	261551	6745195	2,11

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En uavhengig vurdering

av

Organisering og roller i prosjektet «Miljøtiltak ved vraket av U – 864»

Oppdragsgiver:

Kystverket

Utførende:

Risk Management Institute as

Rapport-dato	Versjon	Utført av
25. februar 2014	Utkast	Jon Lereim
26. februar 2014	0	Jon Lereim
06. mars 2014	1	Jon Lereim

Sammendrag

Det er utført en uavhengig vurdering av prosjektet «Miljøtiltak ved vraket av U–864» (videre omtalt som «U-864») med hensyn på prosjektorganisering og tilhørende roller. I tillegg er det gjort en kort drøfting av mulig hensiktsmessig kompensasjonsformat på kontrakter til potensielle leverandører av operative tjenester i prosjektet for å tilstrebe en balansert risikodeling mellom partene og som virker stimulerende på økt effektivitet og gjennomføring.

Innledningsvis er det tatt med noen generelle prosjektorganisatoriske betraktninger som en del av god prosjektskikk og vellykket prosjektgjennomføring. Dette er så blant annet brukt som bakgrunn i evalueringene av organisering og roller i prosjektet U – 864. Videre er det oppsummert noen av hovedutfordringene til en matriseorganisering av prosjekter.

De organisatoriske vurderingene og anbefalingene ga følgende hovedpunkter:

- Prosjekteierrollen må være tydelig og sterk, og kan fortrinnsvis bekles av leder for beredskapsavdelingen, i tråd med tidligere tilrådning fra Kystverket i Sentralt styringsdokument for prosjektet «Heving U–864» fra 2009.
- Eierstyring av prosjektet kan styrkes ved å ha en styringsgruppe for å støtte prosjekteier og sikre et helhetlig organisatorisk perspektiv for Kystverket i kontrollfunksjonen
- Prosjektet kan og bør organiseres som en sterk prosjektmatrise, med tydelig rolledeling mellom prosjektleder og linjelederne i Kystverket
- Den sterke prosjektmatrisen bør fortrinnsvis være bestiller/kunde basert med identifiserte kontrakt-ledere overfor hver av de potensielle leverandører/entreprenører
- Alternativ organisering; dersom det velges en form for integrert prosjektorganisering, en såkalt prosjektallianse, med leverandører i sentrale lederroller inne i organisasjonen, må det sørges for ekstra årvåkenhet med hensyn på rolleavklaring, samt utøvelsen av de respektive lederroller. I tillegg må det også identifiseres en egen kontraktsansvarlig for å ivareta de formelle krav i kontraktene til leverandørene
- Prosjektleder bør fortrinnsvis ikke ha andre sentrale lederroller i prosjektperioden. Dersom det likevel er nødvendig, må en sørge for at det er en klar prioriteringsliste på ulike oppgaver i prosjektet og linjen
- Ledergruppen bør etableres som et kjerne-team hvor medlemmene forplikter seg til å ha mer enn 50 % av tiden i prosjektet
- Unngå «10 %» deltakere i prosjektorganisasjonen. Det er lite effektive ressurser
- Kommunikasjonsansvarlig er en nøkkelrolle og kan eventuelt rapportere direkte til prosjekteier for å løfte den dimensjonen opp på sentralt ledernivå i Kystverket

Vurderinger og anbefaling for kontrakter og kompensasjonsformat:

- Oppgavene er såpass komplekse at en utarbeidet oppgavebeskrivelse trolig ikke vil kunne være fullt ut dekkende for oppgavens utfordringer; følgelig anbefales å benytte «kontrakt med forhandlinger» for å kunne etablere en omforent forståelse for oppgaven og dens utfordringer i løpet av forhandlingene og før signering av kontrakt
- Videre bør det vurderes om alternative kompensasjonsformat er mer hensiktsmessig for å skape en vinn-vinn situasjon med en balansert risikodeling mellom partene. Et kompensasjonsformat med målsum anbefales vurdert for flere av kontrakt-pakkene, uavhengig av løsningsvalg.

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1. Introduksjon

En uavhengig vurdering er gjort av prosjektet «U–864» som Kystverket gjennomfører forprosjekter for og etablerer sentrale styringsdokument (SSD) for.

Vurderingen er avgrenset til prosjektorganisatoriske forhold, samt en vurdering av egnet kontrakts-regime i lys av potensielle risikoer forbundet med operasjonene. Disse vurderingene er gjort med basis i god prosjektskikk slik det er beskrevet i de fleste lærebøker, og erfaring fra større prosjektorganisasjoner.

I diskusjon med representanter for Kystverket i møte hos DNV GL den 12. februar 2014 fremkom det at det i bestillingen fra tidligere Kyst- og fiskeridepartement (nå Samferdselsdepartementet) at det skal utarbeides forprosjekter for to ulike løsningsalternativer. Disse er:

- Tildekking av vrak og forurenset sjøbunn (Alt.1 i KVU)
- Heving av last og tildekking av vrak og forurenset sjøbunn (Alt.3 i KVU)

Uavhengig av alternativ løsning, må prosjektet organiseres og styres på en mest mulig hensiktsmessig måte både med hensyn på miljø og sikkerhet, så vel som effektivitet og smidighet under planlegging og gjennomføring av operasjonene.

Rapporten inkluderer noen generelle prosjektorganisatoriske prinsipper i forkant av selve vurderingen av organisasjonsmodellen som Kystverket hadde foreslått i sentralt styringsdokument for «Heving U -864» fra 2009. Dette styringsdokumentet omfattet kun alternativet med heving av vrak og last, et alternativ som ikke lengre er med i forprosjektfasen. I tillegg er kommentarer som Dovre-gruppen hadde i deres etterfølgende KS2 rapport. Utover dette er Kystverkets Konseptvalgutredning av 2011 samt en uavhengig KS1-rapport fra Møreforskning og Metier tatt med i bakgrunnsdokumentasjonen.

2. Prosjektorganisatoriske forhold og prinsipper

Noen generelle betraktninger

Det er enkelte prinsipper som er grunnleggende i god prosjektledelse og styring, og som inngår i begrepet god prosjektskikk. Blant disse er:

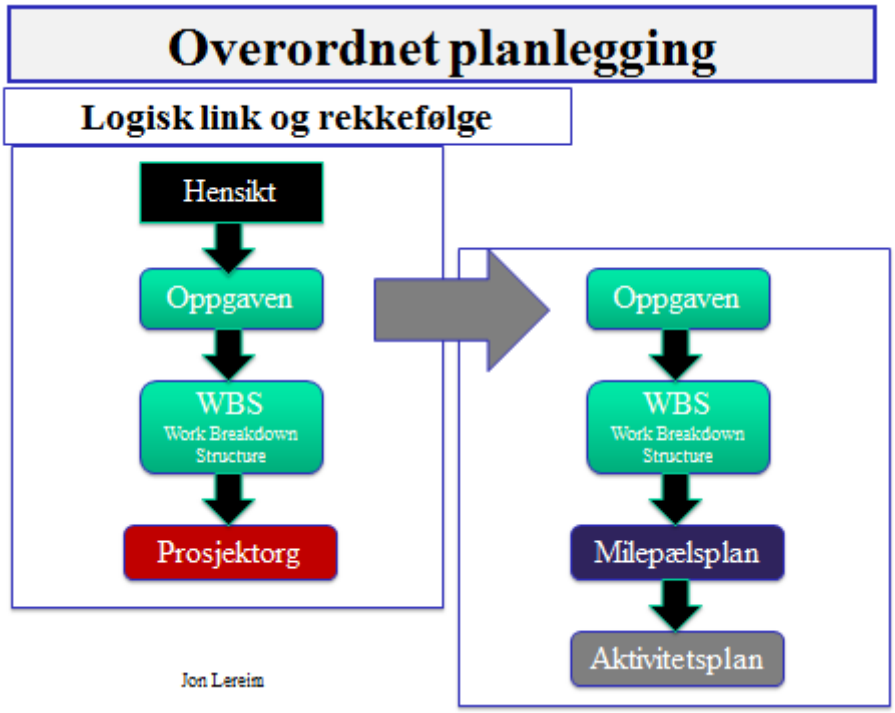
- Prosjektorganiseringen skal understøtte hensikt og oppgave
- Prosjektorganisasjonen må være dynamisk og kunne endres underveis i prosjektet, avhengig av situasjon og behov
- Roller må være tydelig beskrevet, oppfattet og etterlevd
- Unngå «10 %»- deltakere i kjerneteamet til prosjektet
- Sikre kontinuitet i prosjektorganisasjon, spesielt i kjerneteamet
- Lederteamet i prosjektet, kjerneteamet må fremstå som et kollegium hvor vedtak i lederteamet er bindende for alle
- Utøve god eierstyring av prosjektet fra Kystverket sin side.

Noen av disse perspektivene er illustrert i skissene i figur 1 og figur 2. I figur 1 ser man tydelig at hensikt/formål skal sette premissene for oppgavebeskrivelsen (Scope of Work).

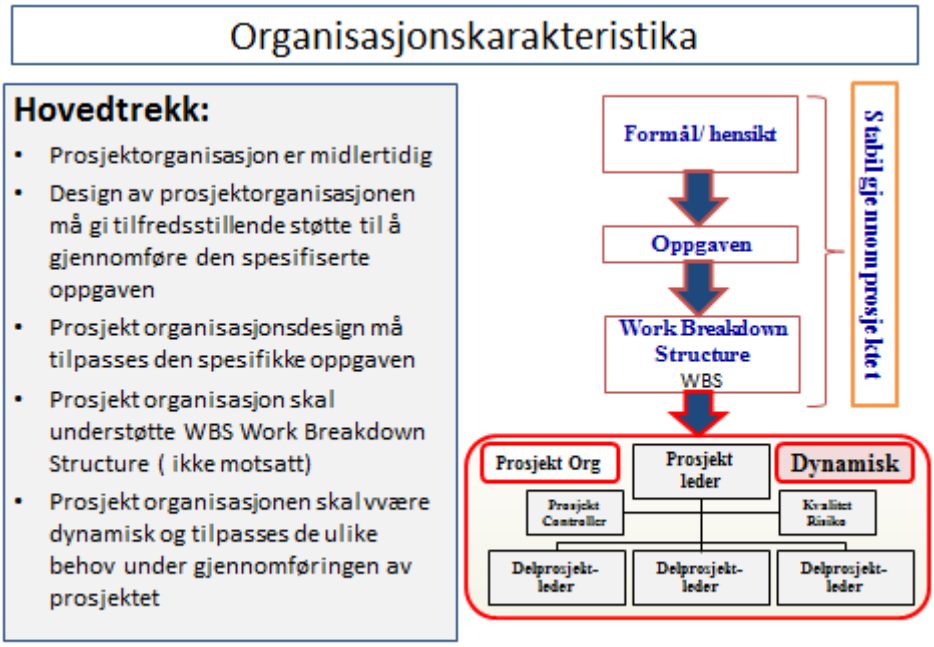
Oppgavebeskrivelsen er grunnlaget for oppdeling av denne i hensiktsmessige deler/delobjekter. Det fremgår av nedbrytningsstrukturen, NBS. (WBS Work Breakdown Structure) Dernest følger design av prosjektorganiseringen, som skal tilpasses til enhver tid hva som er best egnet form i løpet av prosjektgjennomføringen i ulike prosjektfaser.

I forbindelse med utarbeidelse av oppgavebeskrivelsen vil det være klart fordelaktig med tydelige prosjektstrategier. Prosjektstrategi omfatter risiko, teknologi, kontraktstrategi, ressurser(kombinasjon av egne og innleide), prosjektstyringsmåte, hva skal det styres på samt vedtatt prioritering mellom kvalitet, fremdrift og kostnad ved nødvendige valg under gjennomføring. Dette er viktige premisser ved omsetting av prosjektets formål/hensikt til en konkret og god oppgavebeskrivelse.

Utfra oppgavebeskrivelsen lages så en tilhørende milepælsplan. Milepælsplanen illustrerer den logiske rekkefølgen på «tilstander» som skal oppnås. Den må etableres før man lager aktivitetsplanen. Milepælsplanen er kritisk med hensyn på å forstå hele gjennomførings-prosessen som skal lede frem til ferdigstillelse. Denne bør vær godt bearbeidet før prosjektet settes i gang for fullt. Aktivitetsplanen kan da etableres mer effektivt når det er full oversikt over milepælene og i sær rekkefølgen på disse.



Figur 1 Prinsippskisse for sammenhenger i prosjektstruktur og plan



Figur 2 Utdyping av noen organisasjonskarakteristika i prosjekt

3. Roller

Generelt

Mangel på klare roller er en av de mest vanlige feil man opplever i prosjektorganisering og gjennomføring, uansett bransje og prosjekttype. Det gjelder roller i prosjektet så vel som rollene rundt prosjektet. De respektive rollene bør beskrives i form av hva innholdet er til hver rolle, men ikke minst ansvar og myndighet. En sterkt forenklet beskrivelse er gitt nedenfor for noen typiske roller i og rundt prosjekter.

Roller i prosjektet

Prosjektleder:

- Prosjektleder har resultatansvar i prosjektet, hvor resultatansvaret omfatter kvalitet, kostnadsutvikling, fremdrift, risiko og muligheter, helse miljø og sikkerhet.
- Motivator og lagbygger
- Håndtering av prosjektets interessenter

Delprosjektledere (engineering, operasjoner etc.)

- Delprosjektleder har resultatansvar for sin del av prosjektet
- Motivator og lagbygger
- Medlem av kjerne-team/ledergruppen

Støttefunksjoner

- Støtte-funksjon omfatter blant annet kvalitet og risiko, økonomi, prosjektkontroll, HMS
- Internleverandør innen sine spesialfelt og rapportere til resultatansvarlige i prosjektet.

Kjerneteamet

- Ledergruppen bør etableres som et kjerne-team i prosjektet.
- Kjerneteamet skal fungere som et kollegium hvor beslutninger/vedtak er forpliktende
- Kjerneteamsmedlemmer bør være mer enn 50 % engasjert i prosjektet for å oppnå mental tilstedeværelse i hele prosjektperioden

Roller utenfor prosjektet

God prosjektgjennomføring kan lettere oppnås dersom tilgrensende roller er tydeliggjort og aktivisert.

Prosjekteier

- Utøve god eierstyring av prosjektet
- Sette det enkelte prosjekt i en større sammenheng og gjøre prioriteringer
- Utøve en kontrollfunksjon overfor prosjektleder
- Være en støtte for prosjektleder, særlig ved å sikre riktige ressurser inn i prosjekt-teamet til avtalte tidspunkter
- Aktivt prosjekteierskap krever at tilstrekkelig tid avsettes til denne rollen
- Prosjektleder rapporterer direkte til prosjekteier.

Styringsgruppe

- Øverste beslutningsorgan til prosjektet
- Prosjekteier er oftest leder av styringsgruppen
- Begrens antall medlemmer til maksimum 5

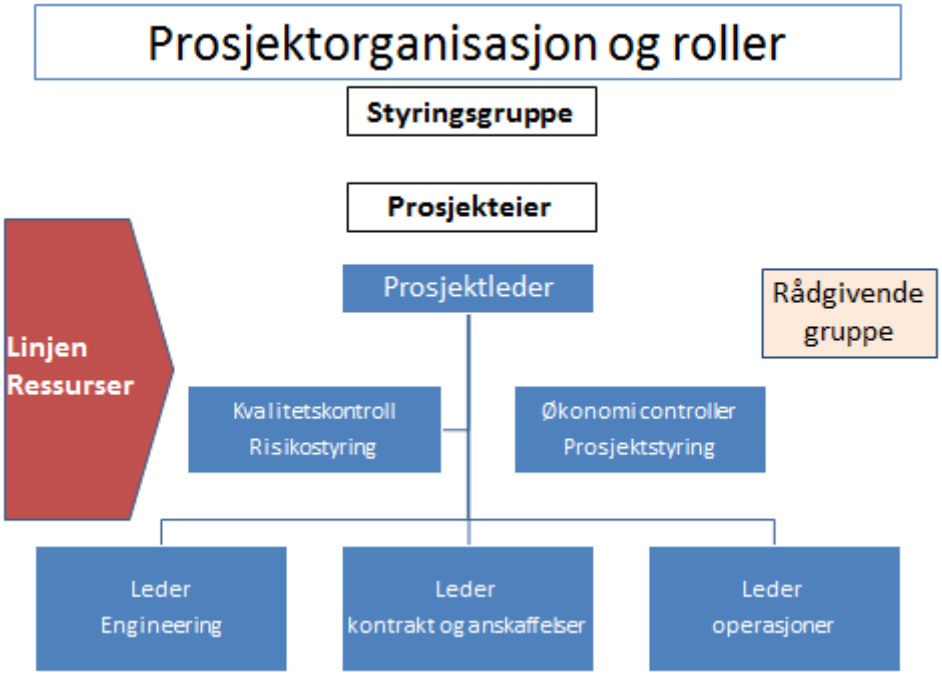
Rådgivende gruppe/referansegruppe

- Skal gi råd til prosjektet og eller styringsgruppen på spørsmål som gis til denne; spørsmålene kan komme fra prosjektmedlem, prosjektledelsen, prosjekteier eller styringsgruppen
- Har ikke beslutningsmyndighet
- Kan fokusere på ett særskilt tema
- Fleksibel organisering, kan kalle inn flere til idedugnader og diskusjoner av særskilte temaer.

Linjeorganisasjonen

- Avgi ressurser til prosjektet, på deltid eller heltid i prosjektperioden
- Utøve faglig kvalitetskontroll innen sitt eget fagområde
- Delta i prosjektrevisjoner
- Personalansvar for prosjektmedarbeiderne i sin enhet

Rollene er illustrert i figur 3 under for et typisk prosjektorganisasjonskart. Rollene kan betjenes på heltid eller deltid avhengig av prosjektets størrelse. Støttefunksjonene kan betjene flere prosjekter samtidig.



Figur 3 Prinsippskisse på et typisk organisasjonskart med roller i og utenfor prosjektet

4. Matriseorganisasjonens særskilte utfordringer

Matriseorganisering er en mye brukt form for en rekke prosjekter. Det medfører at det er en integrert organisering mellom linje og prosjekt. Noe av bakgrunnen for denne organisasjonsformen er ønsket og overbevisningen om en effektiv bruk av nøkkelressursene i en organisasjon, hvor disse kan arbeide på flere oppgaver samtidig.

Nedenfor er listet opp noen særskilte utfordringer for prosjektmatriser:

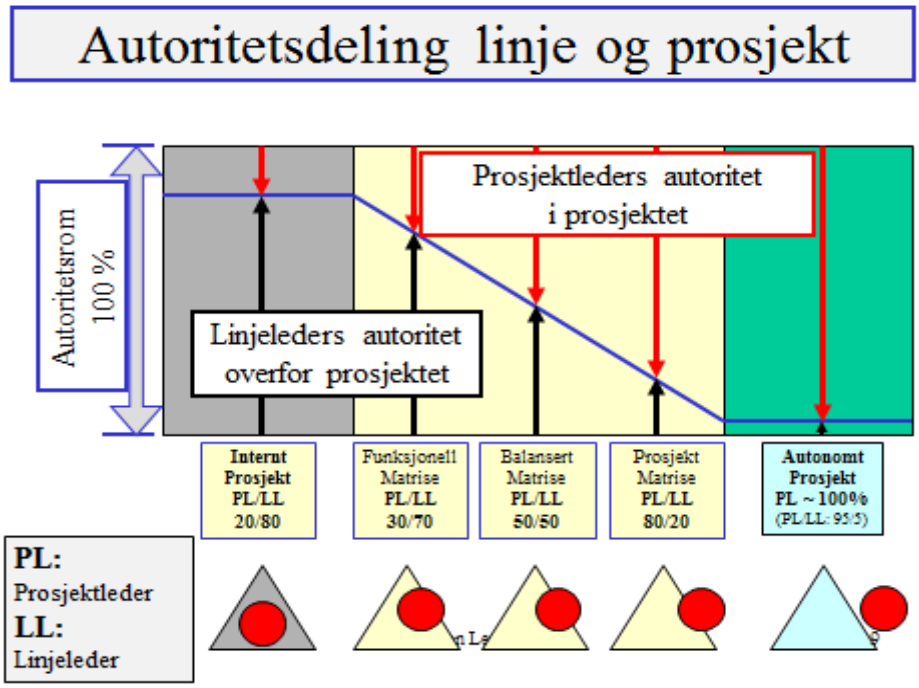
- Det er en delt autoritet mellom linjeleder og prosjektleder, hvem kan bestemme hva
- Prosjektmedarbeidere arbeider med oppgaver både i linjen og i prosjektet
- Prioriteringsrekkefølge mellom linjeoppgaver og oppgaver i prosjektet
- Prosjektmedlemmene utfører for mange oppgaver samtidig

Autoritetsdelingen mellom prosjektleder og linjeleder er særskilt utfordrende. Hva kan og skal prosjektleder ivareta, og hva skal linjen bestemme over er et gjennomgangstema. En bør også tenke gjennom hva som skal være den relative makt-fordeling mellom linjeleder og prosjektleder. Det kan skape mye diskusjon dersom relativ maktfordeling ikke er formalisert.

Matriseorganisering av et prosjekt kan ha høyst ulik maktfordeling mellom linje og prosjekt. Vi har med tre distinkt ulike matriseformer å gjøre; funksjonell matrise, balansert matrise og sterk prosjektmatrise.

I en funksjonell matrise har linjeleder mer makt enn prosjektleder, se figur 4. Motsatt er det for en sterk prosjektmatrise der prosjektleder har mer makt relativt linjeleder.

Den sterke prosjektmatrisen anbefales ofte for leveranseprosjekter, mens en funksjonell matrise er mer egnet til interne prosesser som krever eierskap og forankring av prosesser og løsninger.



Figur 4 Illustrasjon på autoritetsdeling mellom linje og prosjekt

5. Vurdering av organisering og roller i prosjektet «U – 864»

Dokumentasjonsgrunnlag

Det er mottatt dokumentasjon vedrørende organisering og styring av U–864 prosjektet gjennom Kystverkets sentrale styringsdokument for hevingsalternativet fra 2009 (omtalt videre som SSD U-864), etterfølgende KS2 rapport fra Dovre-gruppen med kvalitetssikring av SSD, og et arbeidsnotat om anskaffelsesstrategi fra Kvale Advokatfirma DA som inngår i forprosjektet. Det er også mottatt Kystverkets «Konseptvalgutredning for håndtering av U - 864, samt en KS1 rapport fra Møreforskning og Metier.

Vurdering

SSD U–864 er vurdert som et godt styringsdokument. Definerte effektmål og resultatmål er tydelige. Det samme gjelder de sentrale elementene for vellykket prosjektstyring, samt relevante kritiske suksessfaktorer. Det sentrale styringsdokumentet SSD–864 kan kategoriseres i hovedsak å følge god prosjektskikk. I det følgende er det gitt noen utdypende betraktninger knyttet til prosjektorganisering og roller.

I SSD U – 864, samt i Konseptvalgutredning for håndtering U - 864 er det vist organisasjonskart med de fleste roller involvert. Kapittel 5 i SSD U – 864 gir fyllestgjørende beskrivelse av identifiserte roller, og i det alt vesentlige samsvarer disse med de generelle beskrivelsene gitt i kapittel 3 i denne minirapporten knyttet til organisering. Hvilken organisasjonsmodell som er best egnet diskuteres nærmere.

Prosjektet U – 864 vurderes som såpass komplekst at prosjektleder bør i fortrinnsvis være på heltid, i alle fall minst 80 %, uavhengig av valg av løsning. Det er i tråd med anbefalingen i Konseptvalgutredningen, kapittel 4.10.1 hvor det anbefales å ha prosjektleder i full stilling.

Kystverkets dokumenter viser også at prosjektleder rapporterer til beredskapsdirektør som er prosjekteier; et naturlig valg.

Kapittel 5.4.3 Roller og ansvar beskriver de viktigste rollene i prosjektorganisasjonen. Der fremgår det at leder for skipsvrakseksjonen i beredskapsavdelingen er prosjektleder og at leder for beredskapsavdelingen er prosjekteier.

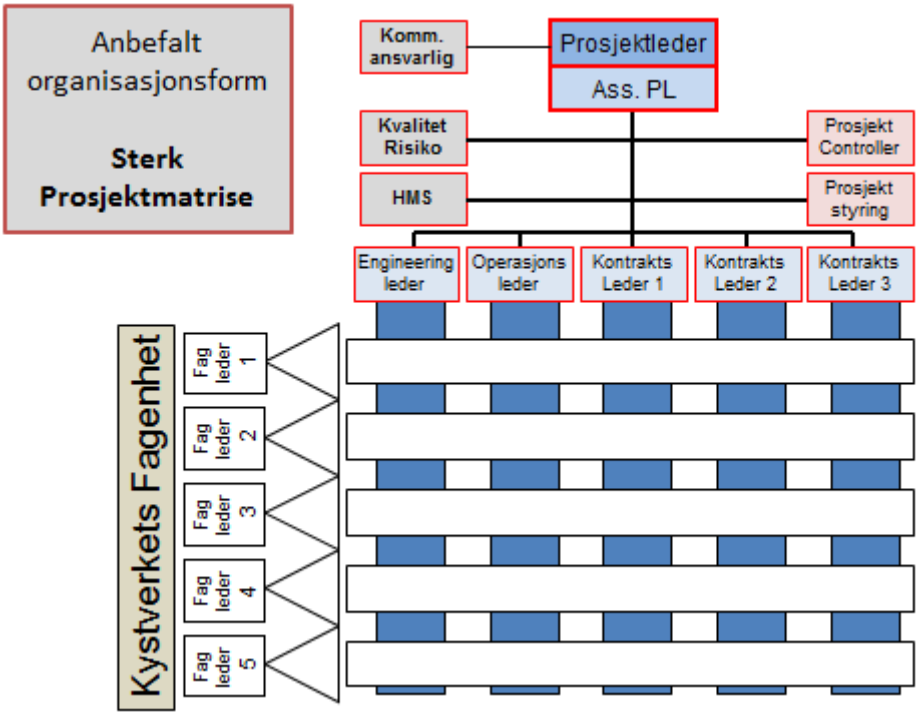
I Dovre/TØI KS2- rapporten kapittel 8 anbefales det at prosjektleder U – 864 rapporterer direkte til kystdirektør som prosjekteier. Prosjekt U – 864 er ved en slik organisering sidestilt Beredskapsavdelingen i den anbefalingen, noe Dovre/TØI tydelig har anbefalt.

Denne vurderingen av prosjektorganiseringen til U – 864 er gjennomført i lys av god prosjektskikk og gjennomgang av SSD – 864 samt KS2 rapporten fra Dovre/TØI.

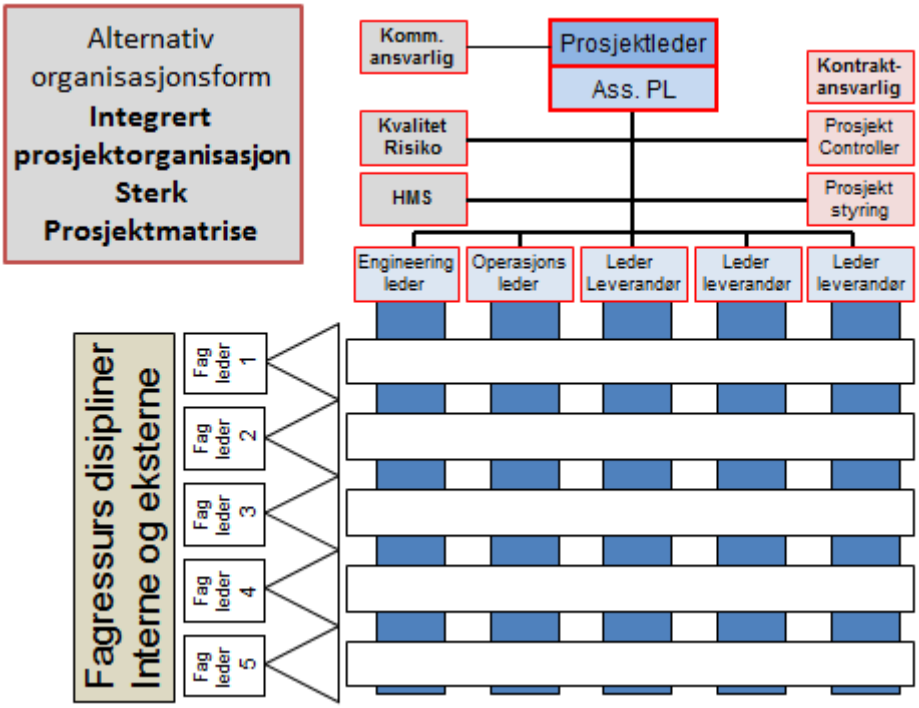
Hovedpunktene er som følger:

- Beskrivelser av roller i SSD 864 er i tråd med vanlig prosjektpraksis og god prosjektskikk
- Utpekt prosjektleder bør i hovedsak være på heltid for prosjekt U – 864
- Prosjekteier må ha tilstrekkelig tid til å utøve rollen som prosjekteier;
- Beredskapsdirektør bør kunne ivareta prosjekteierrollen på en aktiv måte
- En egen kommunikasjonsansvarlig rolle i prosjektet er også nødvendig med tanke på alle de eksterne interessentene til prosjektet.
- Det synes noe uklart hvordan Kystverkets prosjektorganisasjon skal ivareta bestiller-rollen overfor engasjerte leverandører og entreprenører av tjenester. Kontrakts-ledere eller kundeansvarlige kan utpekes overfor hver av hoved-leverandørene (single point of contact).
- Organisasjonskartet i kapittel 5 i SSD – U864 gir inntrykk av en form for en integrert organisasjonsform med leverandørene inne i en felles organisasjon. Dersom det er korrekt, påpekes det at *dette er en særskilt utfordrende måte å organisere et prosjekt på grunnet ekstra krav til tydelighet i roller, og usikkerhet i utøvelse av rollene i en integrert prosjektorganisasjon*. (en prosjektallianse, ref. Kolltveit et. al)
- Plassering av Kystverkets faggruppe som vist i organisasjonskartet kapittel 5 i SSD U -864 virker noe passivt og bør involveres mer aktivt i prosjektet gjennom avklarte roller i en matrise med avtalt % -andel jobb i prosjektet samt rolledeling med linjen
- Prosjektorganiseringen bør etableres som en sterk prosjektmatrise, se figur 4 i dette dokumentet
- Prosjektorganiseringen bør drøftes hvorvidt det skal være en ren kundeorganisasjon med entydige kontaktpunkter overfor leverandører, eller være en såkalt integrert prosjektorganisasjon mellom kunde og leverandører i samme organisasjon, i en prosjektallianse. De to alternative prosjektorganisasjonsformene er vist i figur 5 og 6.
- Organisasjonskartet i kapittel 5.4 i SSD U – 864 Organisering, roller og ansvar viser ingen styringsgruppe til prosjektet, men flere referansegrupper. Referansegruppene virker hensiktsmessige med hver sine fokusområder

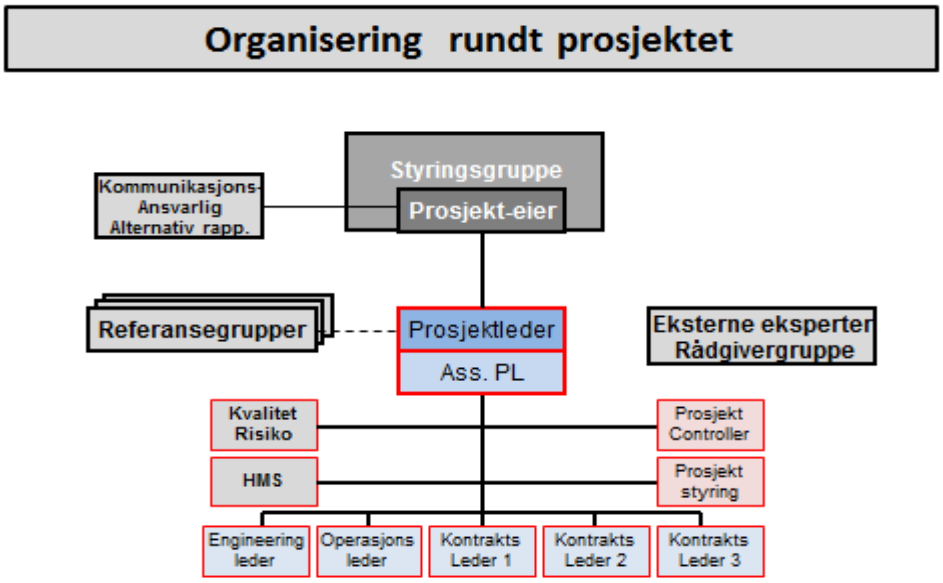
- En styringsgruppe kunne styrke eierstyringen i prosjektet og være en støtte for Kystverket sin eierstyring av prosjektet i å sikre et helhetlig perspektiv. Dette er illustrert i prinsippskissen i figur 7.



Figur 5 anbefalt prinsippskisse for prosjektorganisasjonsform for rent kundeteam; sterk prosjektmatrise med kontrakts-ledere overfor hovedleverandører/entreprenører gir tydelige roller og resultatansvar



Figur 6 viser en prinsippskisse for en alternativ organisasjonsform, en integrert prosjektorganisasjon med formaliserte lederroller til leverandørene inkludert i felles organisasjon, en såkalt prosjektallianse (se Kolltveit et al)



Figur 7 Roller rundt prosjektet, kommunikasjonsansvarlig kan alternativt rapportere til prosjekteier

En ren kundeorganisert prosjektmatrise gir klare grensesnitt overfor leverandører/entreprenører, slik skissen i figur 5 viser, og rollene er enkle å beskrive men ikke minst etterleves.

I en integrert prosjektorganisasjon, en såkalt prosjektallianse, se figur 6, er hovedleverandørene formelt inne i en felles prosjektorganisasjon. Fordelen ved en slik organisering er korte beslutningsveier, da «alle er i samme båt». Praksis har imidlertid vist at det er krevende å gjennomføre et prosjekt med en integrert prosjektorganisering. Det skyldes usikkerhet i etterlevelse av roller, og om man er lojal til prosjektet eller til moder-organisasjon ved viktige veivalg og prioriteringer. Ved denne organisasjonsformen vil det kunne være situasjoner hvor representanter for Kystverket som bestiller/kunde rapportere til en leder fra en av leverandørene. Det kan skape en lojalitetskonflikt, og utøvelse av lederrollene blir ekstra utfordrende. Da kreves en ekstra tydelig rollebeskrivelse og kollegiale krav til styring av prosjektet med en integrert organisasjon hvor prosjektets behov må være overordnet. Kontraktuell oppfølging er også en utfordring i en integrert organisasjon, en prosjektallianse. (*«vi er jo så gode venner, og vi må ikke ødelegge stemningen med kontraktsmessige formalkrav»).* En egen senior kontraktsansvarlig rolle må i dette tilfelle være inkludert, se figur 6.

I begge forslagene til organisering er det introdusert en assisterende prosjektleder som er plassert direkte under prosjektleder. Grunnen er at assisterende prosjektleder skal være stedfortreder for prosjektleder og representerer samme beslutningsmyndighet. Assisterende prosjektleder kan fortrinnsvis ivareta de interne forhold ved planlegging og styring av prosjektet med særlig fokus på kontrakt, prosjektkontroll og styring. Assisterende prosjektleder kan også ivareta de øvrige støttefunksjoner som HMS, kvalitet og risiko.

Prosjektleder bør ha et mer eksternt fokus, overfor prosjekteier så vel som med hensyn på interessenter utenfor prosjektet. I dette er også god ivaretakelse av kommunikasjon gjennom en kommunikasjonsansvarlig og via prosjekteier. Prosjektleder er totalt resultatansvarlig i

prosjektet, og det er naturlig at linjelederne i prosjektet rapporterer til prosjektleder, det er eksempelvis engineering leder, operasjonsleder og kontrakts-lederne mot leverandørene ved den rene kundeorienterte organisasjonsform.

Kjerne-team er også et begrep som er introdusert og som bør vurderes for dette prosjektet. Her bør kjerne-teamet bestå av følgende personer:

- Prosjektleder
- Assisterende prosjektleder
- Engineering-leder
- Operasjonsleder
- Kontrakts-ledere i prosjektlinjen for leverandør 1, … n, ved ren en kundeorientert organisasjon, ved alternativ organisering i en prosjektallianse representant for respektive leverandører
- Prosjektstab/støtte ved behov og tilstede for enkeltstående saker

Kjerneteamet bør forplikte seg som et kollegium. Det medfører at kjerne-teams-medlemmene har to prinsipielle funksjoner:

- En strategisk for hele prosjektet
- En operativ for sin del av prosjektet men innenfor et helhetsperspektiv for prosjektet

Kollegium-prinsippet medfører at en beslutning i kjerneteamet er bindende og forpliktende, for å unngå at den enkelte resultatansvarlige leder kun er seg selv nok («skit i Norge, leve Toten»-syndromet). Det kan sikre helhet og unngå sub-optimalisering i prosjektet. Resultatansvarlige kan ofte av naturlige grunner særskilt fokusere på den operative funksjonen og nedprioriterer den strategiske, hvor strategisk i denne sammenheng menes prosjektstrategiske aspekter som

- Vedtatt prioritet mellom kvalitet, fremdrift og kostnad under gjennomføring
- Teknologistrategi (velkjent teknologi eller pioner)
- Kontraktstrategi (totalentreprise eller delte entrepriser, kompensasjonsformat, …)
- Ressursstrategi (hvilke roller må ivaretas av interne fra Kystverket, hvilke kan ha eksterne innleide etc.)

Det er også foreslått en styringsgruppe. Prosjekteier er det naturlige valg som leder av styringsgruppen, som i dette forslaget er avdelingsdirektør for Beredskapsavdelingen.

Prinsipp om god eierstyring i prosjekter forplikter en til å ivareta en helhet for Kystverket, innad og utad. Derfor bør øvrige medlemmer fra Kystverket kunne ivareta andre perspektiver enn det prosjektspesifikke. Det gjelder eksempelvis det politiske som Kystdirektør eventuelt kan ivareta, miljø og sikkerhet ved avdelingsdirektør for Sjøsikkerhet, og det forvaltningsmessige ved avdelingsdirektør for Kystforvaltningen. Det bør vurderes å ha med ett eksternt medlem i styringsgruppen som ivaretar profesjonelle perspektiver knyttet til god eierstyring av prosjekter og overvåker god prosjektskikk. Prosjektet og prosjektleder vil ha glede av det. Totalt gir dette en styringsgruppe på 5 personer. KS1 rapport gir samme svar.

Forslag til prosjektorganisering er tilnærmet uavhengig av løsningsvalg. Det kan bety noe variasjon med hensyn på antall kontraktsansvarlige i kjerneteamet til prosjektet overfor leverandører/entreprenører, men prinsippene for organisering endres ikke.

Anbefaling vedrørende prosjektorganisering og roller

Ut fra vurderingene ovenfor anbefales følgende:

- Beredskapsdirektør ivaretar prosjekteierfunksjonen, er trolig tettere på og har mer tid tilgjengelig enn kystdirektøren, helt i tråd med sentralt styringsdokument SSD U -864
- Det bør etableres en styringsgruppe som støtter prosjekteier, og prosjekteier utpekes som leder av styringsgruppen. Det anbefales at dette er øverste beslutningsnivå til prosjektet. Med denne designen vil man ivareta Kystverkets behov for mangfold og prioritering på tvers av organisasjonsenhetene, ikke bare beredskapsavdelingens perspektiver og problemstillinger. Det styrker eierstyringen av prosjektet til Kystverkets beste
- U – 864 prosjektet i Kystverket organiseres fortrinnsvis som et bestiller-drevet prosjekt med egen kundeorganisasjon som illustrert i prinsippskissen i figur 5
- Prosjektet bør organiseres som en sterk prosjektmatrise, se figur 4, og med egne kontrakts-ledere overfor hoved-entreprenørene (main contractors), se figur 5
- Alternativ organisering; tydelighet i roller må *særskilt fremheves og forsterkes* dersom det velges en prosjektallianse med bestiller og utførende i samme organisasjon, fig 6
- Det etableres en tydelig autoritetsdeling mellom prosjektleder og respektive linjeledere i Kystverket
- Med en tydelig matrise vil faggruppene involveres aktivt i prosjektet, ikke kun som en ressursgruppe på siden av prosjektorganisasjonen
- Unngå «10 %» deltakere av nøkkelressurser; involverte ressurser bør være så mye involvert at den enkelte er mentalt tilstede i prosessen, ikke som «periodisk gjest». Nøkkelressurser i kjerneteamet bør være minst på 50 % av sin tid på prosjektet, selv om det kan variere over tid.
- Sørge for kontinuitet i kjerneteamet i prosjektet, hvor ledergruppen er kjerneteamet
- Det anbefales ikke at prosjektleder samtidig skal være leder for skipsvrakseksjonen, da det vil kunne skape rolleforvirring og uklarhet med hensyn på prioritering
- Dersom leder av skipsvrakseksjonen skal være prosjektleder i det videre prosjektløpet anbefales det at en stedfortredende seksjonsleder ivaretar seksjonsleder-funksjonen i prosjektets levetid
- Det må etableres en klar prioriteringstabell for ulike oppgaver i prosjektet kontra linjen dersom prosjektleder likevel også skal være seksjonsleder for skipsvrakseksjonen i prosjektets levetid
- Ulike referansegrupper etableres etter behov i løpet av prosjektet og som vist i organisasjonskart i kapittel 5 i SSD U – 864. Identifiserte grupper anbefales
- Det bør vurderes å opprette en uavhengig ekspert- rådgivergruppe som kan aktiviseres ved forespørsel på særskilte emner. Alle i prosjektet kan sende en problemstilling til en slik ekspert-funksjon for nærmere utredning. Representanter for Kystverkets faggruppe kan eventuelt ivareta dette, og supplert med eksterne eksperter ved behov.
- Det kan utpekes en assisterende prosjektleder som også er stedfortreder til prosjektleder. Assisterende prosjektleder er direkte i linjen i prosjektledelsen.
- Prosjektmedarbeidere på deltid må ha avklarte prioriteringstabeller for arbeidet i prosjekt U 864 i forhold til andre forpliktelser
- Kommunikasjonsansvarlig kan eventuelt kobles til prosjekteier i stedet for prosjektledelsen i prosjektet for å synliggjøre viktighet av prosjektet utad, se figur 7.

6. Kontrakts-modeller og risiko

Generelle betraktninger

Det er mange forhold som påvirker hvilke kontraktstandarder og kompensasjonsformater som er egnet. Viktige elementer er grad av modenhet eller presisjonsnivå på oppgavebeskrivelsen, og hvilken part bør eie gjennomføringsrisikoen.

Begge løsningsalternativene, Alt.1 Tildekking og Alt.3 Heving av last er komplekse og det er betydelig usikkerhet knyttet til gjennomføring av operasjonene. Riktignok er alternativet med heving av last vurdert som mer umodent enn tildekkingsalternativet. Imidlertid er tildekkingsalternativet også kjennetegnet av betydelig usikkerhet. Tiltaket er unikt og er et svært viktig og omfangsrikt miljøprosjekt. Det kan ikke vises til tilsvarende prosjekter som tidligere er gjennomført, noe som i seg selv representerer en betydelig usikkerhet.

Grovt forenklet kan følgende retningslinjer gi tilstrekkelige føringer:

1. Ved modne, veldokumenterte og veldefinerte oppgaver vil et prisbasert kompensasjonsformat være hensiktsmessig. Leverandør eier da gjennomføringsrisiko og bestiller/kunde kan ha en liten organisasjon til oppfølging ved milepæler og håndtering av endringer
2. For umodne eller manglende dokumenterte oppgaver kan mer regningsbaserte format være mest hensiktsmessig, hvor bestiller/kunde i hovedsak eier gjennomføringsrisikoen.

Regningsbaserte kompensasjonsformater er hensiktsmessig gitt at bestiller-organisasjonen har nødvendig senior-kontraktkompetanse og kan styre leverandørene tett. Leverandørene kan lett utnytte situasjonen, hvis bestiller/kunde ikke har nødvendig kompetanse og autoritet til å styre kontrakt-prosessen i et regningsbasert regime.

Er det alternativer som kan stimulere til bedre samspill og felles gevinstoppnåelse for bestiller og utfører?

Det bør tilstrebes en dialog mellom bestiller og utfører siden oppgavebeskrivelsene ikke fult ut klarer å definere hva det dreier seg om. Dermed kan nødvendig dialog etableres ved å velge «kontrakt med forhandlinger», samt et kompensasjonsformat som stimulerer til å oppnå felles beste. Flere av kontrakt-pakkene på prosjektet U – 864 bør kunne vurderes etablert og gjennomført med bruk av en såkalt mål-sum som kompensasjonsformat.

Målsum kompensasjonsformat - karakteristika

Prinsippene i en målsum er vist i skissen i figur 8, og kompensasjonsformat med målsum inneholder følgende 5 variable:

- Målsum med avtalt fortjeneste til leverandør
- Gevinstdeling mellom bestiller og utfører ved samlede kostnader lavere enn målsum
- Tak på fortjeneste til leverandør
- Overskridelsesdeling mellom bestiller og utfører ved samlede kostnader høyere enn målsum
- Gulv som begrenser tap hos leverandør.

Hovedregelen er å få en balanse mellom mulighet for gevinst og tap, hvor det bør være omtrent samme sannsynlighet for å få en gevinst som tap fra overskridelser. *(gulrot og pisk)*

En målsum kan oppnå en bedre risikodeling mellom bestiller/kunde og utfører/leverandør. Med en ren regningsbasert kontrakt kan leverandørene oppleve det som et åpent sjekkhefte, med mindre bestiller/kunde er meget erfaren og kan styre kontrakt-prosessen med styrke.

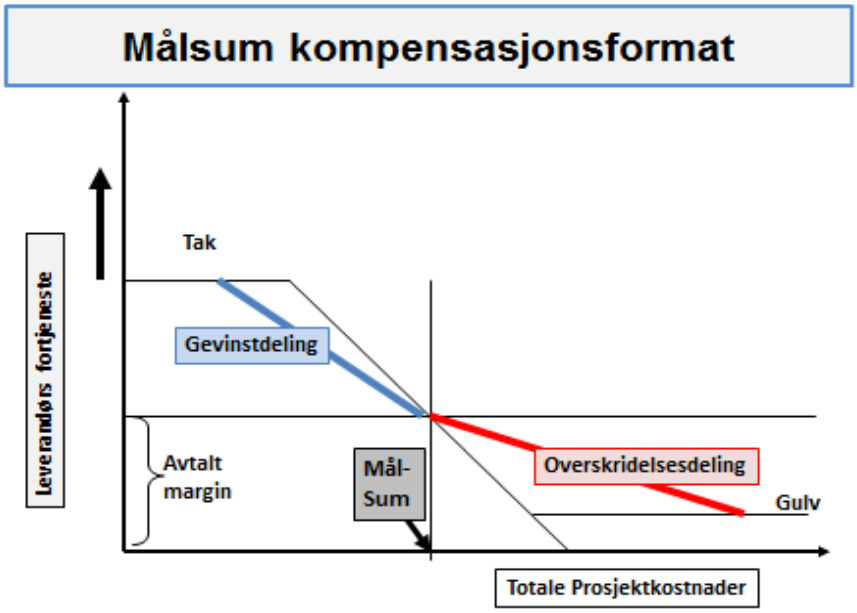
Målsum som kompensasjonsformat synes å gi en bedre balanse og jevnere risikofordeling mellom kunde og leverandør. Det er imidlertid viktig å enes om en målsum som reelt gir omtrent like muligheter for gevinst som overskridelser. Da gir det insentiver til å utføre arbeidet mer effektivt.

Gevinstdeling og overskridelsesdeling er ofte satt til 50/50, men andre fordelinger kan også avtales.

Et tak på fortjenesten til leverandør settes for å hindre slurv og at forenklede løsninger brukes.

Et gulv er definert for å unngå at leverandøren taper uhensiktsmessig mye.

Flere av kontraktpakkene vurderes som egnet til bruk av målsum som kompensasjonsformat.



Figur 8 Prinsippskisse for målsum kompensasjonsformat

Vurdering og anbefaling knyttet til kontrakters kompensasjonsformat

- Et kompensasjonsformat med målsum vil gi bedre risikodeling mellom bestiller og utfører enn en regningsbasert kontrakt under prosjektgjennomføring
- Målsum anbefales vurdert brukt på flere av mulige kontrakt-pakker, særlig der under-leverandører er planlagt brukt. Dette gjelder begge løsningsalternativene 1. Tildekking henholdsvis 3. Heving av last.

7. Referanser

Dokumentasjon fra Kystverket:

- Kystverket: U – 864 Presentasjon (2014)
- Kystverket: Sentralt styringsdokument; Heving av U – 864 (2009)
- KS2 rapport; Heving av U -864, Dovre gruppen & Transportøkonomisk Institutt (2009)
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- Møreforskning og Metier: Kvalitetssikring fase 1 (KS1 – Konseptvalg av Håndtering av U – 864), av 25. januar 2011
- U – 864 Kvale: Utkast til anskaffelsesstrategi, forprosjekt U-864 (2014)

Lærebøker:

- Andersen, E.S., Grude, K., & Haug, T.: «Målrettet prosjektstyring», Fagbokforlaget
- Jessen, S. A.: «Prosjektadministrative metoder» Aschehoug
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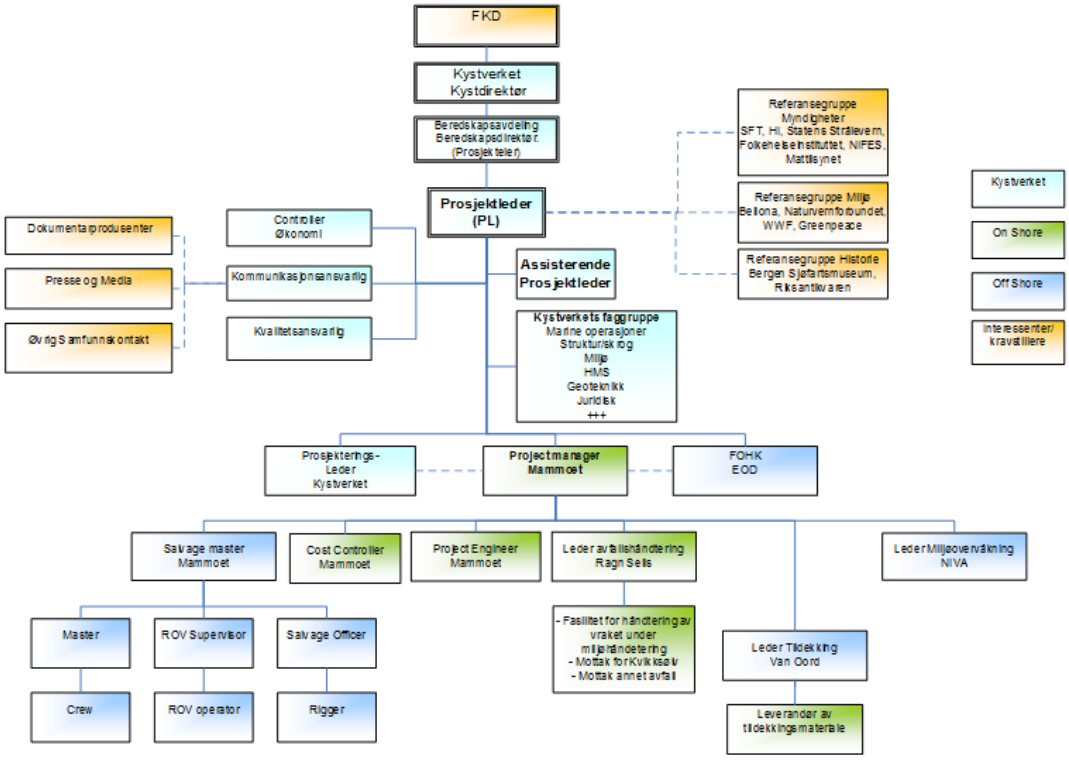
8. Vedlegg – Organisasjonskart fra SSD for Heving fra 2009



Organisasjonskart i kapittel 5.4.1 i SSD for Heving U -864 fra 2009

Vedlegg V0.09

MILJØTILTAK VED VRAKET AV U-864

Spesifisering av metyleringsforsøk

DNV GL AS

Kilde: NIVA rapport 5278/2006

Project name: Miljøtiltak ved vraket av U-864
Report title: Spesifisering av metyleringsforsøk

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Dato: 12.5.2014

Gjengivelse av deler av dette vedleggsdokument som kan føre til mistolkning er ikke tillatt

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1 INNLEDNING

I forbindelse med utredningen av tiltak for den tyske ubåten U-864 har det også vært fokusert på om det kan skje en metylering av kvikksølvlasten ved en tildekking.

Metylering er prosessen hvor uorganisk (rent) kvikksølv omdannes til organisk kvikksølv. For at dette skal kunne skje må det blant annet finnes en karbonkilde til stede.

Det er igangsatt to tester for å vurdere metylering av kvikksølvet fra U-864.

- En test ved Norsk Institutt for Vannforskning (NIVA) med forskningsleder Morten Schaanning som ansvarlig.
- En test ved Texas Tech University med professor Danny Reible som ansvarlig.

I testene gjenskapes situasjonen og effektene knyttet til kvikksølvsedimentene ved Fedje så nøyaktig som mulig, blant annet ved å bruke sedimenter fra området, og sjøvann med karakteristikk i form av oksygeninnhold og saltinnhold som er nær den vi finner ved Fedje. Tilsvarende tester som tar hensyn til de faktiske forholdene på Fedje har ikke blitt gjennomført tidligere. Dette vil derfor gi bedre svar på effekten av å tildekke den forurensede havbunnen på Fedje.

I denne rapporten er de to testene beskrevet.

2 METYLERINGSFORSØK VED NIVA

NIVA skal gjennomføre et eksperiment for å vurdere risiko for dannelse av metylkvikksølv ved tildekking av sedimenter forurenset med metallisk kvikksølv fra U-864. Forsøket skal gjennomføres i mesokosmos-laboratoriet ved Marin Forskningsstasjon Solbergstrand og alle analyser vil bli utført på NIVAs kjemiske laboratorium i Oslo.

På grunn av gode oksygenforhold og lite tilgjengelig organisk karbon vurderes risiko knyttet til dannelse av metyl-kvikksølv (met-Hg) i sedimentene ved Fedje som liten. Likevel kan det ikke utelukkes at noe organisk karbon vil kunne fanges sammen med det forurensede sedimentet under et fremtidig tildekkingslag. I dette forsøket vil det bli simulert en slik situasjon for å teste ut i hvilken grad dannelsen av met-Hg begrenses av tilgangen på organisk karbon.

Et Hg-kontaminert sediment hentet fra Fedje vil tilsettes fire nivåer av organisk materiale i form av marine mikroalger. Dannelse av met-Hg måles deretter månedlig gjennom et halvt år ved prøvetaking av vannet over sedimentene og et begrenset antall snitt nedover i sedimentene. Vannprøvene analyseres med lavest mulige deteksjonsgrense (0,02 ηg/L). Disse prøvene vil øke sjansene for å detektere aktive metyleringsprosesser i sedimentet. Målingene av met-Hg suppleres med målinger av vertikalprofiler av O_2 og H_2S ved bruk av mikroelektroder med måleintervall ≤0,25 mm. Både utlekking og profiler av O_2 og H_2S måles non-destruktivt.

Forsøket igangsettes rundt 1. mai 2014. Forsøksperioden er på 6 måneder, analyser av alle prøver og rapportering vil være ferdigstilt et år fra oppstart, dvs. 1. mai 2015.

Bakgrunn og mer detaljer av forsøksoppsettet er beskrevet i den engelske teksten under.

Background

Mercury-contaminated sediments from the site where the wrecks of the U-864 submarine are situated were collected in January this year. These sediments are known to be heavily contaminated with Hg from previous measurements. Capping the Hg-contaminated site around the U-864 wrecks with clean sediments has been proposed as a mitigation measure. The aim of this project is therefore to carry out microcosm lab experiments to study the effect of capping on mercury speciation in these Hg-contaminated sediments. There is special interest related to investigating how/if the presence of organic matter (in addition to other biogeochemical factors such as dissolved oxygen and other electron acceptors) affects Hg methylation with time. It is hypothesized that capping and the presence of organic matter in the sediments will alter the methylation-demethylation balance leading to an increase of in situ MeHg concentrations relative to uncapped controls. That is capping will encourage the activity of anaerobic bacterial populations, including sulfate reducing bacteria (and other bacteria that aid Hg methylation) at shallow depths beneath a capped Hg-contaminated sediment compared to the uncapped controls.

Microcosm experiments and location

To test this hypothesis, eight microcosm experimental units (four capped and four uncapped) are set up with the following sediment treatments (see Figure 1 below);

i) Control: i.e. no organic matter added

ii) Low organic matter amendment (ca. 30 g-C/m^2 sediment surface area)

iii) Medium organic matter amendment (ca. 90 g-C/ m^2 sediment surface area)

iv) High organic matter amendment (ca. 270 g-C/ m^2 sediment surface area)

The capped treatments will be carried out in parallel with a similar set of four control treatments without a cap, i.e. a total of eight treatments.

Microcosm site

The microcosm experiment will be set up and run at NIVA`s field marine station at Solbergstrand. The station has the necessary resources in terms of equipment (including access to piped fjord seawater from 60 m depth) and personnel and has successfully performed several similar experiments before. The microcosms will be set up in clean polycarbonate aquaria containers with a surface area of ca. 0.1 m^2. A three-centimeter layer of well homogenized Hg-contaminated sediment will be placed on top of a 30 cm clean layer of uncontaminated sediment in each container. The sediment in three of the treatments will be amended with organic matter (a commercially available mixture of four marine microalgae) at three levels while the fourth will not be amended and will act as a control. The capped treatments will be covered with a 3 cm layer of uncontaminated sediment. A similar set of four microcosms but without any cap will be run in parallel. Fjord seawater drawn from a depth of 60 m in the fjord (salinity of 34, temp 6-8°C) will flow over the sediments in all the microcosms. The microcosm layout is depicted in Figure 1 below. In the absence of bioturbation, this will be enough to prevent O_2 penetration to contaminated layer.

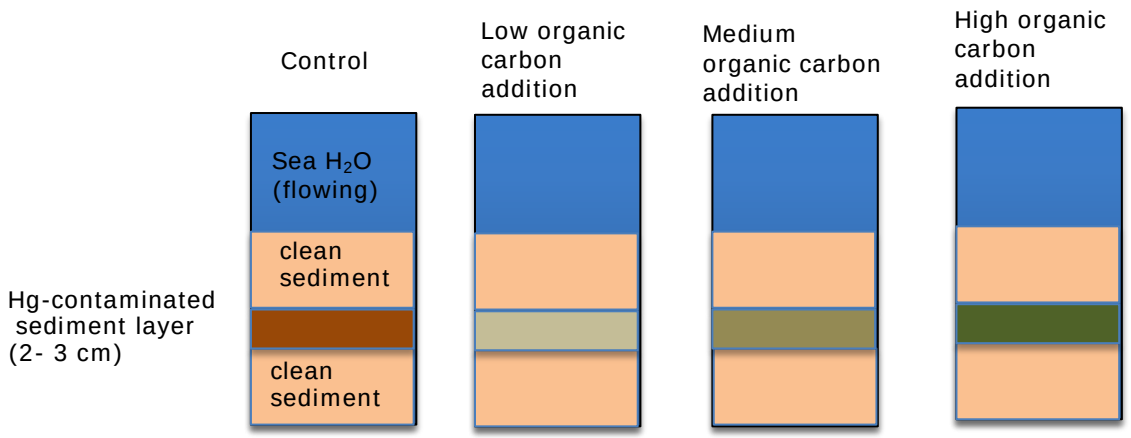

Figure 1: Microcosm experimental set up to study the effect of capping and organic matter on Hg speciation in contaminated sediments sampled from the U-864 seabed site near Fedje. The treatments illustrated include; a control with no organic carbon addition; low, medium and a high organic carbon amendment. The 2-3 cm Hg-contaminated sediment layers lies on top of a 30cm clean sediment layer. A 3 cm layer of same clean sediment is used as a cap in all the treatments. Four similar treatments but without the top clean sediment capping will also be run in parallel as controls. The seawater (8°C) drawn from ca. 60 m depth will flow (at accurate, slow rate about 1 ml/min) on top of open treatments, and aeration will be used to prevent stratification and oxygen deficiency in the overlying water. The capped treatments will be run with higher rate of water exchange, without aeration and additional stirring. The microcosm will be run for ca. six months and sampled every month.

Sampling and Analysis

The microcosm experiments will be run for six months and sample both water, sediment and sediment pore water monthly for measurement of;

i) MeHg and tot.-Hg concentration in both the inflowing and outflowing surface seawater to calculate the sediment-water fluxes of MeHg and tot.-Hg for the uncapped sediment treatments

ii) MeHg and tot.-Hg (at least one time) concentration depth profile. For each of the monthly sampling, a small core through the Hg-contaminated sediment layer will be extracted using double polypropylene tubes. The outer core will be left in the sediment to prevent collapse and stratification disturbance after each sampling. The core collected in the inner tube will be sectioned into 1-3 cm slices and analysed for measurement of total MeHg. Vertical profiles of dissolved oxygen and hydrogen sulfide in pore water will be measured using a microelectrode array.

Mercury speciation analysis; NIVA lab

Water

The methods for determining total mercury (TotHg) and methylmercury (MeHg) in water is based on The United States Environmental Protection Agency (USEPA) Method 1631 (USEPA 2002) and USEPA Method 1630 (USEPA 1998) respectively. In short, MeHg is determined by distillation, aqueous ethylation, purge and trap, and cold vapor atomic fluorescence spectrometry (CVAFS) and TotHg by oxidation, purge and trap and CVAFS. The method detection limits (MDL) are 0.02 ηg/L for MeHg and 0.1 ηg/L for TotHg (3 standard deviations (STD) of blanks). Precision (as relative standard deviation (RSD) of parallel samples) is < 10 % for both methods.

Sediments

Determination of MeHg in sediments is done by organic phase extraction. Samples are first leached with acid and then extracted into dichloromethane (DCM) before back extraction into water. MeHg is then determined by aqueous ethylation, purge and trap, and CVAFS. An aliquot of 2.0 mL of sample is added to approximately 40 mL of DI water in amber glass vials and added acetate buffer solution (2M, 0.600 mL). The MDL is < 0.1 ηg/g (3 STD of blanks for 0.1 g dried sample).

References

USEPA. 1998. Method 1630 Methylmercury in Water by Distillation, Aqueous Ethylation, Purge and Trap, and Cold Vapor Atomic Fluorescence Spectrometry. ed. W. A. Telliard. US Environmental Protection Agency - Office of Water.

USEPA. 2002. Method 1631, Revision E: Mercury in Water by Oxidation, Purge and Trap, and Cold Vapor Atomic Fluorescence Spectrometry. ed. U. S. E. P. Agency.

3 METYLERINGSFORSØK VED TEXAS TECH UNIVERSITY

Formålet med de foreslåtte forsøkene er å foreta en vurdering av det mobile kvikksølvet (THg) og potensialet for metylering til metylkvikksølv (MeHg) under de anaerobe forhold som vil utvikle seg under tildekkingslaget. Kvikksølvforurensede sedimenter fra U-864 mottatt fra NIVA vil få lov til å utvikle anaerobe forhold. Redoksprofiler og endringer i Hg og MeHg vil bli målt som en funksjon av tiden. Det primære målet er en estimering av MeHg i porevann over lang tid, det vil si når sedimentene er fullt redusert. Det er dette MeHg som kan migrere inn i tildekkingen og potensielt redusere effekten av tildekkings-laget. To forskjellige oppsett vil bli brukt i forsøkene:

1. Ampuller inneholdende omtrent 20 ml sediment plasseres i et anaerobt kammer og hvor porevannet prøvetas og analysers for Hg og MeHg hvoretter sedimentet fjernes og analyseres for Hg og MeHg i fast fase.
2. Det brukes mesokosmer inneholdende ca. 1 liter med sedimenter hvor naturlige redoksprofiler får lov til å utvikle seg. Overvåkingen av mesokosmene vil være fokusert på å vurdere gradientene i redoksforholdene og dynamikken av reduksjonen i sedimentene.

Resultatene fra forsøkene vil bli brukt i modellen CapSim for å forutsi migrasjonen (spredningen) av THg og MeHg gjennom tildekkkingslaget. CapSim er et numerisk modelleringsverktøy for tildekkingslag utviklet i Texas Tech University's laboratorium (Reible og Lampert , 2014) . Disse numeriske simuleringene vil gi en oppdatering av tidligere simuleringer (DNV, 2008) for å forutsi hvordan tildekkingen vil oppføre seg.

Forsøkene forventes å gi et estimat på sannsynlige (mobile) porevannskonsentrasjoner av THg og MeHg i de tildekkede sedimentene og fordelingskoeffisienter av THg og MeHg i sedimentene. Fordelingskoeffisientene kan brukes til å estimere porevannskonsen-trasjoner av THg og MeHg på andre steder med lignende sedimenter, men hvor det er forskjellige konsentrasjoner av kvikksølv i sedimentene. Konsentrasjonene av den mobile fasen kan brukes til å oppdatere estimater for THg og MeHg fluks gjennom tildekkingen.

<u>Forsøket igangsettes rundt 1. mai 2014. Forsøksperioden er ca. 6 måneder, analyser av alle prøver og rapportering forventes å være ferdigstilt før utgangen av 2014.</u>

En mer detaljert beskrivelse av forsøket er gitt i den engelske teksten under.

Methods

Sediments received from NIVA are expected to be homogenized and contain approx-imately 8.89 mg/kg THg and 0.59 µg/kg MeHg. The sediment will be subsampled and THg and MeHg in solids will be measured for confirmation. Porewater concentrations in the sediments as received will also be measured by the methods described below.

Weighed aliquots of sediments will be placed into two physical systems as outlined above, that is, vials containing approximately 20 mL of sediments and mesocosms containing approximately 1 L of sediments. 20 vials are expected to be used for the vial experiments and 1-2 mesoscosms will be employed depending upon the availability of

sediments and the desire to reserve some sediments for potential future studies. The manner in which each of these experiments will be conducted is described below.

Vial Experiments

The vials will be filled and retained in an anaerobic chamber under a reducing atmosphere. The maintenance of the samples in an anaerobic environment will simulate the effect of thick cap layer in which oxygen and other easily reduced species will not be expected to penetrate to the underlying sediment. Five vials will be removed at 2 weeks, 1 month and 2 months after the initiation of the experiment and analysed. 5 vials will be reserved and maintained in the anaerobic chamber for possible later analysis if needed to achieve steady state conditions.

Diffusion gradient in thin films (DGT) will be employed for porewater analysis for THg and MeHg. Figure 1 depicts the vial with DGT inserted.

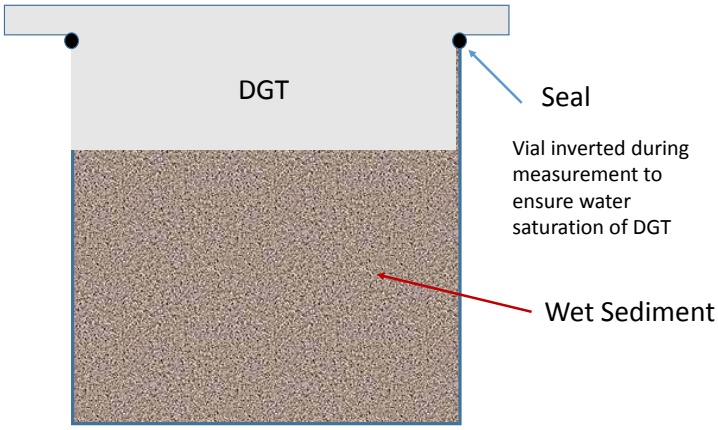

Figure 1: Vial with DGT inserted for THg and MeHg in porewater analysis. Approximately 20 mL of wet sediment fills the vial.

Analysis of each vial will include:

1. DGT analysis for porewater THg and MeHg. The vials used for these studies are especially designed to allow a DGT sampler to be inserted and sealed at the mouth of the vial and maintain contact with the wet sediment. The vials will be inverted to insure water saturation of the sampler. The exposure to the DGTs will be conducted prior to removal from the anaerobic environment since several days of exposure to the sediment are required to measure porewater concentrations of THg and MeHg. The DGT method is described in more detail below.
2. Voltammetric measurements of specific redox couples within the vials. These will be conducted outside of the anaerobic chamber and focused on a location at the sediment mid-depth away from any rapid redox changes that may occur at the sediment surface due to exposure to air. Oxygen (if any), reduced manganese, reduced iron or reduced sulphur (sulphides) are measured by the technique, based upon that developed by Brendel and Luthy, 1996. The measurement approach is described in more detail below.
3. Removal of the sediment from the vials and analysis for solid phase THg and MeHg. THg follows EPA Method 7471 with hot acid digestion while MeHg analysis follows EPA Method 1630.

Mesocosm Experiment

The experimental mesocosm to be used in these studies are shown in Figure 2

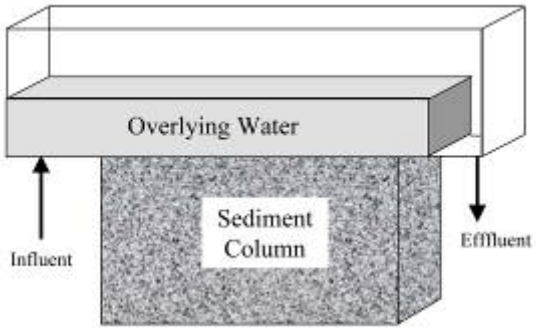

Figure 2: Schematic of experimental mesocosms. Approximately 20 cm x 10cm x 5 cm (LxHxW) sediment layer with 3 cm overlying water

The primary purpose of these mesocosms is to allow development of natural redox conditions with depth over time. Although the sediments are expected to be capped, effectively driving the entire sediment layer anaerobic, the rate at which this occurs will be studied through voltammetry in this system. Voltammetric measurements will be conducted every 2 weeks while water essentially saturated with air will be passed over the surface. The upper layers will remain oxygenated and aerobic while the bottom will eventually become anaerobic. This is expected to require 3-6 months due to the low labile organic matter expected in the sediments. In addition the fully developed redox environment could be available if later studies of particular cap material may be deemed useful. At the end of the stabilization period, DGT profilers can be used to measure vertical profiles of THg and MeHg if desired. Due to the time potentially required for stabilization, these measurements may not be part of the initial reporting.

Analytical methods

Porewater concentrations will be measured by diffusion gradient in thin film devices (DGTs) that we have used in multiple studies of mercury contaminated sediments. DGT approach originally developed of the analysis of metals in aqueous systems by Bill Davison and Hao Zhang of Lancaster University in England (Davidson et al., 1994), to the practical measurement of mercury and methyl mercury in porewater of sediments. Diffusion gradient in thin films (DGT) is a well-developed technique for sampling heavy metals in bulk water and has also been used in sediments. DGT measures the labile portion of heavy metals in typical time frames of 12-48 hours. The technique is quite powerful as it can be used to evaluate major metal pools (organic, inorganic, colloidal bound) as well as to some extent the kinetics of metal supply from the sorbed state to the interstitial. Its use in sediments is not as well developed and the more dense suspension of colloidal and other complexation media typically found in interstitial water may complicate the dynamic response of the DGT sampler.

A schematic of a typical DGT device is shown in Figure 3 below. The shown device is a two dimensional profiler and a smaller piston style sampler is expected to be used in the

vial studies. The layered construction is the same but the exposed surface is simply a 2 cm^2 circular disk. Dissolved contaminants of interest will diffuse across the membrane filter and diffusive gel layer and become sorbed in the underlying resin layer. The DGT device can be implanted into the system of interest (here the sediments) for a short period of time (typically 24-48 hours) and the amount of the contaminant of interest sorbed into the gel over that time is directly related to the concentration in the adjacent porewaters. Specificity can be achieved through proper choice of the diffusion gel layer and the sorbent layer. An agarose diffusive gel and a 3-mercaptopropyl functionalized silica gel resin, which is specific for mercury ions, will be employed for the measurement of mercury as demonstrated by Docekalova and Divis (2005). Divis et al. (2005) and Clarisse and Hintelmann (2006).

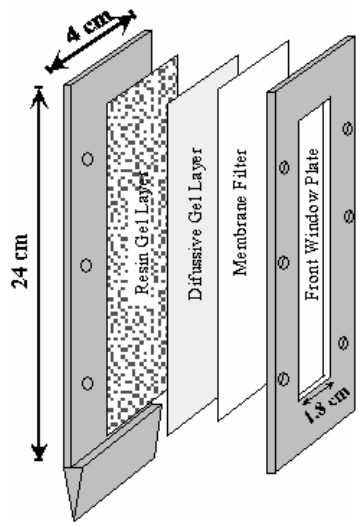

Figure 3: DGT profiler. These will be employed in the mesocosms but a smaller cylindrical piston shape will be used in the vials

The resin layer will be analyzed via digestion in HCl and EPA Method 1631 for THg and via EPA Method 1630 for MeHg. Bulk solid analysis in the vials will be conducted via THg follows EPA Method 7471 with hot acid digestion while MeHg analysis follows EPA Method 1630. Instrumentation that will be used is a Brooks Rand MERX 1400 for automated THg analysis and a Brooks Rand MERX 4400 for automated methyl mercury analysis.

Voltammetry

Over a period of several weeks to months, the development of quasi-steady redox conditions in the mesocosms will be monitored via voltammetry (Brendel and Luther 1995, Himmelheber et al. 2008, Johnson et al. 2009). Profiles of dissolved geochemical species in sediment porewater will be obtained at a vertical resolution of <3mm using a single axis automated micromanipulator (Analytical Instrument Systems, Flemmington, NJ). Analytes include O_2, Mn^{2+}, Fe^{2+}, and dissolved sulfide (DS). The voltammetric electrodes respond to all reduced forms of dissolved sulfide (H_2S and HS-) and measurements do not need to be adjusted for pH. Microelectrodes will be prepared in the laboratory using the method of Brendel and Luther (Brendel and Luther 1995). At the beginning of each profiling event, electrodes will be calibrated for oxygen using a 2-point

calibration, and the method of standard additions will be used for iron, manganese, and sulfide in synthetic seawater with 2mM acetate or HEPES buffers. Scan parameters and detection limits will be the same as those reported in Brendel and Luther (Brendel and Luther 1995). Calibration checks will be performed on electrodes after each profile. Triplicate scans will be made at each depth and duplicate or triplicate electrodes will be spaced 2-3 cm apart.

Voltammetry will also be employed to evaluate redox conditions at the mid-depth in the vials before removal of sediments for solids analysis.

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Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter and greener.

Vedlegg V0.10

MILJØTILTAK VED VRAKET AV U-864

Metode for usikkerhetsanalyse

DNV GL AS

Project name: Miljøtiltak ved vraket av U-864
Report title: Metode for usikkerhetsanalyse

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Gjengivelse av deler av dette vedleggsdokument som kan føre til mistolkning er ikke tillatt

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1 INNLEDNING

I dette vedlegget er metodikken som ligger til grunn for usikkerhetsanalysen av kostnader og varighet for prosjektets forskjellige faser.

2 GENERELT OM KVANTITATIV USIKKERHETSANALYSE

Deterministisk analyse innebærer å bruke det "mest sannsynlige verdi-estimat" av hver variabel i en modell for å regne seg frem til et totalestimat. Sensitiviteten i summen kan bestemmes ved å anslå scenarioer for beste og verste utfall for alle postene. Da tas det ikke hensyn til at det er større sannsynlighet for at den mest sannsynlige verdien inntreffer enn maksimums- og minimumsverdien. Ved å tilegne en fordelingsfunksjon til kostnadspostene og beregne dette stokastisk eller ved simulering tar man hensyn til dette. Begge tilfeller vil gi en gitt fordeling for totalsummen, samt tilhørende forventningsverdi og varians. Av de mest kjente metoder og teknikker kan nevnes momentmetoden, eksakte algebraiske løsninger og Monte Carlo-simulering. Monte Carlo-simulering er den metoden som er mest utbredt på verdensbasis og er valgt til denne analysen.

3 OPPBYGGING AV ANALYSEMODELLEN

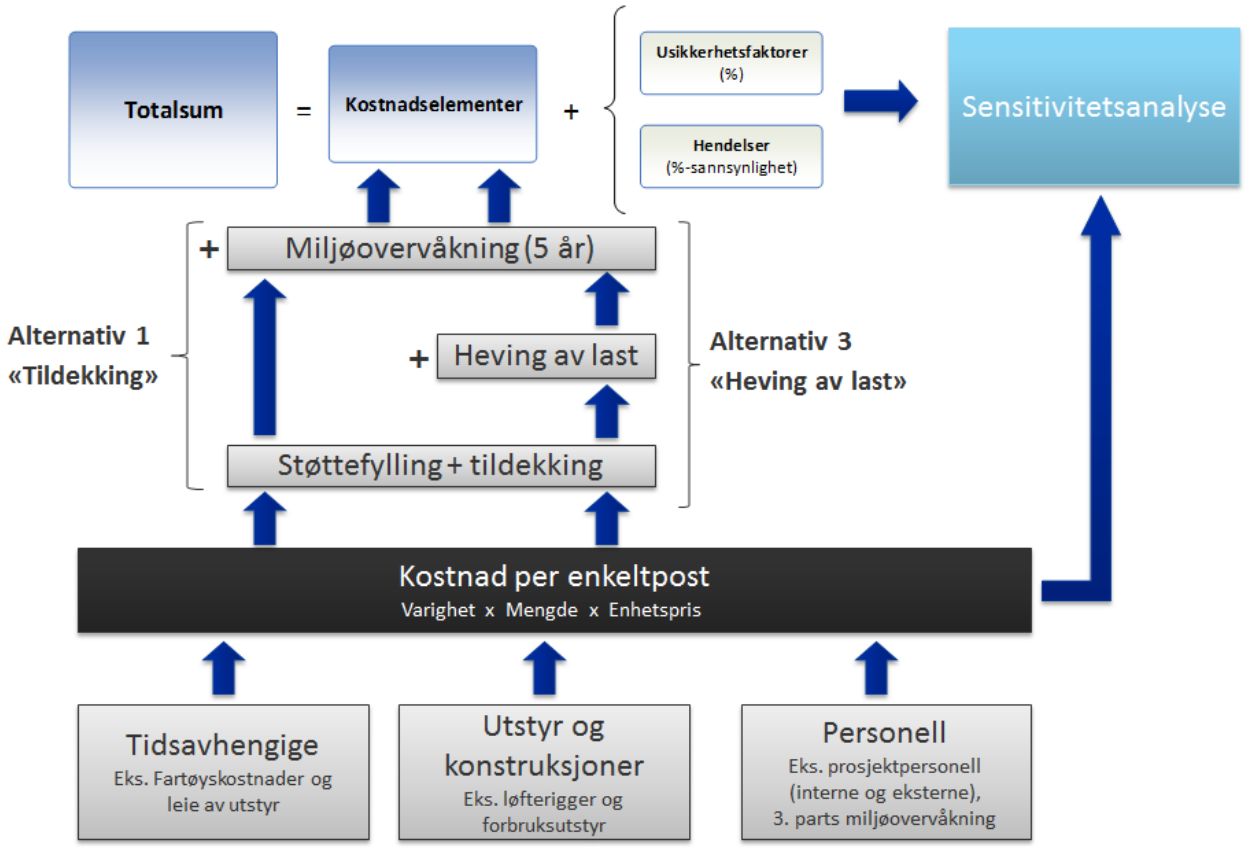
Usikkerhetsanalysen følger standard metode som benyttes i kravene til kvalitetssikring av offentlige investeringsprosjekter utarbeidet av Finansdepartementet. Dette er en anerkjent metode for beregning av usikkerhet i store, komplekse prosjekter. Kystverket har utarbeidet én kostnadsmodell som dekker begge alternativer, Alternativ 1 «Tildekking» og Alternativ 3 «Heving av last», for prosjekt U-864. Modellen bygger på en grunnkalkyle med estimatusikkerhet.

I modellen beregnes de forventede kostnadene for hver definerte kostnad. Kostnaden kan bestå av en enkeltverdi, eller som et produkt av varighet, mengde og/eller enhetspris. Alle disse verdiene har angitt en usikkerhet basert på et trippelestimat. Videre kan kostnadene endres på grunn av systematisk usikkerhet, som vil påvirke en eller flere kostnadsposter i form av overgripende usikkerhetsfaktorer. Det er også avdekket noen hendelser som kan inntreffe med en viss prosent sannsynlighet, og har en kostnad dersom de inntreffer. Disse forholdene er beskrevet nærmere i kapittel 4.

For analyse av forventet varighet ligger samme metodikk til grunn som nevnt i avsnittet over.

Analysen er beregnet ved hjelp av Monte Carlo-simulering med programmet @Risk (Palisade) i et MS Excel-basert verktøy utviklet av DNV GL AS for dette oppdraget.

Figur 1 på neste side viser en forenklet fremstilling av modellen.

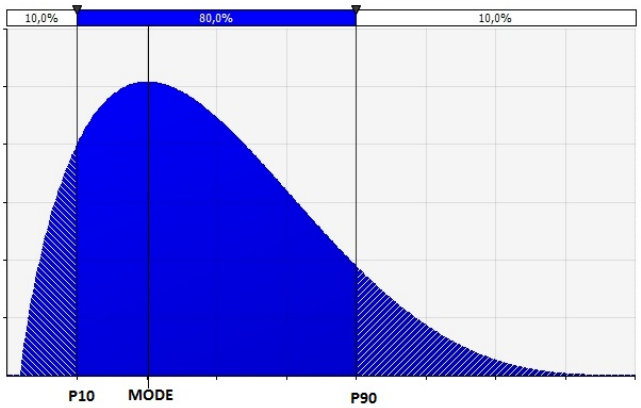


Figur 1 - Fremstilling av beregningsmodellen for begge alternativer

4 METODE FOR USIKKERHETSANALYSE

4.1 Basisestimat: Estimatusikkerhet og korrelasjon

Alle kostnads- og inntektselementer er beskrevet med et trippelestimat – p10, mode og p90. For simuleringen er en Pertfordeling (se figuren under) valgt for å kunne benytte disse inngangsverdiene.



Figur 2: Pertfordeling med trippelestimat.

Budsjettmodellen er detaljert, og inngangsverdiene til beregning av flere budsjettposter antas å ha en avhengighet i variasjonen (samvariasjon). Inngangsverdier som samvarierer (for eksempel tiden det tar å montere ankere i trykkskroget på akterseksjon og forseksjon) er korrelert med en Pearsons korrelasjonsfaktor mellom -1 og 1.

4.2 Faktorberegning

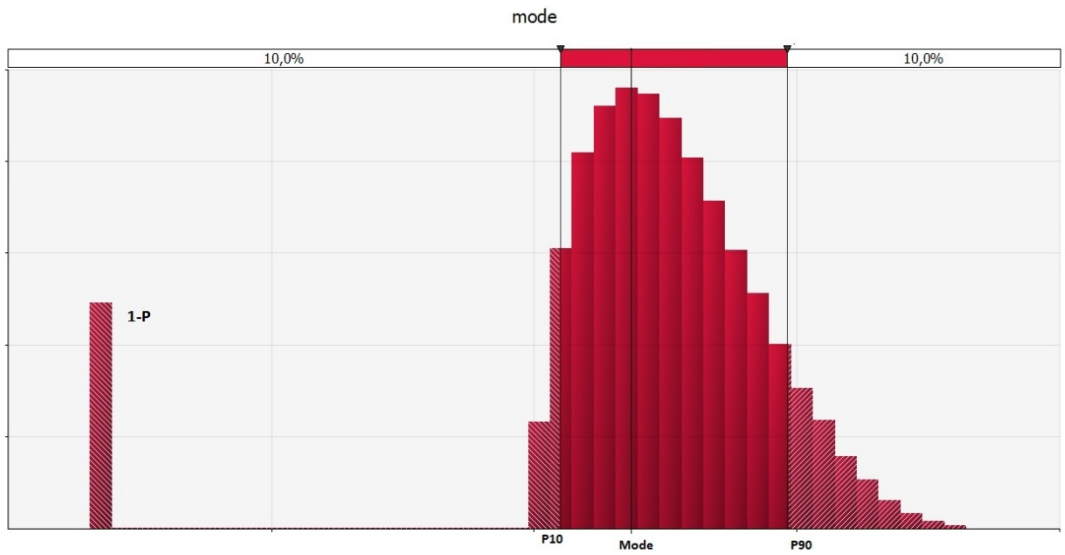
Beregning av en usikkerhetsfaktors påvirkning skjer ved multiplisering av de to fordelingene for kostnadsposten og for usikkerhetsfaktoren. For å isolere faktorens bidrag benyttes kun den prosentvise endringen. Det medfører at dersom faktoren F er oppgitt som en variasjon rundt 0 (for eksempel med trippelanslaget -0,1 – 0,0 – 0,15) vil regnestykket for posten se slik ut:

Bidrag fra F på posten B1 = Forventningsverdi for B1 * F.

Bidraget fra usikkerhetsfaktorene summeres med totalen på samme måte som totaler fra andre kostnads- og inntektsposter.

4.3 Behandling av hendelser

Hendelser er definert som binære fordelinger der hendelsen vil inntreffe med en gitt sannsynlighet. Dersom den inntreffer, er fordelingen til kostnadseffekten beskrevet med et trippelestimat. Kostnadskonsekvensen kan for eksempel beskrives med en Pertfordeling som vist i fremstillingen i figuren under.



Figur 3: Binær hendelse, beskrevet med en sannsynlighet P for at den inntreffer og en fordeling for kostnadskonsekvensen dersom dette skjer.

Det er P % sannsynlig at kostnaden ligger innenfor Pertfordelingen, og (1-P)% sannsynlig at den ikke inntreffer i det hele tatt og kostnaden blir 0. Bidraget fra hendelsene summeres med totalen på samme måte som totaler fra andre kostnads- og inntektsposter.

5 BEGREPSFORKLARING

Dette kapittelet lister opp en rekke ord og uttrykk som er benyttet i rapporten for å forklare disse grundigere. Listen er ikke uttømmende.

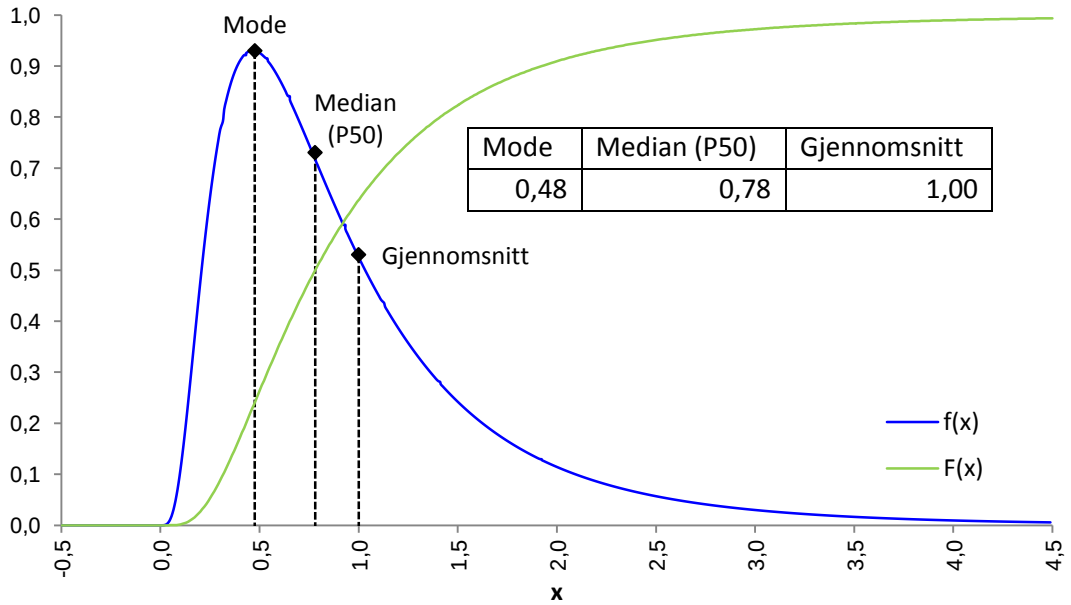
5.1 Grunnleggende statistikk

En variabel som har en spesifikk verdi kalles deterministisk. Til forskjell kan en tilfeldig stokastisk variabel anta et spekter av verdier. Fordelingen av mulige utfall for en stokastisk variabel beskrives av en sannsynlighetsfordeling. De mest brukte statistiske begrepene i denne rapporten er beskrevet i tabellen under.

Tabell 1: Statistiske begreper som brukes i rapporten. Tabellen er hentet fra rapporten DEMO 2000, Det Norske Veritas.

Begrep	Definisjon	Beskrivelse
Sannsynlighetsfordeling	$f(x)$	Fordelingen for ulike utfall av x.
Akkumulert sannsynlighetsfordeling	$F(x) = \int_{-\infty}^{x} f(y)dy$	Sannsynligheten for at et utfall er mindre enn eller lik x.
Forventningsverdi (eng. mean)	$E(x) = \mu = \int_{-\infty}^{\infty} xf(x)dx$	Gjennomsnittsverdien av en fordeling (tyngdepunkt).
Median (P50)	$\frac{1}{2} = \int_{-\infty}^{P50} f(x)dx = \int_{P50}^{\infty} f(x)dx$	Samme sannsynlighet over og under P50.
Mode	$\frac{d}{dx} f(x) = 0$	Verdien der *f(x)* er størst; toppunktet på fordelingen.
Varians	$Var(x) = \sigma^2 = \int_{-\infty}^{\infty} (x-\mu)^2 f(x)dx$	Mål på spredningen i fordelingen.
Standardavvik	$\sigma = \sqrt{Var(x)}$	Roten av variansen.
Percentil Pxx	$F(Pxx) = xx\%$	Sannsynligheten for at utfallet er mindre enn eller lik pxx er xx%, for eksempel F(p10) = 10% = 0,1.
Pearsons korrelasjonskoeffisient	$\rho(x,y) = \frac{COV(x,y)}{\sqrt{VAR(X) \bullet VAR(Y)}}$ $,[-1 < \rho < 1]$	Benevningsfri koeffisient for å beskrive lineære sammenhenger mellom to avhengige variabler.
"Trippelestimat"	Også kalt trepunktsestimat. Det angis tre punkter for å beskrive en sannsynlighetsfordeling som i figuren. Dette kan for eksempel være p10, mode og p90.	

Noen av disse målene er illustrert i Figur 4.



Figur 4: Illustrasjon av noen statistiske parametere. Figuren viser en lognormalfordeling og den korresponderende akkumulerte sannsynlighetsfordelingen.

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Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter and greener.

Appendix V0.11

ENVIRONMENTAL MEASURES FOR THE WRECK OF U-864

Monitoring

Norwegian Coastal Administration

Project name: Environmental measures for the wreck of U-864

Report title: Monitoring

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Gjengivelse av deler av dette vedleggsdokument som kan føre til mistolkning er ikke tillatt

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1 SUMMARY

In 2008 Det Norske Veritas issued twelve studies supporting the overall risk report regarding salvage of U-864 (DNV 2008a). One of these supplementary studies dealt with monitoring of a salvage operation (DNV, 2008c).

In 2013 The Norwegian Costal Administration commissioned DNV GL to work out a steering document and cost estimates for two alternative solutions for U-864.

Alternative 1. Capping of wreck and polluted sediments.

Alternative 2. Salvage of cargo and capping of wreck and polluted sediments. Cargo in this context should be read as mercury canisters.

Based on the two alternatives mentioned above and due to more detailed knowledge there was a need to update the monitoring report from 2008 (this report). In general the same principles for monitoring described in this document should be applicable for any alternative solution for U-864 with some modifications (for example capping vs. salvage). But the basis for this report is alternative 1 and 2 above. A final detailed monitoring program should be worked out when a final solution for U-864 has been decided.

Overall there are 3 central reports that are related to monitoring of the two alternative solutions mentioned above:

1. This report

2. Environmental goals and acceptance criteria for initiatives at U-864 (in Norwegian), DNV 2014b.

3. Capping design and control of capping (in Norwegian), DNV 2014a. This report focuses on control of the cap design and its purpose.

DNV GL's overall suggestion is:

During and after any operation on the U-864 possible spreading of mercury should be monitored in order to make corrective and appropriate actions if needed. The monitoring should be based on recognized techniques in order to make an environmental acceptable operation, and to monitor the long term effect of the operation.

DNV GL's suggested monitoring programme is based on the following:

C1. During operation water samples from two water depths at predefined stations will be analysed for mercury in the field.

C2. Measure turbidity from several depths at predefined stations to ensure real time information on the amount of particles spreading during an operation.

C3. Collect particles with sediment traps in two water depths at predefined stations to ensure time integrated information on spreading of particles during operation.

C4. Use ROV video surveillance to monitor the spreading of particles during an operation.

C5. After the operation, routinely measure the mercury concentration in fish, crabs, sediments and pore water to monitor the long term effect of the operation. Additional soft bottom analysis will give valuable information related to pollution at the location.

Other suggestions on how to monitor spreading of mercury during and after any operation should be evaluated. This may include use of bio indicators or tracer technology. Both methods are briefly discussed in this report.

2 INTRODUCTION

The German submarine U-864 was torpedoed by the British submarine Venturer on February 9 1945 and sunk approximately two nautical miles west of the island Fedje in Hordaland. U-864 was carrying about 67 metric tonnes of metallic mercury that implies a threat to the marine environment.

In September 2007 The Norwegian Costal Administration commissioned Det Norske Veritas to further investigate different alternatives to salvage the wreck and remove the mercury from the seabed. In this context one of the reports published in 2008 (DNV 2008c) described on a general level different options for monitoring a salvage operation and capping of polluted areas around U-864.

In 2013 The Norwegian Costal Administration commissioned DNV GL to work out a steering document and cost estimates for two alternative solutions for U-864.

Alternative 1. Capping of wreck and polluted sediments.

Alternative 2. Salvage of cargo and capping of wreck and polluted sediments. Cargo in this context should be read as mercury canisters.

Based on the two alternatives mentioned above and due to more detailed knowledge there was a need to update the monitoring report from 2008 (this report). In general the principles for monitoring described in this document should be applicable for any alternative solution for U-864 with some modifications (for example capping vs. salvage). A final detailed monitoring program should be worked out when a final solution for U-864 has been decided.

Overall there are 3 central reports that are related to monitoring of the two alternative solutions mentioned above:

1. This report

2. Environmental goals and acceptance criteria for initiatives at U-864(in Norwegian), ref DNV 2014b.

3. Capping design and control of capping (in Norwegian), ref DNV2014a. This report is focused on control of the cap design and its purpose itself.

2.1 Background

The German submarine U-864 was sunk approximately 2 nautical miles west of the island Fedje in Hordaland (**Figure 2-1**). The submarine was on its way from Germany via Norway to Japan with war material and according to historical documents; U-864 was carrying about 67 metric ton of metallic (liquid) mercury, stored in steel canisters in the keel. The U-864, which was broken into two main parts as a result of the torpedo hit, was found at 150-175 m depth by the Royal Norwegian Navy in March 2003. The Norwegian Costal Administration (NCA) has, on behalf of the Ministry of Fisheries and Coastal Affairs, performed several studies on how the risk that the mercury load constitutes to the environment can be handled. In December 2006 NCA delivered a report to the Ministry where they recommended that the wreck of the submarine should be encapsulated and that the surrounding mercury-contaminated sediments should be capped. In April 2007

the Ministry of Fisheries and Coastal Affairs decided to further investigate the salvaging alternative before a final decision was taken about the mercury load.

In 2013 two other alternative solutions were decided to investigate further:

Alternative 1. Capping of wreck and polluted sediments.

Alternative 2. Salvage of cargo and capping of wreck and polluted sediments. Cargo in this context should be read as mercury canisters.

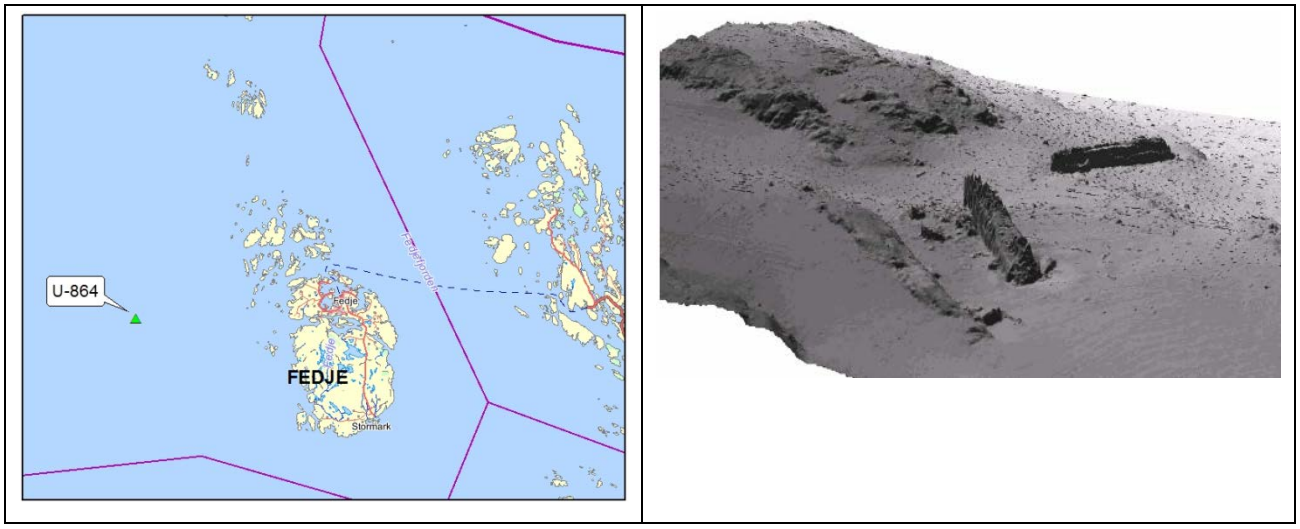

Figure 2-1 Location (left) and a sonar picture of the wreck of U-864 on seabed (right) (from Geoconsult).

2.2 Scope of this report

This report deals with monitoring related to the two alternative solutions mentioned. In general there are still details to work out but the report is meant to give a relatively detailed description of how the monitoring can be carried out. The main ambitions are to monitor spreading of mercury during and after an operation in order to make corrective and appropriate actions if needed. In general the monitoring principles described herein may be applicable, with relatively minor adjustments, regardless of which remediation alternative that will be chosen.

3 DESCRIPTION OF THE AREA AND THE CURRENT SITUATION AT WRECK SITE

3.1 Description of the area

Figure 3-1 shows the location of the wreck. A point by point summary regarding U-864 is given below.

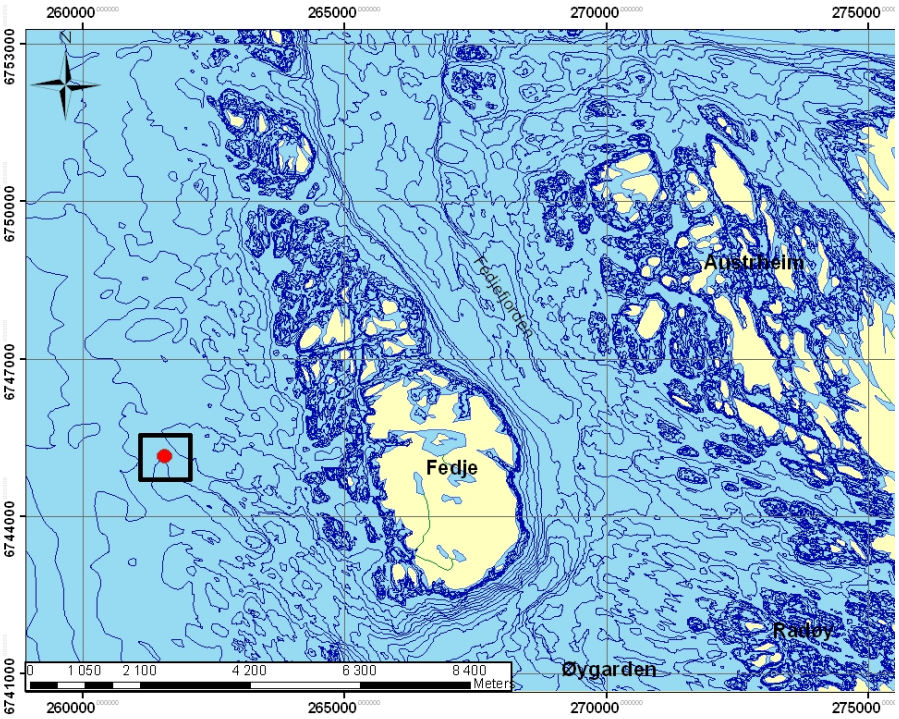

Figure 3-1 Location of U-864 outside Fedje on the west coast of Norway.

3.1.1 Evaluation of the area where the wreck has been localised

- The wreck of U-864 was found on 150 meters depth approximately two nautical miles (3.7 km) west of Fedje in Hordaland County. The area is exposed to rough weather, especially during the winter. Experiences from the surveys show that any measures ought to be carried out in the period from May to August, which has the highest probability for enduring periods of weather that will allow an operation on U-864 to be accomplished.
- The area has a rolling bathymetry. Stability calculations of the sediment in the area indicate an imminent danger of slope failure. This is primarily the case for the fore section of the submarine which lies in an unstable slope with an approximately 15 degrees incline.
- Average velocity of the current 3 m above the bottom is measured to about 0.15 m/s. Maximum velocity is measured to 0.6 m/s. Average and maximum velocity,

40 meters above the bottom, is measured to 0.4 m/s and 1.6 m/s respectively (NIVA 2005 and 2006).

- The area currents are stable, with a northern main course from the surface down to about 110 m. The current turns westward and follows the bathymetry into the deeper layers.

3.1.2 Environmental factors and pollution in the area around the wreck

- Mercury and methyl mercury are found in the sediment, including pore-water. The sediment samples around the wreck show very high concentrations of mercury. It is estimated that 3 kg (DNV 2008b) to 4 kg (NIVA 2005) of mercury is leaking into to the water column each year.
- It has been found concentrations of mercury in fish from the area which are considered to be higher than background values. A connection has been established between the pollutant, dispersion of pollution and accumulation in biota.
- Environmental monitoring on the seafloor during test dredging and excavation shows that such operations will result in resuspension of polluted sediments and will be a risk for mercury release to the surrounding waters and unpolluted sediments.
- The two alternative solutions currently under evaluation include covering the seafloor around the wreck of U-864 and the wreck itself to reduce leaching of mercury from the sediments to acceptable levels. The action area for covering the seafloor is estimated to approximately 47 000 m^2 (DNV 2014a). The action area is restricted to sediments where pollution ranges from 0.63 ppm (class III) to >5 ppm (class V) according to governmental (Environmental directorate) classification system.
- The U-864 had a bunker capacity of 441 tonnes, and it was presumably fully loaded when torpedoed. Large quantities of fuel were observed after it was sunk. The remaining quantity is unknown. In 2013 it was emptied for oil and it is anticipated that only small volumes of oil are inside the wreck today.

3.2 Description of the current situation

The current environmental situation in the area where the wreck is localized is described in several documents. A good understanding of the environmental situation is covered in the following four documents:

1. NIVA (2005a). Miljøovervåking, strømundersøkelser, sedimentkartlegging og miljørisikovurdering knyttet til fase 1 kartlegging og fjerning av kvikksølvforurensning ved U-864.

The objective of the survey was to establish a foundation of facts that could be used to define further measures regarding the removal of the contamination hazard related to U-864.

Summary of the report's conclusions:

- Contamination levels are generally low in water samples except some samples close to the bottom (presumably caused by resuspension during sampling).
- Removal of sediments at rear end of the wreck resulted in increased particle abundance and mercury concentrations (resuspension) in the water column.
- The sediments around the wreck are partly very heavily polluted (up to 10 % mercury)
- Based on the analyses of mercury in the sediments, the remediation area is calculated to approximately 30 000 m^2 containing a minimum of 15 000 m^3 contaminated sediment.
- Sediment of the area can be characterised as sandy with hard clay beneath. There are also parts with stone and gravel.
- The heading of the current in the upper layers is northerly down to 110 m depth, while below this depth the current deflects to the west and follow the bathymetry. The current has an average velocity at 20 m depth of 0.3 m/s (max 1.6 m/s), and 0.15 m/s (max 0.6 m/s) 3 m above the bottom.

2. NIVA (2005b). Utlekking og bioakkumulering av kvikksølv fra sedimenter nær U-864. Resultater fra eksperimentelle undersøkelser. Resultater fra eksperimentelle undersøkelser.

NIVA has completed leaking and bio accumulation tests for total mercury and methyl mercury on sediments where U-864 is localised.

A short summary of the tests show that:

- Mercury bioaccumulates in bristle worms (*Nereis*) and gastropods (*Hinia*). There was a high bioaccumulation of total mercury compared to the control sediment (factor 1300 for bristle worms and 450 for gastropods).
- Methyl mercury bioaccumulates in bristle worms, but to a lesser degree in gastropods.
- Analyses of pore water for total mercury and methyl mercury indicate that the mercury is available for sedimentary organisms. Elevated concentrations of mercury in the sediments increase the concentration of mercury in the pore water.
- Tests indicate an average leakage rate of total mercury from sediment to water to be 142 kg/km^2/year and 0.8 g/km^2/year for methyl mercury. Tests show that within the suggested remediation area of 0.03 km^2, there is a yearly leakage of 4 kg mercury from the sediments to the water column.

3. NIFES (2004, 2005, 2006). Kvikksølvinnhald i fisk og sjømat ved søkkt ubåt (U-864) vest av Fedje.

Analyses of total mercury in selected species of fish and crab were performed by NIFES in the years 2004 to 2006. For cod the analysis showed that average content of mercury to was at level compared to fish caught in the open sea (from The Barents Sea, The Norwegian Sea and the North Sea). The content of mercury in redfish (*Sebastes marinus*)

was above normal level but below the limit value adopted by EU of 0.5 mg mercury/kg wet weight (Commission regulative EC 2001/446). However, some of the samples of crabs (claw meat) and cusks (*Brosme brosme*) had concentrations of Hg above the limit value adopted by EU. In **Figure 3-2** the mercury content in fish and crab for the investigations by NIFES in 2004-2006 are shown.

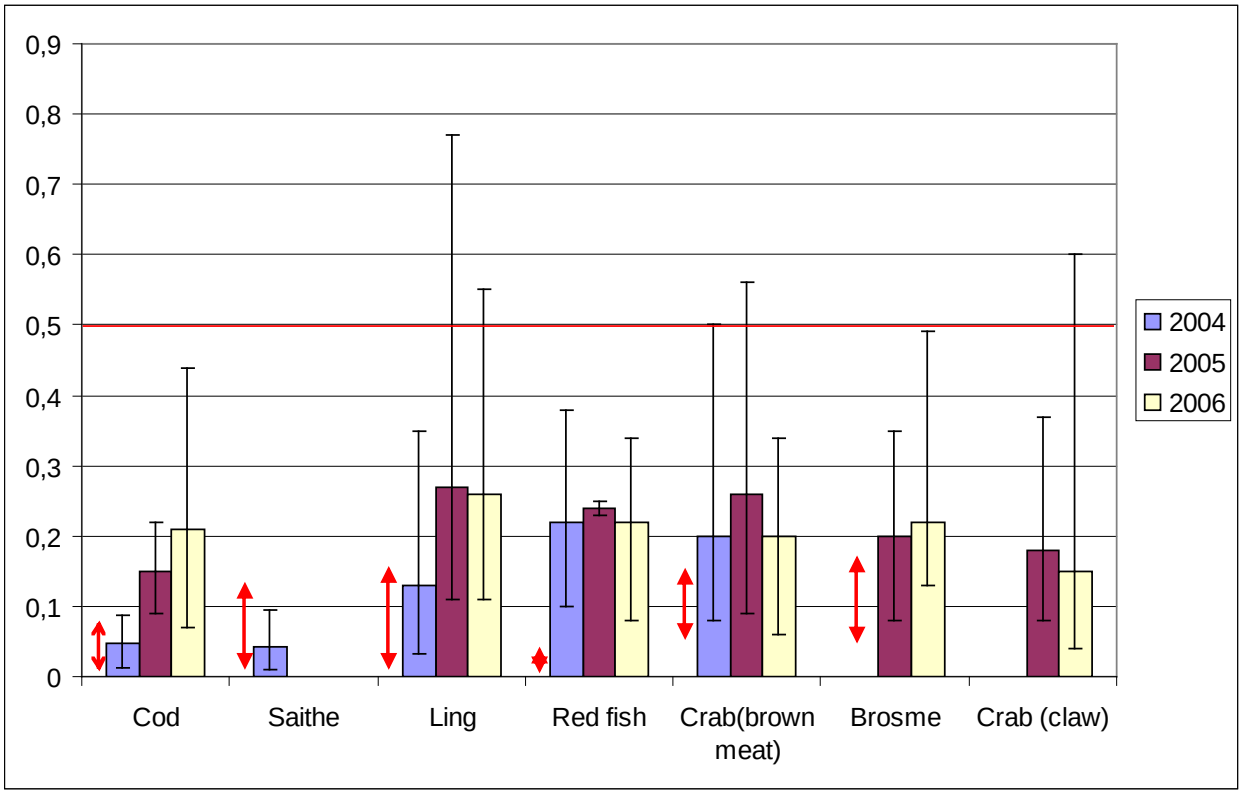

Figure 3-2 Mercury content in fish and crab (mg/kg wet weight) from the sampling performed in 2004-2006 by NIFES. Red arrows indicate normal values (from Norwegian areas unaffected by pollution), columns average values and black bars maximum and minimum values.

See the Coastal Administration internet site (http://www.kystverket.no/) to get access to all reports by NIFES.

4. NIFES (2007 og 2009). Kvikksølvinnhald i fisk og sjømat ved søkkt ubåt (U-864) vest av Fedje.

In general these two investigations are follow-ups of previous investigation. In fact these investigations have been done each year since 2004. The main conclusions in 2009 are that average concentration of mercury in filet of cusk (*Brosme brosme*) was at the same level for the period 2004-2009 (0.27 mg Hg/kg wet weight). Two of 75 individuals had a mercury concentration in filet above EU's limit of 0.5 mg Hg/kg wet weight. Overall the cusks caught near U-864 had lower concentrations of mercury compared to cusks caught further south and north. This indicates that there is not a connection between the pollution around the wreck and mercury concentration in cusk.

There was in general lower mercury concentration in crabs compared to previous years, but this could be an artifact due to the fact that crabs were caught further east than previous years.

5. NIVA (2103). Investigations of mercury during a survey near submarine U-864 outside Fedje in 2013.

During a survey in 2013 NIVA analyzed sediment samples for mercury in order to provide updated information on pollution status around the wreck. Some sediment stations north and west east of the wreck were slightly more polluted with mercury than they were in 2006. Sediment stations east and south-east of the wreck had low concentrations of mercury and had not increased during the period 2006-2013.

4 MONITORING PROGRAM

As mentioned in the introduction a separate document describing control of the capping design and its purpose is described in a separate document (DNV GL 2014 a).

With focus on the general monitoring regime with the purpose to monitor release and spreading of mercury during and after remediation DNV GL's conclusions are:

C1. During operation water samples from 3 and 10 m above sea bottom depths at 12 stations will be analysed for mercury in the field. This means that all necessary analysing equipment must be set up on board the vessel.

C2. Turbidity should be measured from 3 and 10 m above sea bottom at 8 stations to ensure real-time information on the amount of particles spreading during an operation.

C3. Particles should be collected with sediment traps from 3 and 10 m above sea bottom from 8 stations to ensure time integrated information on spreading of particles during operation.

C4. ROV video surveillance should be carried out to monitor the spreading of particles during an operation.

C5. After the operation, the mercury concentration in fish, crabs and pore water should be measured regularly to monitor the long term effect of the operation.

Additional soft bottom analysis will give valuable information related to pollution at the location.

4.1 Environmental goal for the area

NIVA (2006) suggested that: *"the regional environmental goal should be to take measures to prevent that the wreck and its surrounding area will become a source of pollution in the future, as well as prevent that the wreck and the polluted sediments contribute to elevated levels of mercury in seafood (fish and shellfish)"*.

This statement has been put into a more concrete context in a separate document describing environmental goals and acceptance criteria for a remediation of U-864 (DNV GL 2014b).

4.2 The scope for the monitoring activity

A monitoring program is required to monitor possible release of contaminants during and after the remediation alternative that may be chosen for U-864. This includes:

- Monitoring of release during preparations at the site. This may include any dredging or excavation necessary in order to get access to keel and lifting operations.
- Monitoring during final transport of the submarine, if relevant, to a storage/disposal facility will also be covered by the program.
- Monitoring of Hg release from the area after remediation

Monitoring of a final disposal/destruction of the submarine, if relevant, is not included in this work.

The purpose of the suggested monitoring program is:

- To detect acute contaminant release during the operation in real time in order to implement immediate corrective actions to limit or stop the release.
- To collect time-integrative data on contaminant release during the operation in order to document the environmental impact of the operation.
- To collect data on releases of Hg from the area after the remediation in order to document the long-time efficiency of the remediation.

In general the monitoring should be performed by experienced and preferably by accredited personnel. This will secure documentation in accordance with relevant standards of the field work and handling of the samples.

The analysis should preferably be done in a laboratory with accreditation for analysis of total mercury, and preferably also methyl mercury. This is an evaluation that has to be done if possible considering that all analyses shall be done in the field.

4.3 Monitoring methods

Several methods have been reviewed in this study. **Table 4-1** lists some relevant monitoring methods. In addition more traditional long term monitoring methods like sediment sampling, sampling of biota, soft bottom community analysis and use of tracer are described in 4.7 and 4.8.

Table 4-1 Overview of monitoring methods and evaluation of their applicability for real-time monitoring.

Monitoring technique	Real-time monitoring possible (typical response time)	Development status
Passive samplers	No (weeks)	Experimental for mercury
Sediment traps	No (weeks)	Commercial
Turbidity	Yes (sec. or few min.)	Commercial
Water sampling	No (hours)	Commercial
Automated water analysis	Yes (minutes)	Commercial, but status for deployment offshore is unknown
Voltametric	Yes (minutes)	Pilot

mercury determination		
ROV equipped with video camera and sonar	Yes (< sec.)	Commercial (no detection of dissolved contaminants)

Turbidity

Turbidity measurements are a robust and well tested method to monitor the concentration of particles in the water column. Absolute concentrations are probably very difficult so in this context turbidity is more an indirect measure of relative particle concentrations. Turbidity sensors can be placed on stationary buoys at several depth intervals or on a ROV to monitor the operation.

Measurement of turbidity is the most reliable method for real-time monitoring of release and dispersion particles in the sea. Turbidity is a measure of light dispersion caused by particles suspended in the water column. Contaminants are often strongly associated with particles and turbidity gives an indirect measure of particle concentration in the aqueous phase and therefore judgments of contaminant transport can be made. Turbidity monitoring is widely used during dredging operations as an indicator of unacceptable spreading of contaminated sediments. The method allows rapid implementation of corrective measures and is used to monitor dredging operations near the U-864 during performed field investigations.

The disadvantage of relying only on monitoring of turbidity measurements is that it does not directly measure Hg. In the case of uncontrolled release of elemental mercury, mercury drops will settle rapidly on the seabed and be very hard to detect by turbidity measurements. In order to detect such events it is necessary to follow the operation visually by an ROV equipped with a video camera.

ROV

Video monitoring of the operation will be necessary to detect unwanted events during any remediation method that will be chosen for U-864. The unwanted effects of such events are release of mercury or mercury-contaminated material to the marine environment and contamination of a larger area of the seabed.

Passive samplers

Passive samplers are devices containing a substance that accumulates the contaminant of interest over time proportionally to the concentration in the aqueous phase. Diffusive Gradients in Thin films (DGT) are passive samplers suitable for monitoring many metals, the method has however not been tested for mercury according to a study by NIVA (2002). Other materials like mercapto modified silicone have been developed to act as a sorbent for mercury in lab-based analytical methods (Merritt and Amirbahman 2007). These methods are presently at an experimental stage, and it seems that many significant obstacles have to be overcome before such materials are suitable for deployment as passive samplers in the marine environment.

Sediment traps

Particles settling in the water column can be collected by sediment traps. Sediment is collected at selected time-intervals and subsequently analysed for the contaminants of interest. This is a well-documented method that was deployed to monitor mercury transport during dredging close to U-864 in September 2006 (NIVA 2006). Sediment traps have the advantage over water samples that they collect particles during the whole deployment period (weeks or months) and the results will therefore represent the time-integrated mercury load during the deployment.

Water sampling

Release of dissolved mercury to the marine environment should be monitored by direct chemical analysis of water from the site during the whole operation. This would traditionally imply sampling at selected time intervals followed by chemical analysis in an on-site or off-site laboratory facility.

The mercury content in discrete water samples can be analysed with several standardized analytical methods offered by commercial laboratories. Water sampling could be combined with a mobile lab in order to get semi-real-time monitoring. Collecting the samples will presumably be the time-limiting factor in this case.

Automated water analysis

Automated systems for analysis of mercury in water, based on continuous flow, exist for analysis of large sample series in the laboratory. Such systems could be modified to generate near real-time data. This requires continuous pumping of water from the monitoring stations at salvage site to the analysing equipment. This method will require some modification of available standard equipment to do this task. Further evaluation and verification is needed to determine if this is a feasible method to use on-site under off-shore conditions.

4.4 Acceptable level of mercury release

Acceptance criteria are described in more detail in DNV GL (2014 b)

The results from the monitoring must be compared with limits for acceptable release or acceptable concentrations of mercury in water in order to decide when corrective actions are appropriate. The acceptable water concentration can be decided by using toxic effect limits from relevant literature (for example effect limits from the Guidance to risk evaluation of contaminated sediments, published by the Climate- and pollution directorate 2012) or other relevant toxic effect limits.

Alternatively the criteria for acceptable water concentration can be decided based on background concentrations, for example as an acceptable increase in mercury concentration or turbidity during operations. In DNV GL (2014b) an approach is described where acceptable water concentrations of mercury is based on toxic effects limits published in the guidance document (SFT,2007). Regarding turbidity an approach where values are compared with background values is chosen (also described in DNV GL 2014b).

Another approach to identify what is an acceptable release of mercury is to make an environmental budget of the expected mercury release before, during and after the operation. The increased release during the operation must be reasonable compared to the reduction in mercury release which can be obtained by the operation. This is illustrated in the example in **Figure 4-1**, which states that the release of mercury in to the water column will increase during operation but is out-weighted by the reduced flux from the seabed as a result of the actual clean-up operation. Release of mercury settling to the seabed during the operation can increase the contaminated area. The major consequence of this will be increased costs of remediation of a larger area as a part of the final stage of the operation.

In DNV GL (2014b) it is suggested to accept that 30 kg of mercury can spread outside the defined remediation area. This corresponds to about 10 years of leaking without any remediation (current situation) estimated to be 3-4 kg of mercury pr. year. Details around design and implementation of an environmental budget are currently not worked out.

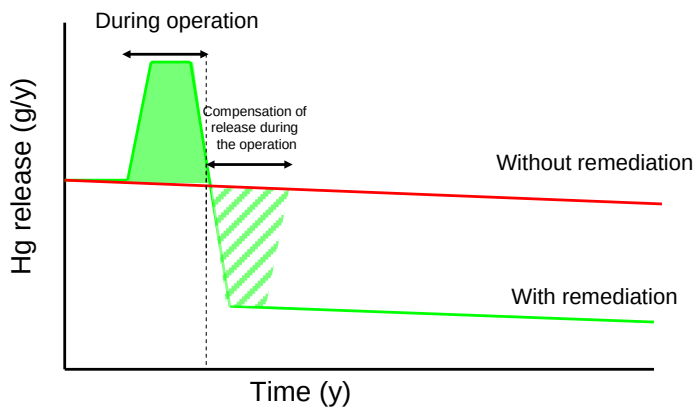

Figure 4-1 Schematic example of a contaminant budget

4.5 Background values for monitoring parameters

In order to compare measurements during the operation with the natural situation in the area it is preferable, or most times necessary, to establish reliable background values for all parameters which will be monitored. Baseline monitoring of all parameters that are included in the final program should therefore start as early as possible and at least one month before the operation starts to be able to document natural variation in the parameters of interest.

4.6 Monitoring during initiative

DNV's conclusions are:

C1. During operation water samples from 3 and 10 m above sea bottom depths at 12 stations will be analysed for mercury in the field. This means that all necessary analysing equipment must be set up on board the vessel. C2. Turbidity should be measured from 3 and 10 m above sea bottom at 8 stations to ensure real-time information on the amount of particles spreading during an operation.

C3. Particles should be collected with sediment traps from 3 and 10 m above sea bottom from 8 stations to ensure time integrated information on spreading of particles during operation.

C4. ROV video surveillance should be carried out to monitor the spreading of particles during an operation.

The main purposes of the monitoring during remediation are:

1) To be able to initiate corrective actions in order to stop or reduce release of particle bound and dissolved mercury. This includes measurements which can give real time data so that corrective actions can be initiated during the remediation.
2) Documentation of the operation with regards to release of particle bound and dissolved mercury

Mercury can be introduced to the water column during remediation from:

- leakage from the wreck parts when these are handled (e.g. lifted).
- loss from the wreck parts if these are lifted from the sea floor.
- re-suspension of sediments during the operation.
- desorption from particles re-suspended to the water column during the operation.
- the pore water in the sediments (when these are disturbed).

The use of passive samplers is not described further because the method seems not to be available for mercury. But if any future bidders or companies that will perform the monitoring during or after any operation have some suggestions on available technology, it is recommended that monitoring by use of passive samplers are reconsidered.

Also any other methods, for example online measurements of mercury, should be considered if future bidders or companies which will perform the monitoring have some suggestions.

4.6.1 Monitoring of mercury by water sampling

In general water samples need to be analysed before any conclusions can be made or before any corrective actions can be implemented. Below are three suggestions on how

water samples may be collected and analysed, each with its advantages and disadvantages:

1. Discrete water sampling – analysis in commercial laboratory on land

Considering that this will be an offshore operation and that the operation may take in the order of days to weeks (depending on the weather), it means that if the samples are analysed on a laboratory on land it may happen that no results are available before the operation is finished. Hence, the water samples will only be input to the documentation on the operation and will not be a tool for implementing corrective actions. This is therefore not recommended.

2. Discrete water sampling – analysis on-board during operation

A second solution is to establish the necessary analysing equipment and personnel on the operating ship or a separate vessel so the analyses can be done sequential during the operation. If this is possible, water samples could be a tool for implementing corrective actions during operations. Expected turn-around time of such a system, using on-board analytical facilities, is in the order of hours. This is a recommended solution. This solution is previously tested by NIVA during work at the site.

3. Automated water analysis – analysis on-board during operation

A third solution is the possibility of deploying on-board automated mercury analyses combined with continuous pumping of water from selected monitoring positions. Continuous flow equipment for mercury is commercial available and bringing this offshore should be feasible. However, to generate near-real-time data, transfer lines should be installed allowing continuous sampling from selected depth. The robustness of the transfer lines under field conditions and the connection to the auto-analyser require further assessment in cooperation with a vendor of the equipment of interest. This solution seems not be “mature” at this stage so it is not recommended. If a practical and robust solution is brought forward this solution should be reconsidered.

Table 4-2 sums up some generalised advantages and disadvantages with the three water sample collecting methods mentioned above:

Table 4-2 Overview over suggested water monitoring methods and evaluation of their applicability

No.	Monitoring technique	Typical response time	Development status
1	Discrete water sampling – analysis in commercial laboratory on land	Days	Commercial and safe
2	Discrete water sampling – analysis on-board during operation	Hours	Commercial, but an analysing lab has to be established on-board. This is the recommended solution today

3	Automated water analysis – analysis on-board during operation	Minutes	Not commercial, needs modification and testing

Acceptance criteria

For very short periods during the operation high peak values of mercury in water can be accepted because the exposure time is limited. For such a shorter period mercury maximum concentration of 0.7 µg/l is suggested (DNV GL 2014b). This value is equivalent to category IV (0.14 µg/l) in the classification scheme (SFT 2007) but without a safety factor of 5 (safety factors are often applied depending on types of test executed to work out effect-limits). The value is based on LC_{50} (Lethal Concentration with 50 % mortality) with tests on fish, where the fish is exposed to this concentration during 4 days. Short peaks with this concentration should therefore not be mortal to fish in the exposed area.

For longer periods a lower acceptance criteria should be used. One option may be to adopt the value of 0.05 µg Hg/l which correspond to category II in the state pollution authority classification scheme (SFT 2007).

One may therefore use a value (0.7 µg Hg/l) as an acceptance criteria for peak values (short duration) and 0.05 µg Hg/l for periods of longer duration, meaning that corrective actions should be made if water concentrations of mercury in any sample is above those concentrations. This is described further in the document dealing with environmental goals and acceptance criteria the DNV GL (2014b).

Sampling strategy

Water samples should be taken in a transect covering the main current direction with increasing distance from the source (meaning the wreck parts).

Considering that huge amounts of water will probably quickly dilute the concentration of mercury in the water column it is suggested that water samples are taken in a transect covering the north, west, east and south direction and in a distance of 100, 200 and 300 m from the wreck parts. This sampling strategy is illustrated in **Figure 4-2**. The exact distance must be decided based on details in the operation plan, the final delimitation of the remediation area and the safety distance any operation demands.

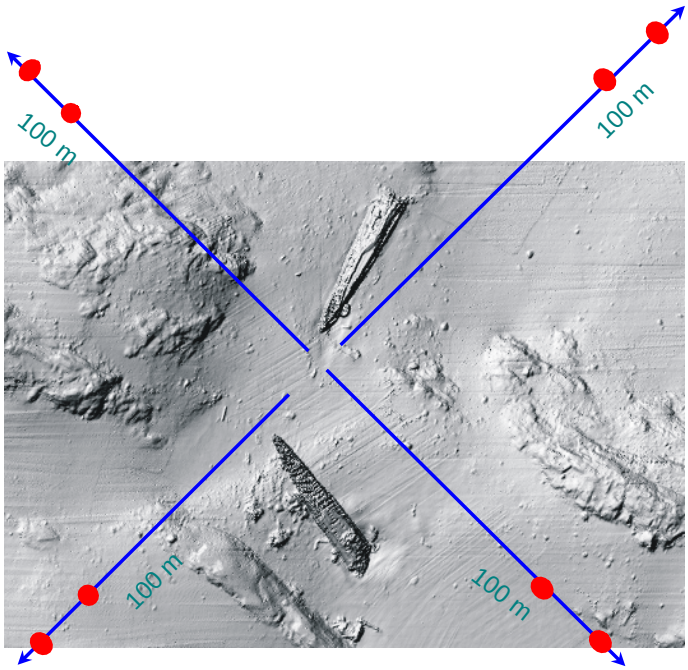

Figure 4-2 Sampling strategy - water samples (distance given not exact, for illustration purpose only).

The water samples should cover several depths in order to reflect the operation, but exact depth should be detailed when it has been decided whether the wreck shall be salvaged or capped. Currently the two alternatives include capping of both sediments and wreck either with or without salvage of the cargo (mercury canisters). Based on these alternatives it is suggested to take water samples 3 m and 10 m above sea bottom. This will result in a total of 24 samples points (12 stations and two depths).

Handling and analysis of samples

The water samples should be kept cool and dark before they are analysed. Appropriate sample bottles should be used to avoid loss of mercury by evaporation.

It is suggested that all of the nearest samples (100 m) are analysed first and if the concentration in these are not above the acceptance criteria the other samples (200 and 300 m) need not to be analysed. If the concentration of mercury in the nearest samples is above the acceptance criteria the 200 m are analysed first and if those also exceeds the acceptance criteria the samples from 300 m are analysed.

4.6.2 Monitoring of particle bound mercury

The monitoring programme should focus on a strategy involving:

- Turbidity measurements
- Sediment traps
- ROV

In addition tracer technology is mentioned as an option but not considered in any further detail.

4.6.2.1 Turbidity measurements

Turbidity is a robust and well tested method to indirect monitor the concentration of particles in the water column. Turbidity sensors can be placed stationary on buoys at several depths, mobile on a ROV monitoring the operation or manually applied from a smaller vessel.

The main two options when using turbidity measurements are:

1) Online turbidity measurements. In this case there is continuous transfer of data to a PC on-board, either wireless transfer or by wire. In this way the operator have directly access to the measurements. It may also be possible to set up an alarm if measurements are above a predefined level (acceptance criteria), for example direct SMS alerts. The advantage with this method is that the data are instant available and it is not necessary to take the probes out of the water in order to download and analyse the data. The downside may be that it is expensive in the sense that much technology is involved and many probes are needed. Some maintenance of the equipment is also probable. Coordination with other operation is important so that the equipment do not come in conflict with other operations.

2) Turbidity measurements without “online view”. In this case the turbidity measurements have to be downloaded manually on-board and analysed. This is a less complex method in the sense that not so much technology is needed. One may also manage this with only a few turbidity probes, for example by using dedicated personnel to sample predefined sampling stations. The downside may be that one need to take the equipment out of the water in order to analyse the data and the data is not instant available as it is with online measurements.

Option 1 above is recommended.

Acceptance criteria

The acceptance criteria should be reviewed based on measured background levels in the area. The measurements should commence at least one month before the operation starts and proceed as close to the start of the operation as possible. The reason for this is mainly that because turbidity naturally varies over the year, which means that measurements of background values too long before the actual operation or in a different period with different conditions may not be valid.

Acceptance criteria for turbidity should not be based on single peak values but as a time integrated value. A suggestion is that the acceptance criteria for turbidity should not be

higher than 5-10 turbidity units (measured as FTU or NTU) higher than the natural background level for more than 20 minutes (which is the same acceptance criteria accepted by the SFT for the remediation project in Oslo harbour. This is also further described in DNV GL (2014b) dealing with environmental goals and acceptance criteria.

Alternatively the acceptance criteria should be based on a contamination budget worked out before the operation starts, see chapter 4.4.

Sampling strategy

One of the unwanted effects of an operation is that contaminated sediments are spread to areas outside the boundaries defined as the high risk area (47 000 m^2, see DNV GL 2014a).

Monitoring results from sediment traps during pilot dredging close to U-864 (NIVA 2006) showed that high levels of mercury were found at all stations except “sedimentfelle 1” (OV 1 in Figure 5-3). This indicates that dredging could cause mercury transport at least beyond the observed distance. In order to detect any spreading outside the high risk area we therefore recommend using the stations from the pilot dredging but with some modifications.

- Move all stations according to the 47 000 m^2 remediation area. The main point is that the stations are located at the perimeter of the remediation area as a measure of amount of mercury spread outside the area during the operation (illustrated in Figure 5-3). Previously the remediation area was set to 30 000 m^2 so the stations should be moved according to a remediation area of 47 000 m^2.
- An additional station (OV 8) is established south-east of U-864 as a reference station. This is upstream the dominating current direction and is assumed to be outside the potential area of influence of the operation.

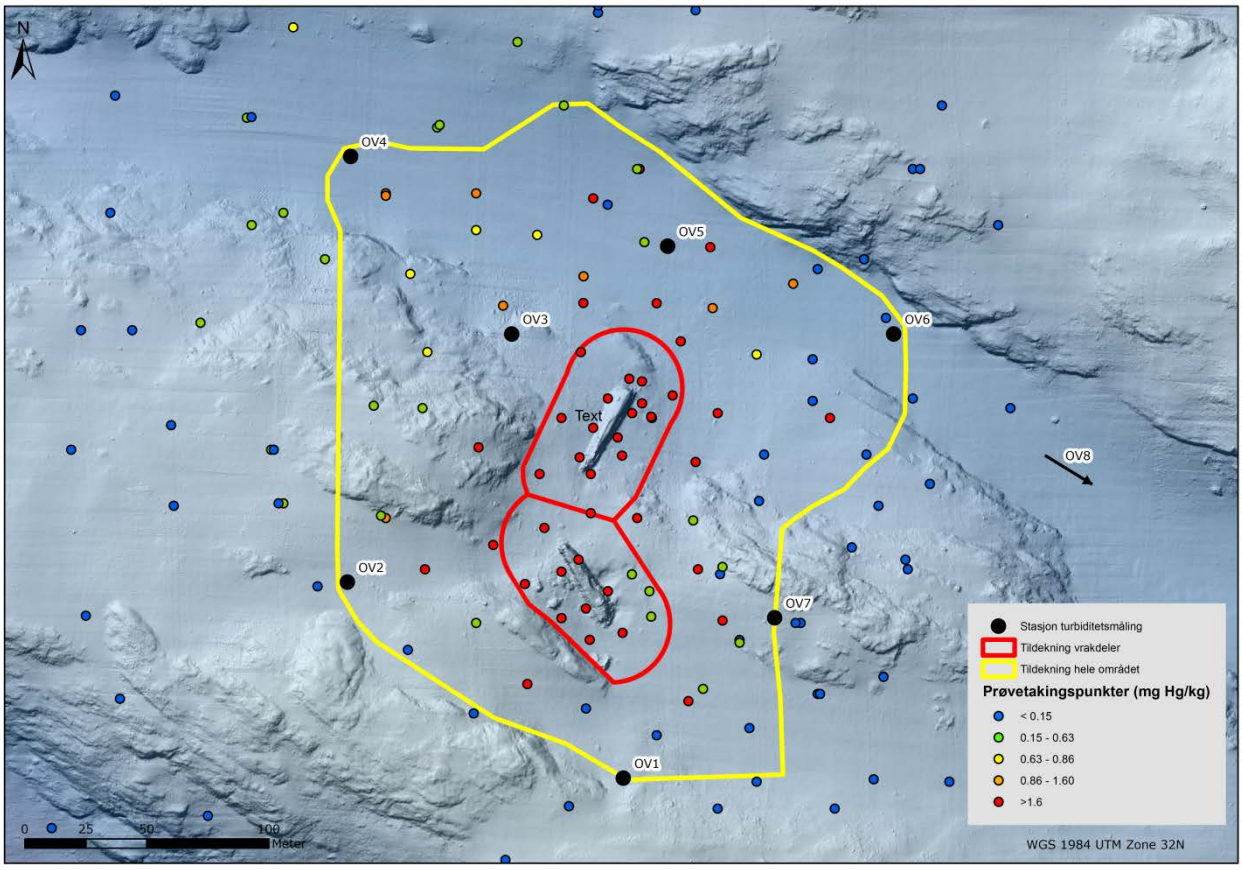

Figure 4-3 Suggested locations for turbidity measurements.

The turbidity sensors should be placed at two depths (3 m and 10 m above the seabed).

If salvage is chosen turbidity measurements should also be used during transport of the wreck to a sheltered location. Exactly how this can be done should be worked out when details around the salvage concept is known. In theory, turbidity probes could be mounted on the barge or transport vessel to monitor during transport.

4.6.2.2 Sediment traps

To document the overall impact of the operation, sediment traps located 3 and 10 m above the seabed should be used at positions OV 1 – 8 (see **Figure 4-3**).

Sediment traps consisting of four tubes with an inner diameter of about 72 mm may be used in order to collect sufficient amount of material for analyses. The mooring arrangement is illustrated in the **Figure 4-4**.

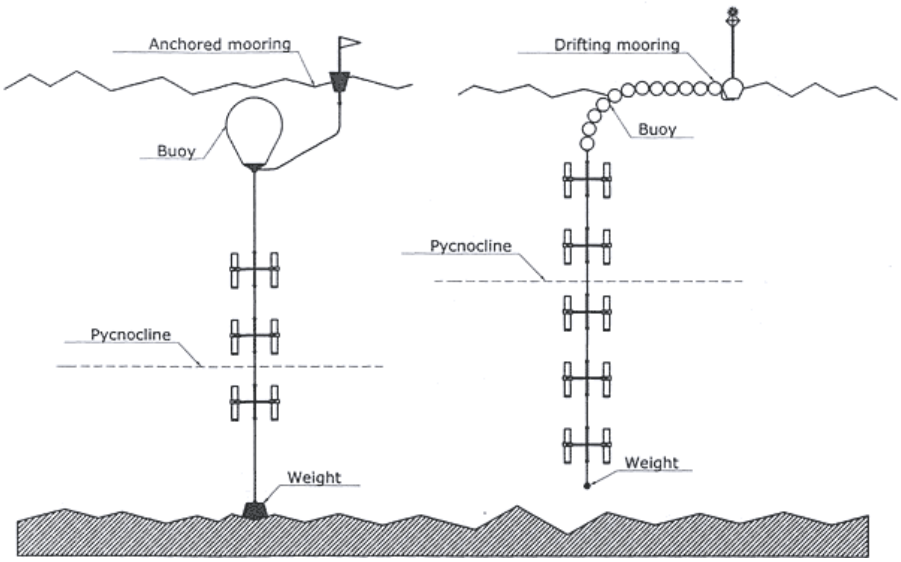

Figure 4-4 Mooring arrangement (for illustration purposes only)

Depending of the duration of the operation, one has to decide if the sediment traps shall be emptied during or after the operation.

In order to acquire background information before the salvage, it is recommended that sampling by use of sediment traps is done over a period for a least one month before the operation starts.

4.6.2.3 Tracer

Tracer technology may be used in order to monitor possible spreading during an operation. The method is only shortly described in this supplementary study, but details may be worked out if this method is considered to give an added value to the overall monitoring program.

The method is not a real-time method, but has the potential to give quantitative results of the sediment spreading from the area. Tracer may be manufactured to mimic the size, density and surface charge of the target species for a wide variety of applications. Another option is to coat a fluorescent signal on to natural sediments (silt, sand) collected from the study site. A number of tracers may for example be added to the sea floor in dissolvable plastic bags, or frozen, in order to prevent any spilling. Tracer collection may be done by sediment sampling or from sediments traps over a given period of time and then the samples can be analysed for tracers in order to detect spreading and to quantify it.

Tracers are used in a wide range of environment projects around the world, including Norway.

4.6.2.4 Remote Operated Vehicle (ROV)

Visual monitoring of the operation should be done with a ROV equipped with video camera and sonar. This equipment can be operated to give full visual documentation of all

stages of the operation. It is probable that several ROVs will be used during the operation and DNV suggests that at least one ROV is to be used for the purpose of monitoring spreading of particles and larger objects.

4.7 Long term monitoring

DNV's conclusion is:

C5. After the operation, the mercury concentration in fish, crabs and pore water should be measured regularly to monitor the long term effect of the operation.

Additional soft bottom analysis will give valuable information related to pollution at the location.

Monitoring after the operation is more resource demanding than during operation. The purpose of this activity is to measure the effect of the remediation over time. The effect of the clean-up operation and the long term monitoring has to be measured against the situation before the operation (current situation/baseline). The long term monitoring can include the following elements:

- Monitoring of mercury in fish and crabs in the remediation area.
- Monitoring of sediment and pore water concentrations of mercury in the remediation area. Pore-water sampling seems to be the only feasible option due to the capping design.
- Monitoring of the soft bottom fauna in the remediation area.

4.7.1 Monitoring of mercury in biota

The monitoring program should be based on the sample program as described by NIFES (2005 and 2006, in Norwegian).

Relevant species for sampling are cod (*Gadus morhua*), cusk (*Brosme brosme*), ling (*Molva molva*), redfish (*Sebastes marinus*) and crab (*Cancer pagurus*).

The fish and crabs shall be caught in three defined areas as described by NIFES (2005, 2006)

- Area 0 is defined as the area in the immediate area to the wreck
- Area 1 is defined as 1 nautical mile north of the wreck
- Area 2 is defined as 2 nautical mile north of the wreck

In addition it is recommended to measure mercury in an area even further away from the locality, both north and south in the Norwegian Coastal current. This is recommended in order to get background values in more near shore areas that will be valuable in order to compare the results from the locality where U-864 is located. The details of the location

of this area should be discussed further, and NIFES, who has performed the monitoring of fish and crab in the area, should be involved.

The fish should be caught alive and the sample should be taken as soon as practical possible after the catch, so that the sample material is as fresh as possible.

It is suggested that an agreement with a local fisherman is done so that the actual fishing can be done by local people well known in the area. Fishing method must be flexible but it is recommended that at least 25 ± 10% individuals of each species are sampled each time.

In earlier investigations (reported by NIFES 2005 and 2006) analysis were done for each individual (not pooled samples). It is recommended to follow the same sampling strategy in the near future, but if the results show rather low concentrations in biota one may shift to analyse pooled samples. Data gathering (catch of fish and crab) should be done in October, which is the same time of the year the catch in 2005 and 2006 were taken. For each catch the following should be documented:

- Species
- Weight (kg)
- Type of sample material (liver, filet, claw meat, crab butter)
- Weight of sample material
- Date of catch
- Mean depth were catch were taken
- Catch method (trawling, line, other)
- Length of each fish, width of carapax of crab
- Area of catch and (coordinates and drawn up on a map)
- Sign of diseases
- A description of any abnormalities

In earlier investigations only filets were analysed. No data exists for liver content of mercury from the area, but it is recommended that liver is included in the monitoring program (this will be discussed further with the Norwegian Food Safety Authority). As previously mentioned the programme may be revised to less extensive sampling and analysing depending on the results.

4.7.2 Monitoring of sediment and pore water

Sediment and pore water should in general be monitored. Sediment sampling is however difficult based on the current capping solution described in DNV GL (2014a), where a coarse erosion layer is suggested to be on top the isolation layer. At current stage only pore water sampling seems feasible. A prerequisite for pore water sampling is to install sampling wells trough the erosion layer.

Sampling of sediments is part of the final control of the capping design. This sampling will be performed before the erosion layer is established. Details around this are described in DNV GL (2104a). In general 25-30 stations inside the remediation area are suggested and about 10 of these stations are also included in a long term monitoring perspective.

A reference station can also be considered. From these 10 stations one may take pore water from the 3 replica sampled, and then analyse a pooled sample from these. Another option may be to take separate samples for pore water analysis. Pore water may be worked up by applying pressure with inert gas through a filter with pore size 0.45 µm or by centrifugation.

All samples should be analysed by an accredited laboratory with relevant detection limits.

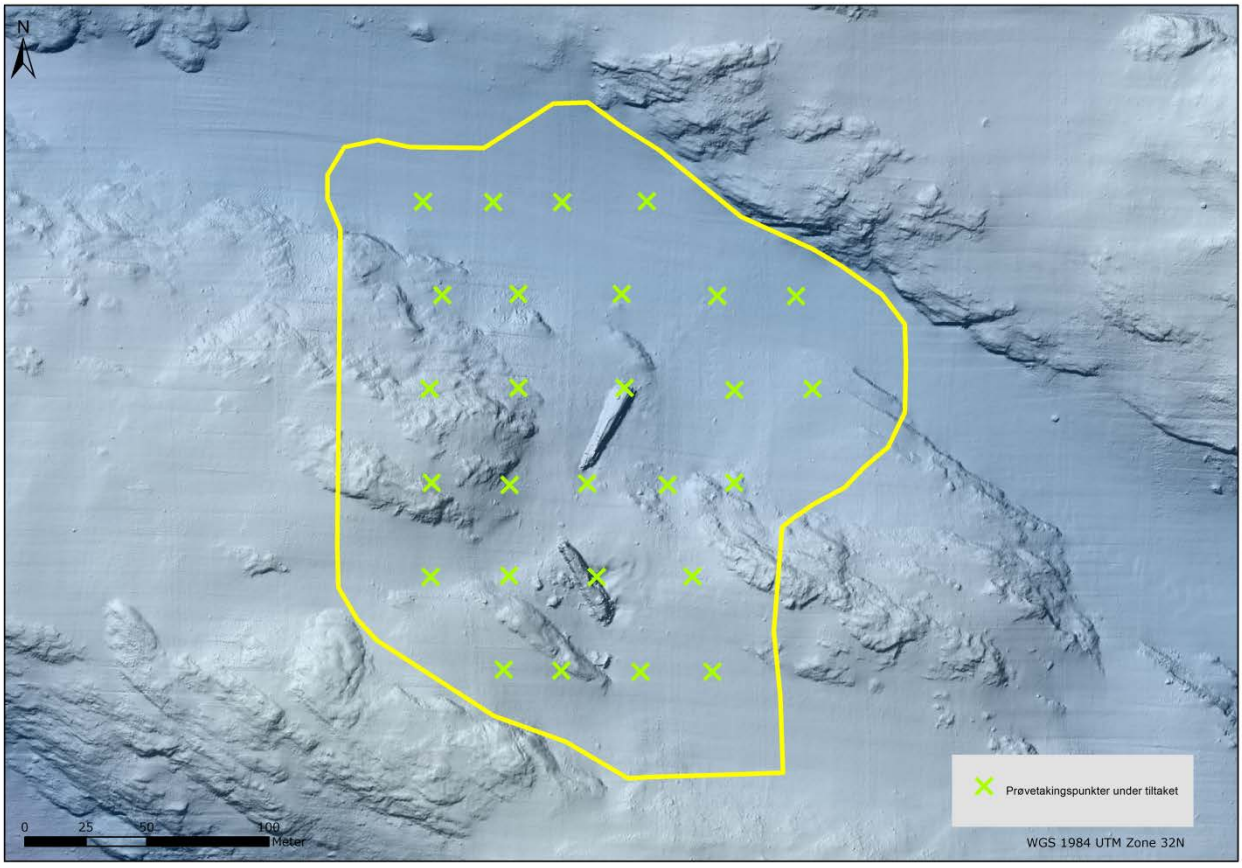

Figure 4-5 Suggested sampling grid for sediments and pore water. Green crosses indicate location of the sampling stations. Yellow line marks the perimeter of the remediation area. Note that sediment samples will only be taken as part of the final control of the capping layer while pore water will be sampled at about 10 of these stations also in a long term perspective.

4.7.3 Monitoring of macro benthic fauna

The use of monitoring macro benthic fauna is mentioned here, but a further discussion of its usefulness is needed when a detailed capping design is in place. A capping of sand and crushed rock in this area will for a short time knock out the bottom fauna within the

remediation area. The use of crushed rock will favour more hard bottom species, meaning a different benthic fauna than exist today (sand bottom) can be expected within the remediation area after capping with crushed rock as an erosion layer.

If benthic analysis is included in the monitoring program one has to include this in the final design of the capping. This is because, like sampling of sediment and pore water, one cannot sample with traditional methods (grab) in a layer of crushed rock (erosion layer).

Macro benthic fauna are traditionally included in environmental monitoring in both offshore and fjord surveys. The reason for this is that the study of benthic communities can give an indication of the effects of pollution, while chemical monitoring of sediments is aimed at assessing the dispersion and concentration levels of pollutants. The benthic fauna is a suitable biological parameter for monitoring the effects of pollution since most of the species have limited mobility and changes in species composition and densities of individuals can therefore easily be identified. The distribution of the fauna can be related to natural variations in environmental parameters such as depth and type of sediment, but also anthropogenic factors such as river borne pollution or other long transported contaminants.

For comparison purposes baseline data from the monitoring area should be collected prior to any remediation. However, even without any background data, monitoring of macro benthic fauna is considered to give valuable input as an effect parameter.

4.7.3.1 Monitoring programme

A suggestion for a sampling programme is shown and described below.

A total of nine sampling stations are placed in a cross directed in the main current direction at the sea bottom (north-west) and at an angle of 90 degrees of the main current. All stations are located near the wreck of U-864 except one reference station which is located at a place most probable unaffected by the mercury pollution around the wreck of U-864.

The location of the sampling stations in **Figure 4-6** are for illustration purposes only and exact location must be decided during the field work based on sediment type and/or where it is possible to get samples.

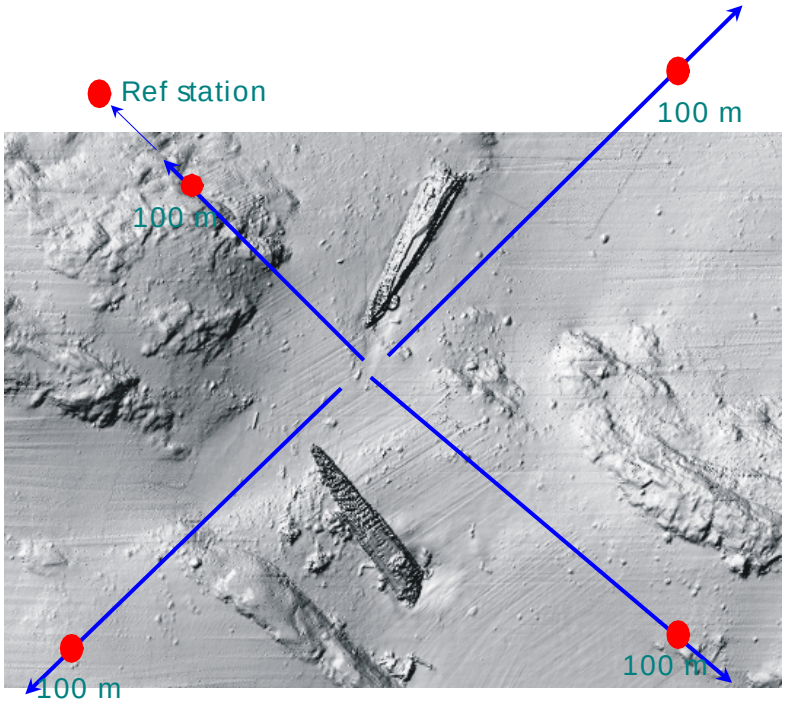

Figure 4-6 Illustration of suggested sampling stations. Red dots illustrate sampling stations (distance given not exact, for illustration purpose only).

For each location five samples should be collected by a van Veen grab with a surface area of 0.1 m^2. All samples should be sieved (mesh size 1 mm, circular holes), preserved and labelled in field before transport and sorting analysis in the laboratory.

Sorting and species identification

In the laboratory the samples shall be washed on 1 mm sieves with (circular holes) to remove preservatives and remaining fine sediment, and then sorted by hand under a magnifying glass. The animals shall be split into the major taxonomic groups; echinodermata, polychaeta, crustacea, mollusca and varia (all other groups) and transferred to 70 % ethanol before further species identification.

All animals shall be identified to the lowest possible taxonomic level (i.e. generally to species level) and the number of individuals per taxon in each sample shall be recorded.

Analytical methods

The statistical and mathematical methods that can be utilised to aid interpretation of the benthic fauna data are summarised below.

- Abundance ratio
- Shannon-Wiener's diversity index, H' (Shannon & Weaver 1963)
- Evenness calculated by Pielou's "evenness" J' (Pielou 1969)
- Expected number of species in a sample of 100 individuals (ES_{100})

Suitable multivariate analysis shall be performed to look at similarity between stations and temporal changes in order to group stations and assess gradients in the benthic communities.

4.8 Other long term monitoring methods

Monitoring of mercury in blue mussels may be relevant in this case. Caged mussels may be set out in cages around the remediation area and analysed for mercury or one may look at some biological indicators such as metallothionein. This is only briefly mentioned here since the monitoring methods described elsewhere in this document are regarded sufficient in order to establish a satisfactory overall monitoring regime with regards to remediation of U-864.

Another option which may be considered is to monitor the concentration of mercury in the benthic fauna. This could be an alternative to more common benthic community analysis as described in chapter 4.7.3. This could be an indicator of the effectiveness of the remediation.

5 GENERAL REMARKS

The suggested monitoring program is relatively comprehensive and complex. Different monitoring technologies and set up, relatively many monitoring stations and online transfer of results are the main reasons why this monitoring operation is considered complex. In addition the monitoring shall be performed within a limited area where the capping operation, also a relatively complex operation, will take place. The results shall be used for decision making and in this context a robust and reliable system is required. These were the reasons why the monitoring program was tested out during the survey in 2014.

Based on general experience and the experience from 2014 survey some general remarks can be done:

- Emphasis must be put on online transfer of data so that a continuous data stream is secured including storage and interpretation of data.
- A robust design of sensor platform and deployment of these should be made in order to avoid damage and losses of sensors both during deployment and during monitoring.
- Avoidance of loss of equipment because of corrosion due to use of acid resistant metal in contact with galvanized metal.
- Calibrated sensors

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Vedlegg V0.12 - Tokt 3b (januar 2014)

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Felles vedleggsrapporter			
V0.12.01	Keel Inspection U-864 (Phase 3b)	DOF Subsea	60
V0.12.02	Målinger av kvikksølv på utstyr hos Franzefoss og Deep C	NIVA	5
V0.12.03	Environmental monitoring during survey by submarine U-864 outside Fedje in 2014	NIVA	51

Keel Inspection U-864 (Phase 3b) (DOF Subsea)

DOF Subsea

KYSTVERKET

Keel Inspection U-864 (Phase 3B) Report

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1 INTRODUCTION

1.1 PROJECT DESCRIPTION

The German submarine U-864 was sunk outside Fedje, west of Bergen (Figure 1.1), in 1945. The submarine was torpedoed midships by a British submarine, broke in two and sank. The wreck is located in approximately 150m water depth. Both wreck sections are standing on the seabed on their keels, with a list of 24 and 15 degrees for forward and aft section respectively. The aft wreck section is situated on flat terrain and the forward section in a relatively steep slope with its bow pointing upwards (Figure 1.2).

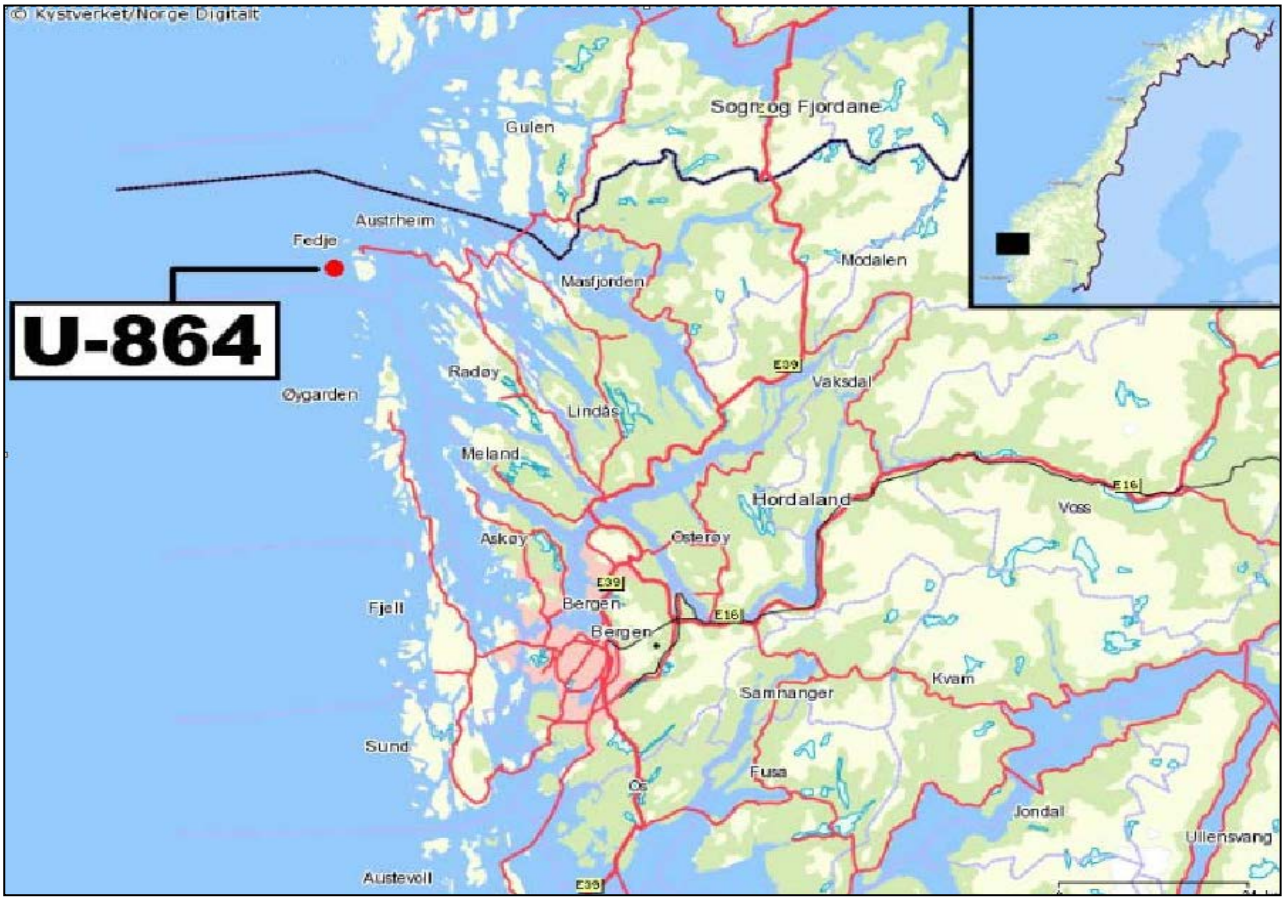


Figure 1.1 Map of U-864 Location

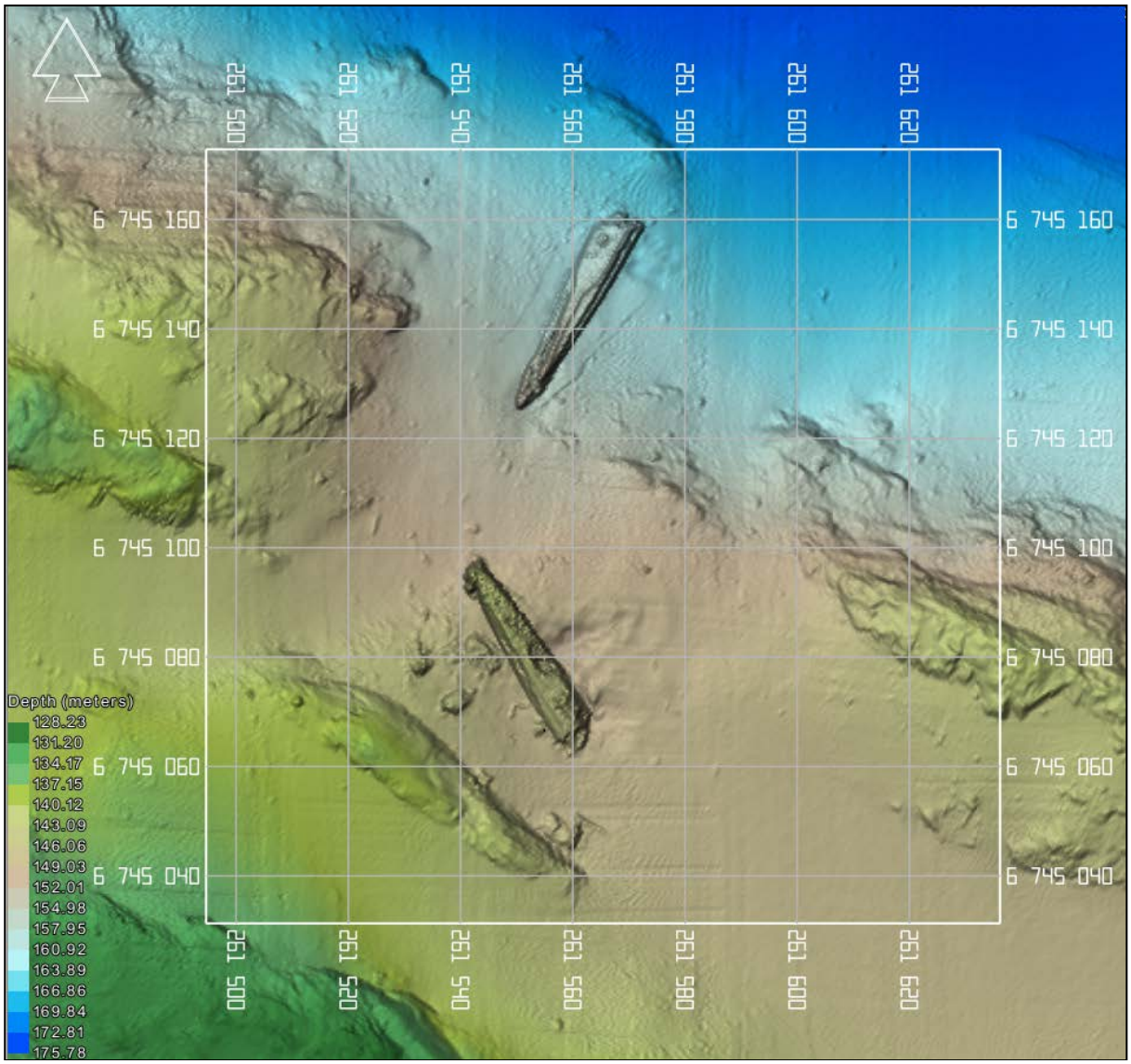


Figure 1.2 U-864 wreck and orientation on sea bed (From Phase 3A Survey, 2013)

U-864 is assumed to contain 67 tons of liquid mercury (Hg), stored in 1857 carbon steel cans in compartments inside the keel. When torpedoed, the mid section of the submarine was blown up and a substantial number of the stored Hg cans were destroyed. This led to significant Hg pollution of the seabed below. The number of Hg cans that have corroded and started to leak is unknown. It is assumed that there are intact Hg cans inside the keel compartments of both wreck sections, but the number of Hg cans and their condition is not known.

Kystverket has performed three offshore survey campaigns of the wreck site, Phase 1 in 2005 and Phase 2 in 2006. Phase 3A was conducted in 2013. Based on the information obtained Kystverket has given recommendations to the Ministry for Fisheries how to minimize the effects of the Hg pollution.

The authorities have decided to further evaluate two different methods of pollution abatement:

- Seal-in the polluted area, utilising sand with special characteristics.
- Retrieve the Hg cans from the keel section and seal-in the polluted area.

This report contains the findings from the Phase 3B Keel Inspection, conducted during January 2014.

1.2 DEFINITIONS AND ABBREVIATIONS

(Some Definitions and Abbreviations may not be applicable for this report)

C-O	Calculated minus Observed
CTD	Conductivity, Temperature and Density
CRP	Common Reference Point
DGPS	Differential Global Positioning System
DSNO	DOF Subsea Norway AS
DTM	Digital Terrain Model
DVL	Doppler Velocity Log
GPS	Global Positioning System
GVI	General Visual Inspection
HiPAP	High Precision Acoustic Positioning system
HSE	Health, Safety and Environment
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
MBE	MultiBeam Echo Sounder
MRU	Motion Reference Unit
MSL	Mean Sea Level
OAS	Obstacle Avoidance Sonar
OM	Offshore Manager
PM	Project Manager
QC	Quality Control
RINEX	Receiver Independent Exchange Format Version 2.10
PPS	Pulse Per Second
RLG	Ring Laser Gyro
ROV	Remotely Operated Vehicle
SBP	Sub Bottom Profiler
S/N	Serial Number
SOW	Scope of Work
SVS	Sound Velocity Sensor
SVP	Sound-Velocity Probe/profile
UNESCO	United Nations Educational, Scientific, and Cultural Organization
USBL	Ultra Short Baseline (acoustic positioning)
UTM	Universal Transverse Mercator projection
WGS-84	World Geodetic System of 1984
SUR	Survey
VR	Vessel Representative
WP	Work Package (Client Supplied)
ZDA	Date and Time (NMEA sentence)

1.3 REFERENCES

Table 1.1 Task Plan Listing

No.	Task Plan	Description of Task	Date
1.	600264-GSUN-O03-0001-01	Pre-survey and target investigation	08/01/2013
2.	600264-GSUN-O03-0002-01	NIVA installation	08/01/2013
3.	600264-GSUN-O03-0003-01	Wet store of periscope	08/01/2014
4.	600264-GSUN-O03-0004-01	Moving Target 8 and Deep C Operations	08/01/2014
5.	600264-GSUN-O03-0005-01	Entering keel and removing Hg canisters	10/01/2014
6.	600264-GSUN-O03-0006-01	Soil Sampling	10/01/2014
7.	600264-GSUN-O03-0008-01	Soil Sampling	14/01/2014
8.	600264-GSUN-O03-0010-01	Recovery of NIVA buoy	14/01/2014

Table 1.2 DSNO Procedures

No.	Document No.	Title
1.	DG-PY-0002	Policy - Health, safety and working environment
2.	DSA-SV-ST-0002	Global Standard - Dimensional Control Vessel and ROV
3.	DSA-SV-GL-0002	Guideline - Motion Calibration System, Javad Navigation Systems (Javad/Vessel)
4.	DSA-SV-PR-0005	Procedure - Heading Sensor Calibration, DSNO
5.	DSNO-SV-PR-0001	Procedure – Doppler and HAIN system checks
6.	DSNO-SV-PR-0002	Procedure – SAIV SD204 STD/CTD Operation
7.	DSNO-SV-PR-0004	Procedure – Vessel Mobilisation
8.	DSNO-SV-PR-0008	Survey Acceptance Test, DSNO
9.	DSNO-SV-PR-0010	Procedure – DGPS Configuration
10.	DSNO-SV-PR-0016	Procedure – Sound Velocity Sensor Verification
11.	DSNO-SV-PR-0017	Procedure – Transfer of Data and Information to Online Surveyor
12.	DSNO-SV-PR-0021	Procedure – Paroscientific Digiquartz Depth Sensor Configuration and Operation
13.	DSNO-SV-PR-0028	Procedure – DGPS Health Check
14.	DSNO-SV-PR-0029	Procedure – Leica Builder R200m Total Station
15.	DSNO-SV-PR-0032	Procedure – Motion Reference Sensor Calibration and Verification
16.	DSNO-SV-PR-0033	Procedure – USBL Calibration and Verification
17.	DSNO-SV-PR-0035	Procedure – Survey QA Checklists
18.	DSNO-SV-PR-0036	Procedure – Collection of survey Data
19.	DSNO-SV-PR-0037	Procedure – Control and Calibration of Total Stations
20.	DSNO-SV-PR-0039	Procedure – Survey Process
21.	DSNO-SV-PR-0044	Procedure – HiPAP Calibration using Kongsberg's APOS
22.	DSNO-SV-PR-0045	Procedure – Multibeam Echo-sounder Calibration and Verification
23.	DSNO-SV-PR-007	Procedure - Pressure Sensor for Draught Measurement
24.	DSA-GO-MN-0001	Process Management – Geology
25.	DSA-GO-GL-0002	Guideline - Video Eventing
26.	DSNO-SV-PR-0027	Procedure – Visualsoft
27.	DSA-MP-ST-0002	Global Standard – Data Processing
28.	DSA-MP-ST-0003	Global Standard – Project start-up and Crew Change
29.	DSA-MP-ST-0004	Global Standard - Survey Data Corrections
30.	DSA-MP-ST-0005	Global Standard - Terrain Modelling
31.	DSA-MP-ST-0006	Global Standard – Data Presentation
32.	DSA-MP-ST-0007	Global Standard - Internal Reporting
33.	DSA-MP-ST-0009	Global Standard – INS-HAIN Post Processing in Navlab
34.	DSNO-MP-PR-0003	Procedure – Water column - use of CTD/SVP Data
35.	DSA-MP-GL-0001	Guideline – NaviEdit
36.	DSA-MP-GL-0002	Guideline – Imaging
37.	DSA-MP-GL-0004	Guideline – Surfer
38.	DSA-MP-PR-0001	Procedure – Cfloor
39.	DSA-MP-PR-0002	Procedure – Navimodel
40.	DSA-MP-GL-0005	Guideline – GIS

No.	Document No.	Title
41.	DSA-MP-GL-0006	Guideline – Autochart
42.	DSA-MP-GL-0007	Guideline – Data Export from AutoCad to ARCGIS
43.	MGI-MAP-O04-0015	Guideline – Seabed Topography Reporting, creating diagrams
44.	DSA-MP-GL-0008	Guideline - Isopach Modelling
45.	DSA-MP-GL-0009	Guideline - Pipeline Inspection
46.	DSA-MP-ST-0012	Global Standard - AutoCad -Designing and Maintaining Production Line
47.	DSA-GO-PR-0001	Procedure – Sub Bottom Profiler (SBP) Operation
48.	DSA-GO-PR-0002	Procedure – Sidescan Sonar (SSS) Operation
49.	DSA-GO-GL-0012	SBP Data Interpretation Procedure
50.	DSA-GO-GL-0013	SSS Data Interpretation Procedure
51.	600246-PJ-O03-0001-03i	Mob and demob procedure
52.	600246-PJ-O03-0003-04i	600246-PJ-O03-0003-04i Operational procedures

Table 1.3 Attachments

No.	Document No	Title	Rev.	Date
1	NIVA 6642-2014	Environmental monitoring during survey by submarine U-864 outside Fedje in 2014		06.05.2014
2	600246-GSUN-G59-0001	Post dredge MBE Survey U-864 stern section	02	13.05.2014

Table 1.4 Revision Table

Rev.	Date	Description
01	01.02.2014	Issued for IDC
02	05.02.2014	Issued for Company Comments
03i	14.05.2014	Issued for Construction

1.4 GEODETIC DATUM

All positions described in this report are referenced using the following geodesy.

Spheroid Parameters	
Datum	WGS-84
Spheroid	WGS 84
Semi-major axis	6 378 137.000 metres
Flattening (1/f)	1/298.2572235630

Projection Parameters	
Projection	UTM – Grid Zone 32 North
Central Meridian	9° East
Latitude of Origin	0° (Equator)
False Easting	500 000 metres
False Northing	0 metres
Scale Factor on CM	0.9996

1.5 Definition of Time

Times quoted are given in local (UTC+1) unless otherwise defined in the text.

2 PROJECT DESCRIPTION

2.1 SCOPE OF WORK

The scope of work consisted of the following tasks for U-864 Phase 3B:

- **Installation of Environmental monitoring sensors including water, sediment and current sampling. A roll and pitch sensor was also mounted on the wreck to monitor any movement.**
- **Relocation and wet store of the U-864 Attack Periscope (near Target 8), which had been discovered during Phase 3A**
- **Removal of detached wreckage from alongside the hull, known as Target 8, which was blocking access to the keel.**
- **Obtain access to the keel investigate and assess extraction of any mercury canisters located.**
- **Assess recovery of mercury canisters from beside the wreck.**
- **An as left MBE survey documenting the disturbance of the site and it's condition after completion of Phase 3B.**

2.2 SUMMARY OF PROJECT ACTIVITIES

2.2.1 Mobilisation

The mobilisation commenced on the 6th of January 2014 at Dokken Quay, Bergen. It was conducted in a safe manner and the alongside stage was completed on the 7th January 2013. The vessel departed at 21:05 to perform offshore testing of both ROV's and the Deep C excavator. Offshore wet testing of the equipment started at 21:53 on the 7th and continued until 05:45 on the 8th January when the vessel started transit to site.

2.2.2 Calibrations

All systems on the vessel had been previously calibrated for prior projects. However, the new UHD66 ROV required several checks and calibrations before certain stages of the operation could commence. As the final as left multi-beam survey was postponed a calibration of this system was not carried out.

2.2.3 Work Performed

On the 8th January 2014 at 09:50 the MV Geosund arrived on location and proceeded to carry out the tasks described in the SOW Section 2.1.

The first task was the location of a suitable place for the magnetic clamp and transponder installation. Following this, a GVI of Targets 8 and 15 as described in report 600252-SSKO-O15-0001 Phase 3A. By 15:50 the clamp and transponder were installed along with the GVI. At 18:25 the weather buoy was deployed and preparations for deploying the environmental equipment took place. Stations OV4, OV3 and OV5 were placed by 24:00 on the 8th January (See Figure 2.1).

During the early hours of the 9th January the deployment continued of monitoring stations OV7, OV6 and OV2. After planning and preparing a task plan the periscope relocation operation proceeded placing it in a wet store location, this was completed by 09:00. The overboard of the NIVA current meter tripod then took place. Due to the proximity of the surface buoy to operations it was decided to relocate it to a new position so that it would not hinder operation further. The next operation at 14:20 involved moving 3 x gun barrels to the wet store location. During this period preparations were made for the grab operations to clear debris from the planned excavation area.

Grab operations commenced at 19:19 in addition munitions exposed were relocated to a wet storage area by the ROV. The grab moved boulders and some wreckage to clear an area for the Deep C excavator but it was unable to dig holes as the hold of the debris took it near its safe working load. It was noted that the area was strewn with interwoven wreckage whilst at the same time the soft seabed meant any movement reduced the visibility, slowing the task. These operations continued until 07:40 on the 10th January when the grab was landed on deck. Water sampling commenced and a toolbox talk conducted prior to the deployment of the excavator. By 11:26 the Deep C excavator was deployed and shovel testing took place. By 15:19 4 x mercury canisters were located and both ROV's were used to check the area for any further ones. The subsea basket was then deployed and the 4 canisters place inside. The Port ROV was then used to collect water samples whilst the Starboard ROV assisted the Deep C excavator. Again it was noted that the soft sediment was significantly reducing visibility, slowing the operation.

At 00:00 on the 11th January the excavator was connected up to the crane and relocated to continue digging. Interwoven debris as mentioned and poor visibility reduced the efficiency of the operation. Further water sampling was completed by 09:26 as digging continued. At 14:08 it was decided to halt the Deep C digging operation and redeploy the grab. The excavator was landed on deck whilst an ROV inspected the work area. At 16:38 the grab was deployed and manoeuvred into position. Multiple attempts were made to remove debris with the grab but each time the load was up to the limit of operation. At 20:02 on the 11th January the grab was recovered and landed on deck after subsea cleaning at 20:44. A round of water samples was conducted by the Port ROV

whilst the Starboard ROV cleared debris at the target hull entry point. During this time an assessment of the work site excavation was conducted. At midnight it was decided to reconfigure the Deep C excavator unit for dredging/suction operations.

The increase in the weather during the early hours on the 12th January limited crane operations but it was still possible to continue ROV debris clearance. At 06:13 seabed sampling occurred with samples deposited in the deployed subsea basket. A 4th 20mm barrel was relocated and a Hg bottle placed in the basket. The subsea basket containing seabed samples was recovered at 09:18. Water sampling again took place whilst the Deep C excavator continued the reconfiguration. At 14:43 the excavator was deployed and at 16:32 dredging operations commenced utilising one of the possible two pumps. During the dredging operations regular water samples were taken. The dredging operation was stopped to allow the evaluation of the work site with respect to access to the hull at 06:54 on the 14th January. After evaluation at 18:45 access was considered acceptable. The Deep C excavator then started the reconfiguration for the manipulator (robotic arms) platform. During this period further water and seabed samples were collected.

On the 15th January the seabed basket was recovered, following this the NIVA tripod (current meter) was recovered then later redeployed after reconfiguring. At 17:33 the reconfigured Deep C excavator with fitted tooling platform (robotic arms) was deployed at the hull entry target zone. Clay was then scraped from the hull to expose the metal surface ready for cutting. At 22:23 cutting of the first hole began, at 03:40 on the 16th of January an initial inspection into the cavity showed nothing and a request to enlarge the aperture was made. Cutting resumed and continued until 11:46 when a second inspection reviled an empty space with no ballast or canisters. At 12:56 a second cut was started to open the adjacent compartment. This continued until 17:18 when an inspection was made of both open compartments. Examination showed that both compartments were empty with no ballast or canisters contained within.

With the inspection complete the excavator was recovered to deck and a site clear up and visual inspection completed. A final round of water sampling was completed by 23:45 on the 16th January. At this time the wind speed increase and crane operation were suspended until 07:37 on the 17th January. Once the weather was within limits the subsea basket was recovered followed by the recovery of the NIVA surface buoy. A final subsea basket deployment and recovery was used to collect the last remaining subsea tools prior to transit back to Bergen. At 16:15 on the 17th with the vessel secure alongside, all project equipment then was demobilised; this was completed by 04:25 on the 18th January.

2.3 ENVIRONMENTAL MONITORING SYSTEMS

Prior to the start of dredging operations MV Geosund deployed an environmental monitoring system consisting of a 7 unit array of combined sediment trap / turbidity sensor units (OV). The array was complimented with a single current sensor (C) and a surface telemetry buoy (SB) which transmitted the data to the shore. The array was deployed on the 8th and 9th of January 2014 (Figure 2.1, Table 2.1). During deployment one monitoring station was damaged and so OV-1 was not populated with sensors. Figure 2.1 also include the Water sample location (WSL) used during the Phase 3b work.

On completion of the operation the current sensor was left in situ and is intended to provide data on site for up to a year.

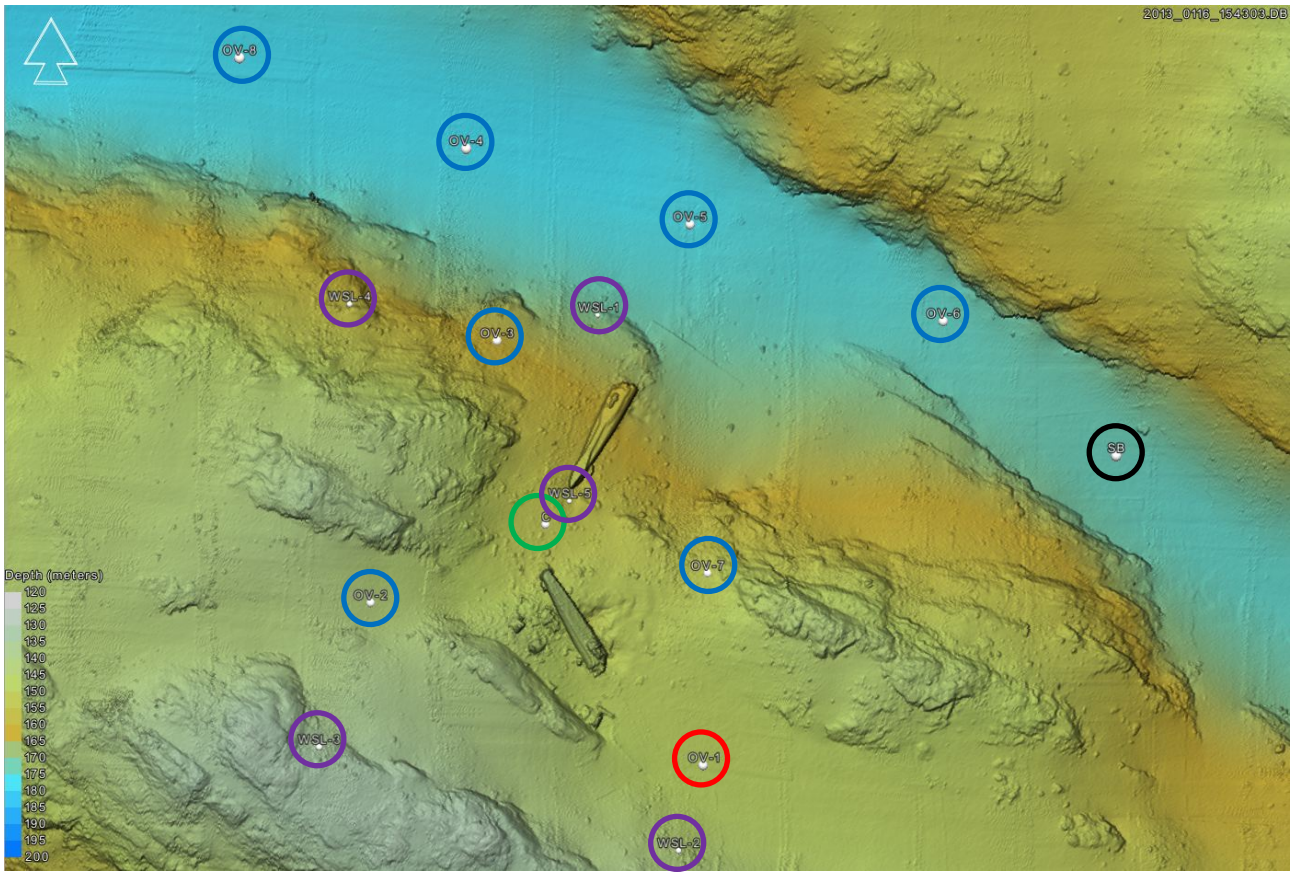


Figure 2.1 Environmental monitoring stations: Turbidity and sediment traps (OV) Blue, Current meter (C) Green, Surface telemetry buoy (SB) Black and Water sampling location (WSL) Purple. (OV-1 not used Red)

Table 2.1 Monitoring station deployment positions

Station Name	Easting (m)	Northing (m)	Note
OV-1	261596	6745032	Not Used
OV-2	261483	6745086	
OV-3	261525	6745175	
OV-4	261514	6745240	
OV-5	261590	6745215	
OV-6	261676	6745183	
OV-7	261597	6745097	
OV-8	261437	6745270	

Station Name	Easting (m)	Northing (m)	Note
Current	261542	6745113	
Buoy	261735	6745138	
Water sample location 1	261559	6745184	
Water sample location 2	261588	6745003	
Water sample location 3	261466	6745037	
Water sample location 4	261475	6745187	
Water sample location 5	261550	6745121	Used when access to location 1,3 & 4 were restricted due to vessel position

A subsea transponder was affixed to the Stern section of the wreck (Figure 2.2) on the 8th of January and regularly interrogated to determine pitch and roll values and quickly identify any movement or rotation of the U Boat (Table 3.2). The magnetic mounting bracket for the inclinometer was left in place at the conclusion of the project to provide a repeatable reference point for future work. See section 3.1 for further details.

Figure 2.2 Subsea transponder (COMPATT) mounted on the Aft of U-864

2.4 SUBSEA OBJECT RELOCATION

During the course of this Phase 3b items were relocated at client request.

2.4.1 Relocation and Wet Store of Artefacts

During the 2013 Phase 3A campaign the Attack Periscope of the U-864 was located (Figure 2.3).

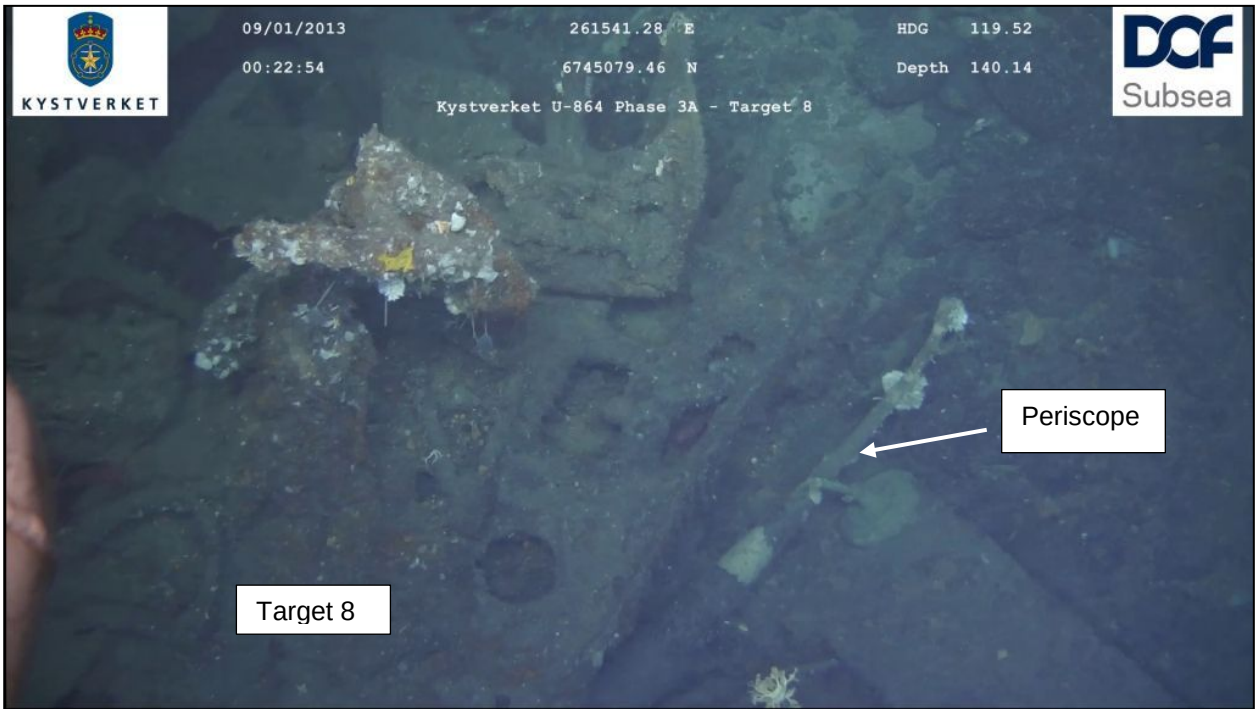


Figure 2.3 U-864 periscope as located during Phase 3A

The Type IXD U Boat was equipped with 2 periscopes, one with a larger diameter view port known as the Search or Observation Periscope, and a second, much smaller version, known as the Attack Periscope.

As the wreck is both globally historically significant and culturally significant for the Norwegian people it was decided to recover this artefact for possible later display in a museum.

The periscope was removed from the area of dredging for protection and wet stored approximately 35m from the wreck site on the 9th January.

Further details can be found in Section 3.2 and 3.3 along with details of other artefacts that were wet stored.

2.4.2 Relocation of Detached Wreckage

A large section of detached wreckage was found to be blocking access to the required dredge area.

Designated Target 8, the large piece of wreckage measured approximately 9.5m x 4.5m and consisted of a section of the U-864's anti-aircraft "winter garden" deck area and conning tower. As such it contained a number of canisters containing 20mm anti-aircraft ammunition which were relocated by the ROV prior to the main operation. Two 20mm Guns were also removed and wet stored before the operation commenced.

The remainder of the wreckage, consisting of decking, fixtures and fittings and sections of the outer conning tower 'skin' were removed through the use of a subsea hydraulic grab.

Target 8 was relocated on the 8th and 9th January.

2.5 KEEL ACCESS AND INVESTIGATION

Although the aft section of the keel was visible (approximately 1m length) this section was not believed to contain any mercury canisters. This assumption was based on the study of a similar U Boat, U-534 in Birkenhead, UK.

To gain access to allow penetration into the keel compartments an area of seabed required excavating. At all times during these operations consideration was given to minimising the pollution risks. To ascertain the pollution levels a program of water and soil sampling was conducted in a frequent cycle throughout the project. Even though a variety of excavating techniques were used, initial investigations suggested there was no significant increase in Hg levels in the wider area.

The excavation of the seabed commenced using the grab (Figure 2.4) to remove surface debris in an effort to clear a safe area for landing the Deep C digger. Figure 2.5 shows an example of the debris in the local area which needed clearing prior to excavation activities.

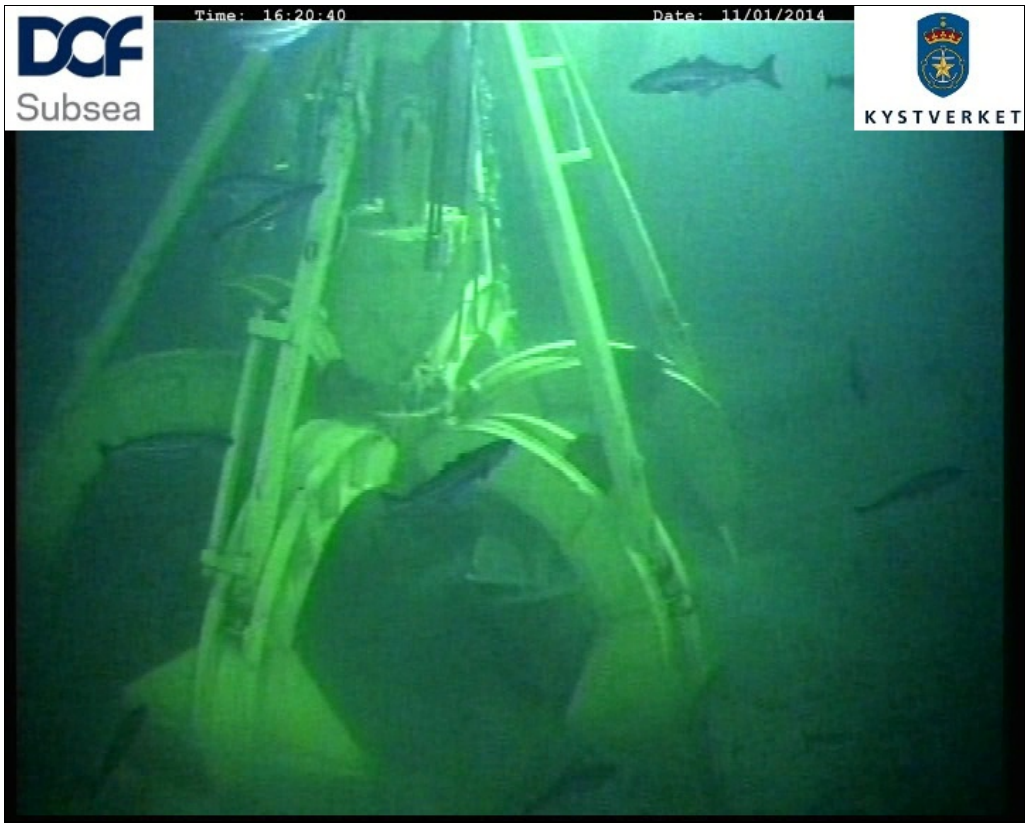


Figure 2.4 Grab in operation

Figure 2.5 Example of debris

Figure 2.6 shows the view from the Deep C operator's perspective of the extent of the debris. This was cleared by both the grab and ROV's to enable digging but due to the interwoven nature of the debris it became apparent that switching to the dredging option was to be considered.

Figure 2.6 View from Deep C showing debris on seabed and excavator with shovel fitted

On completion of re-configuration to dredging mode, operations proceeded with greater efficiency. The hole excavated was kept to a minimum size just big enough to fit the manipulator platform (robotic arms) near the hull.

The Deep C machine was then fitted with two Titan 4 Robotic arms on an extendable pedestal which were used to cut holes in the keel storage areas and to inspect the compartments (Figure 2.7).

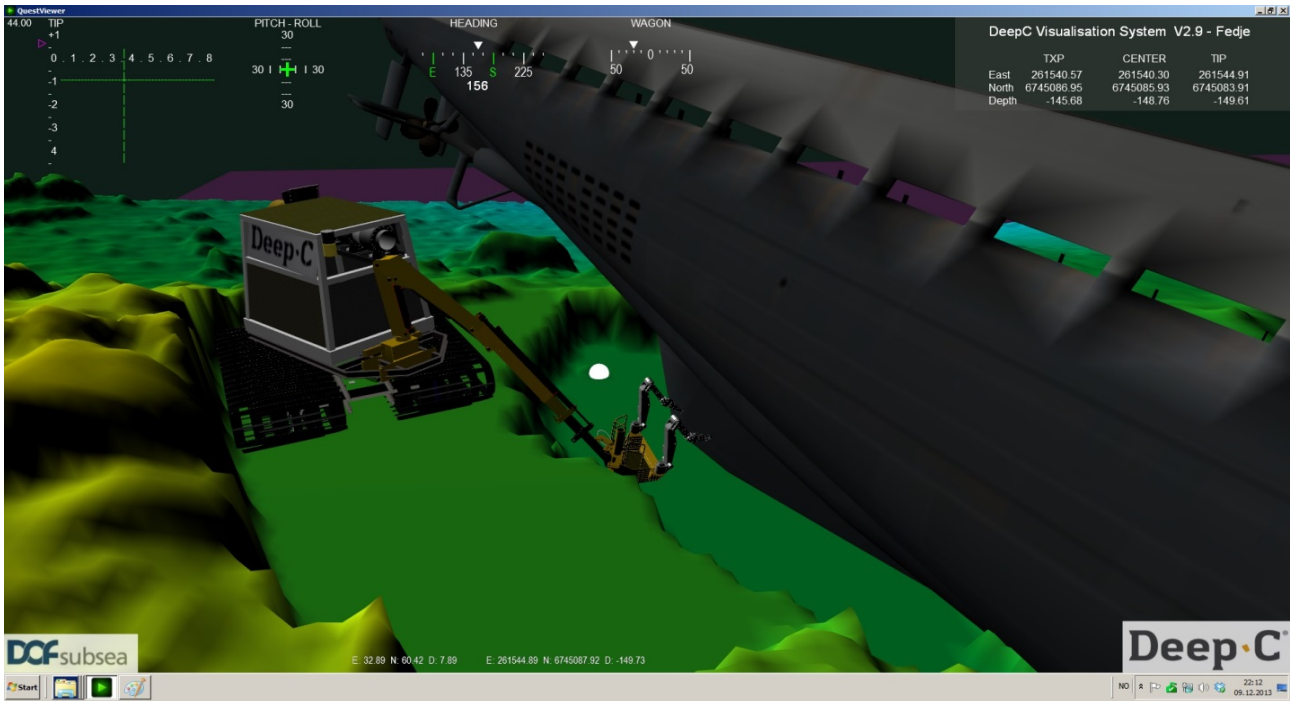


Figure 2.7 Conceptual imagery of Deep C digger fitted with tooling platform (robotic arms)

An examination was made of the keel structure and the method of packing the mercury canisters into the keel. No suspected mercury canisters were found (Figure 2.8 and Figure 2.9).

Figure 2.8 Paired pictures showing 1st entry point and empty compartment

Figure 2.9 Paired pictures showing 2nd entry point and empty compartment

2.5.1 Recovery of Mercury Canisters

Throughout the operation a careful watch was kept by all personnel for any suspected mercury containers. Due to the nature of the tasks being undertaken (dredging and wreckage relocation) it was inevitable that some canisters which had fallen from the wreck on impact would be unearthed. 6 suspected canisters were located on the seabed in areas that had been disturbed during the operation.

Using a purpose built scoop (Figure 2.10), the canisters were removed and placed into an isolation basket for recovery to deck where they were identified and their contents verified. These were delivered to Kystverket on completion of the field work.

Figure 2.10 Recovery of mercury canister with purpose built scoop

3 SUMMARY OF RESULTS

The following chapter summarises the results of operations completed by the MV Geosund over the course of U-864 Phase 3B. Additional information can also be found in the environmental monitoring report from NIVA.

The project benefited from the presence of the Kystverket Project Manager on board the MV Geosund during the project. This ensured that any queries regarding aims, objectives or variations could be addressed quickly and accurately ensuring that project objectives were completed in an effective manner.

3.1 INSTALLATION OF ENVIRONMENTAL MONITORING SYSTEMS

Prior to any disturbance of the seabed a subsea transponder was affixed to the Stern section of the wreck (Figure 2.2 and Table 3.1). The high accuracy inclinometer was interrogated at regular intervals in order to quickly identify any movement or rotation of the U Boat. As can be seen in the Table 3.2 there was no substantial movement of the wreck and the slight variances seen are within the accuracy of the inclinometer unit.

Table 3.1 U-864 compatt location (pitch & roll measurements)

Easting (m)	Northing (m)
261545	6745093

Table 3.2 Roll and pitch readings (note the wreck is Bow down and Port side down)

Date	Time	Roll (˚)	Pitch (˚)	Comment
08.01.14	14:41	21.88	5.04	Compatt installation
09.01.14	15:15	21.92	5.04	Pre grab
09.01.14	19:26	21.92	5.04	Grab
10.01.14	04:45	21.93	5.04	End of grabs
10.01.14	09:51	21.95	4.94	Deep C deployment
10.01.14	13:05	21.89	5.11	
10.01.14	13:51	21.89	5.12	
10.01.14	20:27	21.89	5.11	
11.01.14	05:02	21.89	5.11	
11.01.14	12:20	21.89	5.11	
11.01.14	14:27	21.89	5.11	Deep C recovered
11.01.14	23:13	21.89	5.12	Grab operation
12.01.14	10:13	21.89	5.12	
12.01.14	15:00	21.89	5.12	Dredger in position
12.01.14	16:00	21.89	5.12	Dredging
12.01.14	17:00	21.89	5.12	Dredging
12.01.14	18:00	21.89	5.12	Dredging
12.01.14	19:00	21.89	5.12	Dredging
12.01.14	20:00	21.89	5.12	Dredging
12.01.14	21:00	21.89	5.12	Dredging
12.01.14	22:00	21.89	5.11	Dredging
12.01.14	23:00	21.89	5.11	Dredging

Date	Time	Roll (˚)	Pitch (˚)	Comment
13.01.14	00:00	21.89	5.11	Dredging
13.01.14	01:00	21.90	5.11	Dredging
13.01.14	06:44	21.95	5.07	Move dredger
13.01.14	13:07	21.90	5.10	Dredging
13.01.14	15:23	21.91	5.07	Dredging
13.01.14	16:30	21.91	5.09	Dredging
13.01.14	17:30	21.90	5.09	Dredging
13.01.14	18:30	21.90	5.09	Dredging
13.01.14	19:30	21.90	5.11	Dredging
13.01.14	20:30	21.91	5.11	Dredging
13.01.14	21:30	21.91	5.11	Dredging
13.01.14	22:30	21.90	5.11	Dredging
13.01.14	23:30	21.91	5.10	Dredging
14.01.14	00:30	21.91	5.10	Dredging
14.01.14	01:30	21.91	5.10	Dredging
14.01.14	02:30	21.90	5.09	Dredging
14.01.14	04:47	21.90	5.10	Dredging
15.01.14	16:49	21.90	5.10	Cutting

It should be noted that the figures quoted do not represent an absolute roll and pitch of the after section of the wreck as it is impossible to guarantee that the mounting bracket is aligned exactly. It can be said however that the aft section of the wreck has a stable and consistent roll of approximately 22˚ to port, and a pitch of approximately 5˚ bow down.

3.2 RELOCATION AND WET STORE OF PERISCOPE

As can be seen in Figure 2.3 the periscope was positioned alongside and underneath a large piece of wreckage, designated Target 8. Historical research indicated that the periscope's length, assuming it had been raised at the time of sinking and sheared off level with the periscope support on the conning tower, would be approximately 4m long. If this was the case the base of the periscope would be visible on the other side of Target 8. As it was not visible the periscope was known to be either significantly shorter or bent underneath the wreckage.

An unsuccessful attempt was made during Phase 3A to relocate the periscope with the ROV manipulator. As the ROVs available on MV Geosund were of a more powerful type it was anticipated that they would succeed at a second attempt, however they were also unable to move the periscope.

It was feared that use of the grab to remove Target 8 would cause damage to the valuable artefact and so it was important to attempt to remove it beforehand. The crane was attached to the periscope with a sling, and steady tension applied at an oblique angle until the periscope was freed from the wreckage (Figure 3.1). At this point it was found that the periscope was indeed bent at 90˚ twice along its length however no further significant damage had been caused during recovery.

Table 3.3 U-864 periscope wet store location

Easting (m)	Northing (m)
261510	6745055

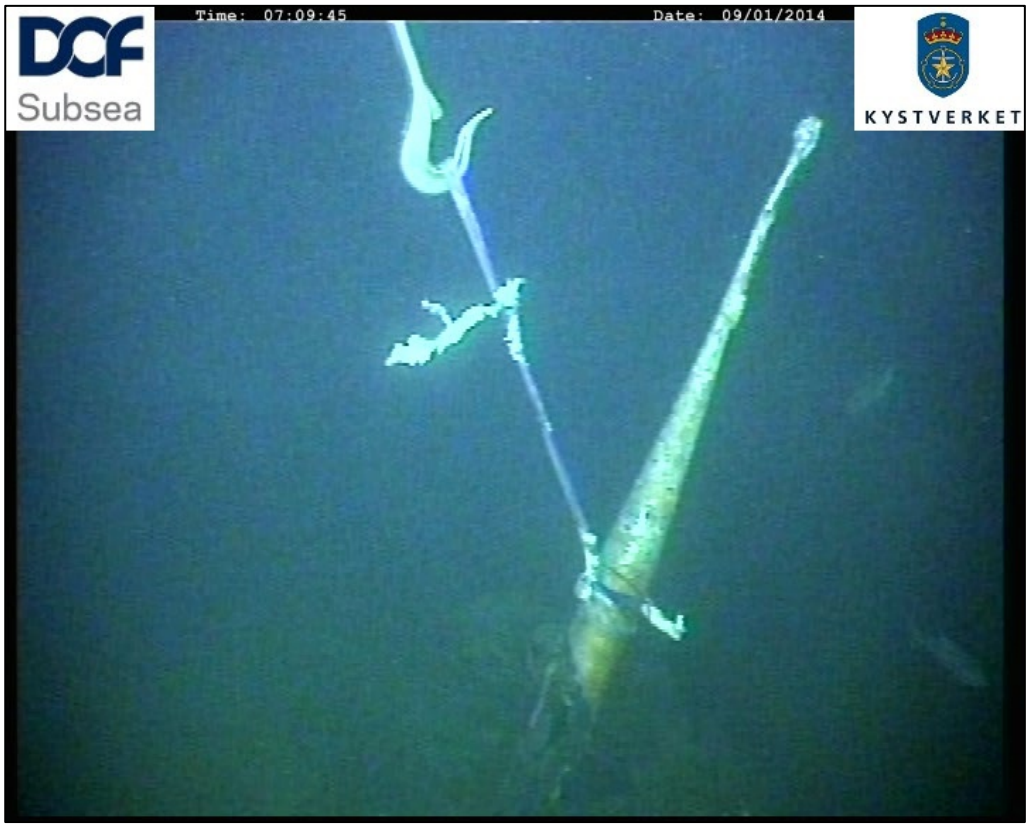


Figure 3.1 Periscope being pulled clear of Target 8

3.3 RELOCATION OF DETACHED WRECKAGE

Within the structure of Target 8 were a number of artefacts of either historic value or hazardous nature. As it was a requirement of the planned dredging that Target 8 be moved the historical and hazardous objects were first removed with the ROV manipulators. Figure 3.2 blow showing the aft part on a historical picture.

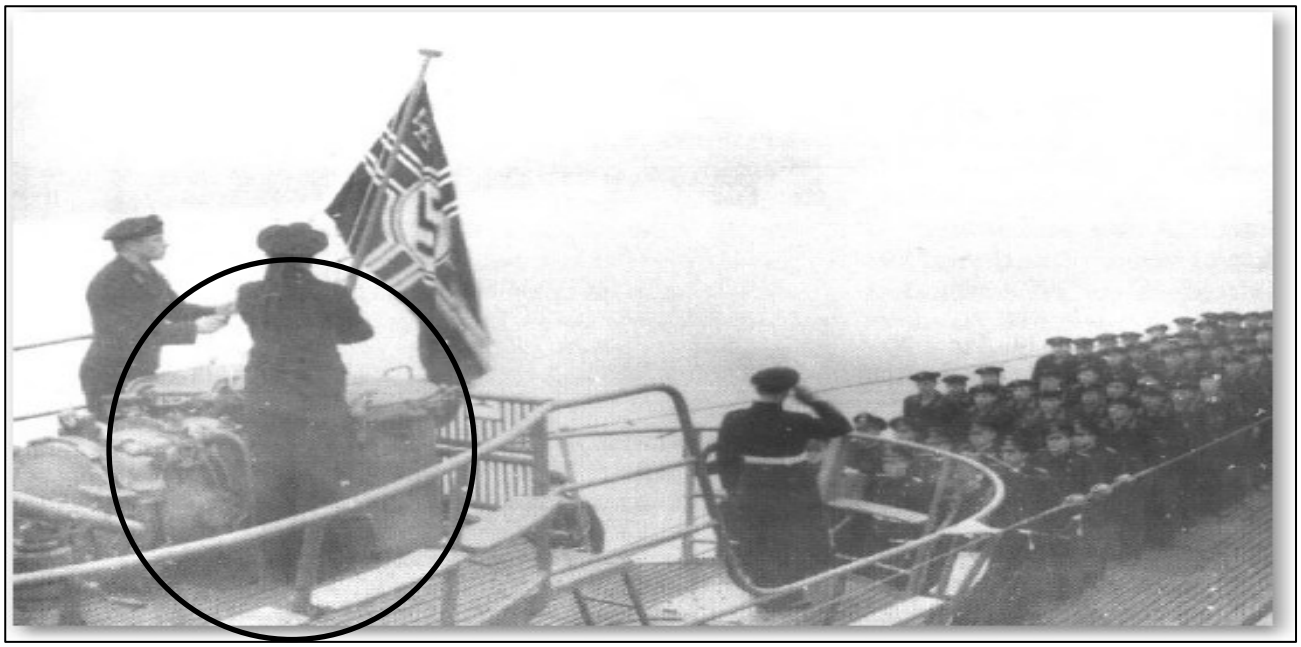


Figure 3.2 U-864 showing after part of Target 8 (circled)

Figure 3.3 Target 8 showing life raft and ammunition canisters

The canisters (Figure 3.3) were believed to contain both 20mm ammunition (Figure 3.4 and Figure 3.5) and inflatable life rafts (Figure 3.6). Use of the grab to relocate these containers had a high potential to split or damage them, spilling ammunition or the raft into the dredge area. Although the life rafts were not immediately hazardous to the operation if allowed to drift around the site they would present an entrapment hazard to the equipment and there was a high potential of them being pushed away from the site by the current thus spreading contamination.

Figure 3.4 20mm ammunition container in situ near Target 8

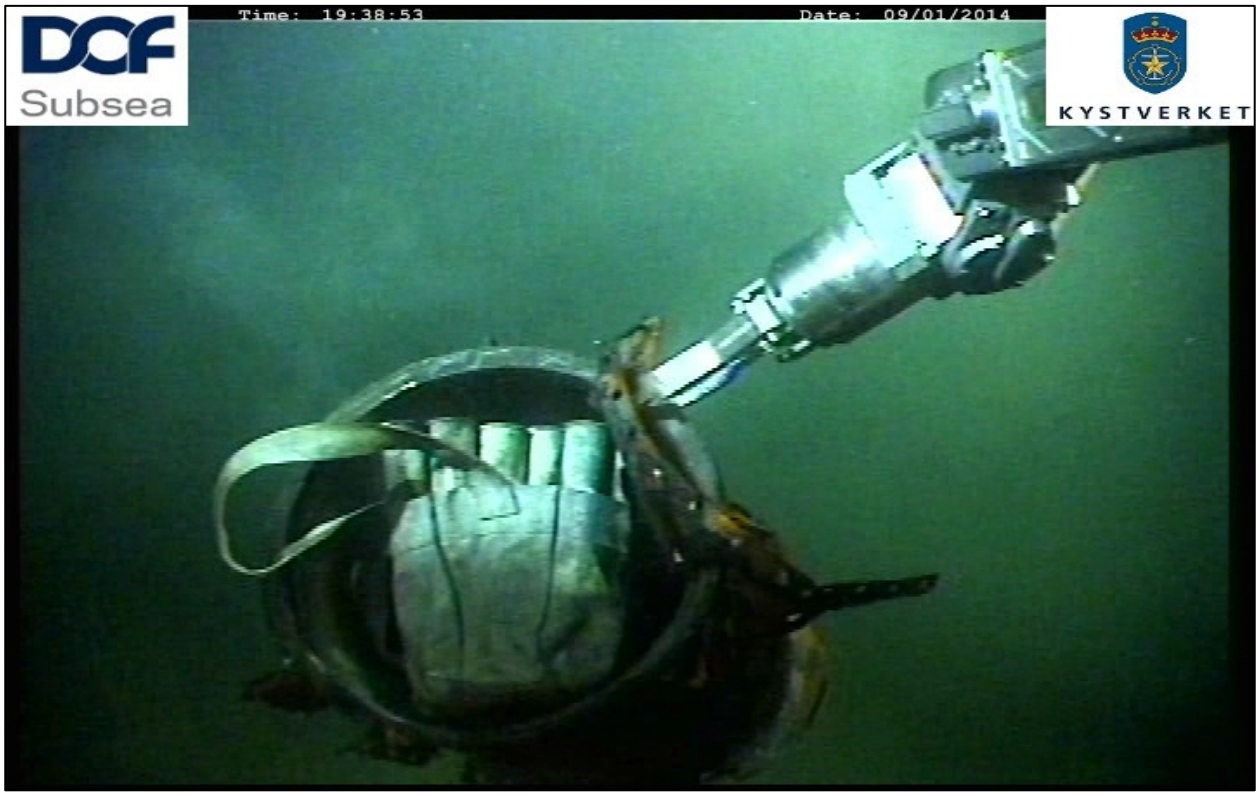


Figure 3.5 20mm ammunition being transported to the wet store area. Note the excellent condition of the satchel

Figure 3.6 Removal of life raft canister. Note the line and lose material representing an entanglement hazard

Two 20mm anti-aircraft guns were removed from Target 8 as they represent a potential historical artefact suitable for museum display. They were left on the seabed location 261528.10E 6745072.91N.

Target 8 was relocated on the 8th and 9th of January to location 261510.62E 6745055.99N

3.4 KEEL ACCESS AND CANISTER EXTRACTION

Although the aft section of the keel was visible (approximately 1m length) this section was not believed to contain any mercury canisters and so a Deep C dredging system was utilised to gain access to an extended length of keel.

Through the use of both a shovel style digger and a 14” suction dredge the area under the starboard side at the after end of the wreck was uncovered to provide access to the keel hatches.

The Deep C machine was then fitted with two Titan 4 Robotic arms on an extendable pedestal which were used to remove the covers on the keel storage areas and to extract the mercury canisters (Figure 2.7).

An examination was made of the keel structure (Figure 3.7 and Figure 3.8) and though no canisters were discovered. As each keel compartment is separated into a port and starboard section a hole was created in the dividing steel plate to examine the contents of the opposite compartment.

Figure 3.7 Imagery of Deep C vehicle accessing the keel 10cm x 10cm hole

Figure 3.8 UHD66 Imagery of Deep C vehicle accessing the keel

3.5 RECOVERY OF MERCURY CANISTERS

Throughout the operation a careful watch was kept by all personnel for any suspected mercury containers. Due to the nature of the tasks being undertaken (dredging and wreckage relocation) it was inevitable that some canisters which had fallen from the wreck on impact would be unearthed and 6 canisters were located on the seabed in areas that had been disturbed during the operation.

Using a purpose built scoop (Figure 2.10), canisters were removed and placed into an isolation basket for recovery to deck. As mentioned the two entry points in the hull revealed empty compartments.

3.6 OVERVIEW OF SITE ON COMPLETION OF PHASE 3B

During the course of Phase 3B artefacts were relocated and equipment left in place. The following table and figure details the locations of these items.

Table 3.4 Location of items on completion of Phase 3B

Description	Easting (m)	Northing (m)
Periscope & Target 8 Items	261510	6745055
20mm Anti-Aircraft Guns	261528	6745073
NIVA Current Monitoring Tripod	261542	6745113
Magnetic Clamp (For Pitch and Roll Compatt)	261545	6745093

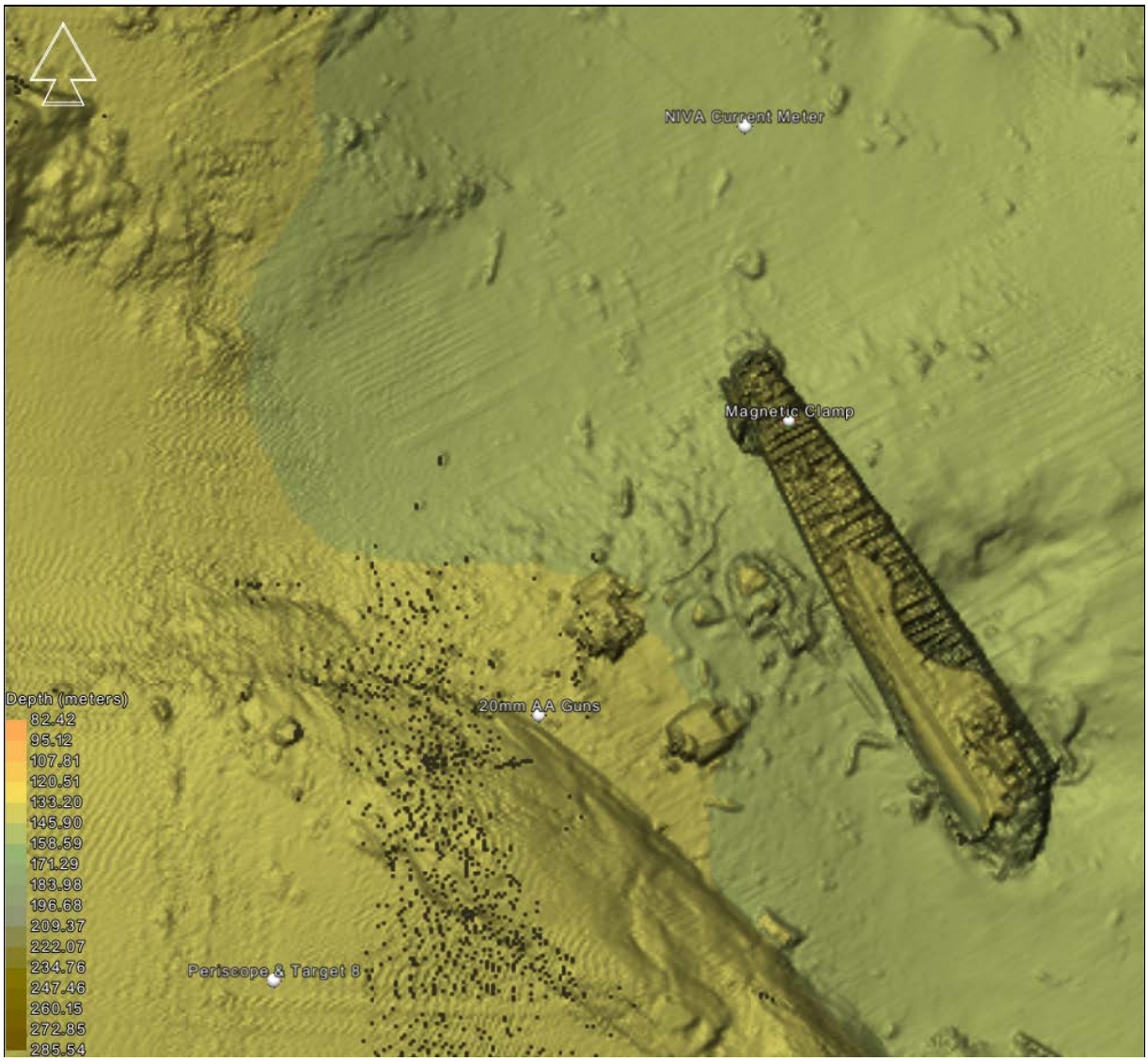


Figure 3.9 Items on the seabed

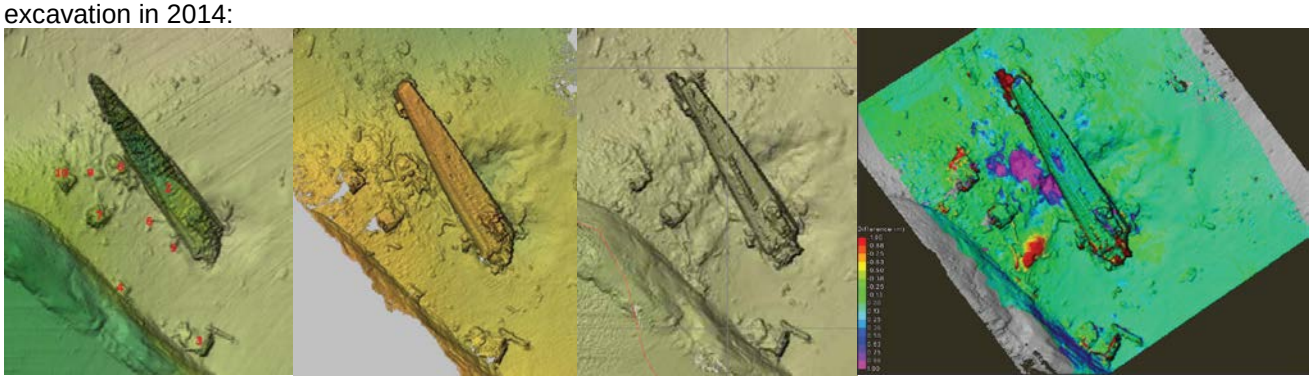
4 AS-LEFT MBE SURVEY

4.1 GENERAL

Initially a ROV MBE survey was planned as a part of the project to document the as left status of the area after the excavation work. Due to priorities made to access the keel within the given timeframe this was agreed to postpone to a later date. This survey was performed by Geosund 6th of April 2014 after mobilisation for another client and passing the area.

4.2 COMPARISON OF DATA

The images below illustrate the current status of the seabed and the changes to the seabed made during the excavation in 2014:



Data from 2004 | Data from 2013 | Data from 2014 | Difference 2013 to 2014 (After excavation)

4.3 U-864 AFT SECTION – MOVEMENTS

The MBE data in 2013 was collected at the start of the campaign and the data in 2014 was collected at the end of the campaign. Looking into the datasets from 2013 and 2014 there is no significant movement of the aft section occurred as a result of the activities in 2013 or the excavation in 2014 ref. illustration in section 4.2 above.

5 EXPERIENCES

5.1 NIVA ENVIRONMENTAL MONITORING

The rigging planned for the environmental monitoring stations showed not to be optimal with regards to deck handling. This resulted in damages to the equipment during crane handling when launching and recovering under the current weather conditions.

This equipment was left on the seabed to be recovered at a later stage. When attempted to be recovered by another vessel in April 2014 – the rigging was found to be corroded and only 2 of 8 stations were found. The final conclusion remains to be presented but obviously a bad combination of metal has been used.

One of the missing stations was later found by the Coast Guard.

The environmental stations were built to send data subsea from all stations to a logging device with a connection to a surface transmitter sending data to shore. This data was accessible from internet. After 2 days the data stopped arriving, but it was assumed that the communication had failed but still logging data subsea. The recovered sensors however showed that there were no data logged due to dead battery on unit. The reason for this is still to be concluded and is currently being evaluated by NIVA and their equipment suppliers.

5.2 ROV CORE SAMPLES

Core samples were taken north of the wreck to document any changes to the contamination in the area. The samples taken were not accepted by the scientist due to their condition and new samples were asked to be taken. Due to time constraints and the priority given to access the keel at the final stage of the field work – these samples were not re-collected during this campaign.

5.3 ORANGE PEEL GRAB

To clear the area for excavation a mechanical orange-peel grab was utilised. This was operated subsea by the ROV. By the nature of this grab's operational limits it was found to be difficult to move smaller objects or selecting less amounts (weight) on each lift.

A hydraulic operated grab would have provided more flexibility to the operations and can be recommended for similar work.

5.4 EXCAVATION

To limit the environmental impact of the excavation a mechanical shovel was developed for the project to move the sediments. This shovel worked as intended, however the sub-seabed conditions with rocks and metal debris hindered effective dredging – as cleaning of the area with the grab was not as complete as hoped for.

Due to the above the spread was converted to excavate by traditional dredging to improve efficiency. This improved progress and provided access the keel as planned.

High resolution sonar was fitted to the WROV to aid the dredging. This equipment did not provide any added value to the project. It could be beneficial to include standard MBE data and CAD capacity for volume calculations for future work.

5.5 ENVIRONMENTAL IMPACT

The sediment trap in location OV-8 (ref. Figure 2.1 above) shoved beyond reasonable doubt that material originating from the dredging activities had spread to this location. Future dredging activities should mitigate such spread of materials to avoid contamination outside the already contaminated area.

5.6 CLEANING OF EQUIPMENT

The project had high focus on HSE throughout preparations and field work.

The excavator had high readings of Hg after the dredging activities and it was a cumbersome job to clean it and to achieve satisfactorily readings. The excavator pump was sent off separately for special cleaning, as well as an additional cleaning campaign of the excavator itself. The ROV's operating in the same area did not have high readings of Hg and for the equipment the severe contamination of Hg was limited to the excavator.

Appendix A: Task plans

DOF subsea delivering solutions at any depth	Document title	Revision date	Page
	PRESURVEY AND TARGET INVESTIGATION	08.01.2014	1 of 3
		Doc no. 600264-GSUN-O03-0001-01	Rev. 01i

Task description :	**Field Main Worksite**		
Pre survey, installation of inclinometer and targetinvestigation.	Name:	U-864 - Fedje	
Worksite: M/V Geosund, Fedje	Water depth:	135 m	
Project: 600246	Position:	Easting	TBC
		Northing	TBC

Summary of tasks:

1. Preparatory works
2. Pre survey
3. Installation of inclinometer
4. Target investigation and possible relocation of periscope

Operational requirements:

Max. wind speed (crane) = 15m/s (30 knots).

Weights and dimensions:

Qty	Description	Dry Weight [kg]	Dimension [mm] L x W x H
1	Inclinometer		

References:

Deck layout

Hg-canister handling, Franzefoss

	Name	Position	Sign
Originator	Marius B. Nesse	Project Engineer	
Checker	Agnete M. Strømme	Lead Engineer	
Approver	Brynjar Wiig	Shift supervisor	

Distribution:

Offshore Manager	1	Master/bridge	1
Deck Foreman	1	Client	1
Subcontractors	3	Crane Operator	1
Offline Survey	1	Online survey	1

Item	TASK DESCRIPTION	PPE	Resp.	Check
1.	Initial status	[-]		

1	Setup vessel on site and perform DP trials.		Bridge	
1	Target Box for working area, landing area for subsea basket and disposal area for target 8 to be displayed on the NAV Screen.		Survey	
1	Position vessel above working area.		Bridge	
1	Weather assessed and approved by Captain and OM.		Offshore Manager	
1	Bridge to monitor current / changes in current prior to and during operation.		Bridge	
1	SJA completed.		Offshore Manager	
1	Lift plans made and approved.		Deck Foreman	
2.	**Preparation**	**PPE**	**Resp.**	**Check**
2.1.	**Note:** **1. Deck Foreman is in charge on deck.** **2. Perform Toolbox talk prior to start of operations.** **3. The sequence in this task plan may change for safety or practical reasons.** **4. Management of change process to be used in the event of procedural changes** **5. Each time any equipment is recovered from seabed to deck, it MUST firstly be cleaned subsea by the ROV and subsequently landed on the contaminated area, ref. deck layout, and cleaned by qualified personnel. Detailed procedures can be found in Appendix B. Everything must be done in conjunction with Franzefoss' procedures.** **6. Particular care must be taken if- and when 20 mm shells are detected on seabed or on any of the equipment. If the shells are detected on deck, an 'all stop' must be called and the safety of the operation re-assessed.**		INFO	
2.2.	Toolbox talks will be held for all relevant personnel throughout this operation. It is also recommended that several smaller TBTs are held for each major step of the operation, rather than one big one at the start-up. **NOTE! If any relevant personnel request a TBT prior to any phase of the operation, that request should be approved and a subsequent TBT should be held.**		INFO	
2.3.	Barrier off aft deck. Only authorized personnel allowed to be on deck. **NOTE! Verbal/visual approval from the deck foreman**	1	Deck Foreman	

	must be given before anyone is allowed to breach the barrier.			
2.4.	Check of all coms between involved parties.		All	
2.5.	Prepare Crane with transponder.	1	Deck Foreman	
2.6.	ROV to carry following equipment: - Inclinometer		ROV	
2.7.	Pre dive checks for ROV completed.		ROV	
2.8.	Obtain green light from bridge to launch ROV and equip ROV with DP-beacon if required.		ROV	
2.9.	Launch ROV, deploy DP-beacon (if applicable) and place inclinometer device on wreck.		ROV	
3.	**Pre survey and target investigating**	**PPE**	**Resp.**	**Check**
3.1.	ROV to perform as found visual inspection of area.		ROV	
3.2.	ROV to locate aft section of the wreck		ROV	
3.3.	ROV to place inclinometer on the wreck.		ROV	
3.4.	ROV to perform target investigation on clients request. Mainly target 8 and 15.		ROV	
3.5.	Investigate possibilities for relocating/recovering periscope (target 8).		ROV/Shift supervisor/ client	
3.6.		1	Deck Foreman	
3.7.	Recover ROV to deck. **NOTE!** **Niva to check for contamination, if any traces of mercury is found Franzefoss will clean according to procedure.**	2/3	ROV	
3.8.			Crane	

DOF subsea delivering solutions at any depth	Document title: OPERATIONAL TASKPLAN	Revision date: 08.01.2014	Page: 1 of 4
		Doc no.	Rev. 05i

Task description :	Field Main Worksite		
Deploy and position monitoring- and water sampling equipment	Name:	U-864 - Fedje	
Worksite: M/V Geosund, Fedje	Water depth:	135 m	
Project: 600246	Position:	Easting	TBC
		Northing	TBC

Summary of tasks:

1. Preparatory works
2. Pre survey
3. Deployment of Niva equipment

Operational requirements:

Max. wind speed (crane) = 15m/s (30 knots).

Weights and dimensions:

Qty	Description	Dry Weight [kg]	Dimension [mm] L x W x H
1	Monitoring buoy	700	
8	Monitoring rigs	300	

References:

Deck layout

Hg-canister handling, Franzefoss

	Name	Position	Sign
Originator	Marius B. Nesse	Project Engineer	PP
Checker	Agnete M. Strømme	Lead Engineer	
Approver	Brynjar Wiig	Shift supervisor	

Distribution:

Offshore Manager	1	Master/bridge	1
Deck Foreman	1	Client	1
Subcontractors	3	Crane Operator	1
Offline Survey	1	Online survey	1

Item	TASK DESCRIPTION	PPE	Resp.	Check
1.	**Initial status**	**[-]**		
1.1.	Setup vessel on site and perform DP trials.		Bridge	
1.2.	Position vessel above working area.		Bridge	

1.3.	Weather assessed and approved by Captain and OM.		Offshore Manager	
1.4.	Bridge to monitor current / changes in current prior to and during operation.		Bridge	
1.5.	SJA completed.		Offshore Manager	
1.6.	Lift plans made and approved.		Deck Foreman	
2.	**Preparation**	**PPE**	**Resp.**	**Check**
2.1.	**Note:** **1. Deck Foreman is in charge on deck.** **2. Perform Toolbox talk prior to start of operations.** **3. The sequence in this task plan may change for safety or practical reasons.** **4. Management of change process to be used in the event of procedural changes** **5. Each time any equipment is recovered from seabed to deck, it MUST firstly be cleaned subsea by the ROV and subsequently landed on the contaminated area, ref. deck layout, and cleaned by qualified personnel. Detailed procedures can be found in Appendix B. Everything must be done in conjunction with Franzefoss' procedures.** **6. Particular care must be taken if- and when 20 mm shells are detected on seabed or on any of the equipment. If the shells are detected on deck, an 'all stop' must be called and the safety of the operation re-assessed.**		INFO	
2.2.	Toolbox talks will be held for all relevant personnel throughout this operation. It is also recommended that several smaller TBTs are held for each major step of the operation, rather than one big one at the start-up. **NOTE! If any relevant personnel request a TBT prior to any phase of the operation, that request should be approved and a subsequent TBT should be held.**		INFO	
2.3.	Barrier off aft deck. Only authorized personnel allowed to be on deck. **NOTE! Verbal/visual approval from the deck foreman must be given before anyone is allowed to breach the barrier.**	1	Deck Foreman	
2.4.	Check of all coms between involved parties.		All	
2.5.	Prepare water sampling equipment for use.	1	NIVA / ROV	

2.6.	Prepare monitoring equipment for deployment.	1	NIVA	
2.7.	Prepare Crane with transponder.	1	Deck Foreman	
2.8.	Pre dive checks for ROV completed.		ROV 1	
2.9.	Obtain green light from bridge to launch ROV and equip ROV with DP-beacon if required.		ROV 1	
2.10.	Launch ROV.		ROV 1	
3.	**Deploy and position monitoring- and water sampling equipment**	**PPE**	**Resp.**	**Check**
3.1.	Move to preparation area. Target box for all environmental monitoring equipment displayed on NAV screen. NIVA to advice as required.		Survey	
3.2.	Prepare anchor for deployment and connect to crane hook.	1	Deck	
3.3.	Pay out on anchor line as the crane lower anchor.	1	Deck	
3.4.	Lower to approx. 10 above seabed and engage AHC if necessary.		Crane	
3.5.	Lower anchor to seabed; ROV to monitor from a safe distance.		Crane / ROV 1	
3.6.	ROV to perform GVI of the anchor landing area.		ROV 1	
3.7.	ROV to release anchor from crane and recover crane to deck.		ROV 1	
3.8.	Rig up current monitoring buoy on deck and connect to crane hook. Use long rigging (approx. 10-12m).	1	Deck	
3.9.	Lift up buoy and slew crane over the side. Lower buoy to sea level and once the buoy is in contact with the water, slew the crane back on deck. **NOTE! Be aware of telemetry equipment 10m below buoy!**	1	Crane/ Deck	
3.10.	Release rigging from crane hook and release buoy.	1	Deck	
3.11.	Attach rigging to environmental monitoring equipment. NIVA to advice as required.	1	Deck Foreman	
3.12.	Reposition vessel to first monitoring location.		Bridge	
3.13.	Deploy monitoring equipment.	1	Crane	
3.14.	ROV to perform GVI of area.		ROV 1	
3.15.	Lower equipment to approx. 10 m above seabed and activate AHC if required. ROV to get visual.	1	Crane	
3.16.	ROV to guide equipment into position and release rigging.			
3.17.	Recover crane to deck.	1	Crane	
3.18.	Repeat section steps 3.2 – 3.7 until all eight stations are positioned on seabed.			
3.19.	The water samples will be taken throughout the operation. The ROV will be equipped with the water sampling equipment, deployed and positioned where water samples are to be taken.		ROV 2 INFO/NIVA	

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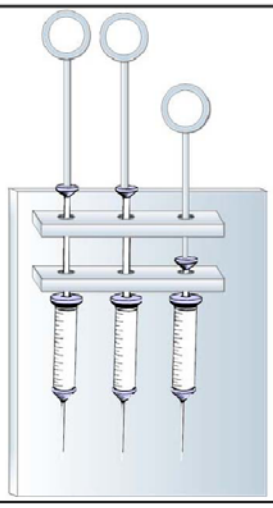
	OPERATIONAL TASKPLAN	08.01.2014	4 of 4
		Doc no.	Rev. 05i

DOF subsea delivering solutions at any depth	Document title	Revision date	Page
	TASK PLAN - RELOCATE AND WETSTORE PERISCOPE	08.01.2014	1 of 4
		Doc no. 600264-GSUN-O03-0003-01	Rev. 01i

Task description : Wetstoring of periscope **Worksite:** M/V Geosund, Fedje **Project:** 600246	**Field Main Worksite**		
	Name:	U-864 - Fedje	
	Water depth:	135 m	
	Position:	Easting	TBC
		Northing	TBC

Summary of tasks:

1. Preparatory works
2. Lift up target 8
3. Rig periscope and pull
4. Cut periscope
5. Move and wetstore periscope

Operational requirements:

Max. wind speed (crane) = 15m/s (30 knots).

Weights and dimensions:

Qty	Description	Dry Weight [kg]	Dimension [mm] L x W x H

References:

	Name	Position	Sign
Originator	Marius B. Nesse	Project Engineer	
Checker	Agnete M. Strømme	Lead Engineer	p.p. H. Pelsholen
Approver	Brynjar Wiig/Rein Henrik Pelsholen	Sift supervisor	H. Pelsholen

Distribution:

Offshore Manager	1	Master/bridge	1
Deck Foreman	1	Client	1
Subcontractors	3	Crane Operator	1
Offline Survey	1	Online survey	1

Item	TASK DESCRIPTION	PPE	Resp.	Check
1.	**Initial status**	**[-]**		
1	Target Box for working area and landing area for periscope on NAV screen		Survey	
1	Position vessel above working area.		Bridge	
1	Weather assessed and approved by Captain and OM.		Offshore Manager	
1	Bridge to monitor current / changes in current prior to and during operation.		Bridge	
1	SJA completed.		Offshore Manager	
1	Lift plans made and approved.		Deck Foreman	
2.	**Preparation**	**PPE**	**Resp.**	**Check**
2.1.	**Note:** **1. Deck Foreman is in charge on deck.** **2. Perform Toolbox talk prior to start of operations.** **3. The sequence in this task plan may change for safety or practical reasons.** **4. Management of change process to be used in the event of procedural changes** **5. Each time any equipment is recovered from seabed to deck, it MUST firstly be cleaned subsea by the ROV and subsequently landed on the contaminated area, ref. deck layout, and cleaned by qualified personnel. Detailed procedures can be found in Appendix B. Everything must be done in conjunction with Franzefoss' procedures.** **6. Particular care must be taken if- and when 20 mm shells are detected on seabed or on any of the equipment. If the shells are detected on deck, an 'all stop' must be called and the safety of the operation re-assessed.**		INFO	
2.2.	Toolbox talks will be held for all relevant personnel. **NOTE! If any relevant personnel request a TBT prior to any phase of the operation, that request should be approved and a subsequent TBT should be held.**		INFO	
2.3.	Barrier off aft deck. Only authorized personnel allowed to be on deck. **NOTE! Verbal/visual approval from the deck foreman must be given before anyone is allowed to breach the barrier.**	1	Deck Foreman	

2.4.	Check of all coms between involved parties.		All	
2.5.	Prepare Crane with transponder.	1	Deck Foreman	
2.6.	Crane to deploy / carry following equipment: - Rigging for moving of periscope.		Crane	
2.7.	Obtain green light from bridge to proceed with operation.		Bridge	
2.8.	Perform visual pre-survey of work area as well as designated wetstore area for periscope. Location to then be marked on NAV Screen – to SW of worksite.		ROV / Survey	
3.	**Lifting target 8 to gain access to periscope**	**PPE**	**Resp.**	**Check**
3.1.	Attach rigging w/open hook to crane – whip line. (Deployment includes the 2x soft strop / needle for next phase)	1	Deck Foreman	
3.2.	Deploy rigging / crane – wet store 2x soft slings / needle.	1	Crane	
3.3.	Lower equipment to approx. 10 m above seabed and activate AHC if required. ROV to get visual.	1	Crane	
3.4.	ROV to guide rigging into position and grab hold of open hook.		ROV	
3.5.	Attach open hook to target 8		ROV	
3.6.	Take up tension until target 8 lifts off. **NOTE! Target 8 should only be lifted off seabed enough to assess the periscopes condition and whether or not it's wedged.**		Crane	
3.7.	If under tension section of Target 8 breaks off – re-assess & expect to re-connect & try again.		ROV	
3.8.	If possible, grab hold of periscope and relocated to designated wetstore area. Recover crane and ROV to deck.		ROV	
3.9.	If periscope appears to be wedged – lower target 8 & release open hook rigging, recover crane to deck and proceed to section 4 of this task plan.		ROV	
4.	**Rig up and pull periscope out from target 8**	**PPE**	**Resp.**	**Check**
4.1.	Attach rigging / strop & needle to periscope and deploy crane. Lower crane to ROVs position.	1	ROV	
4.2.	ROV to attempt to pull on the rigging itself – if appropriate, this can be followed by use of crane – direction of pull with crane is AWAY from base of periscope, in NW direction		ROV	
4.3.	Assess whether or not the periscope seems to come free of target 8. If so proceed to next step; if not proceed to section 5 of this task plan.		ROV	
4.4.	Recover crane & swap hook, once known that it can be moved / wet stored – redeploy crane			
4.5.	Once the periscope is free from target 8, connect 2nd strop as well as that already connected – & connect to crane to lift to wet store location.		ROV	

4.6.	Recover crane and ROV to deck.		ROV	
5.	**Cut periscope**	**PPE**	**Resp.**	**Check**
5.1.	Recover ROV, install diamond cutter & return to worksite.	1	ROV	
5.2.	Cut periscope as close to the base as possible.		ROV	
5.3.	Recover crane & swap hook, once known that it can be moved / wet stored – redeploy crane			
5.4.	Once the cutting is complete and the periscope if free from target 8, connect 2nd strop, to that already attached - & connect to crane to lift to wet store location.		ROV	
6.	**Post survey and final work**	**PPE**	**Resp.**	**Check**
6.1.	As left survey of working area as well as the wetstore area where the periscope is located.		ROV / Survey	
6.2.	Recover ROV to deck. **NOTE!** **Niva to check for contamination, if found Franzefoss will clean according to procedure.**	2/3	ROV	
6.3.				
6.4.				
6.5.				
6.6.				

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	MOVING TARGET 8 AND DEEP C OPERATIONS	08.01.2014	1 of 7
		Doc no. 600264-GSUN-O03-0004-01	Rev. 01i

Task description :
Moving of target 8 and Deep C operations.
.

Worksite:
M/V Geosund,
Fedje

Project:
600246

Field Main Worksite

Name:	U-864 - Fedje	
Water depth:	135 m	
Position:	Easting	TBC
	Northing	TBC

Summary of tasks:

1. Preparatory works
2. Pre survey
3. Target 8 and periscope relocation
4. Dig free- and cut through keel section

Operational requirements:
Max. wind speed (crane) = 15m/s (30 knots).

Weights and dimensions:

Qty	Description	Dry Weight [kg]	Dimension [mm] L x W x H
1	Deep C excavator	9500	4700 x 3200 x 2400
1	Orange peel grab	9500	5530 x 5350 x 5120
2	Cutter		
1	Manipulator frame		

References:
Deck layout
Hg-canister handling, Franzefoss
Deep C dredger manual

	Name	Position	Sign
Originator	Marius B. Nesse	Project Engineer	pp. A. Stenne
Checker	Agnete M. Strømme	Lead Engineer	A. Stenne
Approver	Brynjar Wiig	Shift Supervisor	B. Wiig

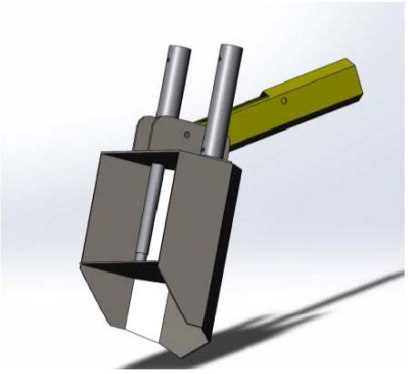
Distribution:

Offshore Manager	1	Master/bridge	1
Deck Foreman	1	Client	1
Subcontractors	3	Crane Operator	1
Offline Survey	1	Online survey	1

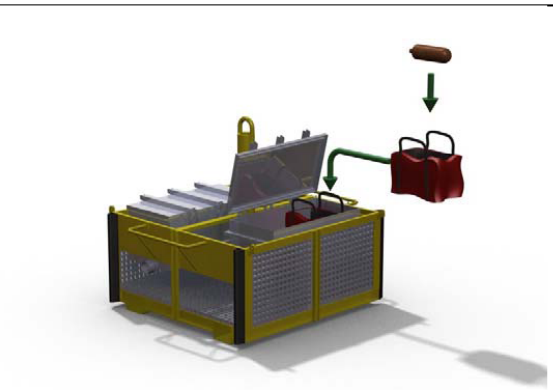
Item	TASK DESCRIPTION	PPE	Resp.	Check
1.	**Initial status**	**[-]**		
1.1.	Setup vessel on site and perform DP trials.		Bridge	
1.2.	Target Box for working area, landing area for subsea basket and disposal area for target 8 to be displayed on the NAV Screen.		Survey	
1.3.	Position vessel above working area.		Bridge	
1.4.	Weather assessed and approved by Captain and OM.		Offshore Manager	
1.5.	Bridge to monitor current / changes in current prior to and during operation.		Bridge	
1.6.	SJA completed.		Offshore Manager	
1.7.	Lift plans made and approved.		Deck Foreman	
2.	**Preparation**	**PPE**	**Resp.**	**Check**
2.1.	**Note:** **1. Deck Foreman is in charge on deck.** **2. Perform Toolbox talk prior to start of operations.** **3. The sequence in this task plan may change for safety or practical reasons.** **4. Management of change process to be used in the event of procedural changes** **5. Each time any equipment is recovered from seabed to deck, it MUST firstly be cleaned subsea by the ROV and subsequently landed on the contaminated area, ref. deck layout, and cleaned by qualified personnel. Detailed procedures can be found in Appendix B. Everything must be done in conjunction with Franzefoss' procedures.** **6. Particular care must be taken if- and when 20 mm shells are detected on seabed or on any of the equipment. If the shells are detected on deck, an 'all stop' must be called and the safety of the operation re-assessed.**		INFO	
2.2.	Toolbox talks will be held for all relevant personnel throughout this operation. It is also recommended that several smaller TBTs are held for each major step of the operation, rather than one big one at the start-up. **NOTE! If any relevant personnel request a TBT prior to any phase of the operation, that request should be approved and a subsequent TBT should be held.**		INFO	

2.3.	ROV personnel to familiarize themselves with the Deep C control container.		ROV	
2.4.	Barrier off aft deck. Only authorized personnel allowed to be on deck. **NOTE! Verbal/visual approval from the deck foreman must be given before anyone is allowed to breach the barrier.**	1	Deck Foreman	
2.5.	Check of all coms between involved parties.		All	
2.6.	Prepare subsea basket for deployment. Prepared with box for Hg canisters.	1	Deck Foreman	
2.7.	Prepare Deep C dredger for use.	1	Deep C	
2.8.	Prepare Crane with transponder.	1	Deck Foreman	
2.9.	ROV to carry following equipment: - HP Jet		ROV	
2.10.	Pre dive checks for ROV completed.		ROV	
2.11.	Obtain green light from bridge to launch ROV.		ROV	
2.12.	Launch ROV.		ROV	
3.	**Remove target 8**	**PPE**	**Resp.**	**Check**
3.1.	ROV and deck crew to familiarize with peel grab handling, ref. Appendix D.	1	ROV / Deck foreman	
3.2.	Prepare orange peel grab for deployment. **NOTE! Make sure hydraulic lock is open.**	1	Deck Foreman	
3.3.	Reposition vessel to target 8's location. Display target 8's current location and the location for the safe disposal area on the NAV screen.		Bridge/ Survey	
3.4.	Perform visual survey of target 8 area.		ROV	
3.5.	If possible, the wreck's periscope is to be recovered to deck; a decision will be made on board after the periscope has been inspected by the ROV.		INFO	
3.6.	Attach grab rigging to crane.	1	Deck Foreman	
3.7.	Deploy grab and lower to approx. 10 m above seabed. Engage AHC if applicable. **NOTE! Once the grabs starts coming off deck, observe closely for any movement in the grab arms. Movement indicates a hydraulic leak, ref. Appendix D.**	1	Crane	
3.8.	Position peel grab over target 8 and lower to seabed/top of target 8.		Crane	
3.9.	ROV to set hydraulic lock to closed and move to safe		ROV	

	distance, but keep visual contact if possible. Use grip handle as required.			
3.10.	Crane to lift up grab, thus grabbing target 8. Use AHC/CT if applicable.		Crane	
3.11.	Easy up on crane until target 8 is free from seabed. Crane to monitor weight. **Max load is 25Te!**		Crane	
3.12.	Reposition vessel to safe disposal area.		Bridge	
3.13.	ROV to set hydraulic lock to open and move to safe distance. **NOTE! If hydraulic lock malfunctions, ROV must manually cut the grab's hydraulic hose.**		ROV	
3.14.	ROV to confirm that target 8 has been released inside disposal area.		ROV	
3.15.	Repeat step 3.8-314 until Target 8 is removed.		INFO	
3.16.	ROV to inspect grab for debris/sediments. Use HP jet if needed.		ROV	
3.17.	Recover grab to deck.	2	Crane	
3.18.	Place in landing area, check for mercury and clean according to procedures.	3	Franzefoss /Deck/Niva	
3.19.	Move grab to storage area, disconnect crane and sea fasten.	1	Crane/ Deck Foreman	
3.20.	ROV to perform GVI of the disposal area.		ROV	
4.	**Deep C operations**	**PPE**	**Resp.**	**Check**
4.1.	Perform visual survey of landing area for subsea basket and Deep C excavator. **NOTE! Landing area can be stabilized using sandbags, if sediments are too soft to support dredger.**		ROV	
4.2.	Perform pre-dive checks on Deep C excavator, according to Deep C check list. Equip Deep C dredger with transponder.		Deep C	

4.3.	Attach crane hook to Deep C excavator rigging and remove sea fastening. **NOTE! Make sure the umbilical is placed securely inside the chute. Pay out approx. 20 m umbilical prior to launch. Also remove grounding wire from frame.**	1	Deck Foreman	
4.4.	Deploy dredger and lower to approx. 10 above seabed. ROV to get visual. Deep C to pay out on umbilical winch. **NOTE! Reposition vessel as required.**	1	Crane	
4.5.	Lower dredger to dedicated area. **NOTE! ROV to monitor umbilical during descent and instruct umbilical winch operator wrt to pay-out.**		Crane/ ROV	
4.6.	Stop on crane at approx. 10 m above seabed. ROV to orientate the dredger for optimal positioning at seabed. Use AHC as required.		Crane / ROV	
4.7.	Land dredger softly on seabed. ROV to make sure dredger is stable and that there's enough slack on the umbilical.		Crane	
4.8.	Perform system check on dredger.		Deep C	
4.9.	Disconnect crane and recover to deck.		ROV / Crane	
4.10.	Align dredger with wreck section and commence excavation of keel.  **NOTE! If any Hg canisters are found in during this phase of the operation, proceed to section 6.11.**		Deep C	
4.11.	Once sufficient mass has been excavated and the keel section is clearly visible, move dredger to recovery area.		Deep C	
4.12.	Launch crane		Crane	
4.13.	ROV to connect crane to Deep C excavator.		ROV	

4.14.	Lift excavator to approx. 10 m above seabed. Run dredger tracks in order to remove seabed material.		Crane / Deep C	
4.15.	ROV to inspect excavator and use water jetting to remove sediments if required.		ROV	
4.16.	Recover Deep C excavator to deck, check for mercury and clean according to procedures.	3	Crane/ Deck/Franzefoss/	
4.17.	Disconnect excavator shovel and sea fasten/store.	2	Deep C	
4.18.	Disconnect power to excavator and high voltage outputs in the PDU.	3	Deep C / Vessel	
4.19.	Re-deploy d excavator and lower to approx. 30 m depth. **NOTE! The purpose of this step is to remove remaining sediments, by moving the dredger through the splash zone.**	3	Crane	
4.20.	Recover Deep C excavator.	3	Crane	
4.21.	Dedicated personnel to clean and inspect excavator in the contaminated area, before repositioning dredger to landing area on deck.	3	Franzefoss / Deep C	
4.22.	Disconnect and park crane.	1	Crane / Deck	
4.23.	ROV to perform visual survey of working area.		ROV	
4.24.	Recover ROV to deck. Check for mercury and clean according to procedures.	2	ROV	
5.	**Recovery of Hg-canisters**	**PPE**	**Resp.**	**Check**
5.1.	Obtain green light from bridge to launch subsea basket.	1	Deck Foreman	
5.2.	Deploy subsea basket.	1	Crane	
5.3.	Lower subsea basket down to approx.10m above seabed. Engage AHC mode if applicable.		Crane	
5.4.	ROV to get visual of the subsea basket.		ROV	
5.5.	Lower subsea basket and land on dedicated area on seabed.		Crane	
5.6.	ROV to disconnect subsea basket from crane.		ROV	
5.7.	Recover crane to deck.		Crane	
5.8.	Place canister in bag		ROV	

	 **NOTE! ROV must be positioned close by and handle the canister bags.**			
5.9.	ROV to place canister bag in basket.		ROV	
5.10.	Repeat steps 6.7 – 6.13 of until all canisters are recovered.		ROV	
5.11.	Deploy crane and lower towards ROV basket. Stop at 10 m above seabed and activate AHC if applicable.		Crane	
5.12.	Deploy crane and lower towards subsea basket; stop at 10 m above seabed and activate AHC if applicable. Easy down on crane towards subsea basket.		Crane	
5.13.	ROV to connect subsea basket rigging to crane hook and recover subsea basket to deck **NOTE! Handling of Hg-canisters is performed by Franzefoss, ref. Appendix B.**	3	ROV	
5.14.	ROV to perform post-survey.		ROV	
5.15.	Recover ROV to deck.	2	ROV	

DOF subsea delivering solutions at any depth	Document title	Revision date	Page
	ENTERING KEEL AND REMOVING HG-CANISTERS	12.01.2014	1 of 6
		Doc no. 600264-GSUN-O03-0005-01	Rev. 01i

Task description : Entering keel and removing Hg-canisters	**Field Main Worksite**		
Worksite: M/V Geosund, Fedje	Name:	U-864 - Fedje	
	Water depth:	135 m	
Project: 600246	Position:	Easting	TBC
		Northing	TBC

Summary of tasks:

1. Preparatory works
2. Drilling through keel section
3. Inspect
4. Remove Hg-canisters

Operational requirements:

Max. wind speed (crane) = 15m/s (30 knots).

Weights and dimensions:

Qty	Description	Dry Weight [kg]	Dimension [mm] L x W x H
1	Deep C excavator	9500	4700 x 3200 x 2400
1	Inspection camera		
2	Cutters		
1	Brush (grinder)		
1	Drillrig		
1	HP Jet		
1	Manipulator frame		
1	Subsea basket		
1	Lights on manipulator frame		
1	Pan/tilt		

References:

	Name	Position	Sign
Originator	Marius B. Nesse	Project Engineer	
Checker	Agnete M. Strømme	Lead Engineer	A. Strømme
Approver	Brynjar Wig	Shift Supervisor	pp. A. Strømme

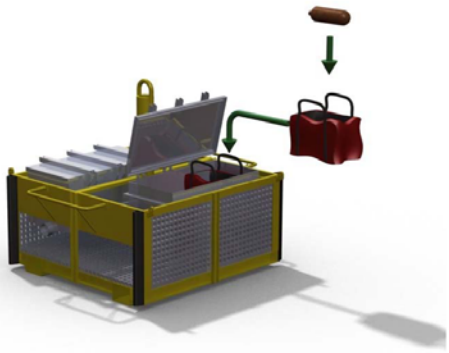
Distribution:

Offshore Manager	1	Master/bridge	1
Deck Foreman	1	Client	1
Subcontractors	3	Crane Operator	1
Offline Survey	1	Online survey	1

Item	TASK DESCRIPTION	PPE	Resp.	Check
1.	**Initial status**	**[-]**		
1.1.	Target Box for working area and landing area for subsea basket displayed on the NAV Screen.		Survey	
1.2.	Position vessel above working area.		Bridge	
1.3.	Weather assessed and approved by Captain and OM.		Offshore Manager	
1.4.	Bridge to monitor current / changes in current prior to and during operation.		Bridge	
1.5.	SJA completed.		Offshore Manager	
1.6.	Lift plans made and approved.		Deck Foreman	
2.	**Preparation**	**PPE**	**Resp.**	**Check**
2.1.	**Note:** **1. Deck Foreman is in charge on deck.** **2. Perform Toolbox talk prior to start of operations.** **3. The sequence in this task plan may change for safety or practical reasons.** **4. Management of change process to be used in the event of procedural changes** **5. Each time any equipment is recovered from seabed to deck, it MUST firstly be cleaned subsea by the ROV and subsequently landed on the contaminated area, ref. deck layout, and cleaned by qualified personnel. Detailed procedures can be found in Appendix B. Everything must be done in conjunction with Franzefoss' procedures.** **6. Particular care must be taken if- and when 20 mm shells are detected on seabed or on any of the equipment. If the shells are detected on deck, an 'all stop' must be called and the safety of the operation re-assessed.**		INFO	
2.2.	Toolbox talks will be held for all relevant personnel throughout this operation. It is also recommended that several smaller TBTs are held for each major step of the operation, rather than one big one at the start-up. **NOTE! If any relevant personnel request a TBT prior to any phase of the operation, that request should be approved and a subsequent TBT should be held.**		INFO	
2.3.	ROV personnel to familiarize themselves with the Deep C control container.		ROV	

2.4.	Barrier off aft deck. Only authorized personnel allowed to be on deck. **NOTE! Verbal/visual approval from the deck foreman must be given before anyone is allowed to breach the barrier.**	1	Deck Foreman	
2.5.	Check of all coms between involved parties.		All	
2.6.	If not already done; prepare subsea basket for deployment. Prepared with box for Hg canisters.	1	Deck Foreman	
2.7.	Prepare Deep C for use, including manipulator frame. Equip manipulator frame with various tools. • 2 x Grinders w/ cutting disk • Spycam	1	Deep C	
2.8.	Prepare Crane with transponder.	1	Deck Foreman	
2.9.	ROV to carry following equipment:- • Drill rig (long hoses) • Grinder w/brush (long hoses)		ROV	
2.10.	Pre dive checks for ROV completed.		ROV	
2.11.	Obtain green light from bridge to launch ROV.		ROV	
2.12.	Launch ROV.		ROV	
3.	**Cut through keel section**	**PPE**	**Resp.**	**Check**
3.1.	Deploy ROV		ROV	
3.2.	Deploy Deep C dredger and lower to approx. 10 m above seabed. ROV to get visual.		Crane	
3.3.	Land Deep C dredger on dedicated area, disconnect rigging and recover crane to deck.	1	Crane/ ROV	
3.4.	Align Deep C dredger with keel section and lower manipulator platform into excavated area. Locate keel compartments.		Deep C/ ROV	
3.5.	ROV to ready grinder w/brush and hand over to Deep C dredger if required.		Deep C / ROV	
3.6.	Deep C dredger to start cleaning off marine growth and corrosion using grinder w/brush if required.		Deep C / ROV	
3.7.	Cut an inspection hole in the keelplate using cutter.		Deep C / ROV	
3.8.	Ready inspection camera.		Deep C / ROV	

3.9.	Insert camera into inspection hole, inspect and evaluate further actions. If it's decided to continue cutting off a keel plate section, proceed to next step.		ROV / Deep C	
3.10.	Commence cutting the keel section plating. Deep C manipulator platform using grinder to cut through keel plate. When/if one grinder blade is insufficient to get through the keel plating, use the second grinder on manipulator frame. **NOTE! It's recommended to maintain as little arm extension as practically possible, in order to limit the strain and reduce the risk for breakdown.**		Deep C/ ROV	
3.11.	Once the plating has been cut off, relocate keel plate to designated disposal area.		ROV	
3.12.	Check for Hg-canisters in exposed keel section. **NOTE! If any canisters are located, proceed to next step. Otherwise proceed to section 3.19**		Deep C/ ROV	
3.13.	Extract Hg-canister from keel section and place in adjacent canister bag		Deep C/ ROV	

	 **NOTE! ROV must be positioned close by and handle the canister bags.**			
3.14.	Once canister bag is full the ROV will fly to subsea basket, place canister bag in basket and return to dredger with an empty canister bag.		ROV	
3.15.	Once there are no more Hg-canisters in the keel section, the ROV will relocate remaining canister bags to subsea basket. Return with an empty canister bag if there are more Hg-canisters to be recovered.		ROV	
3.16.	Deep C to position drillrigg in keel compartment. ROV will control the flow.		Deep C/ ROV	
3.17.	Drill an inspection hole in plate dividing the two keel sections.		Deep C/ ROV	
3.18.	Extract drillrig from keel compartment and hand back to ROV. Inside keel compartment		Deep C/ ROV	

3.19.	Check for Hg-canisters in exposed keel section.		Deep C/ ROV	
3.20.	Extract manipulator frame from keel section.		Deep C/ ROV	
3.21.	Move dredger to recovery area.		Deep C	
3.22.	Deploy crane and lower towards Deep C; stop at 10 m above seabed and activate AHC if applicable. Easy down on crane towards Deep C.		Crane	
3.23.	ROV to connect Deep C to crane hook.		ROV	
3.24.	Lift dredger to approx. 10 m above seabed, disengage AHC (if engaged) and recover dredger to deck.		Crane / ROV	
3.25.	Reposition vessel to subsea basket area and deploy crane.		Bridge / Crane	
3.26.	Come down to approx. 10 above seabed and engage AHC if applicable. Easy down on the crane towards subsea basket.		Crane	
3.27.	ROV to connect rigging to subsea basket.		ROV	
3.28.	Lift to approx. 10 m above seabed, disengage AHC (if applicable) and recover subsea basket to deck.		Crane	
3.29.	ROV to perform post-survey of working area.		ROV	
3.30.	Recover ROV to deck.		ROV	

DOF subsea delivering solutions at any depth	Document title	Revision date	Page
	SOIL SAMPLING	12.01.2014	1 of 3
		Doc no. 600264-GSUN-O03-0006-01	Rev. 01i

Task description : Soil sampling **Worksite:** M/V Geosund, Fedje **Project:** 600246	**Field Main Worksite**		
	Name:	U-864 - Fedje	
	Water depth:	135 m	
	Position:	Easting	TBC
		Northing	TBC

Summary of tasks:

1. Preparatory works
2. Visual inspection of soil sampling location
3. Take ROV held soil samples (tube)
4. Visual inspection of soil sampling location after soil sample has been taken

Operational requirements:

Max. wind speed (crane) = 15m/s (30 knots).

Weights and dimensions:

Qty	Description	Dry Weight [kg]	Dimension [mm] L x W x H
1	Subseabasket		
1	ROV shopingbasket with 8 soilsampling tubes		

References:

Hg-canister handling, Franzefoss
Map of soil sampling locations

	Name	Position	Sign
Originator	Marius B. Nesse	Project Engineer	M. B. Nesse
Checker	Agnete M. Strømme	Lead Engineer	A. Strømme
Approver	Brynjar Wiig	Shift Supervisor	pp. A. Strømme

Distribution:

Offshore Manager	1	Master/bridge	1
Deck Foreman	1	Client	1
Subcontractors	3	Crane Operator	1
Offline Survey	1	Online survey	1

Item	TASK DESCRIPTION	PPE	Resp.	Check
1.	**Initial status**	**[-]**		
1.1.	Target Box for working area and landing area for soil sampling positions displayed on the NAV Screen.		Survey	
1.2.	Position vessel above working area.		Bridge	
1.3.	Weather assessed and approved by Captain and OM.		Offshore Manager	
1.4.	Bridge to monitor current / changes in current prior to and during operation.		Bridge	
1.5.	SJA completed.		Offshore Manager	
1.6.	Lift plans made and approved.		Deck Foreman	
2.	**Preparation**	**PPE**	**Resp.**	**Check**
2.1.	**Note:** **1. Deck Foreman is in charge on deck.** **2. Perform Toolbox talk prior to start of operations.** **3. The sequence in this task plan may change for safety or practical reasons.** **4. Management of change process to be used in the event of procedural changes** **5. Each time any equipment is recovered from seabed to deck, it MUST firstly be cleaned subsea by the ROV and subsequently landed on the contaminated area, ref. deck layout, and cleaned by qualified personnel. Detailed procedures can be found in Appendix B. everything must be done in conjunction with Franzefoss' procedures.** **6. Particular care must be taken if- and when 20 mm shells are detected on seabed or on any of the equipment. If the shells are detected on deck, an 'all stop' must be called and the safety of the operation re-assessed.**		INFO	
2.2.	Toolbox talks will be held for all relevant personnel throughout this operation. It is also recommended that several smaller TBTs are held for each major step of the operation, rather than one big one at the start-up. **NOTE! If any relevant personnel request a TBT prior to any phase of the operation, that request should be approved and a subsequent TBT should be held.**		INFO	
2.3.	Barrier off aft deck. Only authorized personnel allowed to be on deck.	1	Deck Foreman	

	NOTE! Verbal/visual approval from the deck foreman must be given before anyone is allowed to breach the barrier.			
2.4.	Check of all coms between involved parties.		All	
2.5.	Prepare subsea basket for deployment and following equipment: • box for Hg canisters • bucket for collecting soil	1	Deck Foreman	
2.6.	ROV need to carry following equipment: • Basket with 8 (2 spare) soil sample tubes (all marked with ID nr)	1	ROV	
2.7.	Prepare Crane with transponder.	1	Deck Foreman	
2.8.	Pre dive checks for ROV completed.		ROV	
2.9.	Obtain green light from bridge to launch ROV.		ROV	
2.10.	Launch ROV.		ROV	
3.	**Soil sampling**	**PPE**	**Resp.**	**Check**
3.1.	Launch ROV.	1	ROV	
3.2.	Locate position for soil sample, positions on nav screen.		ROV / Survey	
3.3.	ROV to take soil sample. Online to note number and location. **NOTE! Appendix A indicated the areas with expected moderate- and high concentrations.**		ROV/ Online	
3.4.	Repeat step 3.3-3.4 until all 8 samples are collected.		ROV	
3.5.	Recover basket with tubes by crane.	1	Crane/ Deck	
3.6.	Franzefoss to handle all samples taken. ROV held tubes to be handed to Niva.	3	Franzefoss	

DOF subsea delivering solutions at any depth	Document title	Revision date	Page
	RECOVERY OF NIVA BUOY	14.01.2014	1 of 3
		Doc no. 600246-GSUN-O03-0010-01	Rev. 01i

Task description : Recovery of NIVA buoy **Worksite:** M/V Geosund, Fedje **Project:** 600246	**Field Main Worksite**		
	Name:	U-864 - Fedje	
	Water depth:	135 m	
	Position:	Easting	TBC
		Northing	TBC

Summary of tasks:

1. Preparatory works
2. Locate and recover anchor by crane
3. Pull in NIVA buoy
4. Recover NIVA buoy by crane

Operational requirements:

Max. wind speed (crane) = 15m/s (30 knots).

Weights and dimensions:

Qty	Description	Dry Weight [kg]	Dimension [mm] L x W x H
1	NIVA buoy	700	

References:

Deck layout
NIVA guidelines

	Name	Position	Sign
Originator	Agnete M. Strømme	Project Engineer	A. Strømme
Checker	Marius B. Nesse	Project Engineer	M. B. Nesse
Approver	Rein Henrik Pelsholen	Shift supervisor	R. Wilg

Distribution:

Offshore Manager	1	Master/bridge	1
Deck Foreman	1	Client	1
Subcontractors	3	Crane Operator	1
Offline Survey	1	Online survey	1

Item	TASK DESCRIPTION	PPE	Resp.	Check
1.	**Initial status**	**[-]**		
1.1.	Setup vessel on site and perform DP trials.		Bridge	
1.2.	Position vessel above working area.		Bridge	
1.3.	Weather assessed and approved by Captain and OM.		Offshore Manager	
1.4.	Bridge to monitor current / changes in current prior to and during operation.		Bridge	
1.5.	SJA completed.		Offshore Manager	
1.6.	Lift plans made and approved.		Deck Foreman	
2.	**Preparation**	**PPE**	**Resp.**	**Check**
2.1.	**Note:** **1. Deck Foreman is in charge on deck.** **2. Perform Toolbox talk prior to start of operations.** **3. The sequence in this task plan may change for safety or practical reasons.** **4. Management of change process to be used in the event of procedural changes** **5. Each time any equipment is recovered from seabed to deck, it MUST firstly be cleaned subsea by the ROV and subsequently landed on the contaminated area, ref. deck layout, and cleaned by qualified personnel. Detailed procedures can be found in Appendix B. Everything must be done in conjunction with Franzefoss' procedures.** **6. Particular care must be taken if- and when 20 mm shells are detected on seabed or on any of the equipment. If the shells are detected on deck, an 'all stop' must be called and the safety of the operation re-assessed.**		INFO	
2.2.	Toolbox talks will be held for all relevant personnel throughout this operation. It is also recommended that several smaller TBTs are held for each major step of the operation, rather than one big one at the start-up. **NOTE! If any relevant personnel request a TBT prior to any phase of the operation, that request should be approved and a subsequent TBT should be held.**		INFO	
2.3.	Barrier off aft deck. Only authorized personnel allowed to be on deck. **NOTE! Verbal/visual approval from the deck foreman**	1	Deck Foreman	

	must be given before anyone is allowed to breach the barrier.			
2.4.	Check of all coms between involved parties.		All	
2.5.	Prepare Crane with transponder.	1	Deck Foreman	
2.6.	Pre dive checks for ROV completed.		ROV 1	
2.7.	Obtain green light from bridge to launch ROV and equip ROV with DP-beacon if required.		ROV 1	
2.8.	Launch ROV.		ROV 1	
3.	**Recover buoy**	**PPE**	**Resp.**	**Check**
3.1.	Target for buoy location on NAV screen.		Survey	
3.2.	Wind and current assessed and vessel positioned accordingly		Control/ Bridge	
3.3.	ROV to get visual of buoy anchor.	1	ROV	
3.4.	Deploy crane	1	Crane	
3.5.	Lower to approx. 10 above seabed and engage AHC if necessary.		Crane	
3.6.	Attach crane hook to anchor.		Crane / ROV 1	
3.7.	Recover anchor to deck. **NOTE! Pay attention to crane wire.**		Crane / ROV 1	
3.8.	Pull in on rope until buoy to next to shipside.	2	Deck	
3.9.	Recover rigging on buoy to deck and connect to crane hook.	2	Deck	
3.10.	Recover buoy to deck. **NOTE! Be aware of telemetry equipment 10m below buoy!**	2	Crane/ Deck	
3.11.	NIVA to check for Hg, Franzefoss to clean	2	Deck	

Målinger av kvikksølv på utstyr hos Franzefoss og Deep C (NIVA)

Norsk institutt for vannforskning

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DOF Subsea Norway AS
Thormøhlensgate 53C
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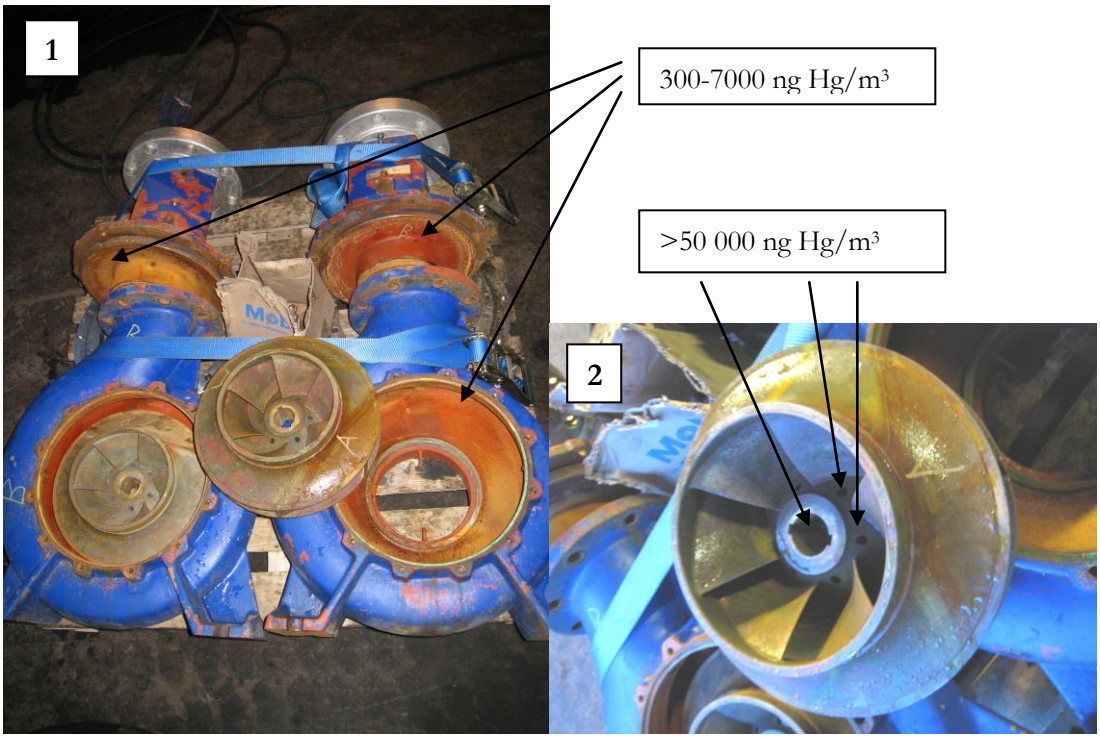
Att: Håvard Berge

Deres referanse	Deres brev av	Vår referanse	Dato
		J.nr. 0272/14 O-14166	24.02.2014

Målinger av kvikksølvdamp ved utstyr fra Deep C som ble brukt på tokt ved Fedje. Målinger foretatt hos Franzefoss (avdeling Knarrevik i Bergen), og hos Deep C i Kristiansund.

Målinger hos Franzefoss, torsdag 20. februar.

Målinger av kvikksølv ble utført med en Lumex RA-915 portabel kvikksølvanalysator. Målinger av kvikksølvdamp fra pumpene ble gjort første gang kl 8:00. Det ble med en gang målt høye konsentrasjoner av kvikksølv på den midtre delen av begge pumpene, i midten og i hull rundt (se bilde 2).



Bilde 1. Pumpene som ble undersøkt for kvikksølvforurensning.
Bilde 2. Stedene på pumpene hvor det ble påvist høye kvikksølvkonsentrasjoner.

Konsentrasjonen av kvikksølv i luft over de andre delene av pumpene var på mellom 300 og 7000 ng Hg/m³. Pumpedelene ble så spylt og vasket med varmt vann og deretter ble det foretatt nye målinger (se tabell).

Tidspunkt for måling		Konsentrasjon ng Hg/m3
Kl 8	På- og i pumpehuset I midten av pumpedel	300 til 7000 >50 000
Spyling		
	I midten av pumpedel	>50 000
Spyling med varmt vann		
	I midten av pumpedel	>50 000
Spyling med varmt vann		
Kl 10	I midten av pumpedel	>50 000
Spyling og børsting		
Kl 10:50	I midten av pumpedel	>50 000
Spyling og børsting		
Kl 12:10		>50 000 på den ene pumpa <12 000 på den andre
Mer spyling og børsting		
Kl 12:40	I midten av pumpedel	3000-8000

Etter flere omganger med spyling og børsting kom konsentrasjonen av kvikksølv ned i 3000-8000 ng/m³ der hvor det hadde blitt målt høye konsentrasjoner.

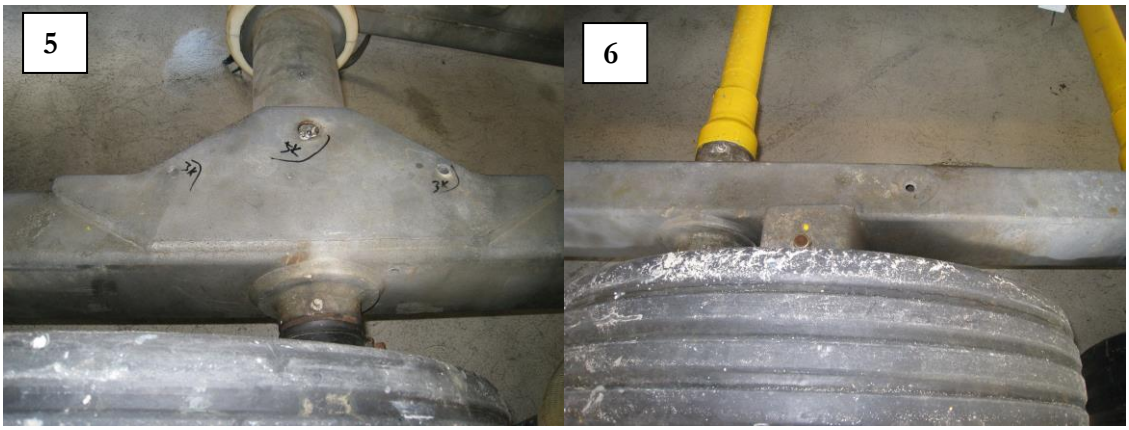
Målinger foretatt hos Deep C i Kristiansund 21. februar.

De første målingene ble foretatt i verkstedhallen hos Deep C kl 8:30. Da var bakgrunnsnivået på 200-400 ng/m^3. Administrativ norm for arbidsmiljø basert på en 8-timers arbeidsdag sier at konsentrasjonen skal være under 20 000 ng/m^3.
(http://www.arbeidstilsynet.no/artikkel.html?tid=78880).
Den 6. februar ble det foretatt målinger av kvikksølv på gravemaskinen. Denne gangen ble det målt på nytt i rammen på maskinen og på beltene som var lagret i et annet verksted.

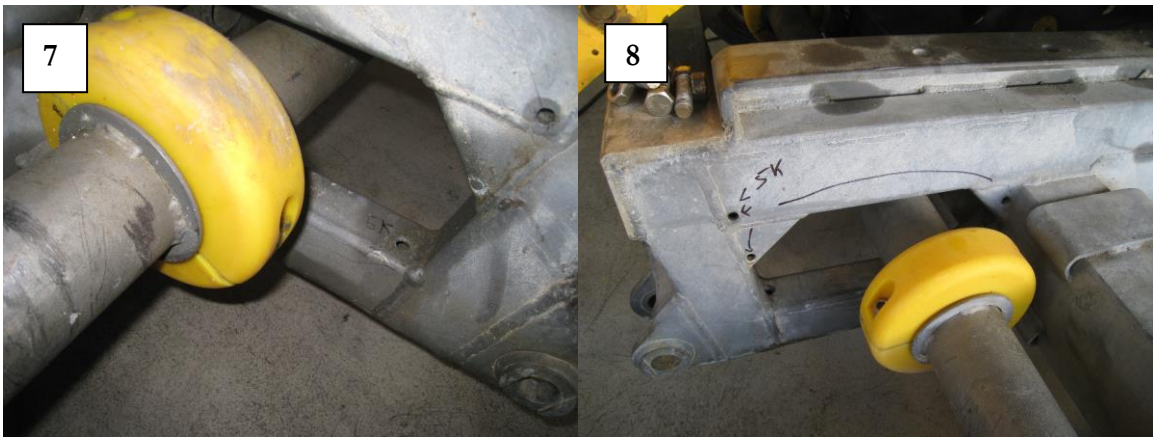
Det ble målt konsentrasjoner av kvikksølv som var på over 50 000 ng/m^3 på tre steder i hulrom i rammen (se bilde 3). Målingene på de andre hulrommene i rammen viste at konsentrasjonen var på lavere eller på samme nivå som ved forrige måling.

Bilde 3. Tre steder i rammen ble det målt konsentrasjon av kvikksølv på over 50 000 ng/m^3.

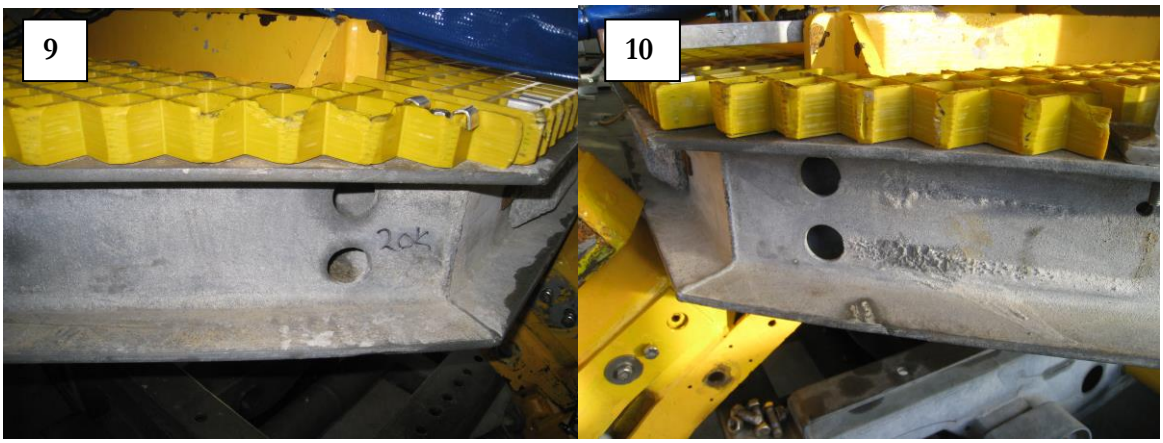
Bilde 4. I rammen på dette stedet ble det målt 10-12 000 ng Hg/m^3, mot 10 000 og 35 000 forrige gang.



Bilde 5. I rammen på dette stedet ble det målt 900-3000 ng Hg/m³.
Bilde 6. I rammen på dette stedet ble det målt mindre enn 1000 ng/m³, mot 5000 ng/m³ 6. februar.



Bilde 7 og 8. I rammen på disse stedene ble det målt lavere enn 2000 ng/m³, mot 5000 ved forrige måling.



Bilde 9. I rammen her ble det målt 6000 ng/m³, mot 20 000 forrige gang.
Bilde 10. I rammen her ble det målt 2500-3000 ng/m³.

Fra kl 8:30 til kl 12:00 ble det gjort flere omganger med spyling med varmt vann og påfølgende målinger i hullene vist på bilde 3. Kl 12:30 var høyeste konsentrasjon i rammen på dette stedet på 11 000 ng/m^3, en stor forbedring.

Det ble gjort nye målinger i hulrom i beltene til maskinen. Disse sto lagret i et annet verksted. Nivåene i hulrom og mellom beltene varierte mellom 200 og 1200 ng/m^3. Dette var omtrent samme nivåer som ved forrige måling.

Det ble også gjort nye målinger på pumpene som ankom fra Franzefoss. Konsentrasjonen varierete mellom 200 og 8000 ng/m^3.

Konklusjon: etter mange omganger med rengjøring er maskinen langt mindre forurenset av kvikksølv. Det er ikke lenger høye konsentrasjoner (over administrativ norm) av kvikksølv i hulrom i maskinen. Det som er igjen av kvikksølvforurensning i maskinen skal dermed ikke kunne medføre høy konsentrasjon av kvikksølv i luften inne i verkstedslokalet hos Deep C.

Med vennlig hilsen
NORSK INSTITUTT FOR VANNFORSKNING

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Environmental monitoring during survey by submarine U-864 outside Fedje in 2014 (NIVA)

Norwegian Institute for Water Research

Environmental monitoring during survey by submarine U-864 outside Fedje in 2014

Photo: Sigurd Øxnevad, NIVA.

Norwegian Institute for Water Research
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Abstract

NIVA has done environmental monitoring during a survey by the wreck of submarine U-864 outside Fedje. The survey was done in January 2014 on the vessel Geosund from DOF Subsea Norway. The main task for NIVA was to monitor if the work by the submarine caused any spreading of contaminated sediment. This was done by monitoring of turbidity around the wreck and analysis of mercury in water samples. A water current profiler was deployed in the mid area between the two main wreck sections. NIVA also did measurements for mercury in air on the vessel.
The digging and dredging in the contaminated area caused some spreading of particles contaminated with mercury, but the concentrations in the water samples were low (class II (good) or less). One sediment trap (10 m above the seabed) recovered from a position ca 200m northwest of the operation center contained 4.2 mg Hg/kg dry weight. This is classified as class V (very bad). The high concentration of mercury in the sediment trap shows that the digging and dredging has caused spreading of contamination. Model calculations based on the measurements available from the survey, showed that particle spreading will occur mainly towards northwest. Sediment fractions with size of more than 100 µm will settle within the 50 m model grid surrounding the operation. Particles with size 63 µm will not have travelled far beyond 200 m northwest of the operation center, but fine clay fractions (20 µm) may be transported up to 1 km away. It can be assumed that smaller sized particles will not constitute any significant fraction of the bulk sediment.

4 keywords, Norwegian	4 keywords, English
1. Fedje	1. Fedje
2. Ubåt U-864	2. Submarine U-864
3. Kvikksølv	3. Mercury
4. Turbiditet	4. Turbidity

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Environmental monitoring during survey by submarine U-864 outside Fedje in 2014

Preface

NIVA has done environmental monitoring during a survey by the wreck of submarine U-864 outside Fedje. The survery was done in January 2014 on the vessel Geosund from DOF Subsea Norway. The vessel Libas from Liegruppen was also used for retrieving of turbidity rigs. Monitoring of turbidity and water current were done by Pierre Franqois Jaccard and Odd Arne Skogan. Measurements of mercury were done by Ivar Martin Dahl and Sigurd Øxnevad. Modelling of sedimentation was done by André Staalstrøm. Sigurd Øxnevad has been project manager at NIVA.
Håvard K. Berge from DOF Subsea Norway was our contact person during the project.

The present version is a complete, quality assessed, but not final NIVA-report. That means it is still open for modifications based on comments from the contractors.

Oslo, 6.5.2014

Sigurd Øxnevad

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Summary

In January 2014 NIVA participated in a survey by the wreck of submarine U-864 outside Fedje. NIVAs role was to do environmental monitoring during the survey. For safety reasons, equipment that had been used on the seabed or near the seabed was checked for mercury pollution when it was placed on deck. No high concentrations of mercury were found in air in the ROV hangar. The Deep C excavator and dredger got very polluted with mercury. Liquid mercury was found on the excavator and high concentrations of mercury vapour were detected on several places on the machine.

Water samples were taken during the operations, and a total of 74 water samples were analysed. Mercury was detected in only small concentrations in the water samples. The concentrations of mercury in the water samples were in class I (background) and class II (good). The digging and dredging in the contaminated area caused some spreading of particles contaminated with mercury, but the concentrations in the water samples were low.

One sediment trap (10 m above the seabed) from rig OV8 was recovered. The sediment in this trap contained 4.20 mg Hg/kg dry weight. This is classified as class V ("very bad"). The high concentration of mercury in the sediment trap shows that the digging and dredging has caused spreading of mercury.

Due to loss of turbidity rigs there is not sufficient data to assess spreading of contamination with particles. Data for turbidity showed that there were several peaks of turbidity and some longer time periods with high turbidity measured on rig C a little north of the aft section.

Model calculations based on

- current and turbidity measurements on rig C,
- water samples collected from ROV and
- sediment material trapped at station OV-8,

showed that particles larger than 63 µm will sediment less than 100 m from the operation center; most actually within the 50 m model grid surrounding the working area. Typically, 50 to 80% of the sediment on the site is larger than 63 µm. The model showed that silt and clay fractions will be spread further away from the operation site. Particles of 63 µm will sediment mostly within 200 m, whereas the smaller size fractions of 20 µm may be transported up to 1 km through the water mass before settling on the sediment. Due to the prevailing current directions the particles will spread primarily towards northwest. It is assumed that particles smaller than 20 µm constitute a small fraction of the bulk sediment. Thus, we conclude that spreading of contaminated particles will be small beyond 1 km from the operation center.

Dissolved fractions of mercury have not been investigated in this work. However, previous measurements of water samples with suspended sediments have shown that the concentration of dissolved mercury is very small compared to the particulate fraction.

Sammendrag

I januar 2014 deltok NIVA på et tokt ved ubåt U-864 utenfor Fedje. NIVAs rolle var å utføre miljøovervåking. Av sikkerhetshensyn ble det gjort målinger av kvikksølvdamp på alt utstyr som hadde vært i kontakt med sjøbunnen i nærheten av ubåten. Det ble ikke påvist noen høye konsentrasjoner av kvikksølv i luft i ROV-hangaren, men det ble påvist høye konsentrasjoner av kvikksølv på gravemaskinen og mudringsslangen som hadde blitt brukt til arbeid ved ubåtvraket.

Vannprøver fra fire stasjoner rundt ubåtvraket ble analysert for kvikksølv. Vannprøvene ble tatt gjennom hele perioden, og totalt 74 prøver ble analysert. Det ble bare påvist lave konsentrasjoner av kvikksølv i vannprøvene. Konsentrasjonene av kvikksølv i vannprøvene var i klasse I (bakgrunn) og klasse II (god tilstand). Vannprøver som ble tatt bak mudringsslangen mens det pågikk mudring viste noe høyere konsentrasjoner av kvikksølv, men nivåene var likevel lave. Analysene av vannprøvene viste en sammenheng mellom partikkelinnhold og kvikksølv. Det betyr at det er grunn til å anta at der hvor det observeres høy turbiditet vil det også være økte konsentrasjoner av kvikksølv.

En sedimentfelle (fra 10 m over sjøbunnen) fra rigg OV8 ble tatt opp. Prøven i denne fellen inneholdt 4,20 mg Hg/kg tørrvekt, som klassifiseres som svært dårlig (klasse V). Vi skal være varsomme med å konkludere på grunnlag av en enkelt prøve, men funnet av kvikksølv i denne sedimentfellen indikerer at grave- og mudringsarbeidene ved ubåten har medført spredning av kvikksølv minst 200 m nordvest for operasjonsområdet.

På grunn av tap av turbiditetsrigger har vi ikke nok data til å vurdere partikkelspredning godt nok. Data fra den midtre turbiditetsriggen (C) viser at det var flere topper med høy turbiditet og at det også var lengre perioder med høy turbiditet på stasjonen rett nord for der hvor det foregikk arbeid ved ubåten.

Modellberegninger basert på strøm- og turbiditetsmålinger fra rigg C, vannprøver samlet inn ved hjelp av ROV og sediment fra sedimentfellen fra stasjon OV-8 viser at partikler større enn 63 µm vil ha sedimentert mindre enn 100 m fra det sentrale arbeidsområdet. Anslagsvis 50 – 80 % av sedimentet i dette området er større enn 63 µm. Modellen viser at silt- og leirefraksjonene kan ha blitt spredt lengre vekk fra arbeidsområdet. Partikler på størrelse 63 µm vil i hovedsak ha sedimentert innenfor en radius på 200 m, mens partikkelfraksjoner på 20 µm kan ha blitt transportert opp til 1 km med vannmassene før de har sunket til bunnen. På grunn av de rådende strømforholdene vil partiklene primært ha drevet i nordvestlig retning. Det antas at partikler mindre enn 20 µm utgjør en liten del av sedimentet. Vi konkluderer derfor med at det har vært lite spredning av forurenset materiale lengre enn 1 km fra det sentrale arbeidsområdet.

Løste fraksjoner er ikke undersøkt i dette arbeidet. Erfaringer fra andre operasjoner har vist svært liten utløsing av kvikksølv fra suspenderte, forurensede sedimenter så det er rimelig å anta at spredning av kvikksølv i all hovedsak vil være knyttet til spredning av partikler.

1. Background

In February 1945 the German submarine U-864 was sunk outside Fedje, on the south western coast of Norway. The submarine was torpedoed midship, broke in two and sank, and is located at 150 m depth. U-864 is assumed to have had 67 tons of liquid mercury onboard, stored in 1857 carbon steel cans in compartments inside the keel. When torpedoed, the mid-section of the submarine was blown up, and an unknown number of the steel cans were destroyed and mercury was spread to pollute the surrounding seabed. Mercury cans may also have corroded during the decades that have passed since the torpedition event and started to leak mercury to the seabed.

The authorities have decided to further evaluate two different methods of pollution abatement:

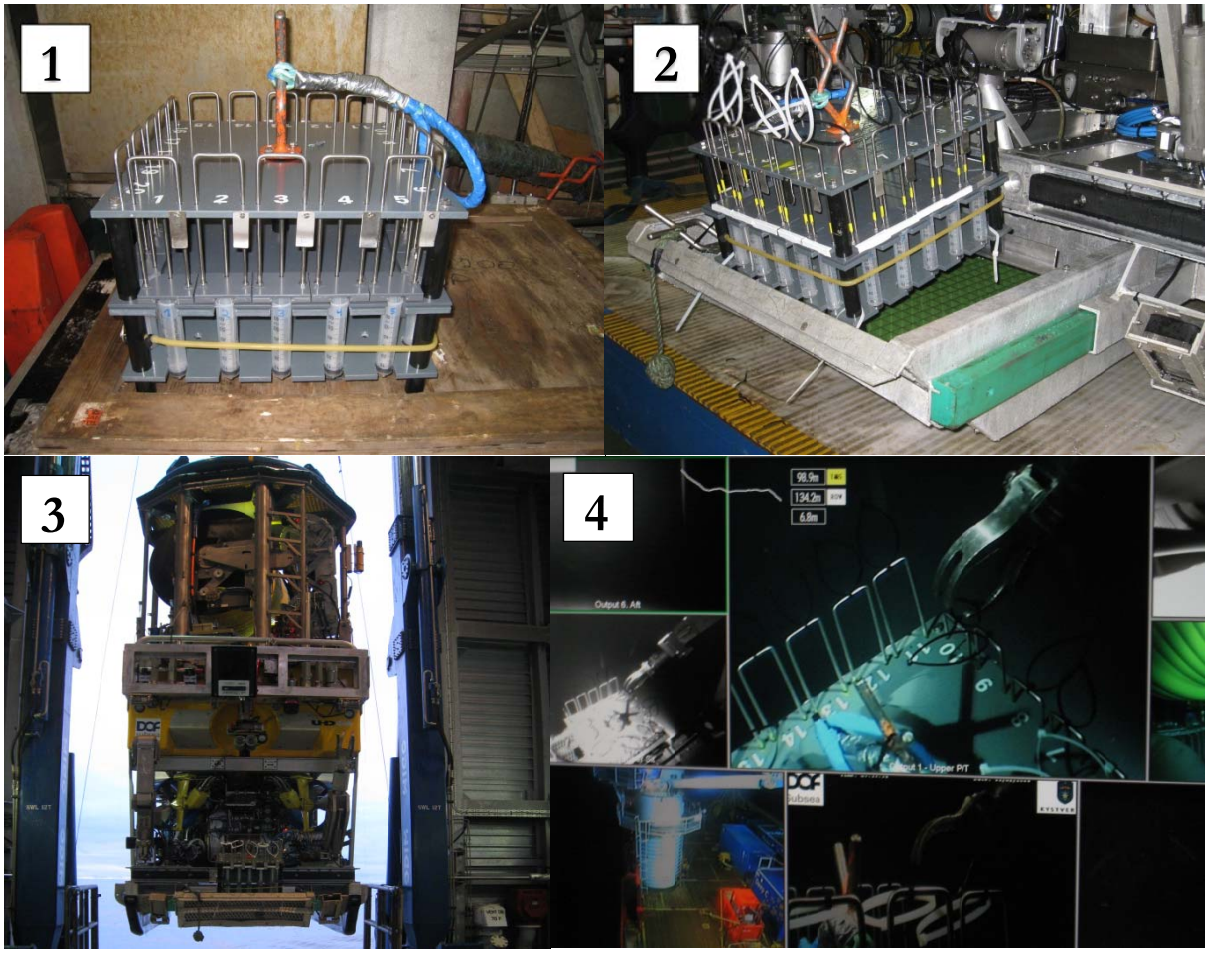
- Seal-in the polluted area, utilizing sand with special characteristics
- Retrieve the mercury cans from the keel section and seal-in the polluted area

In January 2014 NIVA participated on a survey to provide the NCA (Kystverket) with information to identify different risks and gain information on the feasibility of salvaging Hg canisters from the wreck of the U-864. NIVA did environmental investigations and monitoring during the survey.

2. Materials and methods

2.1 Water sampling

Water samples were taken with a water sampler made at NIVA, designed for taking 20 water samples in 60 ml syringes (Pictures 1-4). The water sampler was mounted on a ROV and operated by the ROV crew.



Pictures 1-4. The water samples were taken with a water sampler mounted on a ROV (photos: Sigurd Øxnevad, NIVA).

Water samples were taken at four stations (WSL-1, to WSL-4, Figure 1). Samples were taken at two depths, 3 and 10 meters above the seabed. Samples were taken at station WSL-5 on 13.1.2014 since there were only limited access to the stations due to the position of the vessel.

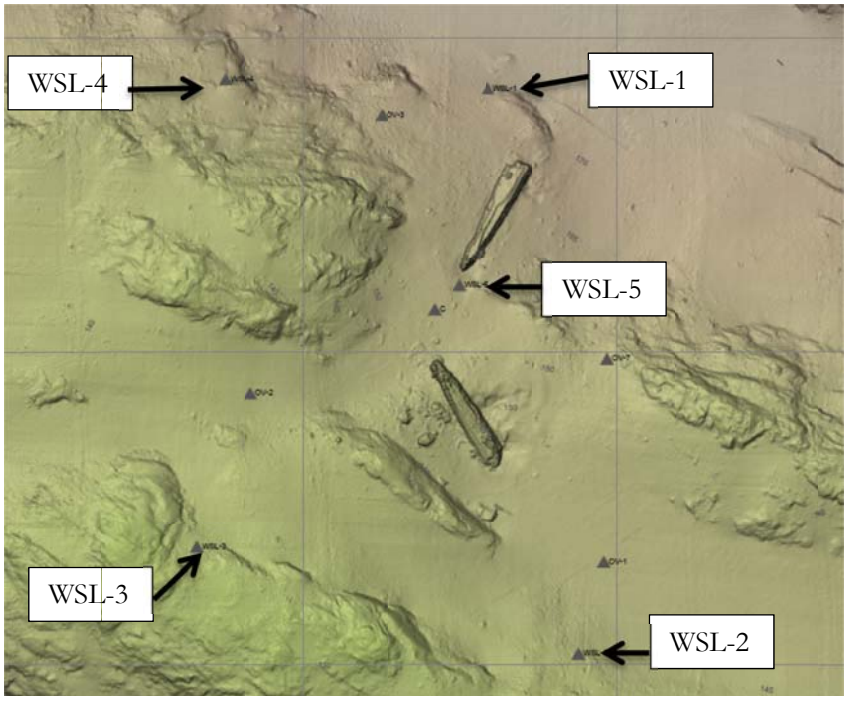


Figure 1. Water samples were collected around the wreck of submarine U-864 for analysis of mercury.

2.2 Measurements for mercury in air as part of HSE procedures

For safety reasons, equipment that had been used on the seabed or near the seabed was checked for mercury pollution when it was placed on deck. Personal protective equipment class 2 (including half face mask respirator with filters type HgP3) was used until the equipment and area was declared safe (picture 5). A portable Lumex Zeeman Mercury Analyzer was used to check for mercury vapour. The instrument is a multifunctional atomic absorption spectrometer with Xeeman background correction, which eliminates the effect of interfering impurities. It does not require gold amalgam pre-concentration and subsequent regeneration steps. This enables the user to conduct real time monitoring and detection of mercury vapour. The detection limit was 2 ng/m^3. Administrative norm for mercury vapour is 0.02 mg/m^3 (20 000 ng/m^3, veiledning om administrative normer for forurensning i arbeidsatmosfære, http://www.arbeidstilsynet.no/artikkel.html?tid=78880).

Picture 5. Measurement of mercury in air around a ROV that had just been landed on deck (photo: Fillip Andersen, Franzefoss).

2.3 Analysis of mercury in water samples

Water samples were analysed with a portable Lumex Zeeman Mercury Analyzer RA-915+, with a RP-91 attachment for liquid samples (Picture 6). The analytical principle is atomic absorption spectrometry using cold vapour technique. Mercury in the water sample is reduced with tin chloride to metallic mercury, and the vapour is flushed into an analytical cell of 10 meter optical path. This ensures high sensitivity and a detection limit of 0,5 - 1 ng/l could be achieved. A 10 ml water sample was used for the analysis of mercury.

Picture 6. Water samples were analysed with a portable Lumex Zeeman Mercury Analyzer RA-915+, with a RP-91 attachment (photo: Sigurd Øxnevad, NIVA).

The results were classified according to the classification system of the Norwegian Environmental Agency for classification of environmental quality in fjords and coastal water (Table 1, from Bakke *et al.* 2007).

Table 1. Classification system for concentration of mercury in water (from Bakke *et al.* 2007).

	Class I Background	**Class II Good**	**Class III Moderately polluted**	**Class IV Bad**	**Class V Very bad**
Mercury (µg Hg/l)	**<0.001**	**0.001 – 0.048**	**0.048 – 0.071**	**0.071 – 0.14**	**>0.14**

2.4 Analysis of mercury in sediment from sediment traps

Sediment was analysed with a Lumex RA-915+ Mercury Analyzer with pyrolyzer PYRO-915+. Combined with a two-chamber atomizer (PYRO-915+), the instrument can determine mercury content in solid samples such as sediment. The detection limit is 1.0 µg/kg in solid samples. A certified marine sediment reference material (MESS-3) was used as standard for the analysis of sediment samples.
The results were classified according to the classification system of the Norwegian Climate and Pollution Agency for classification of environmental quality in fjords and coastal water (Table 2) (Bakke et al. 2007).

Table 2. Classification system for concentration of mercury in marine sediments (from Bakke et al. 2007).

	Class I Background	**Class II Good**	**Class III Moderately polluted**	**Class IV Bad**	**Class V Very bad**
Mercury (mg/kg) dry weight	**<0.15**	**0.15 – 0.63**	**0.63 – 0.86**	**0.86 – 1.6**	**>1.6**

2.5 Monitoring of turbidity and water current

On January 8th to 9th seven rigs with instruments for monitoring of turbidity was deployed around the wreck of submarine U-864 (Figure 2). The intention was to deploy 8 rigs, but one rig got damaged during the lifting operation.

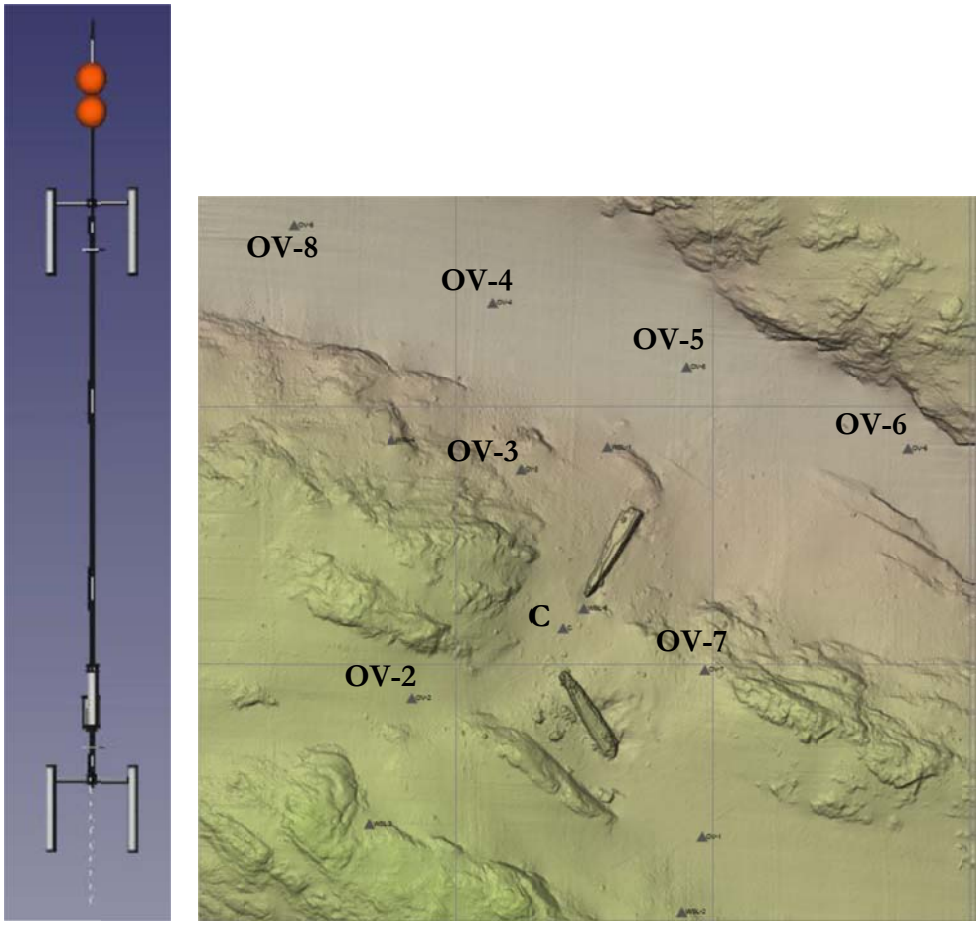


Figure 2. Turbidity rigs were deployed on 7 stations (OV-2 - OV-8) around the submarine wreck, and one turbidity sensor was mounted on the water current meter rig (C).

Turbidity was monitored at seven stations and water current was monitored at one station (Figure 2). The turbidity rigs were designed with turbidity sensors and sediment traps 3 and 10 meters above the seabed. Each rig had underwater modem and battery housing for transferring on-line measurements. The rigs also had a 100 kg anchor and buoyancy. Turbidity was acquired with AML MicroX Turbidity sensors (0-100 NTU).

Water current was measured through the whole water column in 5 m vertical cells with a Nortek Continental acoustic Doppler profiler. The water current profiler and turbidity sensor were deployed in a tripod frame (Picture 7). The turbidity sensor was installed at the same level as the profiler head. Measured deployment depth at profiler head was approximately 150 m. An IXSEA Oceano 2500 acoustic release was installed on the tripod. The tripod was retrieved up on deck, and logged data was unloaded. Extra battery was mounted to the tripod before it was deployed back to the same position for further logging of water currents.

Picture 7. Tripod with water current profiler and turbidity sensor being deployed (photo: Sigurd Øxnevad, NIVA).

A surface buoy with acoustic modem, battery and GPRS router was deployed for transfer of online measurements (Figure 3).

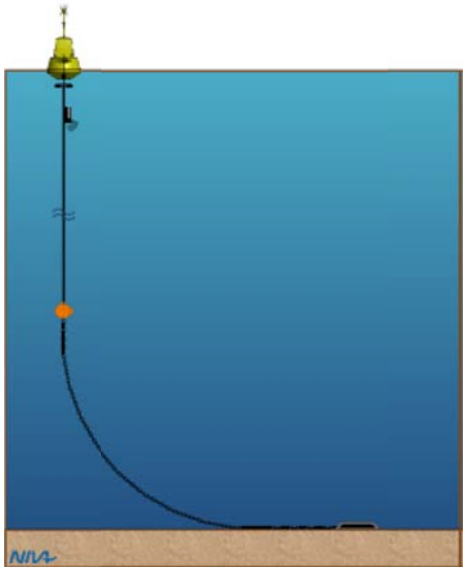


Figure 3. Figure of surface buoy with mooring, and picture of surface buoy outside Fedje (photo: Sigurd Øxnevad, NIVA).

Turbidity sensors were set up to measure turbidity every 15 seconds and "pushed" these values directly to the underwater acoustic modem on the local station. The underwater modem was set up to be in "Data Logger mode" and would then store data continuously in records in its local memory.
The acoustic surface modem made queries towards all the underwater modems at regular intervals specified by LabView program running on a PC that was locally at the NIVA office in Oslo. The acoustic surface modem communicated with a GPRS modem in the buoy which communicated with the PC at NIVA, Oslo. The queries from the PC in Oslo started on 9 January at 14.42, and the last query was executed on 16 January at 18:28 The LabView program in Oslo was programmed to ask for data every 15 minutes for turbidity and every 30 minutes for current.

2.6 Modelling sedimentation of particles

2.6.1 Objectives and general assumptions

Digging activity in sediments will whirl up a cloud of suspended particles. This cloud will be transported with the currents while the particles sink down until they settle at the sea bed some distance downstream. The objective of the model is to describe the lateral transport and sedimentation of Hg-contaminated particles suspended in the water column from activities undertaken during the operation described in this report.

Current in the water column as well as turbidity near the sea bed was measured at a station close to where the activity took place. The current was measured every 10 minutes with a vertical resolution of 5 m. The turbidity is a measure of suspended particles, and it is frequently assumed that a turbidity of 1 NTU correspond to a particle concentration of 1 g/m³ (Sørensen et al. 1993). This assumption applies also to this work.

Since current measurements only are available at one site, we assume no horizontal variation in the current field. This approximation is acceptable if the particles settle within a few hundred meters from the release point.

The Lagrangian particle tracking model described below, is referred to as NIVATRAC in the following.

2.6.2 Mathematical description of the model

Initially we have a particle released at a position ($x^{n=1}$, $y^{n=1}$ and $z^{n=1}$) at the time $t^{n=1}$ at the first timestep, $n = 1$, of the simulation. We have the relations

$$\frac{dx}{dt} = u$$

$$\frac{dy}{dt} = v \qquad (1)$$

$$\frac{dz}{dt} = w$$

By using a forward in time numerical scheme, we can calculate the position based on the relations (1) if the velocities u, v and w are known

$$x^{n+1} = x^n + u^n \cdot \Delta t$$

$$y^{n+1} = y^n + v^n \cdot \Delta t \qquad (2)$$

$$z^{n+1} = z^n + w^n \cdot \Delta t$$

The horizontal velocities, u and v are interpolated to the correct time and depth from the current measurements.

2.6.3 Sinking velocity

The vertical velocity,w, is calculated based on Stokes law

$$w = \frac{\rho_s - \rho}{18\mu} g d^2 \qquad (3)$$

Here ρ_s is the density of the particle (2.7 g/ml), ρ and μ are the density and viscosity of the sea water, g is the acceleration of gravity and d is the particle diameter.

2.6.4 The shape of the initial particle cloud

In the model, the initial cloud is represented by particles released at ten different depths above the seabed. The concentration of particles in the cloud is assumed to vary linearly from the measured value at the bottom to the background value at 10 m above the seabed. The shape of the cloud is assumed to be a cone, with a radius of 7.5 m at the seabed and a height of 10 m.

The unknown shape of the initial cloud is the largest source of uncertainty in the calculations, but this will only affect the absolute values of the sedimentation rate, and not the horizontal distribution pattern. The volume and particle distribution in the cone was scaled to fit the amount of particles collected in the sediment trap recovered 200 m away from the position of the cone. Particles are released every 10 minutes, but only if the concentration is above the background value, which was set to the lowest turbidity measured at station C.

For each class of particles it is assumed that the measured turbidity is a result of a cloud of uniform particles, all with size d.

2.6.5 Calculating sedimentation

The trajectories of the different particles are calculated until they reach the seabed because of sinking. The position is then stored, and the mass of all the particles that land within grid cells of size 50 x 50 m^2 are summed up. This is used to estimate the sedimentation rate. The density of the particles (ρ_s) are set to 2.7 g/ml in this calculation.

3. Results

3.1 Measurements for mercury vapour

Results from the measurements of mercury in air are presented in Appendix A.. No high concentrations of mercury were found in the ROV hangar. The Deep C excavator and dredger got very polluted with mercury, and cleaning turned out to be time consuming and difficult.

Liquid mercury was found on the Deep C machine on several places. After thorough flushing of the Deep C machine, liquid mercury and sediment was caught in the silt cloth (picture 8), but a few drops of mercury were also found on the wooden deck (picture 9).

Pictures 8 and 9. Mercury and sediment on the silt cloth (7), and mercury on the wooden deck (8) (photos: Sigurd Øxnevad, NIVA).

After the equipment was unloaded from deck, some of the wooden beams were removed. No liquid mercury was spotted on deck underneath the beams.

3.2 Mercury in sediment samples

Sediments were collected from the most contaminated area close to the submarine and from an area north of the contaminated site. In the area close to the wreck, approximately 50L of sediment was collected in two bags using the ROV and a steel shovel. The purpose of this sampling was to supply sediment for methylation experiments run at NIVA, Solbergstrand and in U.S. The bags were shipped to Solbergstrand in a metal barrel and three replicate subsamples were collected and analysed for total and methyl mercury. The results are shown in Table 3. The concentrations were 5-6 times higher than the boundary value for environmental class V "Very bad". The relatively low concentrations of methyl Hg confirmed previous conclusions that the environmental conditions at the U-864 site are not favourable for the methylation process.

Table 3. Total and methyl mercury in sediment collected near the submarine. The sediment was collected with a shovel operated by the ROV, and three replicate subsamples (A, B and C) were taken from the batch sample after arrival at NIVAs research station at Solbergstrand.

Sample	Total Hg (mg/kg dw)	Methyl Hg (mg/kg dw)
A	8,0	0,0012
B	8,8	0,0003
C	10,0	0,0003

Core samples from the area to the north were sampled by the ROV, but the cores were violently shaken and tipped over several times during handling both by the ROV and winching onboard. This caused severe vertical mixing of the sediments inside the core. The objective was to compare with previously collected samples to assess potential changes in the concentration of Hg within the top 0-2 cm layer, but the cores were not suitable for addressing this question. It was intended to collect new core samples later during the cruise, but this task was not given priority towards the end of the cruise

3.3 Mercury in water samples

The results from analysis of water samples are presented in Appendix B. The majority of the 74 water samples collected in syringes mounted on the ROV were below detection limit of 1 ng/l total Hg. 12 samples had detectable levels of Hg, the highest concentration was 7,3 ng/l in a sample collected on January, 12th. All of the 12 samples with detectable levels of Hg were classified as class II "good". The statistical analyses in figure 4 shows a positive correlation between turbidity and total concentration of mercury determined in the water samples.

Dissolved fractions may spread far from the dredging site without showing up neither on turbidity sensors nor in sediment traps. However, filtration of samples with suspended sediments has shown that most of the mercury occur in the particulate fractions (Schaanning et al., 2007).

3.4 Mercury in sediment from sediment trap at OV8

One sediment trap (10 m above the seabed) from rig OV8 was recovered. The sediment in this trap contained 4.20 mg Hg/kg dry weight. This is classified as class V (very bad). 98 % of the sediment particles were smaller than 63 µm in size. The high concentration of mercury in the sediment showed beyond reasonable doubt that the material trapped at OV8 originated in the digging and dredging activities at the submarine.

In two water samples with elevated concentrations of mercury, the concentrations were 7 ng/l and turbidity 18. The NTU scale is approximately correspondent with particle concentration so that 1 NTU equals 1 mg/l. Thus the two water samples had a sediment concentration of 7 ng Hg/18 mg sediment or 0,4 mg Hg/kg which is less than the concentration found in the trap. Sediment concentrations will vary from one location to another and with sediment depth so that the concentrations in the suspended particles are likely to vary during the operation. Also the concentration will vary with particles size so that the concentrations on the finest fractions which are carried the longest distance may be different from the bulk sediment suspended at the operation site. Thus, we would not expect a close match, and concludes that particles with similar or higher content of Hg than those found in the water samples have been transported in the water a distance of at least 200 m from the operation site to OV8.

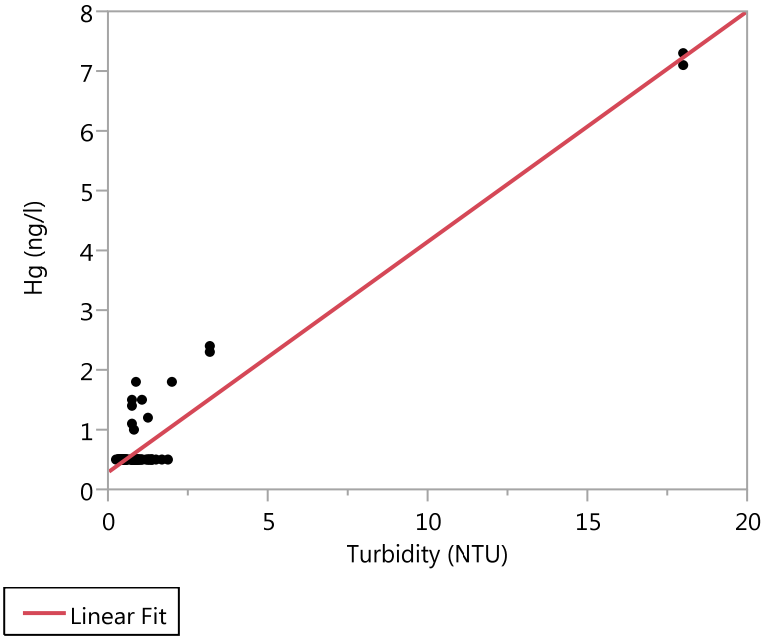
3.5 Monitoring of turbidity and water current

Water current profiles are shown in Figure 5. The water current was mainly in northern direction, and the current speeds decreased from 50-100 cm/s.

The turbidity sensor on the tripod rig (C) was nearest to the work site by the aft section of the submarine. The turbidity monitoring showed that there were some turbidity peaks the 10th and 11th of January, a longer period with high turbidity the 12th of January, and some high peaks the 13th and 14th of January (Figure 6). Typical current speed was about 20 cm/s with variation between 0 and 50 cm/s.

The available turbidity data from stations OV2, OV3, OV6 and OV8 are shown in Appendix C. The registrations showed that there were no high peaks from 8th to 9th of January. On station OV2 there

Bivariate Fit of Hg (ng/l) By Turbidity (NTU)



Linear Fit

Hg (ng/l) = 0,3147138 + 0,3855845*Turbidity (NTU)

Summary of Fit

RSquare	0,917468
RSquare Adj	0,916321
Root Mean Square Error	0,331546
Mean of Response	0,82973
Observations (or Sum Wgts)	74

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	87,980179	87,9802	800,3842
Error	72	7,914415	0,1099	**Prob > F**
C. Total	73	95,894595		<,0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0,3147138	0,042624	7,38	<,0001*
Turbidity (NTU)	0,3855845	0,013629	28,29	<,0001*

Figure 4. Correlation between turbidity and concentration of mercury in all (n=74) syringe samples. Concentrations less than the detection limit was assigned 0,5 ng/l in this analyses.

The samples taken behind the dredger hose while dredging, had higher turbidity and a little higher concentrations of mercury, but were still not very polluted. The concentrations of mercury found in water close to the dredger was at the same level as found during dredging operations in 2006 (Uriansrud *et al.* 2006).

were only low turbidity values from the sensor 3 meters above the seabed, however on the sensor 10 meters above the seabed the turbidity increased from 2 to a maximum of 48 NTU during 9th to 11th of January. There is no apparent rationale to explain the difference between this and the other sensors. The registrations appear spurious and care should be taken when interpreting the data. On station OV6 there were no peaks in turbidity during 9th to 11th of January.

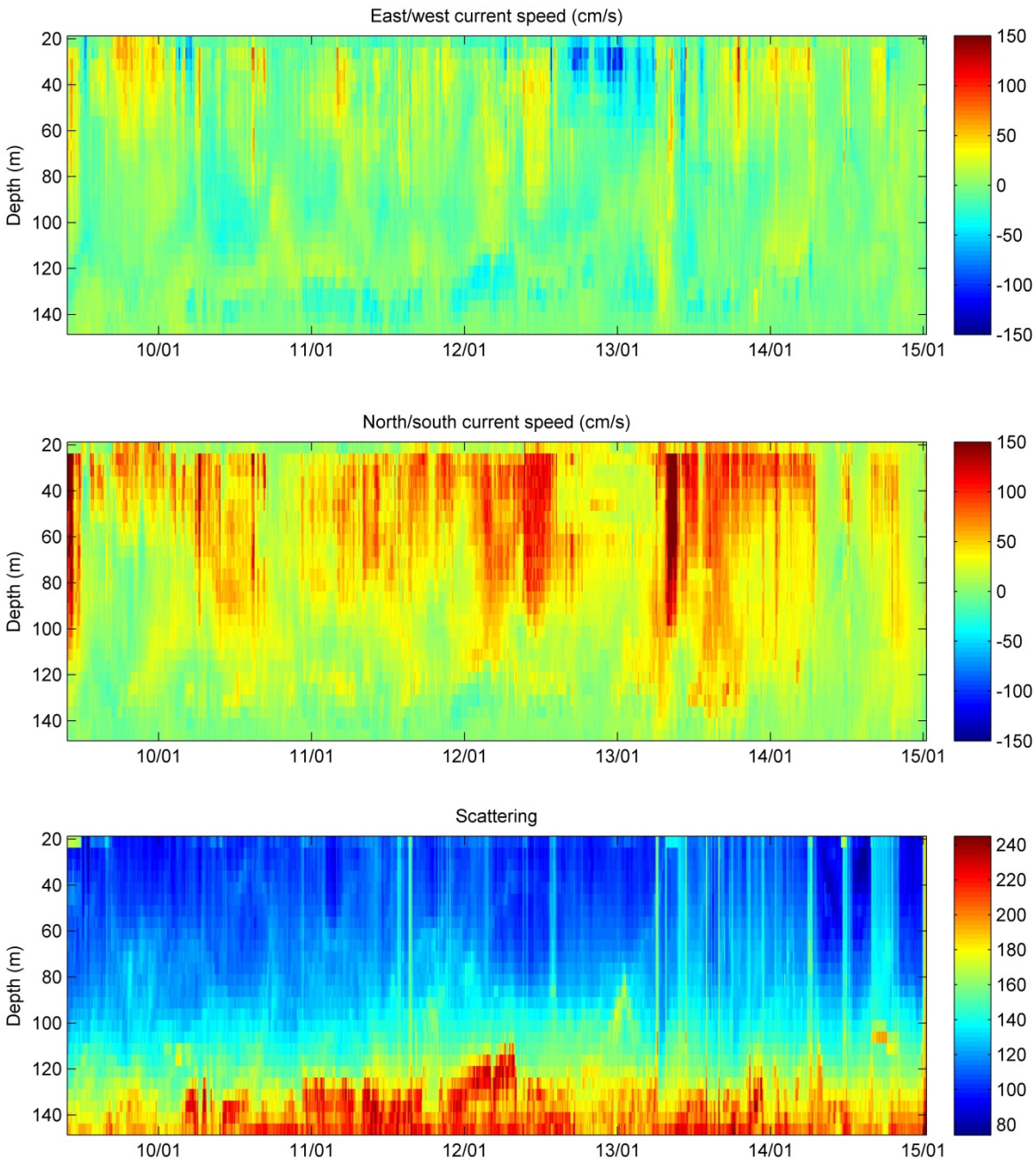


Figure 5. Upper panel: Current speed in the east-west direction. The color scale indicates the current speed in cm/s. Middle panel: Current speed in the north-south direction. The color scale indicates the current speed in cm/s. Bottom panel: Scattering from the ADCP current meter, indicating the particle concentration in the water column.

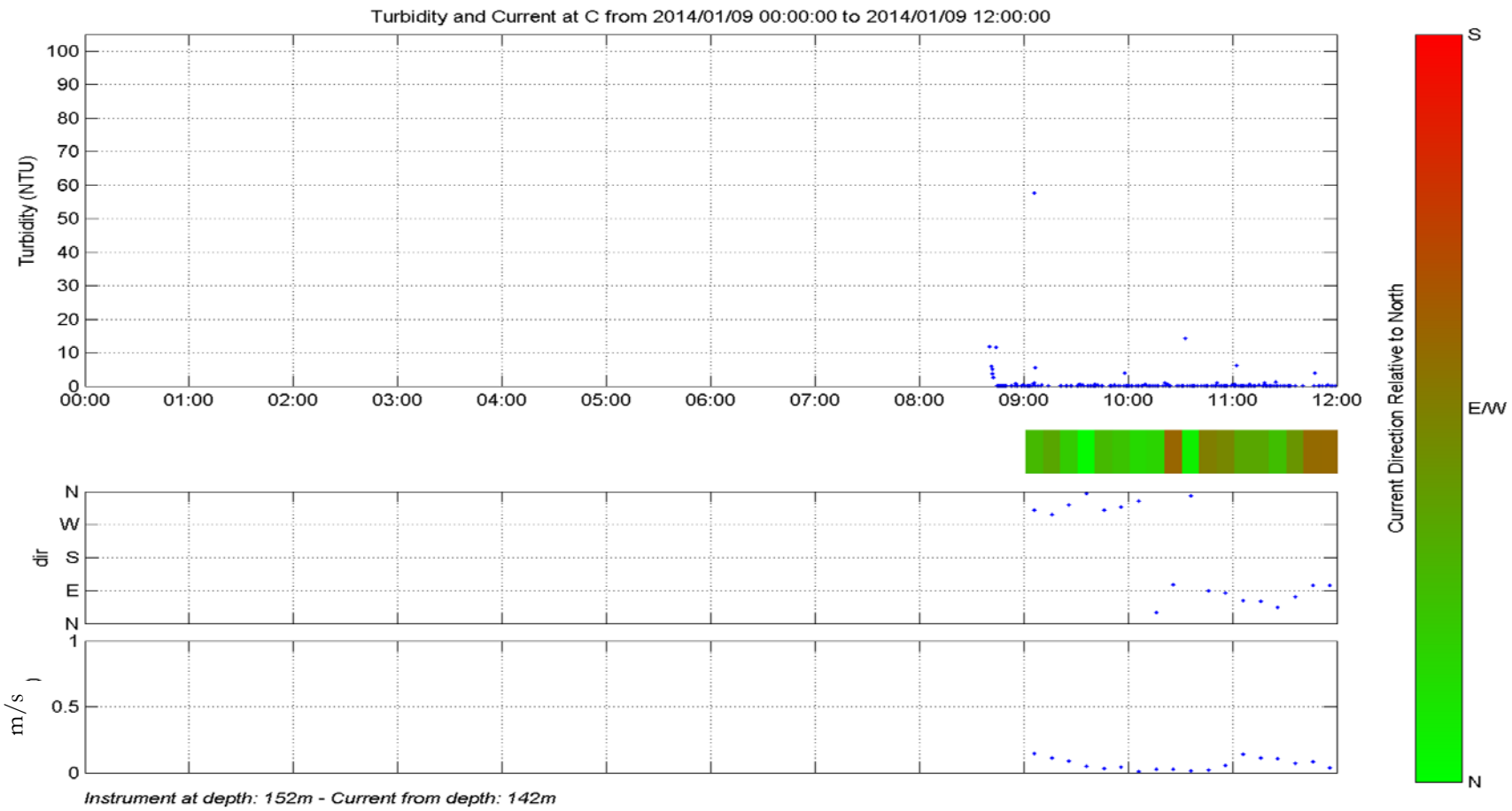
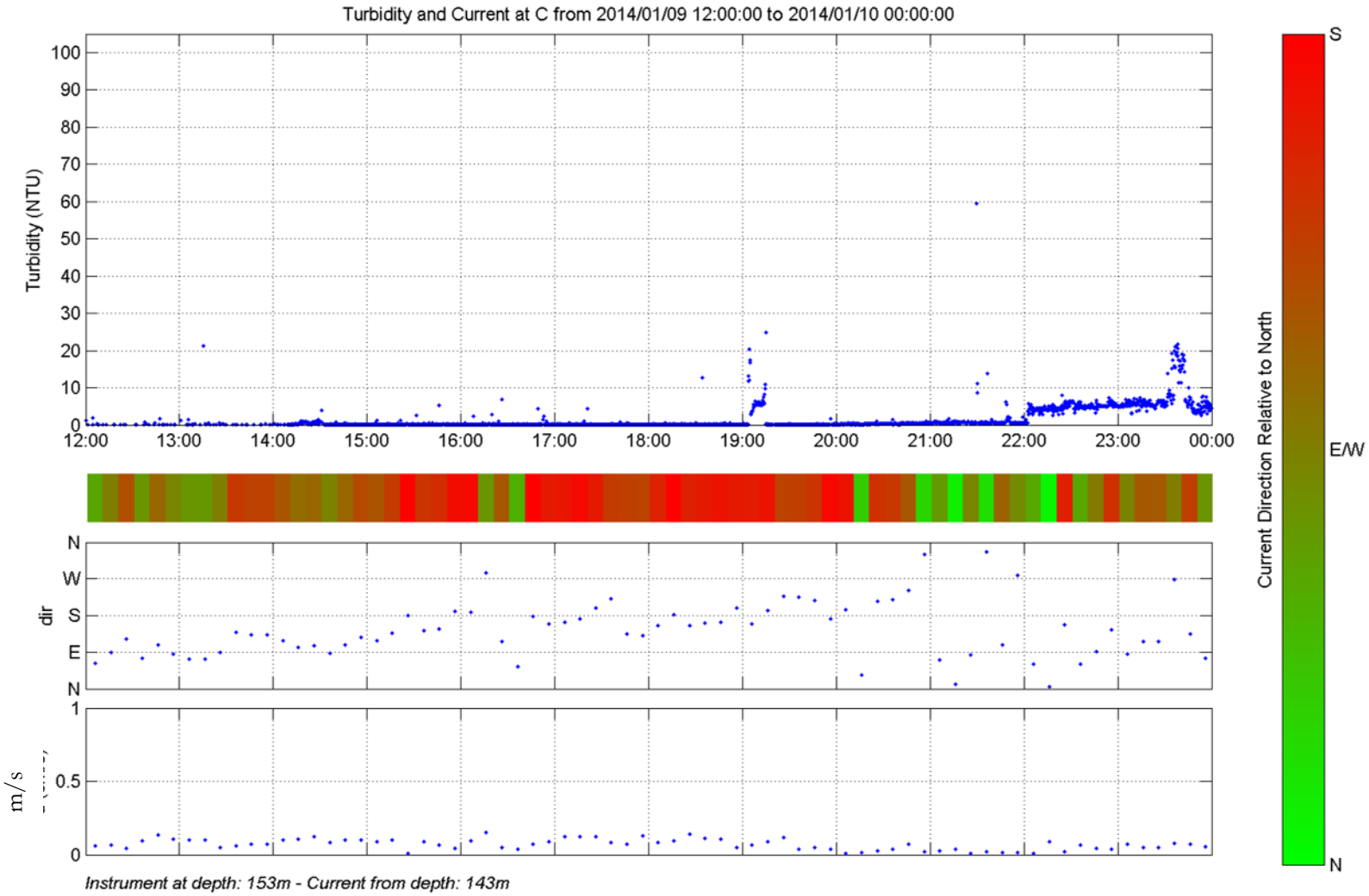


Figure 6. Turbidity and water current monitored at station C (between the two wreck sections). Data are presented in time series plot for turbidity, horizontal current direction and magnitude. Colour patches represent current direction relative to north. Assuming subsea operations were mainly located around the southern wreck part, position C for turbidity and current measurements can be found almost right north. Hence, the patches show whether the current is in the direction from subsea operations to position C (green) or opposite (red). Time is shown in UTC time. The figure continues on the following pages….


Turbidity and Current at C from 2014/01/09 12:00:00 to 2014/01/10 00:00:00
Turbidity (NTU)
100
90
80
70
60
50
40
30
20
10
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12:00
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15:00
16:00
17:00
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19:00
20:00
21:00
22:00
23:00
00:00
dir
N
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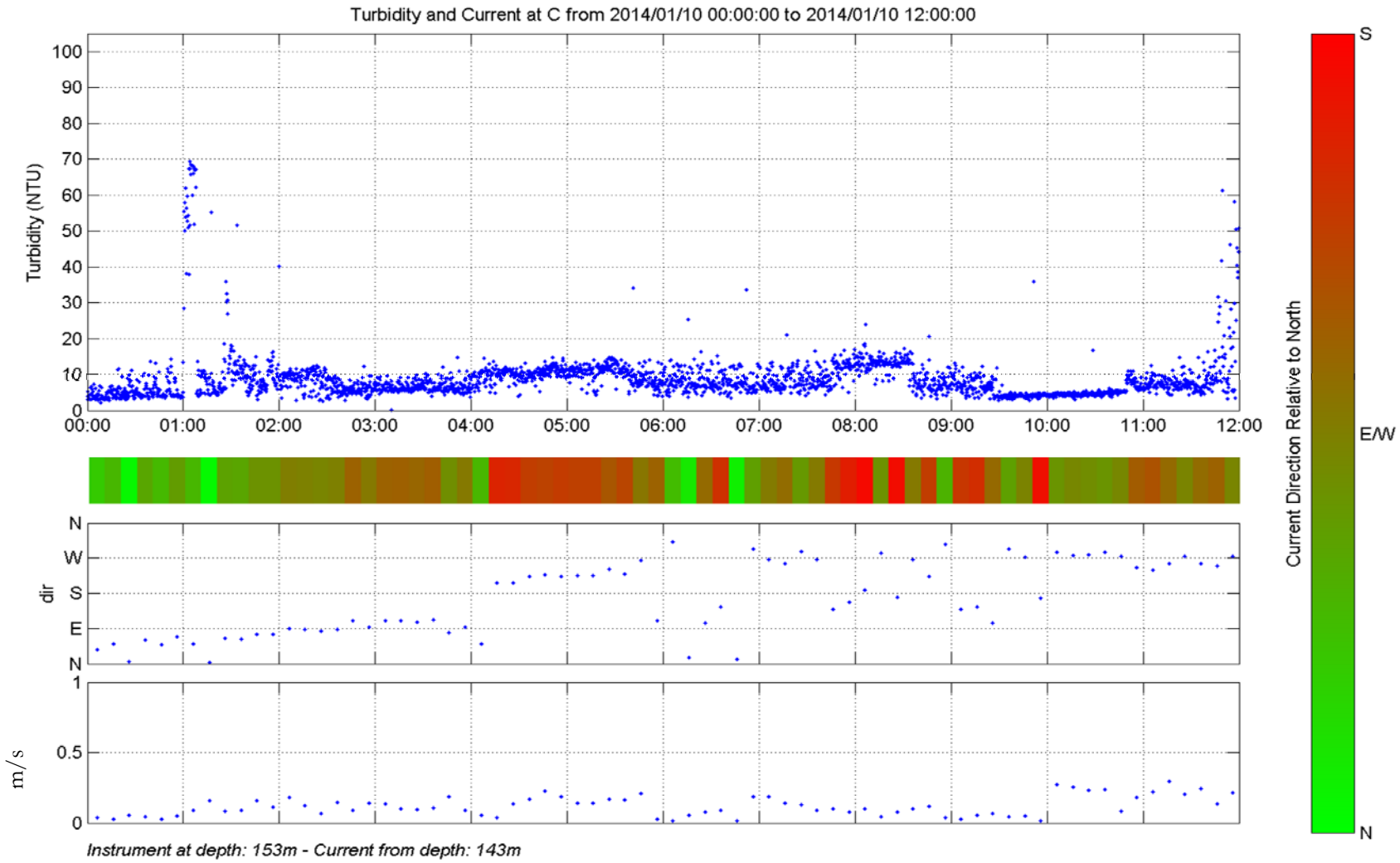
m/s
1
0.5
0
Current Direction Relative to North
S
E/W
N
Instrument at depth: 153m - Current from depth: 143m


Turbidity and Current at C from 2014/01/10 00:00:00 to 2014/01/10 12:00:00
Turbidity (NTU)
100
90
80
70
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50
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30
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00:00
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Current Direction Relative to North
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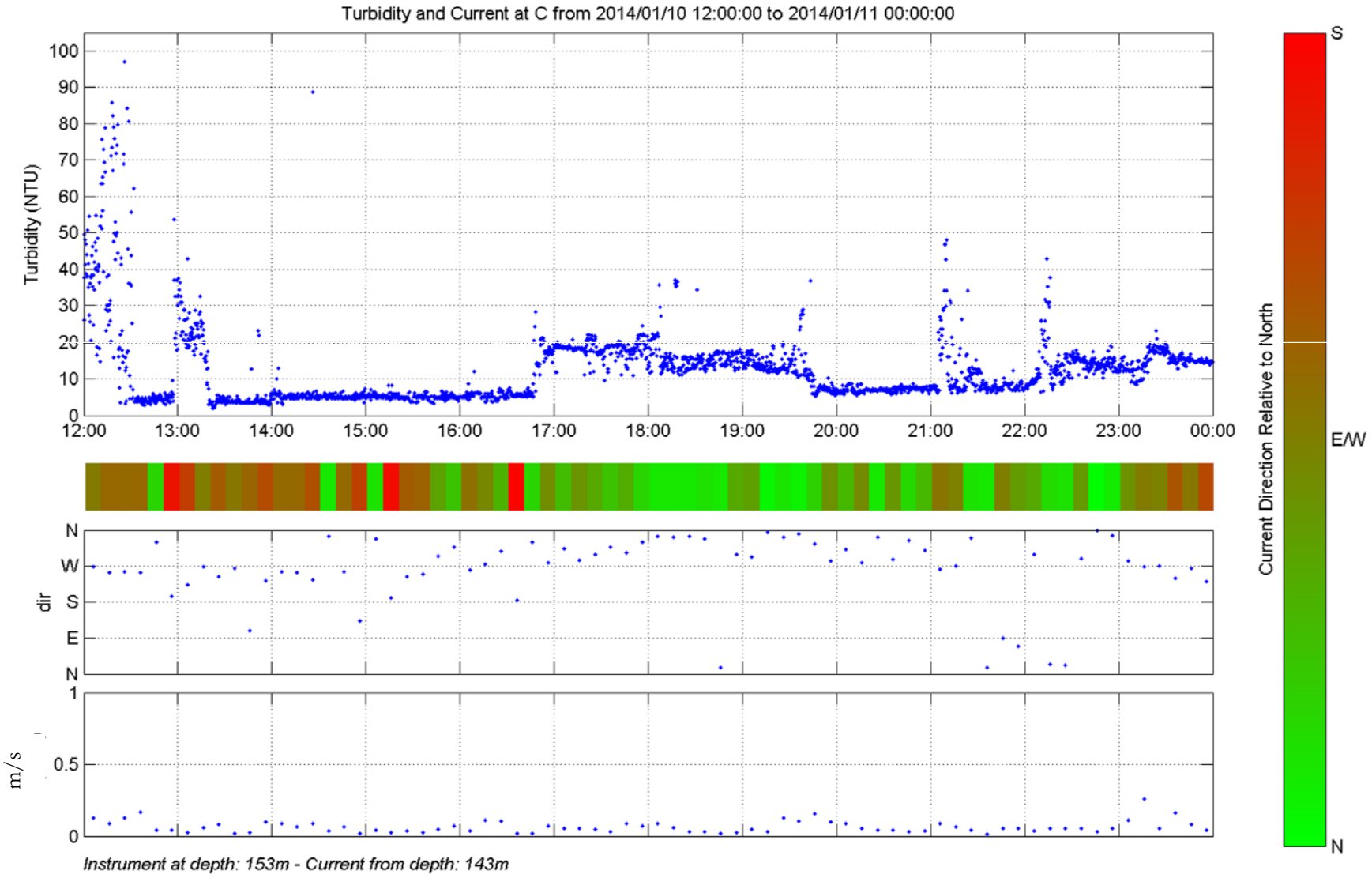
Instrument at depth: 153m - Current from depth: 143m


Turbidity and Current at C from 2014/01/10 12:00:00 to 2014/01/11 00:00:00
Turbidity (NTU)
100
90
80
70
60
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40
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Current Direction Relative to North
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E/W
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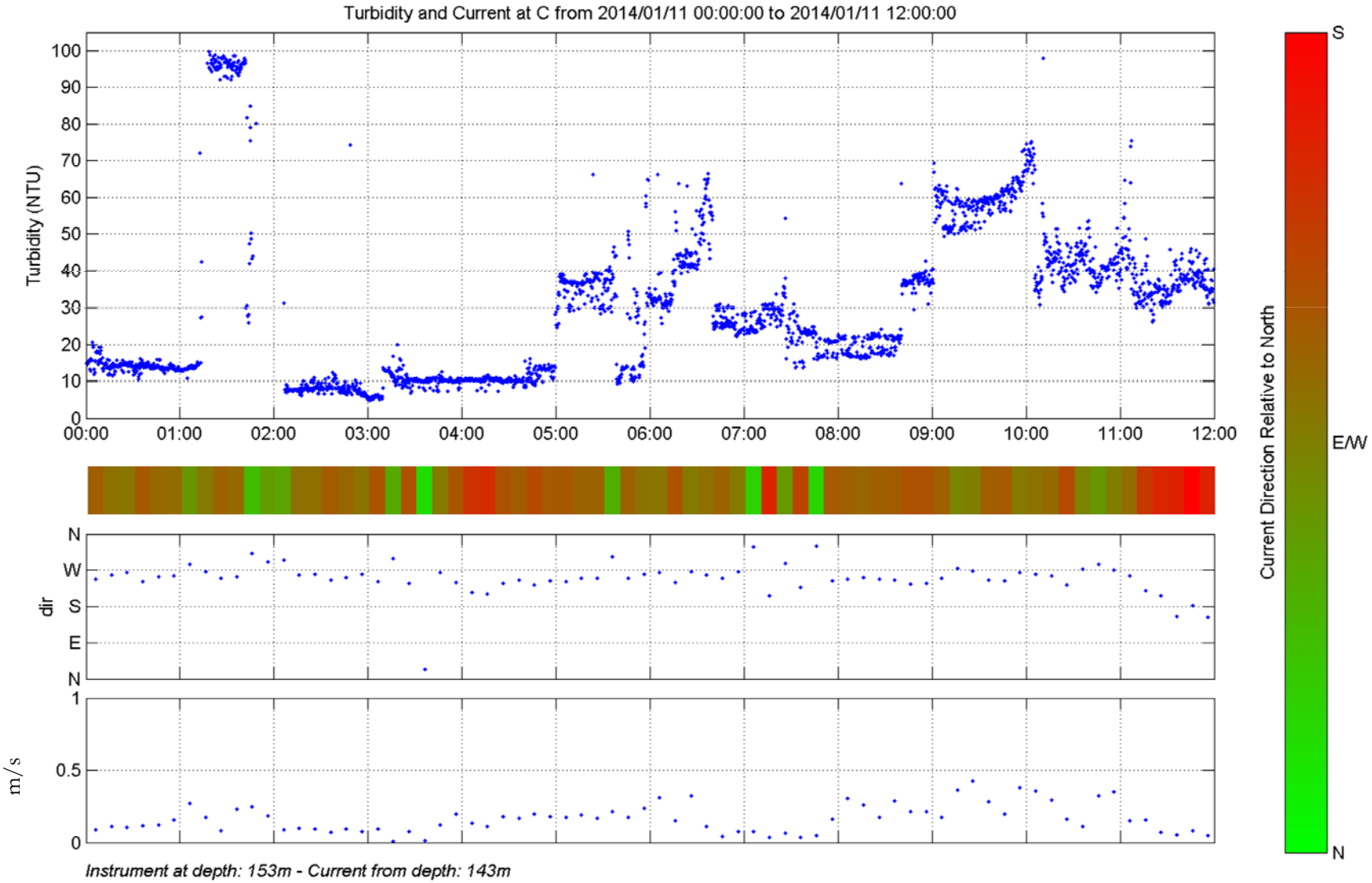
Instrument at depth: 153m - Current from depth: 143m


Turbidity and Current at C from 2014/01/11 00:00:00 to 2014/01/11 12:00:00
Turbidity (NTU)
100
90
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02:00
03:00
04:00
05:00
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dir
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Current Direction Relative to North
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E/W
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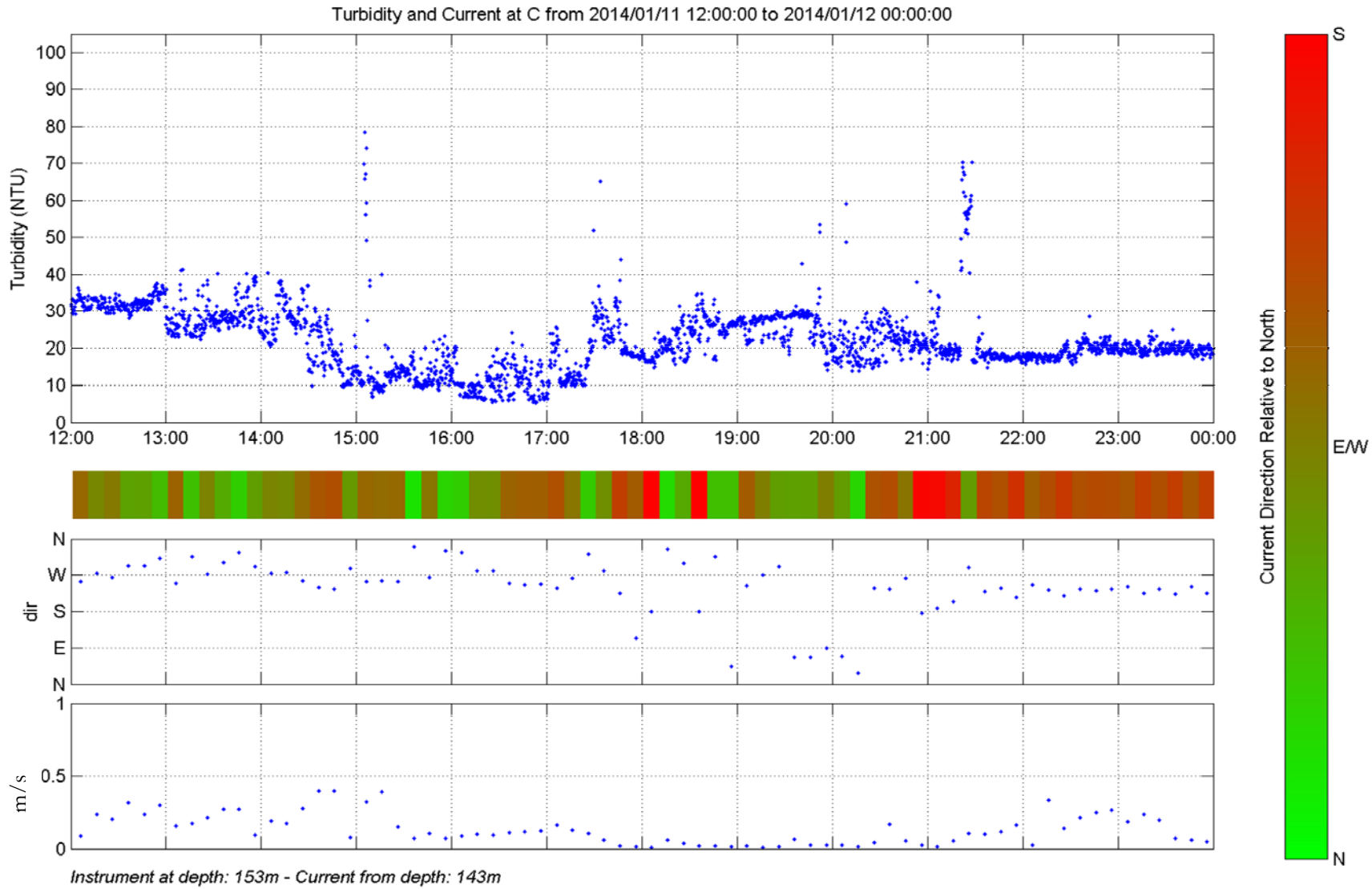
Instrument at depth: 153m - Current from depth: 143m


Turbidity and Current at C from 2014/01/11 12:00:00 to 2014/01/12 00:00:00
Turbidity (NTU)
100
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Current Direction Relative to North
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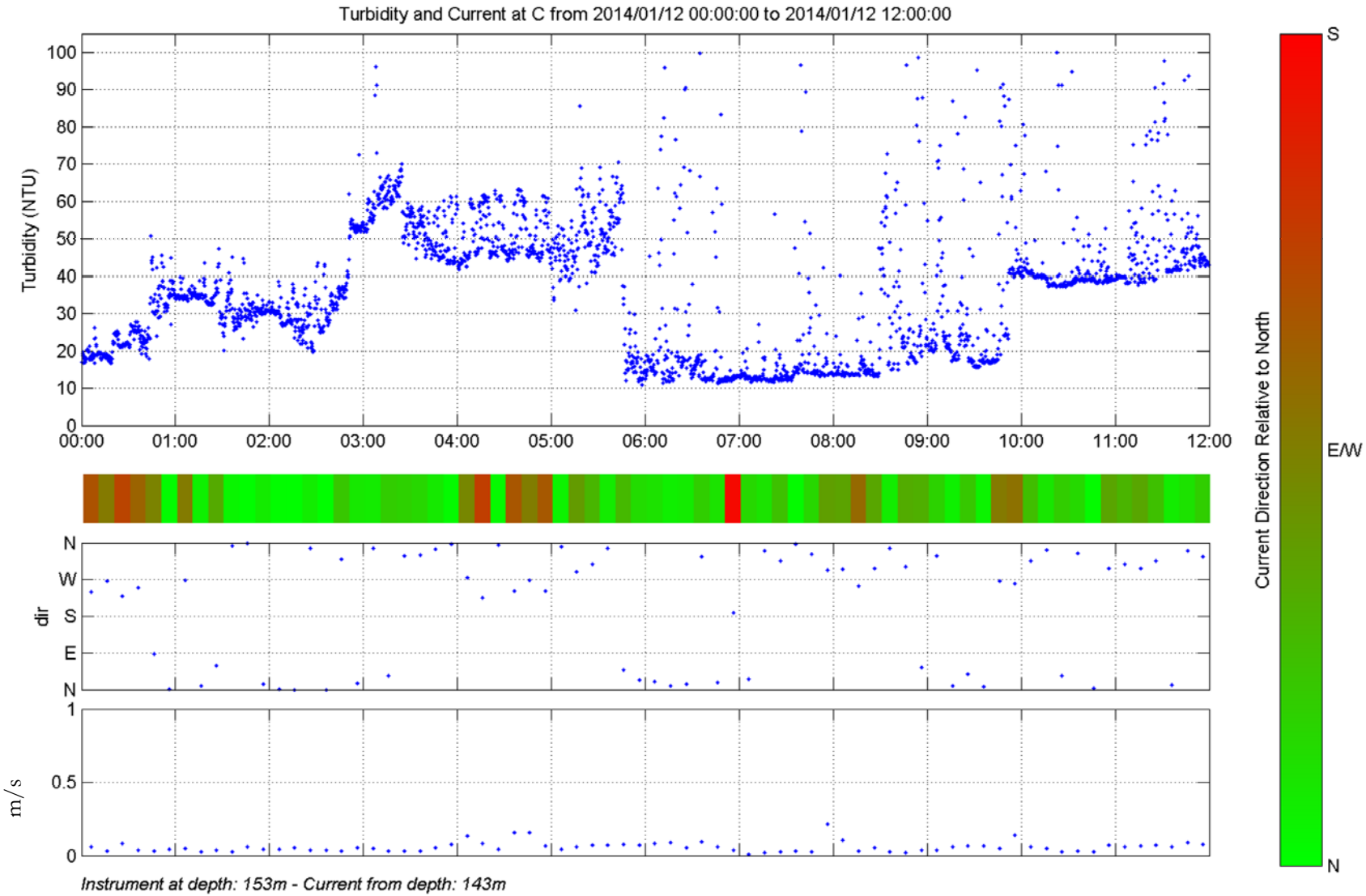
Instrument at depth: 153m - Current from depth: 143m


Turbidity and Current at C from 2014/01/12 00:00:00 to 2014/01/12 12:00:00
Turbidity (NTU)
100
90
80
70
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50
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Current Direction Relative to North
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E/W
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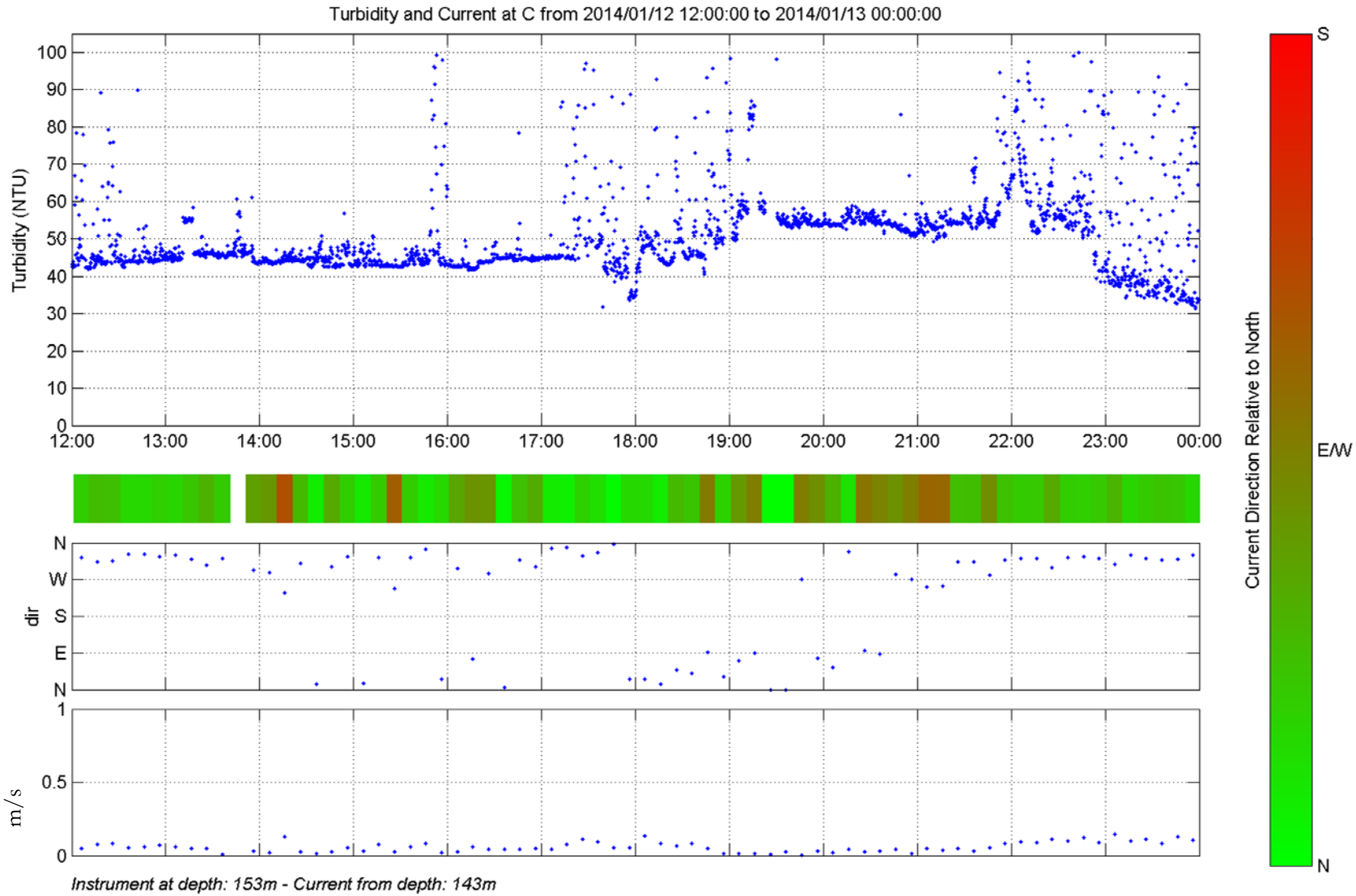
Instrument at depth: 153m - Current from depth: 143m


Turbidity and Current at C from 2014/01/12 12:00:00 to 2014/01/13 00:00:00
Turbidity (NTU)
100
90
80
70
60
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Current Direction Relative to North
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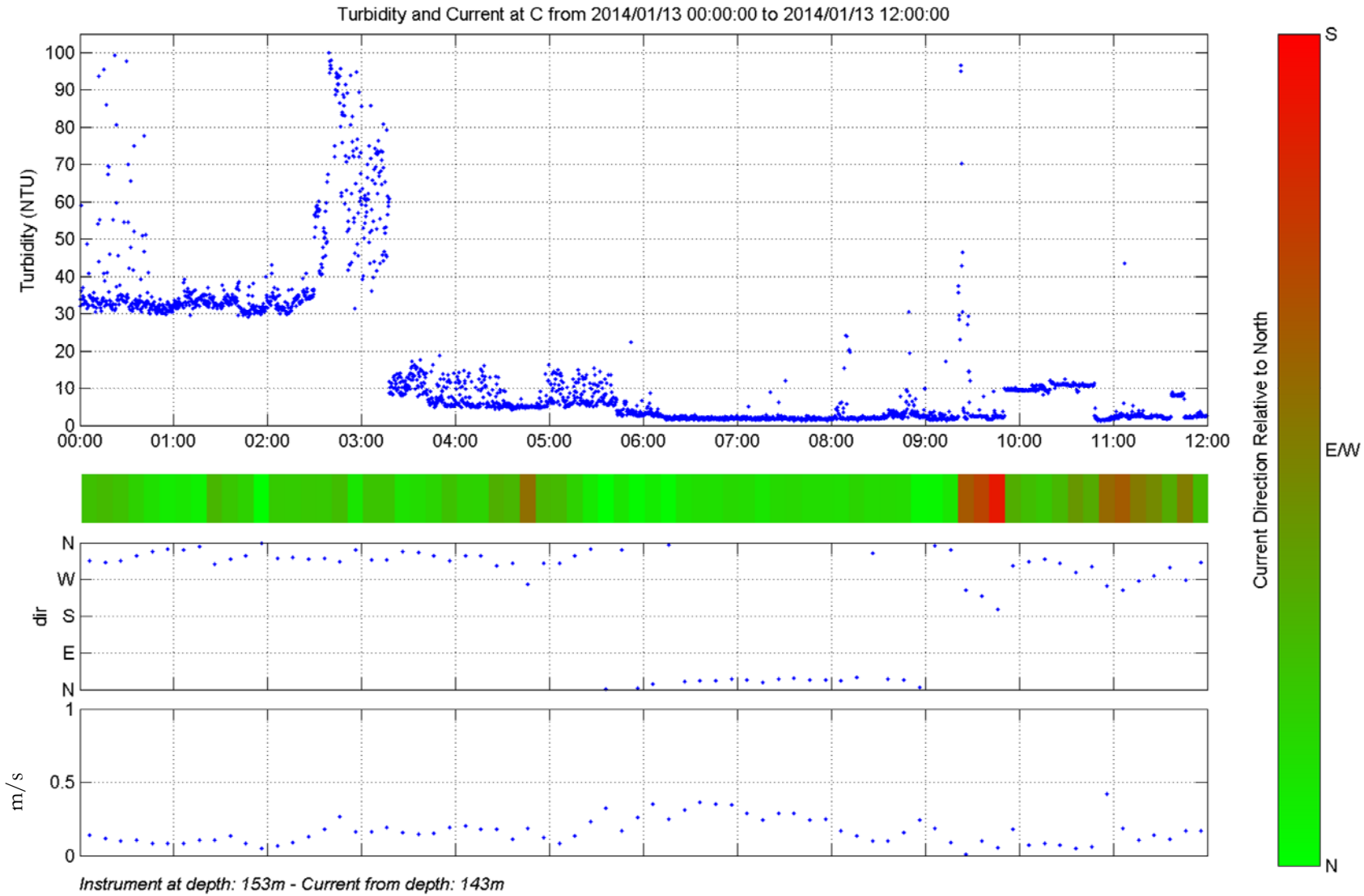
E/W
N
Instrument at depth: 153m - Current from depth: 143m


Turbidity and Current at C from 2014/01/13 00:00:00 to 2014/01/13 12:00:00
Turbidity (NTU)
100
90
80
70
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Current Direction Relative to North
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E/W
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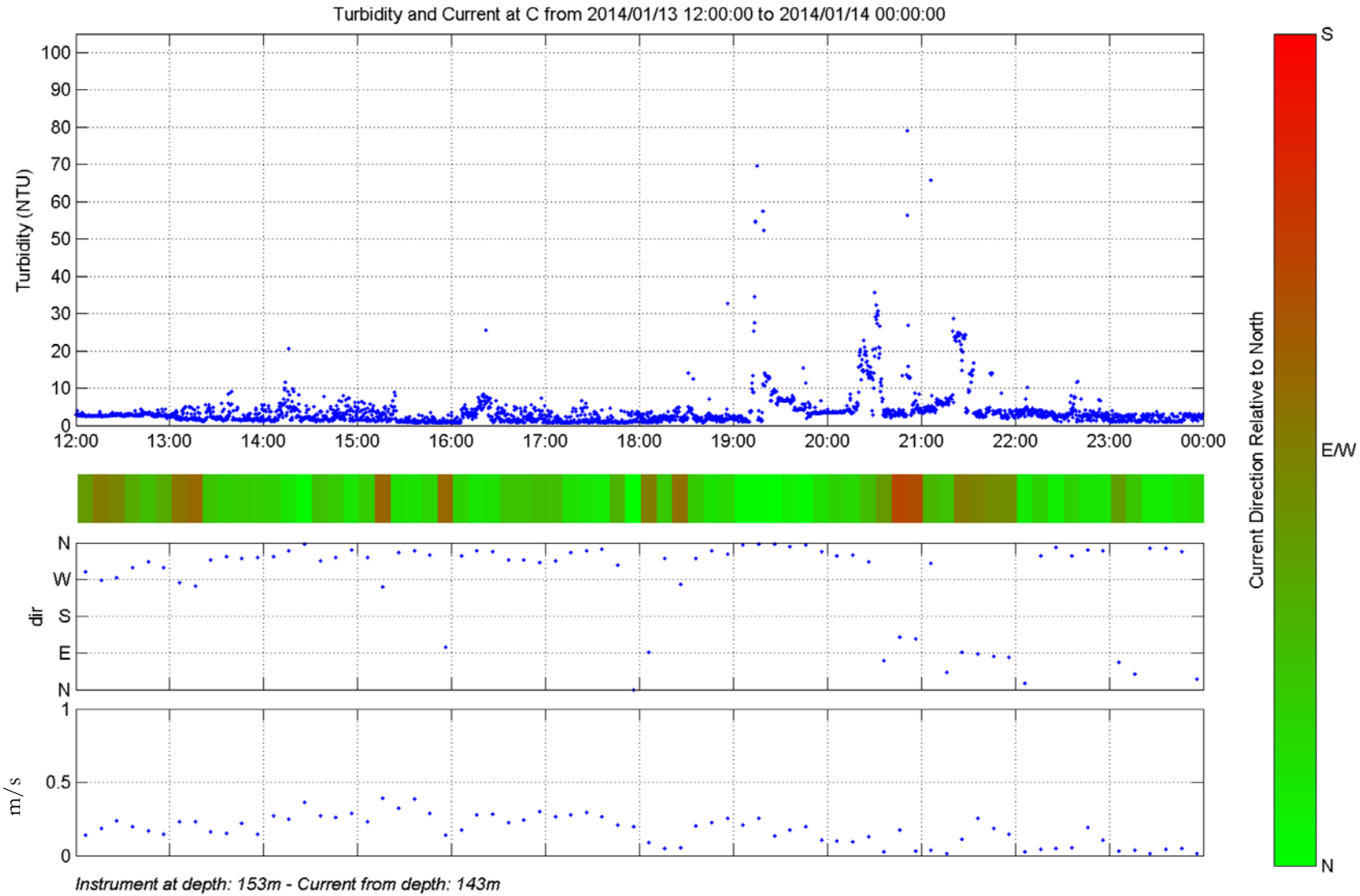
Instrument at depth: 153m - Current from depth: 143m


Turbidity and Current at C from 2014/01/13 12:00:00 to 2014/01/14 00:00:00
Turbidity (NTU)
100
90
80
70
60
50
40
30
20
10
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12:00
13:00
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m/s
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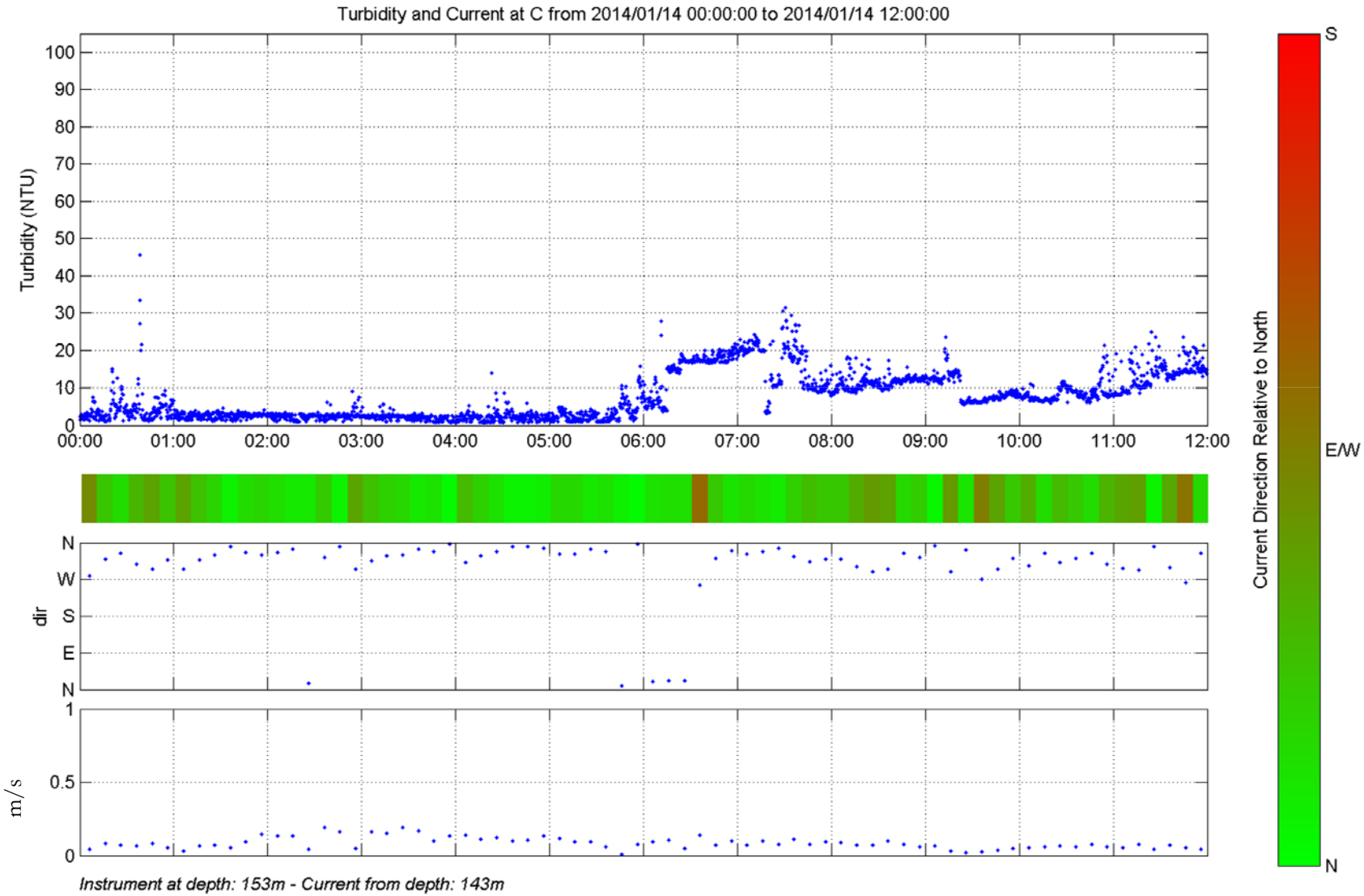
Current Direction Relative to North
S
E/W
N
Instrument at depth: 153m - Current from depth: 143m


Turbidity and Current at C from 2014/01/14 00:00:00 to 2014/01/14 12:00:00
Turbidity (NTU)
100
90
80
70
60
50
40
30
20
10
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00:00
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dir
N
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m/s
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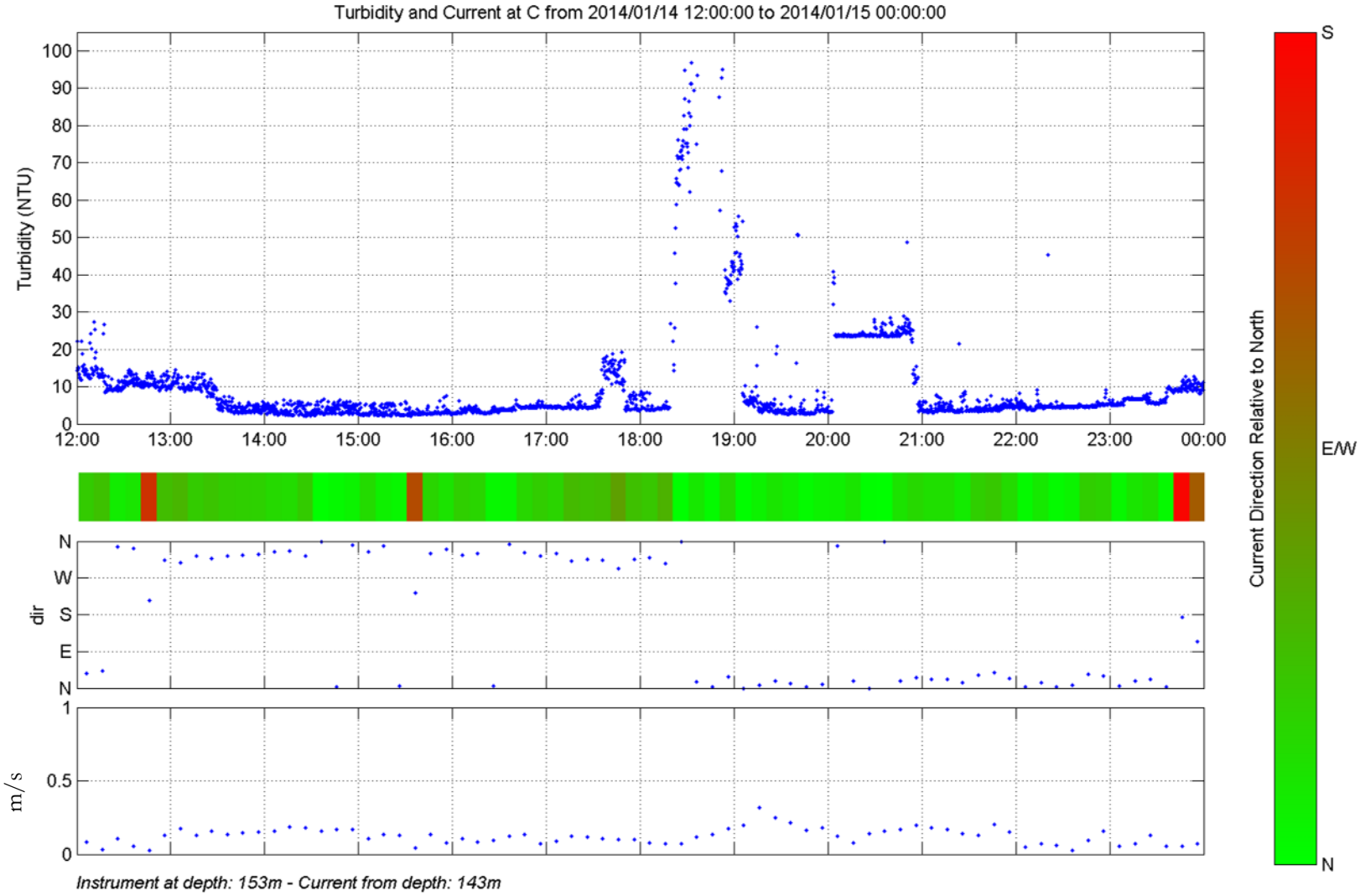
Current Direction Relative to North
S
E/W
N
Instrument at depth: 153m - Current from depth: 143m


Turbidity and Current at C from 2014/01/14 12:00:00 to 2014/01/15 00:00:00
Turbidity (NTU)
100
90
80
70
60
50
40
30
20
10
0
12:00
13:00
14:00
15:00
16:00
17:00
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dir
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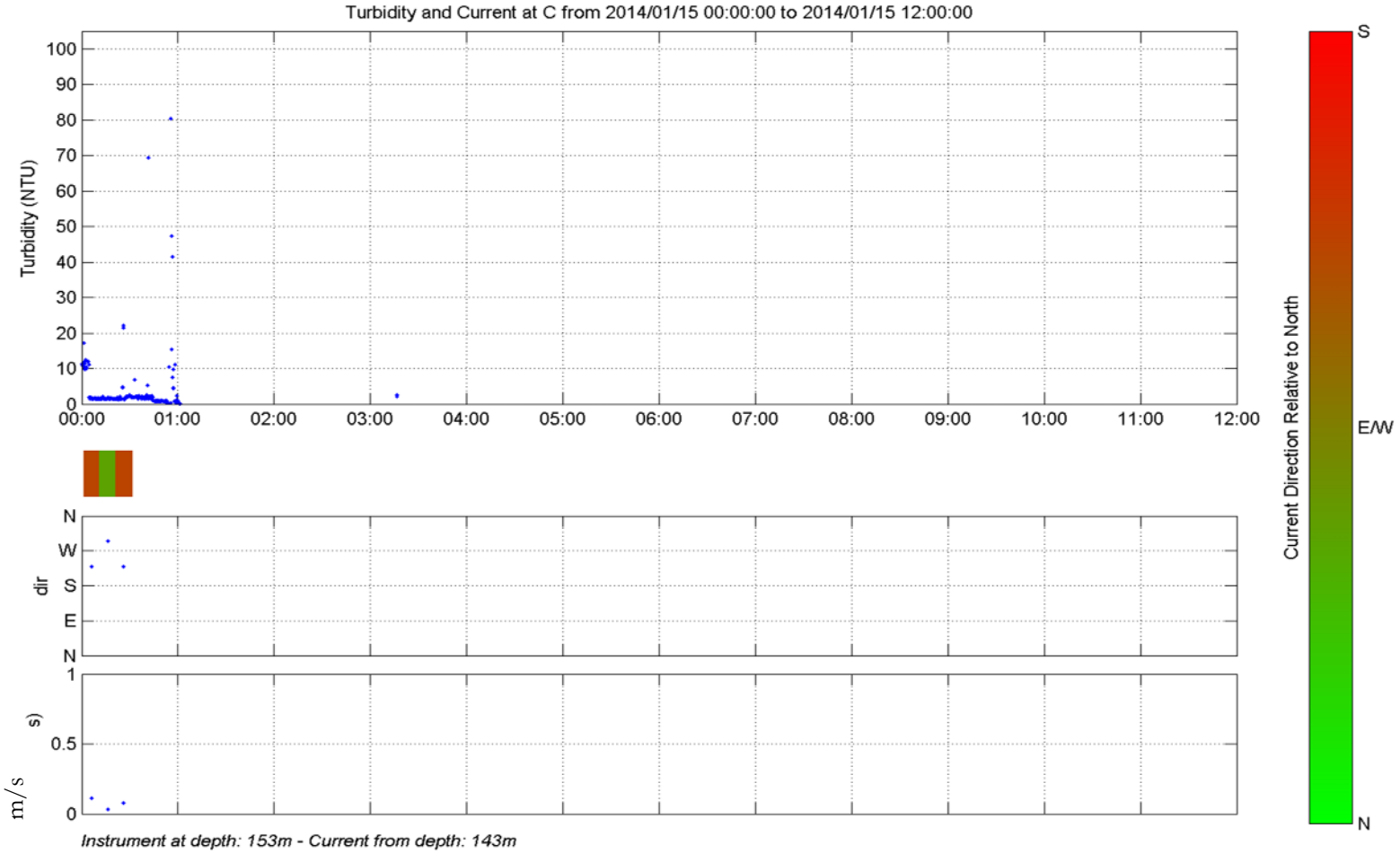
0
Current Direction Relative to North
S
E/W
N
Instrument at depth: 153m - Current from depth: 143m


Turbidity and Current at C from 2014/01/15 00:00:00 to 2014/01/15 12:00:00
Turbidity (NTU)
100
90
80
70
60
50
40
30
20
10
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00:00
01:00
02:00
03:00
04:00
05:00
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dir
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m/s
1
0.5
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Current Direction Relative to North
S
E/W
N
Instrument at depth: 153m - Current from depth: 143m

3.6 Modelled sedimentation

The regression curve calculated in Figure 4 (eq. 4) gives a relation between turbidity and concentration of mercury in the cloud of particles suspended in the water mass.

$$Hg(ng\ l^{-1}) = 0.315 + 0.386 \cdot Turbidty(NTU) \qquad (4)$$

This relation (4) was also shown to be reasonably consistent with the concentration of Hg found in the sediment trap at OV8 and can be used together with NIVATRAC to estimate the sedimentation of mercury around the operation area. Four different particle classes are modelled, where the sinking velocity is given by (3). For each of the particles classes shown in Figure 7, it is assumed that all of the particles in the initial cloud is uniform and of the given particle size.

Analysis of the sediments in the sediment trap at station OV-8 showed that 98 % of the particles were smaller than 63 µm. This is confirmed by the modelling that showed that particles bigger than 63 µm will sink to the seabed within 100 m from station C.

At station OV-8 the concentration of mercury was measured to 4.20 mg Hg/kg dry weight. Based on estimates of the total dry weight in the sample and the horizontal area of the sediment trap, the sedimentation of mercury will have been 0.7 ± 0.6 mg/m^2 in the area where the trap was located. The plots in Figure 7 were calibrated so that the concentration at station OV-8 was within this range for particle size 30, 40 and 63 µm. The last plot, with particle size 20 µm, was calibrated so that the maximum concentration was within the range of the measured value at station OV-8.

It can be seen from Figure 7 that the cloud of particles does not reach far beyond station OV-8 if all of the size of the particles are close to 63 µm. Smaller particles will spread over a considerably larger area. If for example a large amount of the particles in the initial cloud is of particle size 20 µm or smaller, the model suggests that sedimentation of Hg may have been as high as 100 mg/m^2 as far as 1000 m from the release point. This scenario is likely to represent maximum spreading during this operation. The particle size distribution within the trapped material is not known, but it appears unlikely that particles of size 20 µm or less constitute a significant fraction of the bulk sediment.

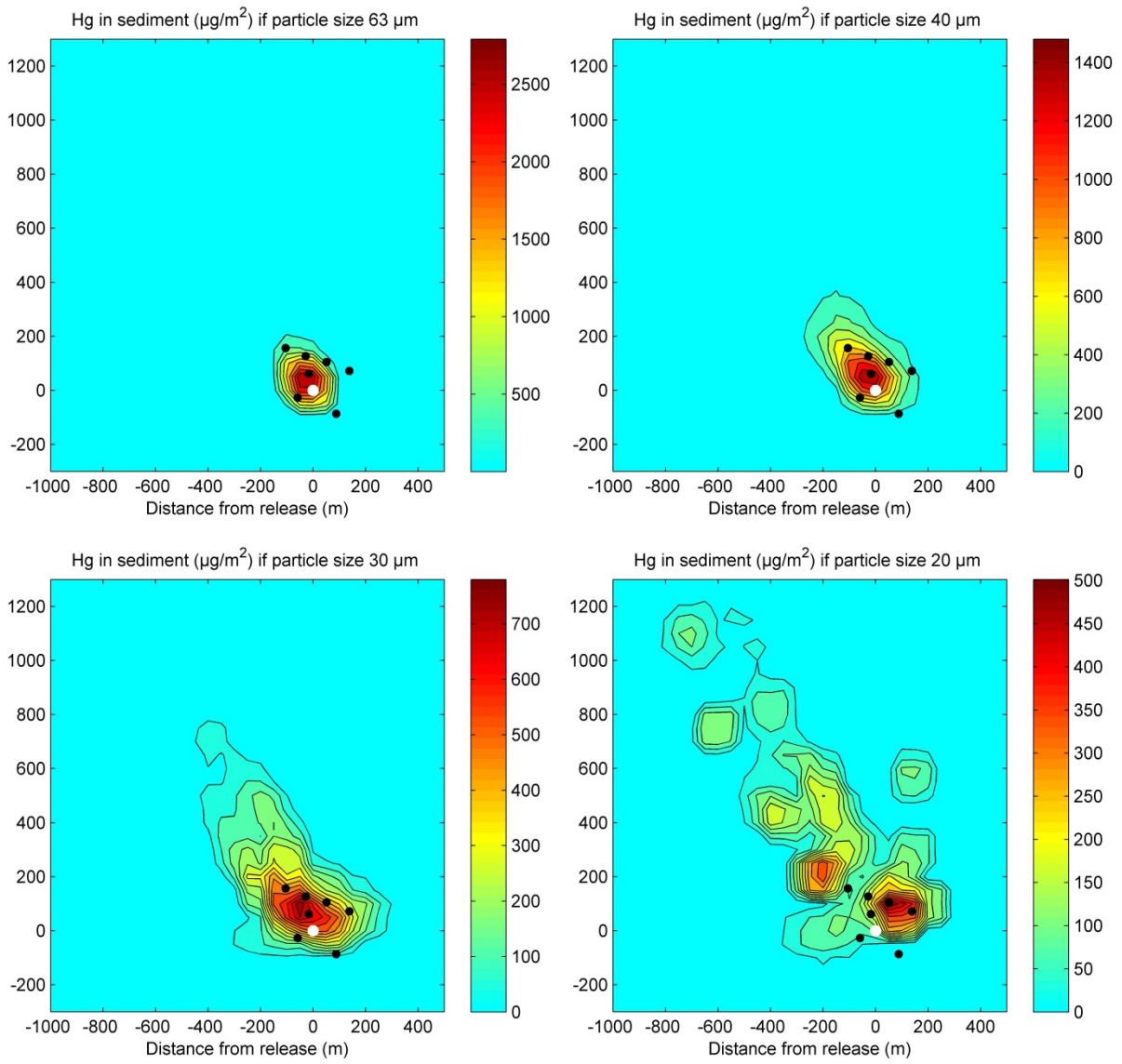

Figure 7. Results from the modelling of sedimentation of mercury (µg Hg/m² of the bottom) during the operation at Fedje 9.-15.01.2014. The model is based on measurements of currents and turbidity at station C (white circle) and sediments trapped at station OV8. The black points represent the positions of the OV stations, see Figure 2. Dispersion of particles is modelled for four different particle classes.

4. Conclusions and recommendation

No high concentrations of mercury were found in air in the ROV hangar. The Deep C excavator and dredger were found to be significantly contaminated with mercury during inspection on deck after the operation. Liquid mercury was found on the excavator and high concentrations of mercury vapour were detected on several places at the machine.

Mercury was detected in only small concentrations in the water samples. The concentrations of mercury in the water samples were in class I (background) and class II (good). The digging and dredging in the contaminated area caused some spreading of particles contaminated with mercury, but the concentrations in the water samples were low.

One sediment trap (10 m above the seabed) from rig OV8 was recovered. The sediment in this trap positioned approximately 200 m northwest of the operation center contained 4.2 mg Hg/kg dry weight. This is classified as class V (very bad). The high concentration of mercury in the sediment trap shows that the digging and dredging has caused spreading of contamination.

Due to loss of turbidity rigs there is not sufficient data to assess spreading of contamination with particles. Data for turbidity showed that there were several peaks of turbidity and some longer time periods with high turbidity measured on rig C a little north of the aft section were most of the digging and dredging operations were undertaken.

Model calculations based on current and turbidity measurements on rig C, water samples collected from ROV and sediment material trapped at station OV-8 showed that particles larger than 63 um will sediment less than 100m from the operation center. Most actually with the 50 m grid at the operation center. Typically, 60 to 90% of the sediments on the site is larger than 63 um. The model showed that silt and clay fractions will be spread further away from the operation site. Particles of 63 um will sediment mostly within 200m, whereas the smaller size fractions of 20 um may be transported up to 1 km through the water mass before settling on the sediment. Due to the prevailing current directions the particles will spread primarily towards northwest. It is assumed that particles smaller than 20 um constitute a very small fraction of the bulk sediment.

In order to verify the model results on spreading during this operation, it may be considered to collect new sediment cores in the operation area for comparison with mercury concentrations in previously collected samples. By fine sectioning of the top layer it should be possible to verify the spreading of mercury calculated by the model.

5. References

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Uriansrud, F., Skei, J., Mortensen, T., Dahl, I. & Wehde, H. 2006. Miljøovervåking, strømundersøkelser, sedimentkartlegging og vurdering av sedimenttildekking – Fase 2 kartlegging ved U-864 høsten 2006. NIVA rapport 5279-2006.

Appendix A. Measurements of mercury vapour

Concentrations of mercury detected in air during the survey.

Date	Time	Location for Hg measurement	Concentration (ng Hg/m³)
7. Jan		In lab container	2-10
8. Jan	14:20	In ROV hangar (and on ROV)	1-10
	17:00	In ROV hangar (and on ROV)	1-8
9. Jan	15:00	In lab container	1-8
10. Jan	02:15	On deck before bringing up any equipment	3-5
	03:30	On deck	0-4
	07:20	In ROV hangar (and on ROV)	1-10
	08:00	By orange peel grab	1-10
	10:30	In ROV hangar (and on ROV)	1-10
	20.30	In lab container after measurements of water samples	1-5
	21:30	In ROV hangar (and on ROV)	0-8
	23:25	In ROV hangar (and on ROV)	0-7
11. Jan	03:15	In ROV hangar (and on ROV)	1-7
	07:00	In ROV hangar (and on ROV)	1-8
	09:10	In ROV hangar (and on ROV)	1-8
	15:40	In ROV hangar (and on ROV)	1-7
	16:00	By Deep C excavator	1-8
	18:45	In lab container	1-5
	21:00	By orange peel grab	1-10
	21:10	In ROV hangar (and on ROV)	1-7
12. Jan		On basket for sediment samples	0-10
	14:30	In lab container	1-8
	17:15	In ROV hangar (and on ROV)	1-10
	17:50	In ROV hangar (and on ROV)	1-8
	17:40	By basket for sediment samples after cleaning	1-10
	19:50	In lab container	Ca 150
		In lab container over garbage bin	380
	20:30	In lab container	47
13. Jan	13:45	In lab container	15-25
	15:50	In lab container	4-10
	16:05	In ROV hangar (and on ROV)	1-8
	22:00	In ROV hangar (and on ROV)	1-10
		Over damaged sediment corer in ROV hangar	675
14. Jan	07:30	In lab container	7-10
	07:50	In ROV hangar (and on ROV)	
		Over a "warm black box"	200-250
		On "cup" used for lifting Hg-canisters	425
	08:00	In ROV hangar (and on the other ROV)	2-7
	08:10-09:40	On Deep C excavator and dredging hose	
		On dredging hose	>50 000
		Several places on excavator	20 000-30 000
		On dredging hose after a lot of flushing	2000-3000
	09:45	On wooden deck	2-42
	10:50	On parts of ROV	120-150
	14:10	In ROV hangar (and on ROV)	2-260
		On warm components on ROV	260
	14:45	Found liquid Hg on wooden deck	

Date	Time	Location for Hg measurement	Concentration (ng Hg/m³)
	15:00	In ROV hangar (and on ROV)	1-20
		In lab container	15-20
	15:15	On excavator	20-6000
		On parts of dredging hose	225-460
	18:15	In lab container	40-60
		On air intake in lab container	120
	19:45	On deck	20-50
		On deck close to dredger	100-200
	21:30	In lab container	120-350
	23:10	On damaged sediment corer on ROV hangar	10-20
15. Jan	01:00	On basket with sediment samples	20-30
	05:00	In ROV hangar (and on ROV)	1-15
	09:10	On basket with sediment samples	67-165
	13:20	In Deep C container, floor	10-65
		on dirty strap	400-800
	14:20	By rig for current measurements	5-22
	14:30	On Deep C excavator, over gravel and clay	480-970
	18:40	In lab container	40
	23:20	In ROV hangar (and on ROV)	1-15
16. Jan	07:30	In ROV hangar (and on ROV)	5-32
		On warm component	975
	14:40	In ROV hangar (and on ROV)	
		On plate of steel from the submarine	107
		On grinder	24
	20:30	In ROV hangar (and on ROV)	5-20
	20:45	On excavator	10-50
		In cavities	650
	21:50	On excavator after cleaning	10-40
		In same cavities	1000
	22:45	On excavator after cleaning	
		In same cavities	1000-2000
	22:55	In ROV hangar (and on ROV)	5-40
	23:10	On excavator after more cleaning	
		In same cavities	2000
	23:30	In ROV hangar (and on ROV)	1-20
17. Jan	03:20	In blue dredger hose	>50 000
	03:50	In blue dredger hose after more flushing	10 000-30 000
	04:15	In blue dredger hose after more flushing	10 000-30 000
	04:50	In blue dredger hose after more flushing	20 000
	07:50	On working gloves of Deep C personnel	>50 000
	10:00	On basket and equipment on dirty area	25-950
		On sandbags	>50 000
	12:30	In ROV hangar (and on ROV)	0-24
		On warm component	235
	13:00	On equipment on ROV basket	3-510
	18-19	On Deep C machine, platform	30-98
		In dredger hose	50-380
	20:25-21:30	In ROV hangar (and on ROV)	0-70
18. Jan	04:55-5:30	On deck after unloading of equipment	5-280
		On marked area on wooden deck	200-340
	10:15	On marked area on deck	510

Date	Time	Location for Hg measurement	Concentration (ng Hg/m³)
	10.45	**On deck after removal of six wooden beams**	**100-1200**

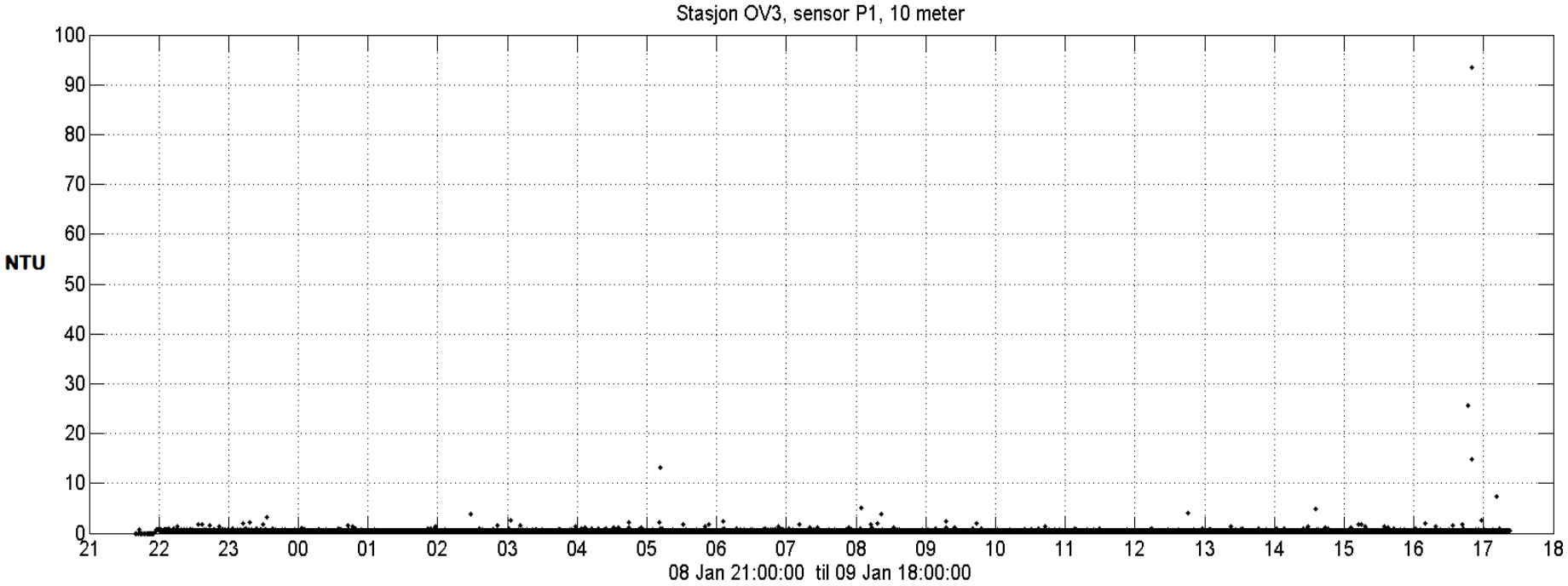
Appendix B. Mercury in water samples

Concentrations of mercury in water samples taken near submarine U-864 during the survey. The results are presented according to the classification system shown in table 1.

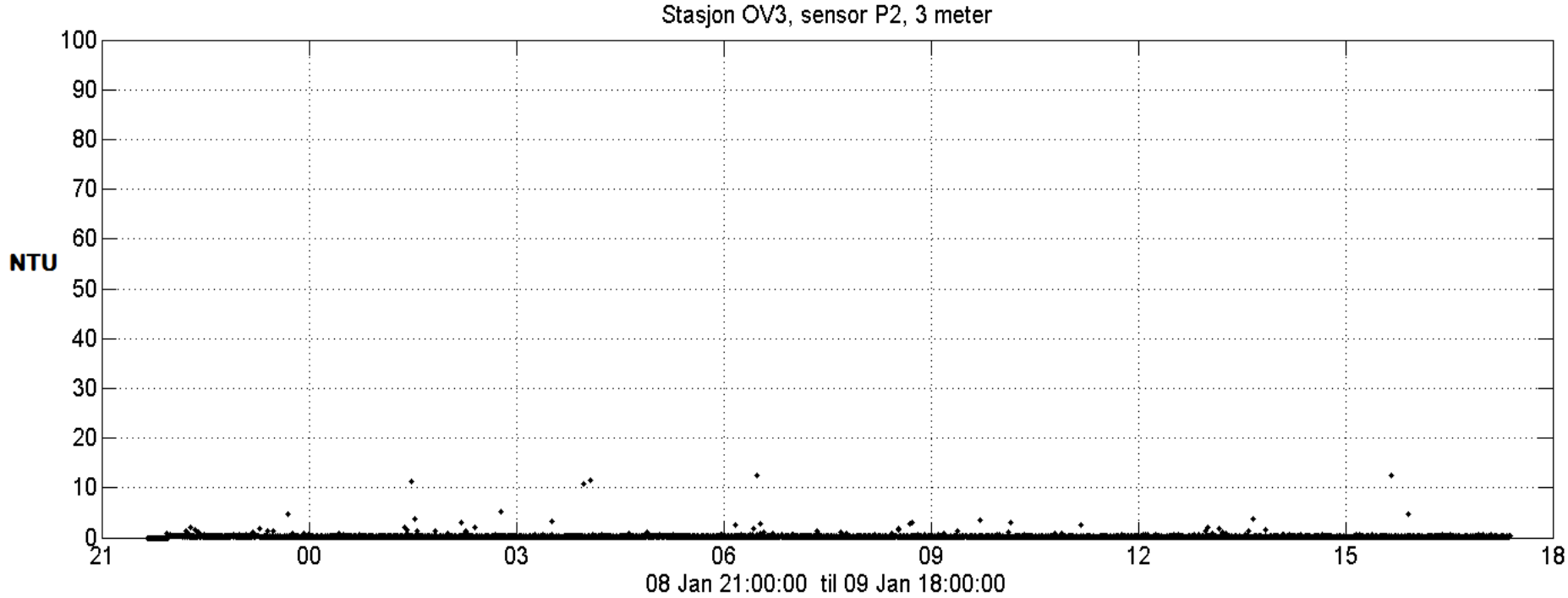
Date	Time	Station	Elevation over seabed	Turbidity	Concentration ng Hg/l
10. Jan	09-10	WSL-3	3 m	0.77	<1.0
	09-10	WSL-3	10 m	0.77	<1.0
	09-10	WSL-4	10 m	0.79	<1.0
	09-10	WSL-4	3 m	0.83	<1.0
	09-10	WSL-1	10 m	0.83	<1.0
	09-10	WSL-1	3 m	1.39	<1.0
	09-10	WSL-2	10 m	1.08	<1.0
	09-10	WSL-2	4 m	0.90	<1.0
	22:15-23:10	WSL-3	3 m	0.39	<1.0
	22:15-23:10	WSL-3	10 m	0.37	<1.0
	22:15-23:10	WSL-4	10 m	0.30	<1.0
	22:15-23:10	WSL-4	3 m	0.29	<1.0
	22:15-23:10	WSL-1	10 m	0.26	<1.0
	22:15-23:10	WSL-1	3 m	0.36	<1.0
	22:15-23:10	WSL-2	10 m	0.29	<1.0
	22:15-23:10	WSL-2	3 m	0.42	<1.0
11. Jan	07:45-08:40	WSL-3	3 m	0.43	<1.0
	07:45-08:40	WSL-3	10 m	0.44	<1.0
	07:45-08:40	WSL-4	10 m	0.92	<1.0
	07:45-08:40	WSL-4	3 m	0.53	<1.0
	07:45-08:40	WSL-1	10 m	0.64	<1.0
	07:45-08:40	WSL-1	3 m	0.58	<1.0
	07:45-08:40	WSL-2	10 m	0.47	<1.0
	07:45-08:40	WSL-2	3 m	0.53	<1.0
	21:40-22:35	WSL-2	10 m	0.86	<1.0
	21:40-22:35	WSL-2	3 m	1.20	<1.0
	21:40-22:35	WSL-3	10 m	0.48	<1.0
	21:40-22:35	WSL-3	3 m	0.55	<1.0
	21:40-22:35	WSL-1	10 m	0.59	<1.0
	21:40-22:35	WSL-1	3 m	0.40	<1.0
	21:40-22:35	WSL-4	10 m	0.44	<1.0
	21:40-22:35	WSL-4	3 m	0.46	<1.0
12. Jan	08:35-09:30	WSL-3	10 m	1.22	1.2
	08:35-09:30	WSL-3	3 m	1.40	<1.0
	08:35-09:30	WSL-2	10 m	1.33	<1.0
	08:35-09:30	WSL-2	3 m	1.71	<1.0
	08:35-09:30	WSL-4	10 m	1.23	<1.0
	08:35-09:30	WSL-4	3 m	0.95	<1.0
	08:35-09:30	WSL-1	10 m	1.36	<1.0
	08:35-09:30	WSL-1	3 m	1.25	<1.0
	18:15-19:15	WSL-1	10 m	0.79	<1.0
	18:15-19:15	WSL-1	3 m	0.78	1.1
	18:15-19:15	WSL-4	10 m	0.80	<1.0
	18:15-19:15	WSL-4	3 m	0.72	<1.0
	18:15-19:15	WSL-2	10 m	0.75	<1.0
12. Jan	18:15-19:15	WSL-2	3 m	0.73	1.4

Date	Time	Station	Elevation over seabed	Turbidity	Concentration ng Hg/l
	18:15-19:15	WSL-2	3 m	0.73	1.5
	18:15-19:15	Dredger exhaust	10 m	3.16	2.4
	18:15-19:15	Dredger exhaust	10 m	3.16	2.3
	18:15-19:15	Dredger exhaust	3 m	1.50	<1.0
	18:15-19:15	Dredger exhaust	3 m	18.0	7.3
	18:15-19:15	Dredger exhaust	3 m	18.0	7.1
	18:15-19:15	WSL-3	10 m	0.66	<1.0
	18:15-19:15	WSL-3	3 m	0.81	<1.0
13. Jan	16:30-17:05	WSL-2	10 m	0.92	<1.0
	16:30-17:05	WSL-2	3 m	1.09	<1.0
	16:30-17:05	WSL-5	10 m	1.31	<1.0
	16:30-17:05	WSL-5	3 m	0.86	<1.0
14. Jan	03:50-04:25	WSL-4	3 m	0,81	1.0
	03:50-04:25	WSL-4	10 m	0,72	<1.0
	03:50-04:25	WSL-1	3 m	1.04	1.5
	03:50-04:25	WSL-1	10 m	0.86	1.8
	03:50-04:25	WSL-2	3 m	0.91	<1.0
	03:50-04:25	WSL-2	10 m	0.79	<1.0
	03:50-04:25	WSL-3	3 m	1.02	<1.0
	03:50-04:25	WSL-3	10 m	0.98	<1.0
16. Jan	22:15-23:05	WSL-3	3 m	2.00	1.8
	22:15-23:05	WSL-3	10 m	1.85	<1.0
	22:15-23:05	WSL-2	10 m	0.31	<1.0
	22:15-23:05	WSL-2	3 m	0.40	<1.0
	22:15-23:05	WSL-4	10 m	0.54	<1.0
	22:15-23:05	WSL-4	3 m	0.80	<1.0
	22:15-23:05	WSL-1	3 m	0.54	<1.0
	22:15-23:05	WSL-1	10 m	0.49	<1.0

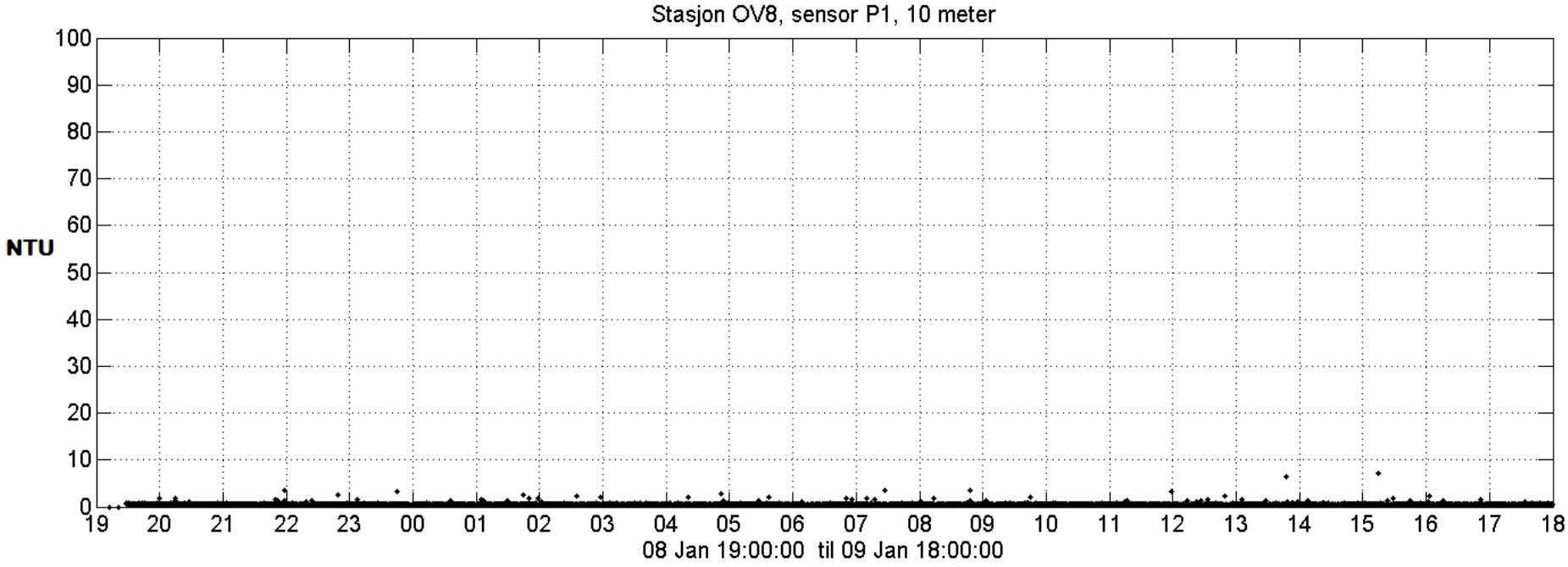
Appendix C. Turbidity data



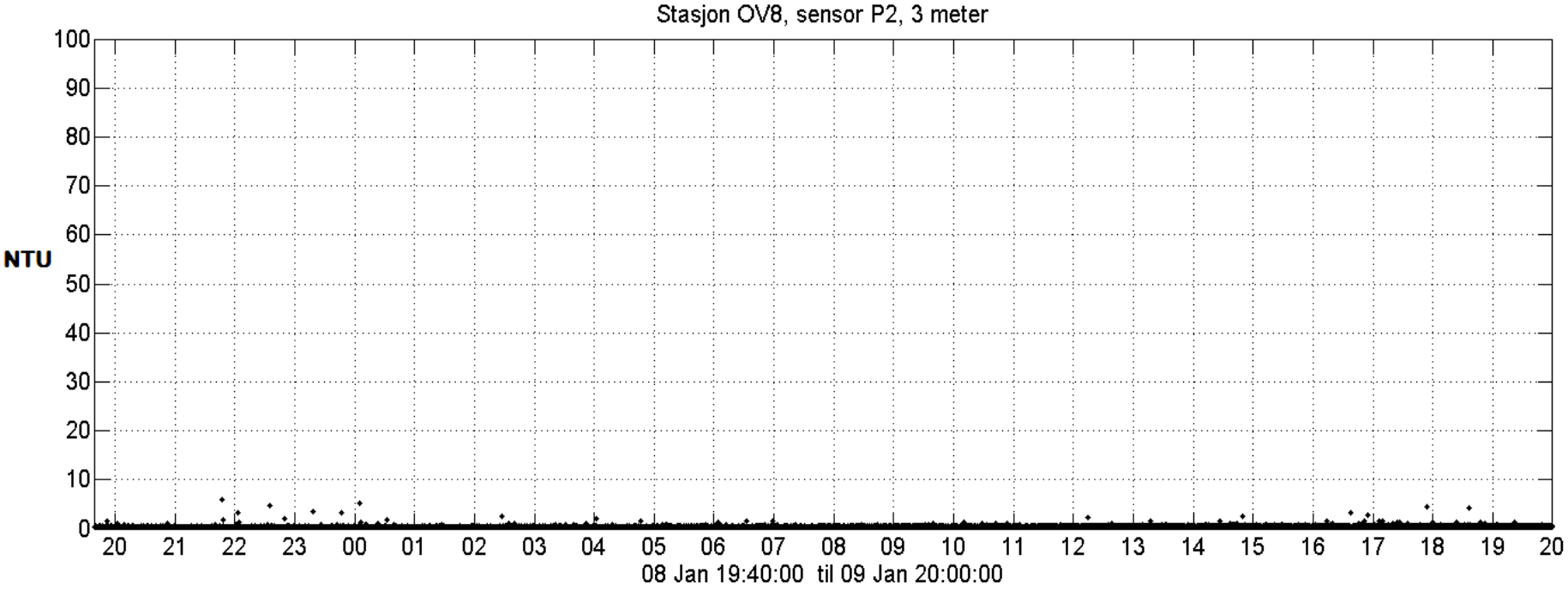
Turbidty measurements from station OV3 at 10 m above the seabed. Time is shown in UTC time.



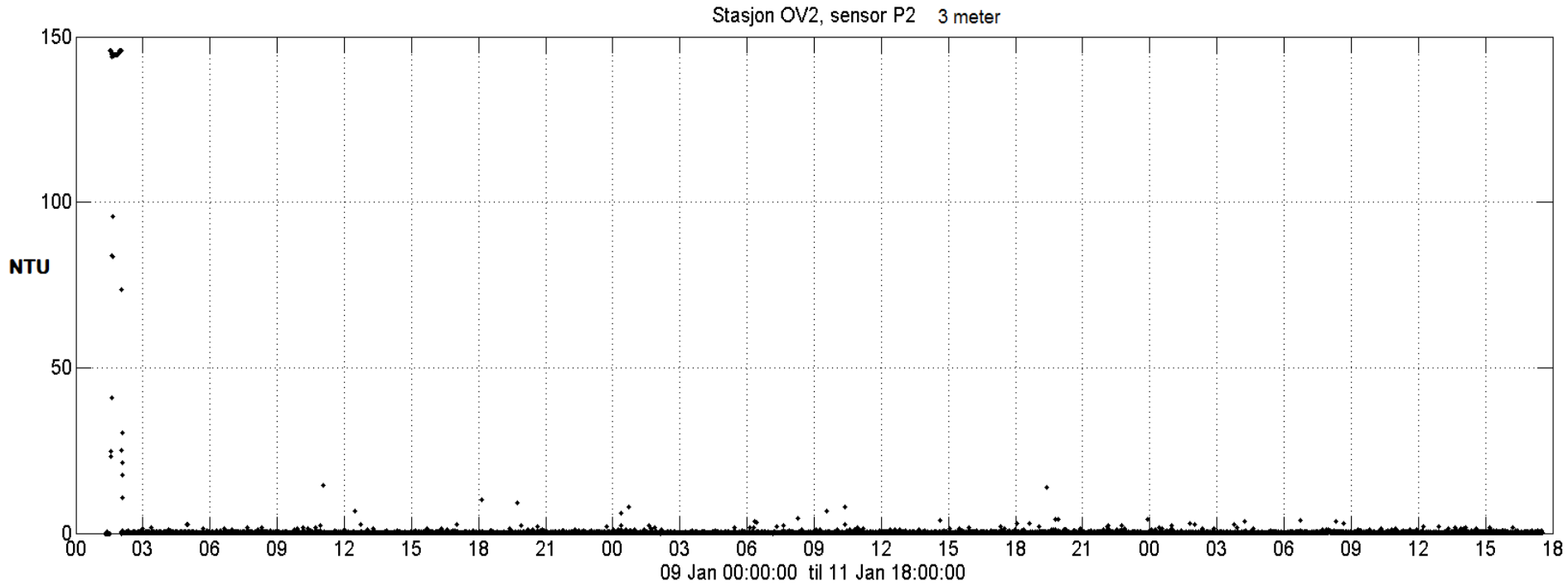
Turbidity monitored at station OV3 at 3 m above the seabed. Time is shown in UTC time.



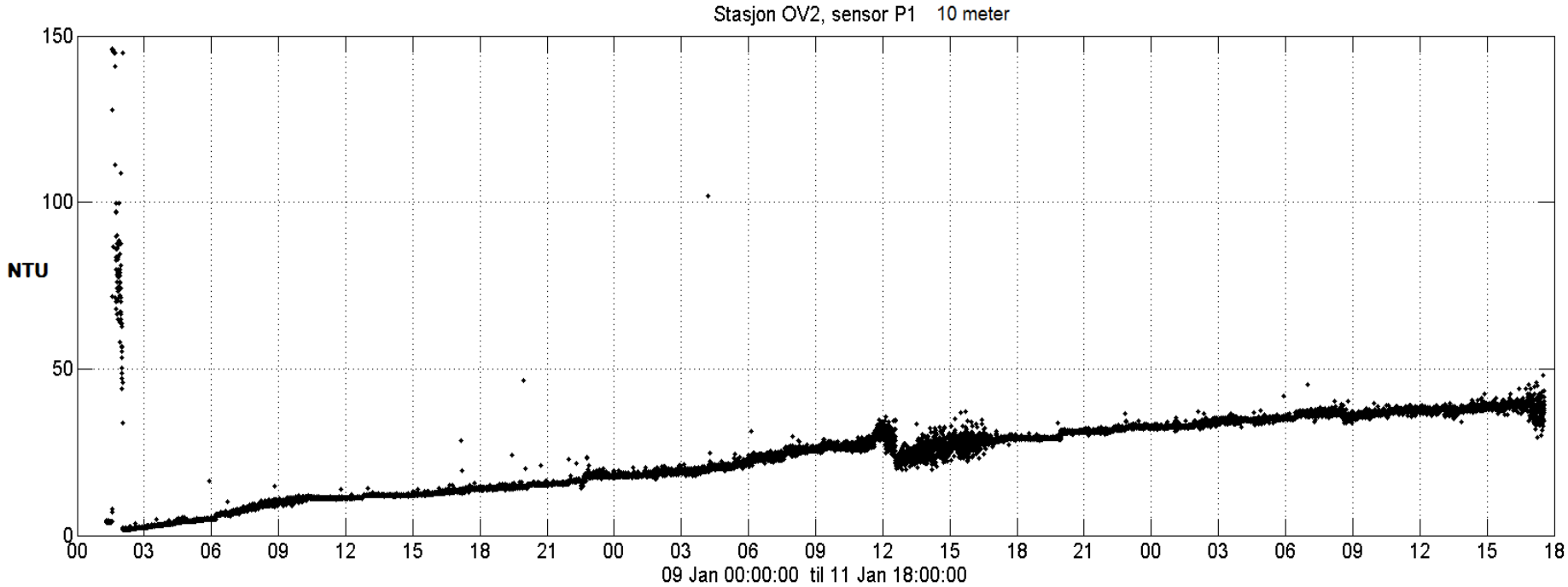
Turbidity monitored at station OV8 at 10 m above the seabed. Time is shown in UTC time.



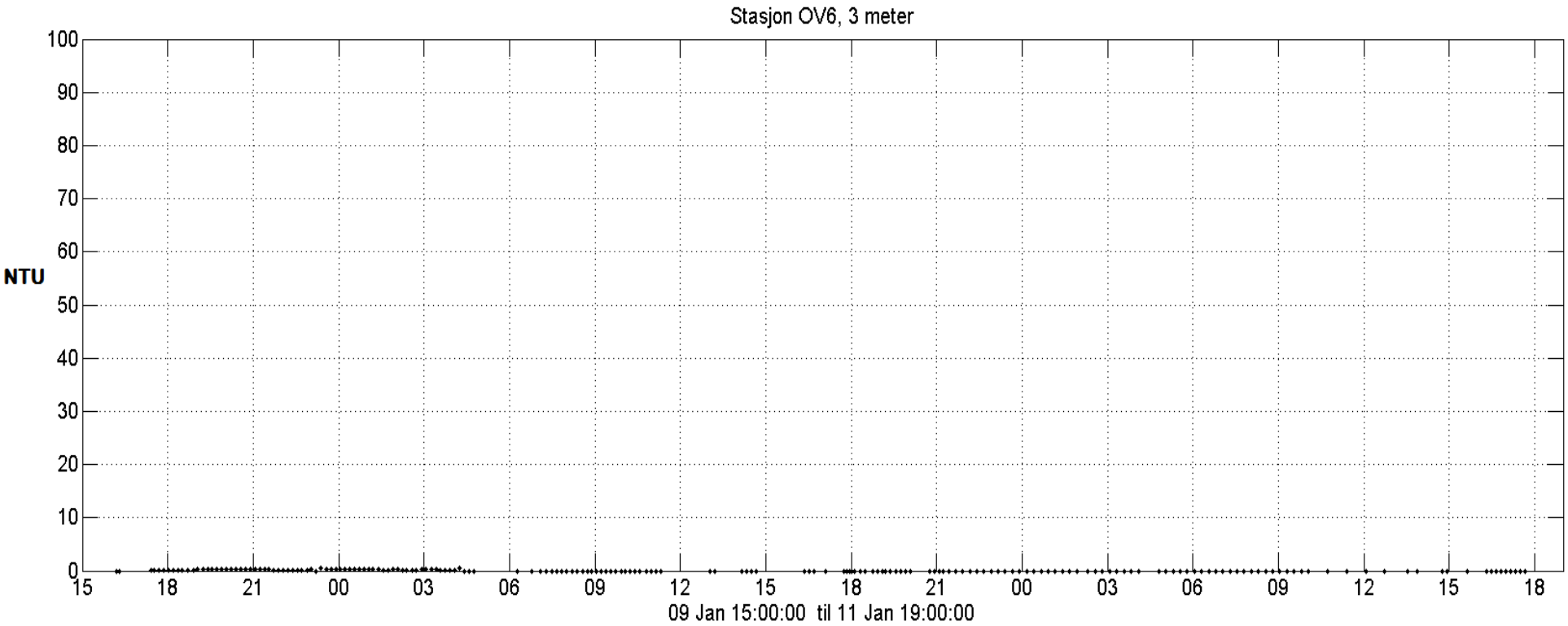
Turbidity monitored at station OV8 at 3 m above the seabed. Time is shown in UTC time.



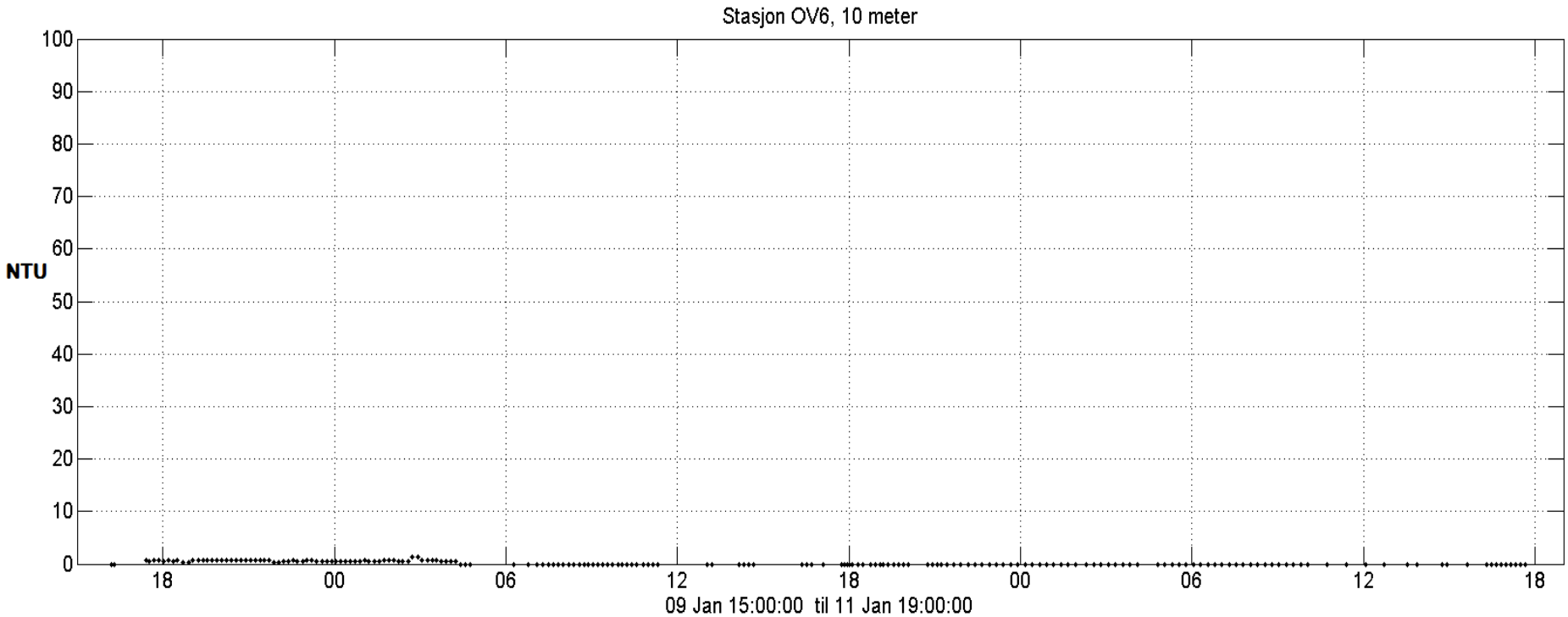
Turbidity monitored at station OV2 at 3 m above the seabed. Time is shown in UTC time.



Turbidity monitored at station OV2 at 10 m above the seabed. Time is shown in UTC time.



Turbidity monitored at station OV6 at 3 m above the seabed. Time is shown in UTC time.



Turbidity monitored at station OV6 at 10 m above the seabed. Time is shown in UTC time.

Vedlegg V3.01

MILJØTILTAK VED VRAKET AV U-864

Fremdriftsanlyse for Alternativ 3 “Heving av last”

DNV GL AS

Project name: Miljøtiltak ved vraket av U-864

Report title: Fremdriftsanlyse for Alternativ 3 “Heving av last”

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Dato: 12.5.2014

Gjengivelse av deler av dette vedleggsdokument som kan føre til mistolkning er ikke tillatt

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1 INNLEDNING

I dette vedlegget er resultatene fra usikkerhetsanalysen av fremdrift for «Miljøtiltak ved vraket av U-864» Alternativ 3 Heving av last (heretter kalt Alternativ 3) beskrevet.

Analysen er gjennomført i en simuleringsmodell utviklet spesielt for dette prosjektet, og dekker både kostnads- og fremdriftsusikkerhet. For generell informasjon om metodikk og modellen, se Vedlegg V0.10.

En analyse av antall kvikksølvflasker som man kan forvente å heve under en operasjon er gjennomført, da dette har innvirkning på hvor lang tid en operasjon vil ta og forventet måloppnåelse ved tiltaket.

2 GENERELT OM MODELLEN

Det er gjort en usikkerhetsanalyse av gjennomføringstid for prosjektet. Dette er gjort ved å sette trippelestimater for varigheten av alle operasjonssteg og analysere total gjennomføringstid ved hjelp av Monte Carlo simulering.

Forutsetninger:

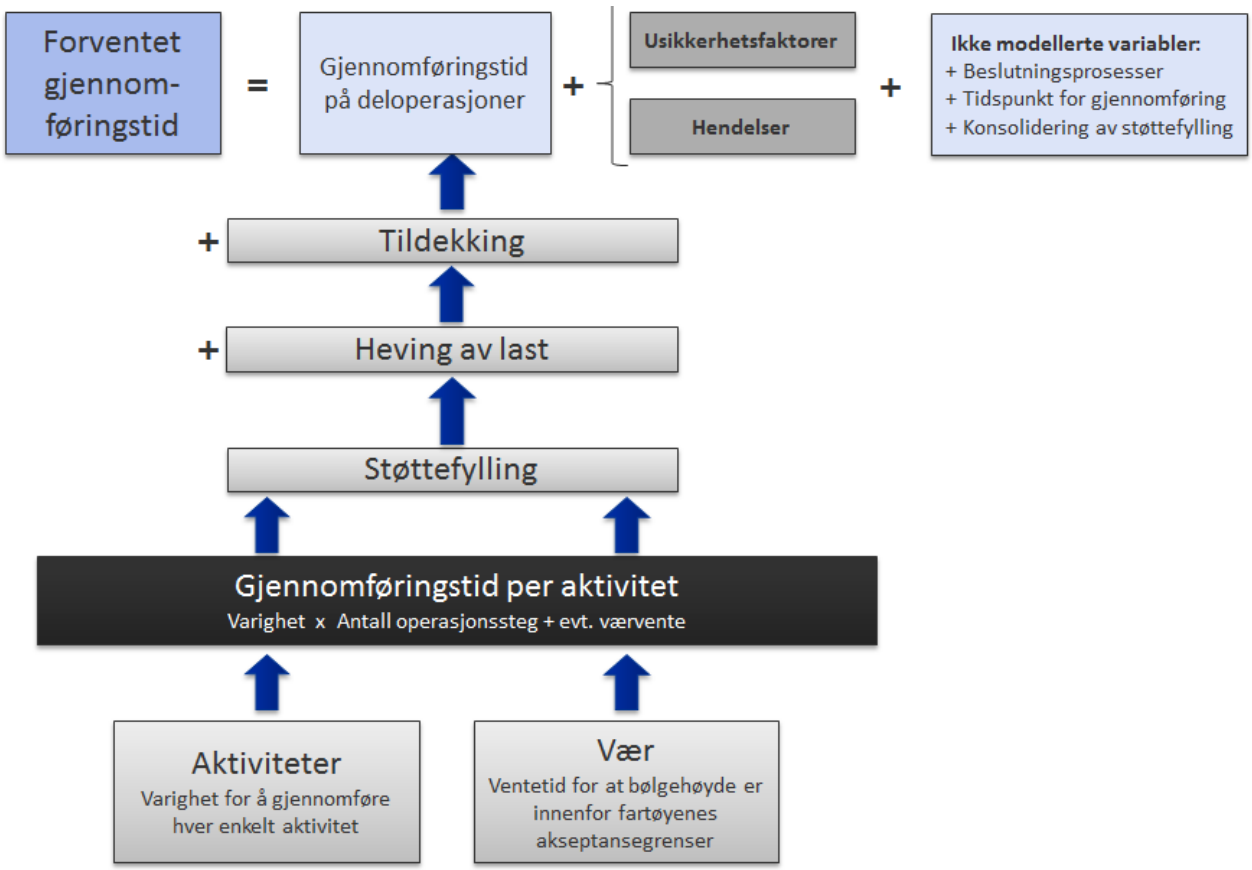
- Kun gjennomføringstiden av å bygge støttefyllingen, operasjon for heving av kvikksølvflasker og å legge ut tildekkingsmassene er analysert.
- Støttefyllingen trenger tid for konsolidering av massene for å gi tilstrekkelig bæreevne. Dette er analysert til å være minst ett år, og derfor valgt som varighet for dette i prosjektplanen (ref. Vedlegg V0.06).
- Enkelte aktiviteter kan gjennomføres i parallell og adderes derfor ikke.
- Fartøyet som benyttes for å legge ut støttefylling og tildekkingsmassene (en «Rock dumper») har en kapasitet på 25.000 tonn, som tilsvarer ca. 12.500 m^3 stein. Lasting, transport og utlegging av massene er vurdert å ta fem dager per tur.
- Det er gjennomført en kostnads- og tidsanalyse for tre prinsipielt forskjellige løsninger for heving av last: «Rulle», «Rigg» og «Krybbe». Disse er beskrevet i Vedlegg V3.06. I kostnadsanalysen og fremdriftsanalysen analyseres en løsning som består av alle tre løsninger, der disse er vektet likt. Dette er gjort fordi det ikke foreligger noen anbefaling for hvilken løsning som bør velges, og en evt. gjennomføring kan være en helt annerledes løsning enn de tre som er foreslått. Ved å vurdere alle tre løsninger gir det et riktigere bilde av usikkerheten i Alternativ 3 på det nåværende tidspunkt.
- Dersom kriteriene for maksimal bølgehøyde (HS) for de benyttede fartøyene overstiges, må operasjonen vente på at været løyer. Erfaringer fra offshore-operasjoner, samt verktøyet SafeTrans[1], er lagt til grunn for vurderingene av forventet ventetid i modellen.
- Korrelasjon er ivaretatt for aktiviteter som er forventet å samvariere.
- Antall kvikksølvflasker som man kan forvente å få hevet er svært usikkert, og derav tiden det vil ta å hente ut kvikksølvflaskene av kjølkassen. Det er laget en egen modell for å beregne forventet antall kvikksølvflasker som kan heves. Beskrivelse og resultater fra denne er gjengitt i kapittel 4.

[1] http://www.marin.nl/web/JIPs-Networks/Public/Safetrans.htm

Avgrensninger:

- Gjennomføringstid for formelle beslutningsprosesser (kvalitetssikring med påfølgende behandling) er ikke analysert.
- Vurdering av hvilket tidspunkt på sesongen man ønsker å gjennomføre de ulike tiltakene er ikke vurdert, herunder at man velger å vente med å gjennomføre deler av prosjektet. Et argument for å vente kan være å finne optimalt tidspunkt med hensyn til kostnader for leie av fartøy (pga. sesongvariasjoner) og tidspunkt med forventet godt vær (bølgehøyde/vind).
- Andre utsettelser av tiltaket som kan inntreffe.

I Figur 1 er en prinsippskisse av modellen vist.

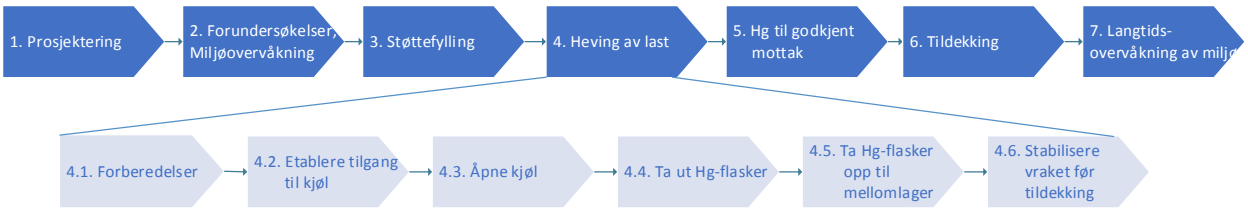


Figur 1 Modell for analyse av gjennomføringstid

Som figuren over viser, beregnes forventet gjennomføringstid for å legge ut støttefylling, heving av last og tildekking hver for seg. I tillegg til summering av estimatusikkerhetene, så vil den forventede gjennomføringstiden også påvirkes av identifiserte usikkerhetsfaktorer og hendelser. For detaljert beskrivelse av alle variabler se kapittel 6.

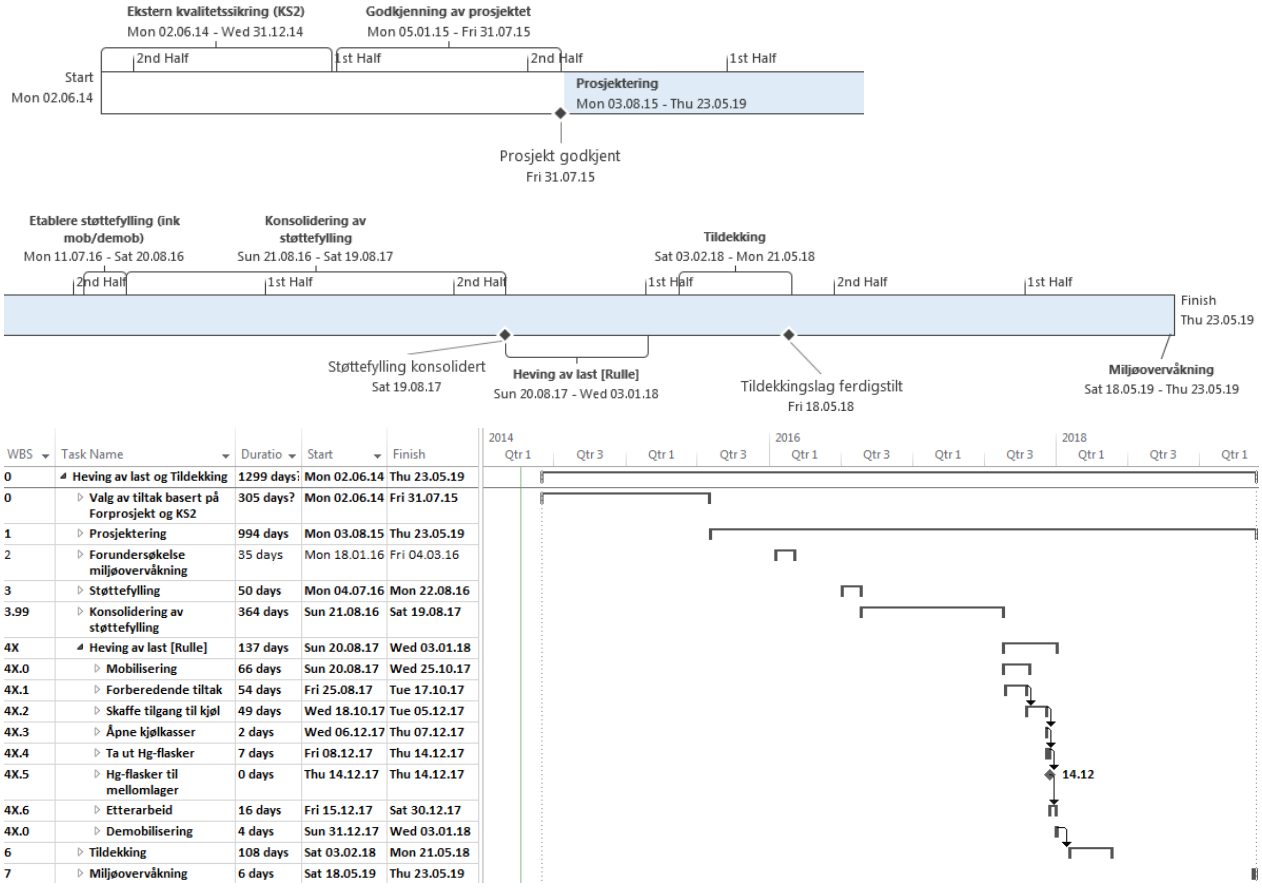
3 PROSESS OG AKTIVITETER

Figur 2 viser den overordnede prosessen for tiltaket. Prossessteg 3,4 og 6 er analysert mht. gjennomføringstid.



Figur 2 Overordnet prosess for Alternativ 3

I Figur 3 er prosjektets tidslinje og Gantt-diagram (med delprosesstegene for 4) presentert. Tidspunkter og varighet for prossessteg 0, 1, 2, 3.99 og 7 er kun veiledende, og vil kunne endres basert på beslutningsprosesser, ambisjon for gjennomføringshastighet og valg av hvilken tid på sesongen de ulike operasjonene gjennomføres.



WBS	Task Name	Duratio	Start	Finish
0	Heving av last og Tildekking	1299 days	Mon 02.06.14	Thu 23.05.19
0	Valg av tiltak basert på Forprosjekt og KS2	305 days?	Mon 02.06.14	Fri 31.07.15
1	Prosjektering	994 days	Mon 03.08.15	Thu 23.05.19
2	Forundersøkelse miljøovervåkning	35 days	Mon 18.01.16	Fri 04.03.16
3	Støttefylling	50 days	Mon 04.07.16	Mon 22.08.16
3.99	Konsolidering av støttefylling	364 days	Sun 21.08.16	Sat 19.08.17
4X	Heving av last [Rulle]	137 days	Sun 20.08.17	Wed 03.01.18
4X.0	Mobilisering	66 days	Sun 20.08.17	Wed 25.10.17
4X.1	Forberedende tiltak	54 days	Fri 25.08.17	Tue 17.10.17
4X.2	Skaffe tilgang til kjøl	49 days	Wed 18.10.17	Tue 05.12.17
4X.3	Åpne kjølkasser	2 days	Wed 06.12.17	Thu 07.12.17
4X.4	Ta ut Hg-flasker	7 days	Fri 08.12.17	Thu 14.12.17
4X.5	Hg-flasker til mellomlager	0 days	Thu 14.12.17	Thu 14.12.17
4X.6	Etterarbeid	16 days	Fri 15.12.17	Sat 30.12.17
4X.0	Demobilisering	4 days	Sun 31.12.17	Wed 03.01.18
6	Tildekking	108 days	Sat 03.02.18	Mon 21.05.18
7	Miljøovervåkning	6 days	Sat 18.05.19	Thu 23.05.19

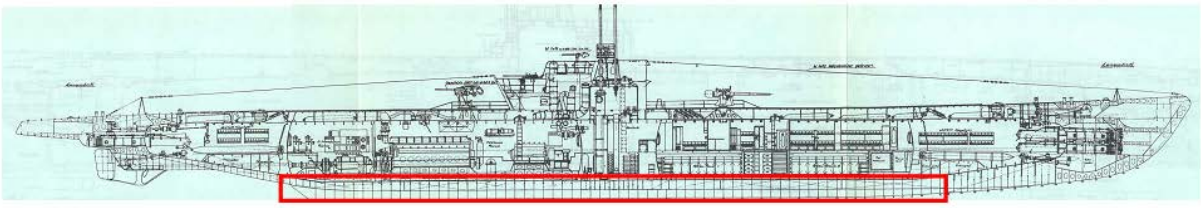
Figur 3 Tidslinje og Gantt diagram for Alternativ 3

Varighetene på aktivitetene i figuren over er forventede varigheter inklusive påslag for usikkerhetsfaktorer. Usikkerheten i varighet for alle offshore-operasjonene (hovedprosess 3, 4 og 6) er analysert og resultater gjengitt i kapittel 5.

4 FORVENTET ANTALL KVIKKSØLVFLASKER SOM KAN HEVES

4.1 Bakgrunn

Lastepapirene til U-864 lister blant annet opp at fartøyet hadde 1857 kvikksølvflasker. Basert på erfaring fra tilsvarende oppdrag antas det at disse er lagret i fartøyets kjølkasser /D01/. Dette tilsvarer ca. 65 tonn. I kjølkassene ble det normalt stuet ca. 100 til 130 tonn blylodd som ballast, avhengig av hvordan fartøyet ellers var lastet. Ikke alle kjølkassene (ca. 130) ble benyttet til ballast, en del forble tomme. Kvikksølvflaskene som U-864 hadde med seg erstattet en del av denne ballasten, men lastepapirene sier ikke noe om hvor i kjølen dette ble stuet. Da U-864 seilte fra ubåtbunkeren på Laksevåg hadde den kjølkasser som enten var fylt med 1) blylodd, 2) kvikksølvflasker eller 3) var tomme.



Figur 4 Skipstegning av U-864 (kjølkassene er markert med rødt)

Da U-864 ble torpedert, ble fartøyet delt i to større vrakdeler. Midtseksjonen der torpedoen traff, ble sprengt i mange deler og ligger hovedsakelig spredt rundt akterseksjonen. Sedimentprøver fra området rundt vraket er sterkt kvikksølvforurenset. Dette tyder på at en del av kvikksølvflaskene var lastet i midtseksjonen og ble sprengt i stykker når torpedoen detonerte. Mengden av kvikksølv som ble spredt er ikke kjent. De resterende kvikksølvflaskene antas fortsatt å være i kjølkassene.

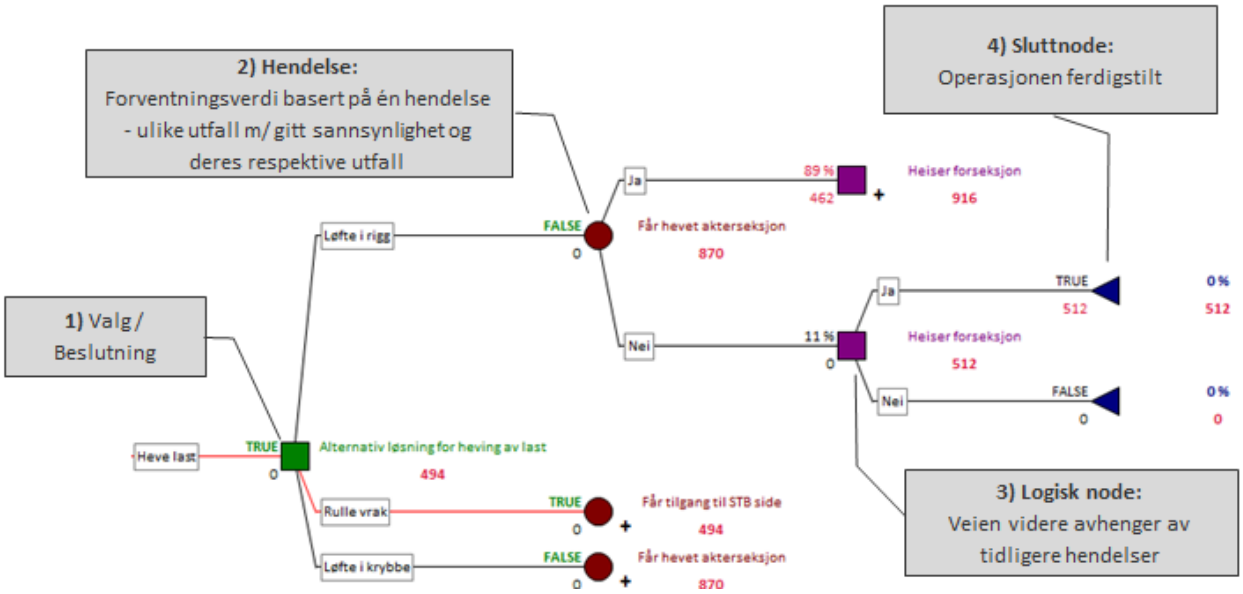
Antall kvikksølvflasker som man kan forvente å hente ut av kjølkassene er interessant av følgende årsaker:

- For å kunne estimere hvor lang tid det vil ta å hente ut kvikksølvflaskene av kjølkassene, og herav kostander.
- For å kunne estimere hvor mye det vil koste å behandle og lagre kvikksølvet etter en heving.
- For å vurdere mulig måloppnåelse ved gjennomføring av en heving av lastoperasjon.

Som det fremgår over, er antall flasker som kan forventes å bli hevet svært usikker. Det er derfor utarbeidet en egen modell som analyserer forventet antall flasker som kan bli hevet. Denne modellen er beskrevet i kapittel 4.2, mens resultatene av analysen er gjengitt i kapittel 4.3.

4.2 Generelt om modellen

For å beregne antall forventede flasker som kan heves er verktøyene PrecisionTree og @Risk fra Palisade benyttet. PrecisionTree er et verktøy som etablerer et hendelsestre, mens @Risk simulerer ulike utfall av input til hendelsestreet. I hendelsestreet er det tatt utgangspunkt i tre alternative metoder for å få tilgang til kjølkassene. Et hendelsestre er nyttig å bruke i dette tilfellet, fordi en heving av last operasjon vil bestå av forskjellige kombinasjoner av 1) valg/beslutninger for «veien videre», 2) hendelser med usikre utfall, 3) logiske avhengigheter som bestemmer neste trinn og 4) sluttnode med usikre utfall (operasjonen er ferdig). I figuren nedenfor er disse fire typene av noder vist:



Figur 5 Utsnitt av hendelsestreet for beregning av forventet antall flasker som kan heves

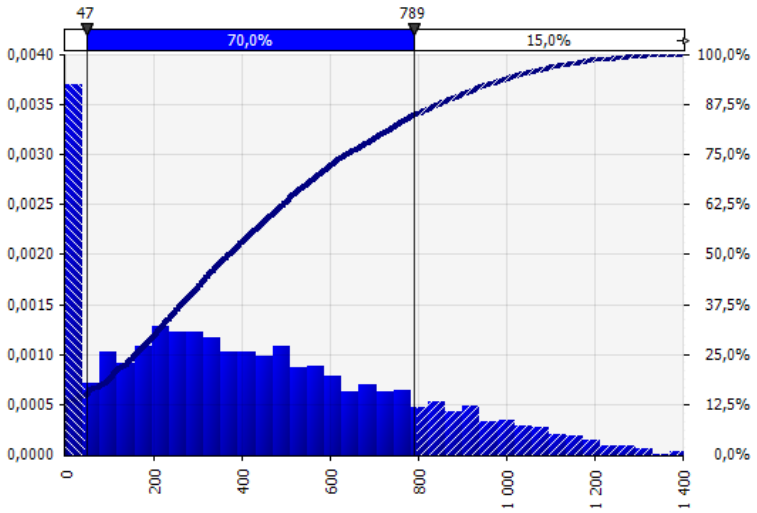
Figuren over viser kun et lite utsnitt av hendelsestreet som modellen er basert på. «Løfte i rigg» og «Løfte i krybbe» har tilsvarende deltrær, mens «Rulle vrak» er betydelig større på grunn av at det er flere enkeltsteg i prosessen.

For å kunne beregne forventet antall flasker som kan heves ved en operasjon er alle de variablene som påvirker dette inkludert i modellen. Av disse variablene er det mange variabler vi ikke har noe informasjon om, kun antagelser som derfor har stor usikkerhet. Alle usikre variabler er gitt et trepunktsestimat, slik at denne usikkerheten fanges opp i resultatene som presenteres. Estimatusikkerheten for disse variablene er beskrevet i kapittel 6.4.

4.3 Resultater

I figuren nedenfor er resultatene fra analysen gjengitt for de tre foreslåtte metodene. «Rigg» og «Krybbe» har like forutsetninger i modellen, og derfor like resultater, og derfor presentert sammen.

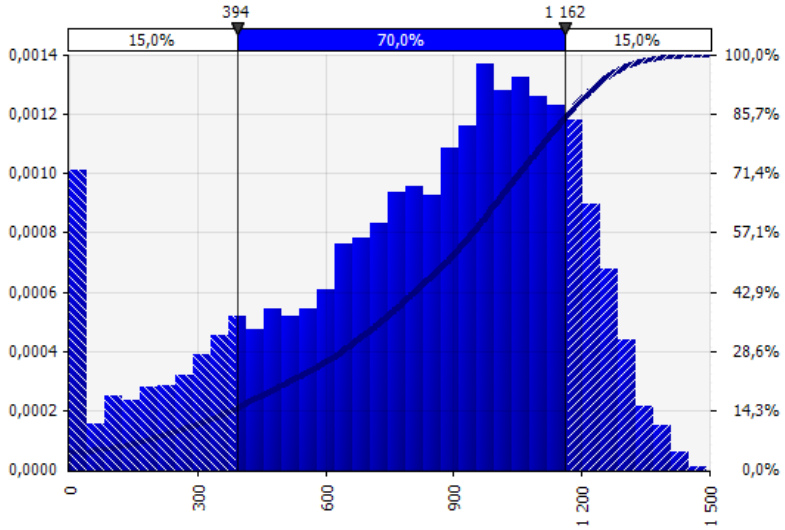
«Rulle»:



Analyseresultater	
Forventet antall flasker som heves	419
p15-verdi	47
p50-verdi	369
p85-verdi	789
Standardavvik	324
Relativt standardavvik	77 %

Figur 6 Forventet antall flasker som kan heves for "Rulle"-løsningen – 420 flasker

«Rigg» og «Krybbe»:



Analyseresultater	
Forventet antall flasker som heves	807
p15-verdi	394
p50-verdi	882
p85-verdi	1162
Standardavvik	351
Relativt standardavvik	44 %

Figur 7 Forventet antall flasker som kan heves for "Rigg"/"Krybbe"-løsningen – 810 flasker

Resultatene av analysene viser at forventet antall kvikksølvflasker som kan heves er ca. 420 for «Rulle» og ca. 810 for «Rigg» og «Krybbe». Årsaken til at «Rigg» og «Krybbe» nesten har dobbelt så høy forventningsverdi, er at «Rulle»-løsningen består av flere enkeltprosesser, hvor en eller flere av disse kan mislykkes og/eller at neste steg ikke gjennomføres. Det å rulle skroget vil kreve fjerning av store mengder masser for å sikre tilgang, noe som kan bli krevende. Skroget må også mest sannsynlig rulles begge veier for å få tilgang til begge sider av kjølkassen. Rulling innebærer at kjølen utsettes for store krefter som kan ødelegge kjølen i større eller mindre grad. I sum gjør dette at antall kvikksølvflasker som kan forventes hevet er lavere for «Rulle» enn «Rigg» og «Krybbe». Derimot er det maksimale antall flasker man kan hente ut omtrent likt for begge løsninger, nesten 1500.

Som det fremgår av resultatene over, er det svært høy usikkerhet når det gjelder antall kvikksølvflasker som kan forventes å bli hevet. For «Rulle» er 70 % konfidensintervallet mellom ca. 50 og 780 flasker. For «Rigg» og «Krybbe» er intervallet ca. 390 til 1160 flasker. De mange variablene som det ikke finnes tilgjengelig informasjon om, der man må basere seg på antagelser, er årsaken til den svært store usikkerheten. Dette er eksemplifisert nedenfor:

Dersom:

- de fleste kvikksølvflaskene er av den «lille» typen[2], da vil det kunne være svært mange kjølkamre som var fylt med ca. 40 kvikksølvflasker i hver. Dette reduserer det totale antall kamre som er fylt med kvikksølvflasker.

OG

- kvikksølvflaskene ble hovedsakelig stuet i midtskips, det vil si i midtseksjonen som er sprengt vekk.

OG

- store deler av kjølen er ødelagt, det vil si i større utstrekning enn de 7 meterne midtseksjonen utgjør. Dette pga. torpederingen og deformasjon når vraket traff sjøbunnen.

[2] Det er funnet flere typer kvikksølvflasker i sedimentene rundt vraket, og disse varierer i størrelse og utforming. Avhengig av størrelsen på flaskene, er det anslått at et kjølkammer kunne romme mellom 22 og 40 kvikksølvflasker.

vil det medfører at alle, eller de aller fleste, kvikksølvflaskene ble ødelagt da U-864 ble torpedert og sank. I verste tilfelle vil man ikke få hevet noen kvikksølvflasker, selv om hevingsoperasjonene i seg selv er vellykket.

Men motsetningen til eksempelet over er like sannsynlig, og innebærer at:

dersom

- de fleste kvikksølvflaskene er av den «lille» typen, da vil det kunne være svært mange kjølkamre som var fylt med ca. 40 kvikksølvflasker i hver. Dette reduserer det totale antall kamre som er fylt med kvikksølvflasker.

OG

- kvikksølvflaskene ble hovedsakelig stuet i hver ende av fartøyet, det vil si at et mindretall ble ødelagt da midtseksjonen ble sprengt i stykker.

OG

- mindre deler av kjølen er ødelagt, det vil si i mindre utstrekning enn de 7 meterne midtseksjonen utgjør

vil det medføre at kun et fåtall av kvikksølvflaskene er ødelagt, og en vellykket operasjon vil kunne heve et stort antall. Resultatene fra analysene gir et maksimalt antall hevede kvikksølvflasker til nesten 1500 stykker.

4.4 Konklusjon

Som det fremgår av analysene er det stor usikkerhet i antall kvikksølvflasker som kan heves. Forventningsverdien er ca. 420 og 810 kvikksølvflasker for hhv. «Rulle» og «Rigg»/«Krybbe». Relativt standardavvik er svært høyt: hhv. 77 % og 44 %. Den store usikkerheten skyldes at det er svært begrenset med informasjon som finnes om kjølens tilstand og antall flasker per kjølkammer, mens det finnes ingen informasjon om hvor flaskene ble stuet i kjølen eller hvor stor bruddsonen på kjølen er. Toktet som ble gjennomført i januar hadde som et av målene å få noe mer informasjon om hvordan kvikksølvflaskene ble stuet (antall i hvert kammer) og tilstanden til flaskene, men dessverre var de to kamrene som man fikk tilgang til tomme.

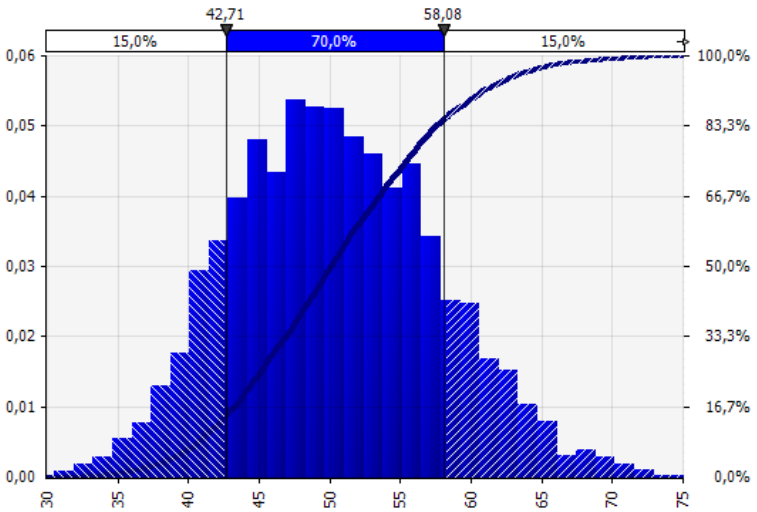
For å kunne redusere den usikkerheten som er beskrevet i kapittel 4, må det gjøres større nye og langt mer omfattende undersøkelser av kjølen enn det som ble gjort under toktet i januar. Men kjølen er svært vanskelig tilgjengelig, og en slik undersøkelse vil i praksis bety at selve tiltaket (Alternativ 3) iverksettes.

5 RESULTATER

Nedenfor presenteres resultatene fra analysen av gjennomføringstid for å etablere støttefylling, heving av last og tildekke forurensede masser.

5.1 Hovedprosess 3: Støttefylling

Resultatene av analysen for gjennomføringstid for å etablere støttefyllingen er vist nedenfor.

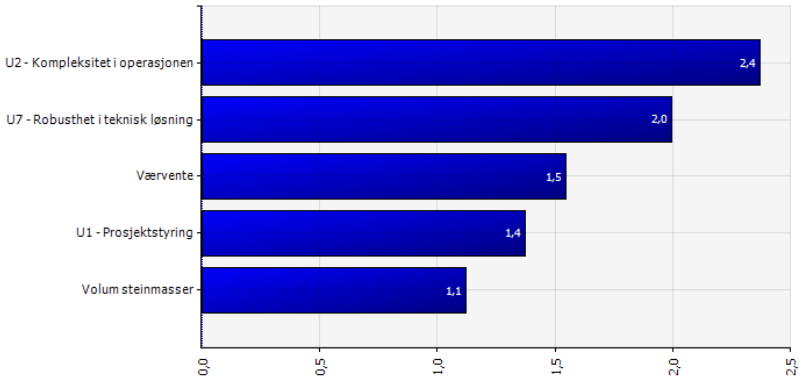


Analyseresultater	
Forventet gjennomføringstid	50
p15-verdi	43
p50-verdi	50
p85-verdi	58
Standardavvik	7
Relativt standardavvik	14 %

Figur 8 Sannsynlighetstetthetsplott, S-kurve og resultater for støttefylling (antall dager) – forventet gjennomføringstid: 50 dager

Analysen viser at den forventede gjennomføringstiden for etablering av støttefyllingen er 50 dager, og at det med 70 % sannsynlighet kan gjennomføres på mellom 43 og 58 dager. Dette inkluderer mobilisering og demobilisering av støttefartøy og steindumpefartøy.

I figuren nedenfor er det listet i et tornadoplott de fem variablene som bidrar mest til usikkerhetene i gjennomføringstid for etablering av støttefylling.



Figur 9 Tornadoplott[3] for støttefylling (antall dager)

Nedenfor er disse seks variablene beskrevet kort. For mer informasjon om de enkelte variablene, se kapittel 5. Variabler som starter med «U» er en usikkerhetsfaktor.

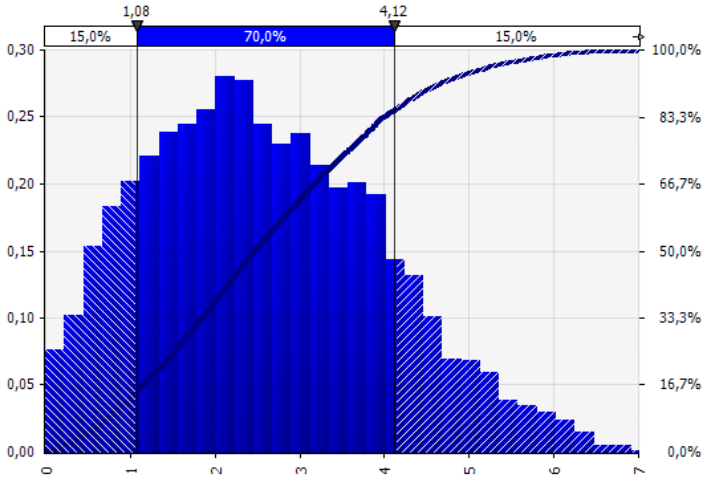
[3] Verdien angir hvor mye total gjennomføringstid vil øke dersom angitte variabel øker med ett standardavvik.

- **U2 Kompleksitet i operasjonen**. Dette er den variabelen som bidrar med mest usikkerhet, og representerer usikkerhet knyttet til antall arbeidssteg, bruk av spesialutstyr og gjennomføring av forundersøkelser mv.
- **U7 Robusthet i teknisk løsning.** Valg av teknisk løsning for å gjennomføre operasjonen vil i seg selv kunne øke eller redusere gjennomføringstid betydelig ut fra 1) hvor lang tid valgte teknologi muliggjør en rask operasjon eller ikke, og 2) type fartøy som er nødvendig og effektiviteten til dette. Videre vil robusthetene i løsningen innvirke på i hvor stor grad man er rustet til å møte uforutsette hindringer.
- **Værvente.** Fartøyene som benyttes i operasjonen, og spesielt steindumperfartøyet, har begrensninger ift. maksimal bølgehøyde under operasjon. Se Figur 5 som viser forventet værvente.
- **U1 Prosjektstyring**. Denne variabelen representerer prosjektets evne til å ta gode beslutninger under prosjektering og gjennomføring. Tilstrekkelig med ressurser og at disse har rett kompetanse har stor betydning for gjennomføringstiden.
- **Volum steinmasser.** Mengden stein som er nødvendig å legge ut avgjør direkte hvor lang tid operasjonen vil ta.

For å redusere usikkerheten i gjennomføringstid bør det sikres:

- god prosjektering slik at effektive og robuste løsninger utarbeides.
- at prosjektet er bemannet med tilstrekkelig mengde med ressurser og rett kompetanse slik at effektive løsninger for gjennomføring av operasjonen utarbeides, samt at raske og effektive grep kan gjøres dersom gjennomføringen møter på utfordringer.

Figuren nedenfor vises et sannsynligtetthetsplott og s-kurve over værvente for etablering av støttefyllingen.

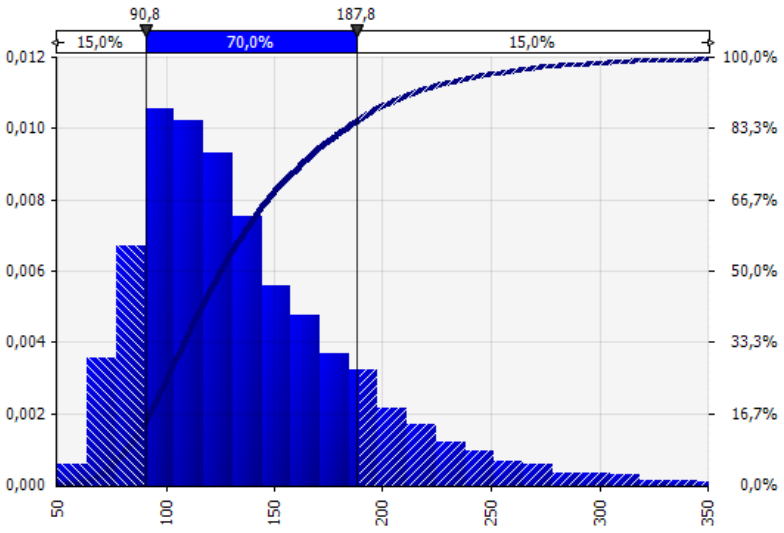


Figur 10 Sannsynligtetthetsplott over værvente ifm etablering av støttefylling (antall dager)

Som det fremgår av figuren over må det med 70 % sannsynlighet forventes å bli mellom 1 og 4 dager med værvente (totalt) i løpet av operasjonen.

5.2 Hovedprosess 4: Heving av last

Resultatene av analysen for gjennomføringstid for heving av last er vist nedenfor.

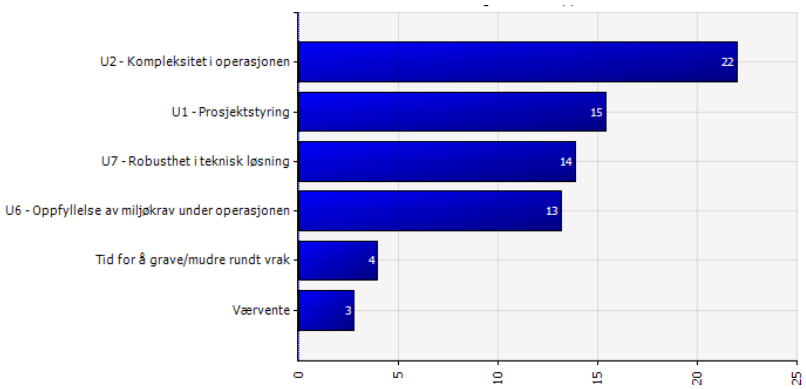


Analyseresultater	
Forventet gjennomføringstid	137
p15-verdi	90
p50-verdi	125
p85-verdi	185
Standardavvik	52
Relativt standardavvik	38 %

Figur 11 Sannsynlighetstetthetsplott, S-kurve og resultater for eving av last (antall dager) – forventet gjennomføringstid: 140 dager

Analysen viser at den forventede gjennomføringstiden for heving av last er ca. 140 dager, og at det med 70 % sannsynlighet kan gjennomføres mellom ca. 90 og 190 dager. Dette inkluderer mobilisering og demobilisering av fartøy. Det er med andre ord stor usikkerhet i varighet av en slik operasjon.

I figuren nedenfor er det listet i et tornadoplott de seks variablene som bidrar mest til usikkerhetene i gjennomføringstid for heving av last.



Figur 12 Tornadoplott[4] for støttefylling (antall dager)

Nedenfor er disse seks variablene beskrevet kort. For mer informasjon om de enkelte variablene, se kapittel 5. Variabler som starter med «U» er en usikkerhetsfaktor.

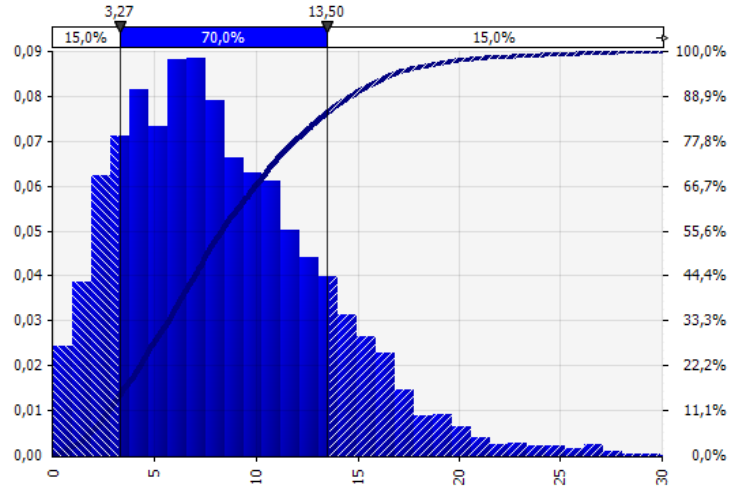
[4] Verdien angir hvor mye total gjennomføringstid vil øke dersom angitte variabel øker med ett standardavvik.

- **U2 Kompleksitet i operasjonen**. Dette er den variabelen som bidrar med mest usikkerhet, og representerer usikkerhet knyttet til antall arbeidssteg, nødvendighet av spesialutstyr og gjennomføring av forundersøkelser mv.
- **U1 Prosjektstyring**. Denne variabelen representerer prosjektets evne til å ta gode beslutninger under prosjektering og gjennomføring. Tilstrekkelig med ressurser og at disse har kompetanse har stor betydning for gjennomføringstiden.
- **U7 Robusthet i teknisk løsning.** Valg av teknisk løsning for å gjennomføre operasjonen vil i seg selv kunne øke eller redusere gjennomføringstid betydelig ut fra 1) hvor stor grad valgte teknologi og metode muliggjør en rask operasjon og 2) type fartøy som er nødvendig og effektiviteten til dette. Videre vil robusthetene i løsningen innvirke på i hvor stor grad man er rustet til å møte uforutsette hindringer.
- **U6 Oppfyllelse av miljøkrav under operasjonen.** Området rundt vrakdelene er sterkt forurenset, og operasjoner på eller rett over sjøbunnen vil virvle opp forurensede sedimenter. Dette har erfaringene fra arbeid på vrakstedet påvist. Det er etablert kriterier mht. spredning av sedimenter som operasjonene må holde seg innenfor. Dersom grenseverdiene overskrides, må operasjonen stoppe til verdiene er tilstrekkelig lave og/eller metodikk for gjennomføring må evalueres. Dette medfører derfor forsinkelser i operasjonen, og fare for at tiltaksområdet øker i omfang ved at forurensede sedimenter spres utenfor dagens tiltaksområde.
- **Tid for å grave rundt vrak:** «Rulle»-operasjonen vil kreve at store mengder masser fjernes fra begge sider rundt vraket, totalt opp mot 2000 m^3. Dette arbeidet er krevende å gjennomføre, spesielt ettersom det er svært forurensede masser som skal fjernes. Fjerningen av masse må skje på en slik måte at forurensede sedimenter ikke virvles opp og spres utenfor tiltaksområdet. Erfaringer fra toktet i januar 2014 viser at denne delen av operasjonen kan ta svært lang tid.
- **Værvente.** Fartøyene som benyttes i operasjonen har krav til maksimal bølgehøyde under operasjon. Se Figur 5 som viser forventet værvente.

For å redusere usikkerheten i gjennomføringstid bør det sikres at:

- prosjektet blir godt prosjektert slik at effektive og robuste løsninger utarbeides.
- prosjektet er bemannet med tilstrekkelig mengde med ressurser og rett kompetanse slik at effektive løsninger for gjennomføring av operasjonen utarbeides, samt raske og effektive grep kan gjøres dersom gjennomføringen støter på utfordringer.
- løsningen for heving av last må være designet slik at den i minst mulig grad virvler opp forurensede sedimenter.

Figuren nedenfor vises et sannsynligtetthetsplott over værvente for «heving av last».

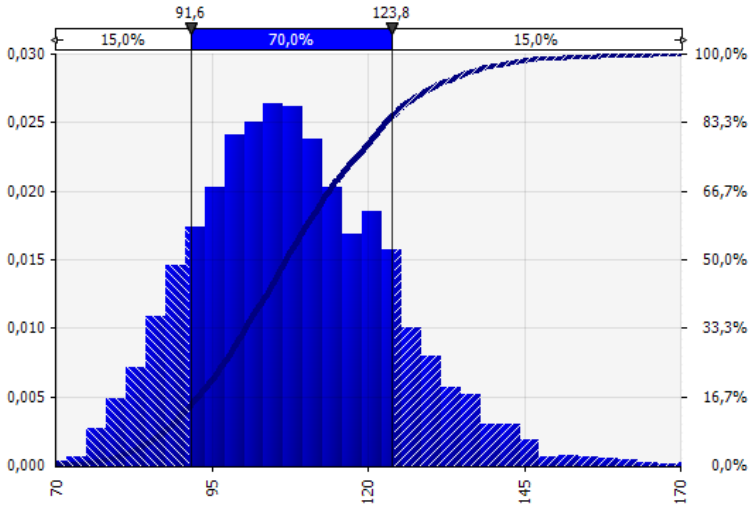


Figur 13 Sannsynligtetthetsplott og S-kurve over værvente ifm heving av last (antall dager)

Som det fremgår av figuren over må det med 70 % sannsynlighet forventes å bli mellom 3 og 14 dager med værvente (totalt) i løpet av operasjonen.

5.3 Hovedprosess 6: Tildekking

Resultatene av analysen for gjennomføringstid for å tildekke tiltaksområdet med rene masser er vist nedenfor.

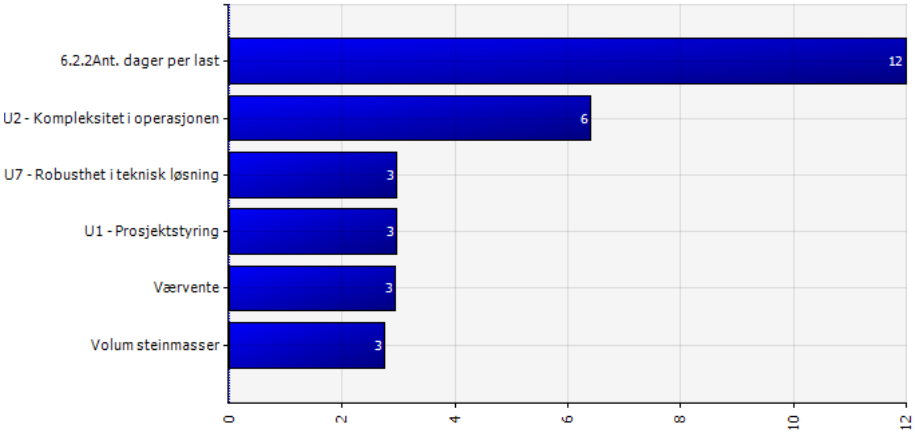


Analyseresultater	
Forventet gjennomføringstid	108
p15-verdi	93
p50-verdi	106
p85-verdi	124
Standardavvik	15
Relativt standardavvik	14 %

Figur 14 Sannsynlighetstetthetsplott, S-kurve og resultater for tildekking (antall dager) - forventet gjennomføringstid: 110 dager

Analysen viser at den forventede gjennomføringstiden for å legge ut tildekkingslaget er 108 dager, og at det med 70 % sannsynlighet kan gjennomføres mellom ca. 90 og 120 dager. Dette inkluderer mobilisering og demobilisering av støttefartøy og steindumpefartøy.

I figuren nedenfor er det listet i et tornadoplott de seks variablene som bidrar mest til usikkerhetene i gjennomføringstid for tildekking.



Figur 15 Tornadoplott[5] for støttefylling (antall dager)

Nedenfor er de fem variablene som bidrar med mest usikkerhetene beskrevet kort. For mer informasjon om de enkelte variablene, se kapittel 5. Variabler som starter med «U» er en usikkerhetsfaktor.

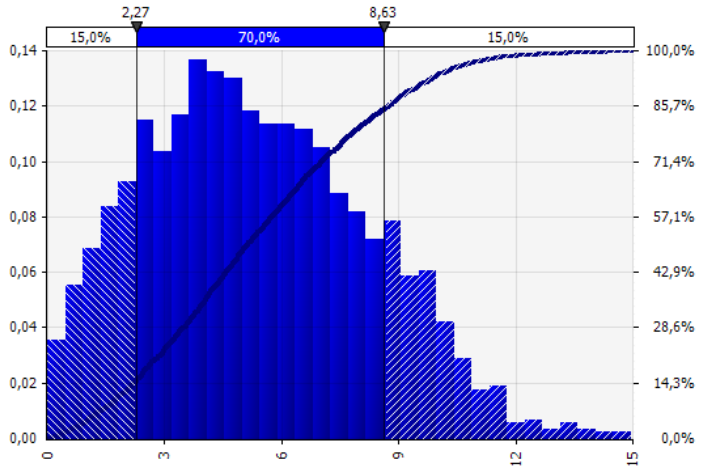
- **6.2.2 Antall dager per last.** Som det fremgår av figuren er dette den variabelen som klart innvirker mest på usikkerheten i gjennomføringstid. Mer konkret er det variabelen antall dager fartøyet bruker på å 1) laste fartøyet med stein (25.000 tonn), 2) transittere til tiltaksområdet og 3) legge ut steinmassene. Det er forventet at det tar 5 dager per tur, og at fartøyet trenger 13 turer for å legge ut de ca 160.000 m^3 med stein. Dersom hver tur tar 1 dag lengre, vil det medføre at gjennomføringstiden øker med 13 dager.
- **U2 Kompleksitet i operasjonen**. Denne variabelen representerer usikkerhet knyttet til antall arbeidssteg, nødvendighet av spesialutstyr og gjennomføring av forundersøkelser mv.
- **U7 Robusthet i teknisk løsning.** Valg av teknisk løsning for å gjennomføre operasjonen vil i seg selv kunne øke eller redusere gjennomføringstid betydelig ut fra 1) hvor stor grad valgte teknologi og metode muliggjør en rask operasjon og 2) type fartøy som er nødvendig og effektiviteten til dette. Videre vil robusthetene i løsningen innvirke på i hvor stor grad man er rustet til å møte uforutsette hindringer.
- **U1 Prosjektstyring**. Denne variabelen representerer prosjektets evne til å ta gode beslutninger under prosjektering og gjennomføring. Tilstrekkelig med ressurser og at disse har rett kompetanse har stor betydning for gjennomføringstiden.
- **Værvente.** Fartøyene som benyttes i operasjonen, og spesielt steindumperfartøyet, har krav til maksimal bølgehøyde under operasjon. Se Figur 5 som viser forventet værvente.
- **Volum steinmasser.** Mengden stein som er nødvendig å legge ut avgjør direkte hvor lang tid operasjonen vil ta.

[5] Verdien angir hvor mye total gjennomføringstid vil øke dersom angitte variabel øker med ett standardavvik.

For å redusere usikkerheten i gjennomføringstid bør det sikres at:

- operasjonen med å legge ut steinmassene detaljeres grundig, at kapasiteten på tilgjengelige steindumpefartøy vurderes nøye, samt at avstand til og kapasitet på ulike leverandører av tildekningsmasser analyseres.
- prosjektet er bemannet med tilstrekkelig mengde med ressurser og rett kompetanse slik at effektive løsninger for gjennomføring av operasjonen utarbeides, samt raske og effektive grep kan gjøres dersom gjennomføringen støter på utfordringer.

Figuren nedenfor vises et sannsynligtetthetsplott over værvente for etablering av tildekkingen.



Figur 16 Sannsynligtetthetsplott og S-kurve over værvente ifm etablering av støttefylling (antall dager)

Som det fremgår av figuren over må det med 70 % sannsynlighet forventes å bli mellom 2 og 9 dager med værvente (totalt) i løpet av operasjonen.

6 BESKRIVELSE AV VARIABLER

6.1 Estimatusikkerhet

I tabellen nedenfor beskrives variablene som har innvirkning på varigheten av operasjonene knyttet til støttefylling og tildekking.

Tabell 1 Estimatusikkerheter for Støttefylling og Tildekking[6]

CBS	Støttefylling	P10	Mode	P90	Forventet
3.0.1/6.0.1	Mobilisere support vessel	-25 %	2 dg	+35 %	2,1 dg
3.0.2	Mobilisere rock dumper	-25 %	2 dg	+35 %	2,1 dg
3.0.3	Demobilisere support vessel	-25 %	1 dg	+35 %	1,1 dg
3.0.4	Demobilisere rock dumper	-25 %	1 dg	+35 %	1,1 dg
Usikkerhetsvurdering		Generell usikkerhet, usymmetrisk for å ivareta om mer utstyr og klargjøring er nødvendig for å kunne gjennomføre operasjonen.			
Usikkerhetsfaktorer:		U2 (¼), U5, U7 (¼)			
3.0.99/3.2.99 6.0.99/6.2.99	Værvente Denne virker som en faktor: Værvente = (sum varigheter) * (1+ % forventet værvente)	0 % (laveste verdi)	5 %	10 %	6 %
Usikkerhetsvurdering		Basert på erfaring og statistiske værdata, må en påregne ca. 5 % ventetid under slike operasjoner. Det er lagt et generelt usikkerhetsspenn på dette som dekker alt fra ingen værvente (0 %) til mer sjø og dobbelt så mye værvente (10 %).			
3.1.	Sette ut/ta inn utstyr (miljø)	-25 %	8 dg	+35 %	8,3 dg
Usikkerhetsvurdering		Generell usikkerhet, usymmetrisk for å ivareta at erfaringsmessig tar operasjoner noe lenger tid enn forventet.			
Usikkerhetsfaktorer:		U2 (¼), U5, U7 (¼)			
3.2.1/6.2.1	Masser (m3)	-5 %	78.412m^3 156.824m^3	+5 %	78.412m^3 156.824m^3
3.2.2	Døgn per lasting/losing	4 dg	5 dg	6 dg	5 dg
3.2.4	Optimering av tildekkingsmasser	3 dg	4 dg	5 dg	4 dg
6.2.4	Oppmåling med bathymetri (fylling rundt vrak)	3 dg	4 dg	5 dg	4,2 dg
6.2.7	Utsetting, etterarbeid og kontroll av målestaver	-20 %	2 dg	+35 %	2,1 dg
6.2.8	Oppmåling med bathymetri (av blandingslaget)	-20 %	4 dg	+35 %	4,2 dg
6.2.9	Sluttkontroll: Oppmåling bathymetri (av tildekking) og film m/ ROV	-20 %	5 dg	+35 %	5,2 dg
6.2.10	Sluttkontroll: Sedimentprøvetaging	-20 %	2 dg	+35 %	2,1 dg
Usikkerhetsvurdering		Generell usikkerhet, usymmetrisk for å ivareta at erfaringsmessig tar operasjoner noe lenger tid enn forventet.			
Usikkerhetsfaktorer:		U2 (¼), U5, U7 (¼)			

[6] CBS (Cost Breakdown Structure) viser til aktivitetsnummeret, der første siffer angir hovedprosess (se Figur 2). For full beskrivelse av CBSen, se Vedlegg V3.02. Dersom en usikkerhetsfaktor er vurdert å ikke virker fullt på en variabel, er andelen angitt i parentes.

I tabellen nedenfor beskrives de variablene som har innvirkning på varigheten av operasjonene knyttet til heving av last. Estimatusikkerheten for varigheter er relativt stor og satt svakt asymmetrisk (-25 %/+35 %), da erfaring viser at operasjoner av denne typen ofte heller tar noe lengre tid enn kortere tid enn forventet. Detaljert design vil kunne redusere denne tidsusikkerheten noe. Usikkerhet i varighet som skyldes vær, kompleksitet og metodikk håndteres ved hjelp av faktorer.

Tabell 2 Estimatusikkerhet for Heving av last og Transport til godkjent mottak[7]

Post	Støttefylling	P10	Mode	P90	Forventet
4X.0	Mob-/Demobilisere offshore construction vessel	-25 %	6 dg	+35 %	6,3 dg
4X.0	Mob-/Demobilisere support vessel	-25 %	3 dg	+35 %	3,1 dg
4X.0	Mob-/Demobilisere anchor handling vessel	-20 %	6 dg	+35 %	6,3 dg
4X.0	Mob-/Demobilisere hopper dredger	-20 %	7 dg	+35 %	1,1 dg
Usikkerhetsvurdering		Generell usikkerhet, asymmetrisk for å ivareta om mer utstyr og klargjøring er nødvendig for å kunne gjennomføre operasjonen.			
Usikkerhetsfaktorer:		U2 (¼), U5, U7 (¼)			
4X.1.1.1	Fjerne deler på formskrog, feste ankre.	-30 %	70 ankre 0,4t per anker	+30 %	28,3 dg
4A.1.1.2	Installere bukker	-25 %	8 dg	+35 %	8,3 dg
4A.1.1.3	Innstallere ankere (til vinsjer)	-25 %	5 dg	+35 %	5,2 dg
4Bx.1.1.2	Forberede område for rigg/krybber	-25 %	10 dg	+35 %	10,4 dg
4Bx.1.1.3	Installere rigg/krybber	-25 %	6 dg	+35 %	6,3 dg
4A/B1.1.1.4	Installere sub-sea-vinsjer (hhv.	-25 %	6/8 dg	+35 %	6,3/8,3 dg
4B2.1.1.4	Feste wire til løftefartøy	-25 %	2 dg	+35 %	2,1 dg
4A.1.1.5	Stramme wire	-25 %	1 dg	+35 %	1,0 dg
4B1.1.5	Installere oppdriftselementer	-25 %	3 dg	+35 %	3,1 dg
4B1.1.1.6	Installere wire til skrog	-25 %	1 dg	+35 %	1,0 dg
4Bx.1.1.5/7	Injisere vann under skrog (i parallell med aktivitet over)	-25 %	1 dg	+35 %	1,0 dg
Usikkerhetsfaktorer:		U2, U5, U6, U7			
4A.1.2.1	Fjerne steiner og vrakrester med klo	-25 %	6 dg	+35 %	28,3 dg

[7] CBS (Cost Breakdown Structure) viser til aktivitetsnummeret, der første siffer angir hovedprosess (se Figur 2). De forskjellige løsningene er benevnt som følger: 4A = Rulle, 4B1 = Rigg, 4B2 = Krybbe. Der estimatene er felles for en eller flere av disse løsningene, er dette benevnt med en X. Dersom en usikkerhetsfaktor er vurdert å ikke virke fullt på en variabel, er andelen angitt i parentes. For full beskrivelse av CBSen, se Vedlegg V3.02.

Post	Støttefylling	P10	Mode	P90	Forventet
4A.1.2.2	Mudre langs kjølen (egen modell basert på volum og bruk av klo vs mudring)	21 dg	31 dg	43 dg	32 dg
4A.1.2.4	Rulle vraket over på den ene siden (rulleoperasjoner)	-25 %	2 dg	+35 %	2,1 dg
4A.1.2.5	Mudre/fjerne vrakdeler for å gi ROV tilgang	-25 %	4 dg	+35 %	4,2 dg
4A.1.2.6	Installere arbeidsrigg	-25 %	2 dg	+35 %	2,1 dg
4A.1.2.7	Rengjøre kjølplater	-25 %	4 dg	+35 %	4,2 dg
4A.1.2.8	Rulle vraket over på motsatt side	-25 %	2 dg	+35 %	2,1 dg
4Bx.1.2.1	Løfte vraket (hhv. i rigg og over til krybbe)	-25 %	2 dg	+35 %	2,1 dg
4Bx.1.2.2	Fjerne steiner og vrakrester med klo/ROV	-25 %	4 dg	+35 %	4,2 dg
4Bx.1.2.3	Mudre/rense kjølen	-25 %	2 dg	+35 %	2,1 dg
4Bx.1.2.4	Installere arbeidsrigg	-25 %	2 dg	+35 %	2,1 dg
Usikkerhetsfaktorer:		U2, U5, U6, U7			
4B1.1.3.1	Borre/kutte sideplater	-25 %	2 dg	+35 %	2,1 dg
4B1.1.3.2	Fjerne sideplater (i parallell med aktivitet over)	-25 %	2 dg	+35 %	2,1 dg
Usikkerhetsfaktorer:		U2, U5, U6, U7			
4X.1.4.1-3	Ta ut løse flasker, flasker som har rustet, flytende Hg (egen modell for beregning av tid. Færre forventede flasker for rulle enn rigg/krybbe)	Rulle: 3 dg R/K: 6 dg	Rulle: 7 dg R/K: 10 dg	Rulle: 13dg R/K: 16 dg	8 dg 11 dg
4A.1.4.4	Flytte Hg-flasker til våt-lager (i parallell med 4X.4.1-3)				
4A.1.4.5	Flytte flytende Hg til våt-lager (i parallell med 4X.4.1-3)				
Usikkerhetsfaktorer:		U2, U5, U6, U7			
4X.1.5.x	Ingen aktiviteter, er foreslått at kvikksølvflasker lagres i våtlager på sjøbunn og transporteres direkte til endelig lager.				0 dg
Usikkerhetsfaktorer:					
4X.1.6.1/2	Fjerne sub-sea vinsjer	-25 %	5 dg	+35 %	5,2 dg
4A1.1.6.1	Fjerne oppdriftselementer	-25 %	1 dg	+35 %	1,0 dg
4A.1.6.2	Fjerne bukker, og rengjøre og transport	-25 %	5 dg	+35 %	5,2 dg
4A.1.6.3	Flytte ankre (til forseksjon)	-25 %	5 dg	+35 %	5,2 dg
4Bx.1.6.3	Fjerne rigg /krybber	-25 %	6 dg	+35 %	6,3 dg
Usikkerhetsfaktorer:		U2, U5, U6, U7			

6.2 Usikkerhetsfaktorer

I tabellen under er det listet de usikkerhetsfaktorene som har innvirkning for gjennomføringshastigheten. For U2, U6 og U7 er disse modellert til kun å virke med 75 % effekt, da antatt ca. 25 % av faktorene omhandler kostnader som ikke genereres pga. medgått tid, som for eksempel kostnader for utstyr.

Tabell 3 Usikkerhetsfaktorer

U	Usikkerhetsfaktorer		Beskrivelse
U1	**Prosjektstyring**		*Prosjektets evne til å ta gode beslutninger. Denne modelleres slik at den gir påslag eller fradrag på de andre faktorene som prosjektressursene kan ha en innvirkning på kostnadene til.*
Lav	-33 %	Tilstrekkelig med svært kompetente ressurser.	
Mode	0 %	Som forventet og som ligger til grunn i kostnadsanalysen.	
Høy	66 %	Lav bemanning i organisasjon, og ikke med rett kompetanse.	
U2	**Kompleksitet i operasjonen** *(omvendt korrelert med CBS 1.2)*		*Operasjonen mer eller mindre kompleks enn forventet. Antall arbeidssteg, bruk av spesial-utstyr, nødvendighet av forundersøkelser, «plunder og heft» mv.*
Lav	-15 %	Færre hindringer enn forventet medfører lavere forbruk av dyrt materiell og/eller at operasjonen tar kortere tid enn forventet.	
Mode	0 %	Som forventet og som ligger til grunn i kostnadsanalysen.	
Høy	+45 %	Operasjonene møter på mange uforutsette hindringer som krever mer bruk av dyrt materiell og/eller medfører at operasjonen tar lengre tid. Tilstanden og forholdene til baugen er lite utforsket (grunnet ustabil skråning).	
U5	**Vær**		*Endringer i vær som øker gjennomføringstiden*
Lav	0 %	Godt vær som ikke medfører noen utsettelser.	
Mode	+5 %	Tidvis dårlig vær (høy sjø) som medfører noen forsinkelser.	
Høy	+10 %	Dårlig vær (høy sjø) som medfører lengre forsinkelser.	
U6	**Oppfyllelse av miljøkrav under operasjonen**		*Kravene til miljø ligger fast. Teknisk utførelse vil derimot kunne medføre et antall stopp i operasjonen som vil medføre ventekostnader.*
Lav	-20 %	Gode løsninger og kontroll med utførelse gir færre antall stopp i operasjonen enn forventet	
Mode	+0 %	Som lagt til grunn i kostnadsanalysen.	
Høy	+20 %	Valgt gjennomføring og dårligere kontroll med utførelse gir flere antall stopp i operasjonen enn forventet.	
U7	**Robusthet i teknisk løsning** *(omvendt korrelert med CBS 1.2)*		*Valg av teknisk løsning reduserer eller øker kostnadene, og i hvor stor grad man er rustet til å møte uforutsette hindringer.*
Lav	-20 %	Gode tekniske løsninger som er robuste mot uforutsette hendelser og som reduserer gjennomføringstid og kostnader.	
Mode	0 %	Som forventet og som ligger til grunn i kostnadsanalysen. Det er tatt høyde for en relativt tidkrevende operasjon, mens kostnadene som ikke er tidsavhengige er estimert på bakgrunn et normalt kostnadsbilde.	
Høy	+20 %	Mangelfulle/ensidige og kostbare tekniske løsninger og/eller som i liten grad håndterer uforutsette hendelser som øker gjennomføringstid.	

Faktorene U2 og U7 er korrelert med kostnadsposten 1.2.1 «Engineering Tildekking», som medfører at dersom prosjektet bruker mer tid og kostnader i designfasen, vil sannsynligheten for mer «plunder og heft» (U2) og dårligere løsninger (U7) reduseres. I motsatt fall øker disse.

6.3 Hendelser

I tabellen under er den identifiserte hendelsen som kan påvirke gjennomføringstiden for «Tildekking» beskrevet. For «Støttefylling» er det ikke identifisert noen spesielle hendelser som ikke blir ivaretatt av usikkerhetsfaktorene.

Tabell 4 Hendelser

	Hendelse	p	P10	Mode	P90	Forventet
H2	Må hente steinmasser til tildekking utenfor Bergensregionen	20 %	1.05	1,08	1,16	1,1
	Beskrivelse	Dersom pukkverk i Bergen-regionen ikke har tilstrekkelig med kapasitet til å levere all stein, ivaretar denne hendelsen at steindumpefartøyet må transittere utenfor Bergens-regionen for masser. Verdiene over er en beregnet verdi for den andelen den totale transittiden øker med, dersom hhv. 10 %, 20 % eller 40 % av volumet må hentes i f. eks Stavanger-regionen. Det ar anslått at transitten øker med ca. 1 dag per tur pga. lengre transitt.				

6.4 Hendelsestre

Som beskrevet i kapittel 4 er det laget en modell, i form av et hendelsestre, som estimerer forventet antall kvikksølvflasker som kan bli hevet. I tabellen nedenfor er estimatusikkerheten for alle variablene som inngår i denne modellen beskrevet. Der det ikke er angitt verdier for p10, Mode og p90 antas disse verdiene som sikre.

Tabell 5 Estimatusikkerhet på variabler som inngår i hendelsestreet

Navn/beskrivelse	p10	Mode	p90	E
Antall kvikksølvflasker. Beskrevet i lastepapirene, og en konservativ vurdering tilsier at dette antallet faktisk ble lastet i kjølen.				1857
Lengde på kjøl. Tegningene viser 130 kjølkammer, og disse ble målt til 70 cm bredde (ref V3.09)				45,5 m
Lengde kjøl som er ødelagt. Lengden på midtseksjonen som er ødelagt vet man er 7m, men bruddsonen mot kjølkassene er usikker og om kjølen ble ødelagt når vrakdelene traff sjøbunn. Det er tidligere beregnet at ca. 14m er ødelagt /D02/, som er benyttet som mode. Ammunisjonskammeret var under sentral i midtseksjon og det er antatt at dette ble avsatt når torpedoen detonerte, noe som kan ha ødelagt en større del av kjølen. Usikkerhetsspennet er derfor asymmetrisk.	10m	14m	25m	17m
Andelen av kjøl som er ødelagt for akter vs. forskipet. Dette får betydning for om kun en av vrakdelene lykkes å bli hevet. Antas like sannsynlig at en større andel er ødelagt på forseksjon som akterseksjon. Benytter Uniform-fordeling for å analysere dette, der skjevheten i fordeling av den ødelagte kjølen (for- vs. akterseksjon) er angitt i %.	- 15 %	0 %	+ 15 %	0 %
Antall flasker per kammer. Kvikksølvflaskene som er funnet har ulik størrelse og påvirker antall flasker det er plass til i hvert kammer. Dette igjen får betydning for antall kammer det er lagret kvikksølvflasker i. Det eneste man vet med sikkerhet er at de to akterste kamrene på STB side er tomme (fra toktet i januar 2014). Basert på de flaskene som er funnet kan én kjølkasse inneholde fra 22 til 40 kvikksølvflasker. Størrelsene på flasker av samme type varierer også, og ulike flasker kan ha blitt stuet i samme kammer for å fylle dette best mulig. Det er derfor lagt inn en diskret fordeling på 22, 28, 34 og 40 flasker med lik sannsynlighet for hver, for å beregne andelen av de ulike variantene. Det antas også at det er likt lastet på STB og BB side (ballast, kvikksølvflasker eller tomme kamre) for å sikre korrekt trim.		p = 25 % for hver: 22, 28, 34 eller 40 flasker per kjølkasse		Med 1857 flasker gir det en forventning om at 63 kamre inneholdt flasker.
Korrosjon. Andelen flasker som er korrodert i stykker slik at kvikksølvet har rent ut.	5 %	10 %	20 %	13 %

Navn / beskrivelse	p10	Mode	p90	E
Får løftet vrakdelene (rigg / krybbe). Sannsynligheten for at operasjonen med å løfte akterskip og forskip opp slik at kjølkassene blir tilgjengeliggjort. Sannsynlighetene beregnes separat for begge løsninger, samt for akter- og forseksjon.	80 %	90 %	100 %	89 %
Får rullet akterseksjon til styrbord. Sannsynligheten for at operasjonen med å rulle akterseksjon slik at kjølkassene blir tilgjengeliggjort.	70 %	85 %	100 %	83 %
Får rullet akterseksjon til babord. Sannsynligheten for at operasjonen med å rulle akterseksjon slik at kjølkassene blir tilgjengeliggjort.	60 %	75 %	90 %	75 %
Får rullet forseksjon til styrbord / babord Sannsynligheten for at operasjonen med å rulle forseksjon slik at kjølkassene blir tilgjengeliggjort.	35 %	50 %	65 %	50 %

Betingede sannsynligheter.

I de logiske nodene i hendelsestreet (ref. Figur 5) vil utfallet av hva som skjer videre avhenge av utfallet i tidligere operasjonssteg. Dette fordi man har gjort seg noen erfaringer som man vil basere sine nye valg på. Nedenfor er de betingede sannsynlighetene i modellen beskrevet.

- Rigg/krybbe:
  - Dersom løft av akterseksjon går som forventet, løftes også forseksjon med sannsynlighet p=90 %. Årsaken til at denne ikke er 100 %, er at resultatet av status og antall kvikksølvflasker i kjølen på akterseksjonen kan medføre at man ikke tar (tids)kostanden med å heve også forseksjon.
  - Dersom det å løfte akterseksjon viser seg mer krevende enn forventet (p= 33 %) vil det være en lavere sannsynlighet (p=80 %) at også forseksjon løftes.
  - Dersom løfting av akterseksjon mislykkes, så reduseres sannsynligheten for at man gjennomfører løft av forseksjonen p=70 %.
- Rulle akterseksjon til babord (starter med å rulle til styrbord)
  - Dersom rulling av akterseksjon til styrbord (STB) går som forventet, rulles akterseksjon mot BB med p=90 % sannsynlighet. Årsaken til at denne ikke er 100 %, er at resultatet av status og antall kvikksølvflasker i kjølen på akterseksjonen kan medføre at man ikke tar (tids)kostanden med å rulle også til babord (BB).
  - Dersom det å rulle akterseksjon til STB viser seg mer krevende enn forventet (p= 33 %) vil det være en lavere sannsynlighet (p=50 %) at akterseksjonen forsøkes å bli rullet til BB.
  - Dersom rulling av akterseksjon til STB mislykkes, så reduseres sannsynligheten for at man gjennomfører rull til BB til p=33 %.

- Rulle forseksjon
    - Dersom man lyktes med å rulle akterseksjon begge veier, rulles forseksjon med p=90 % sannsynlighet. Årsaken til at denne ikke er 100 %, er at resultatet av status og antall kvikksølvflasker i kjølen på akterseksjonen kan medføre at man ikke tar (tids)kostanden med å rulle forseksjon.
    - Dersom det å rulle akterseksjon kun lykkes en av veiene vil det være en lavere sannsynlighet (p=50 %) for at man forsøker å rulle forseksjon. Det er antatt vanskeligere å rulle forseksjonen enn akterseksjonen pga. at forseksjonen ligger i en skråning med 20° helling.
    - Dersom det ikke lykkes å rulle akterseksjon noen av veiene, så reduseres sannsynligheten for at man forsøker å rulle forseksjon til p=33 %.
- Rulle forseksjon STB (starter med å rulle til babord)
    - Dersom rulling av forseksjon til BB går som forventet, rulles forseksjon mot STB med p=90 % sannsynlighet. Årsaken til at denne ikke er 100 %, er at resultatet av status og antall kvikksølvflasker i kjølen på akterseksjonen kan medføre at man ikke tar (tids)kostanden med å rulle også til babord (BB).
    - Dersom det å rulle forseksjon til BB viser seg mer krevende enn forventet (p= 33 %) vil det være en lavere sannsynlighet (p=50 %) at forseksjonen forsøkes å bli rullet til STB.
    - Dersom rulling av forseksjon til BB mislykkes, så reduseres sannsynligheten for at den forsøkes å bli rullet til STB til p=33 %.

7 KILDER OG REFERANSER

Dok ID	Dokument	Utarbeidet av	Dato
D01	Salvage of U-864 – Supplementary study no.7: Cargo	DNV	04-07-2008
D02	Konseptvalgutredning for håndtering av U-864	Kystverket	04.01.2011

About DNV GL

Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter and greener.

Vedlegg V3.02

MILJØTILTAK VED VRAKET AV U-864

Usikkerhetsanalyse Alt. 3 “Heving av last”

DNV GL AS

Project name: Miljøtiltak ved vraket av U-864
Report title: Usikkerhetsanalyse Alt. 3 “Heving av last”

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Dato: 12.5.2014

Gjengivelse av deler av dette vedleggsdokument som kan føre til mistolkning er ikke tillatt

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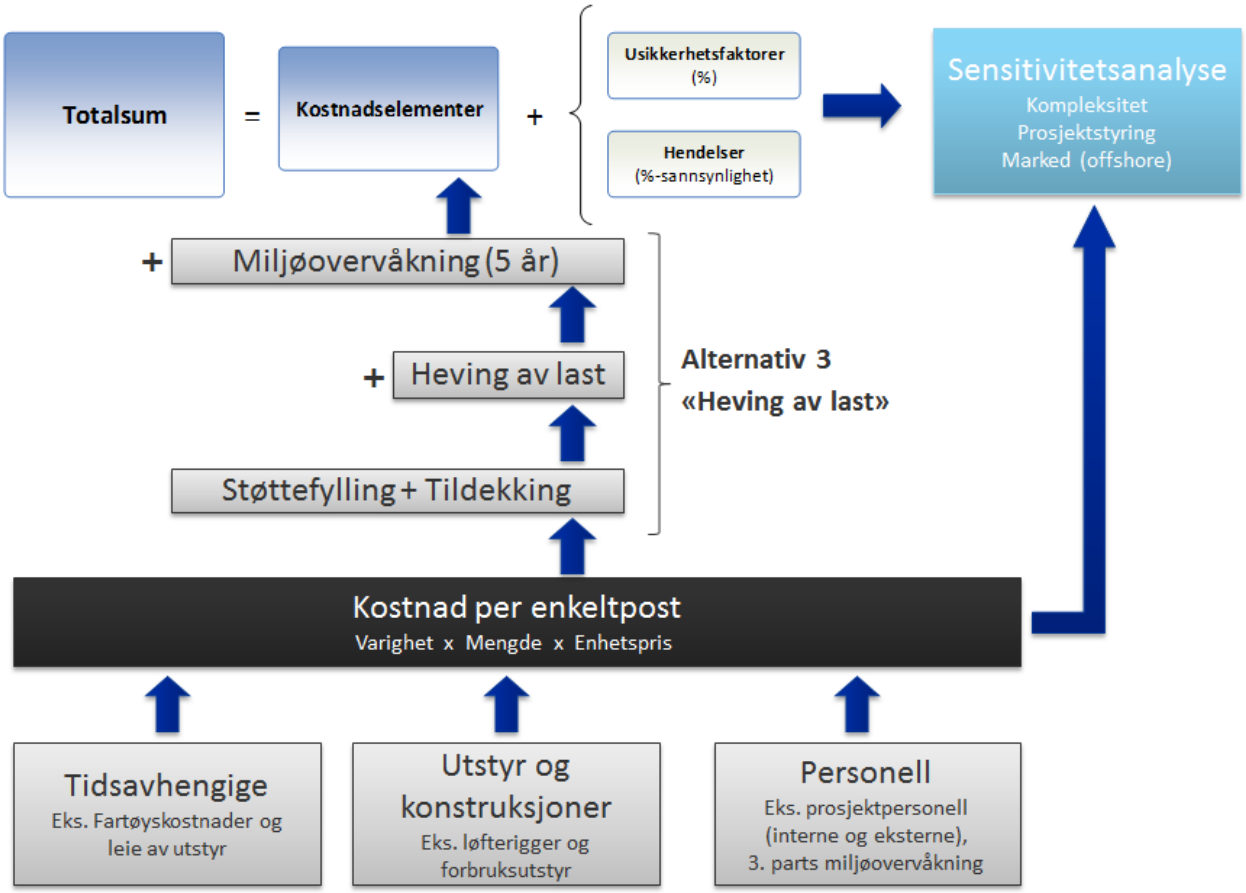
1 INNLEDNING

I dette vedlegget er resultatene fra usikkerhetsanalysen av kostnader for «Miljøtiltak ved vraket av U-864», herunder Alternativ 3 Heving av last (heretter kalt Alternativ 3) beskrevet.

Analysen er gjennomført i simuleringsmodell utviklet spesielt for dette prosjektet, og som dekker både kostnads- og fremdriftsusikkerhet. For mer informasjon om metodikk og modellen, se Vedlegg V0.10. I dette vedlegget er kun resultatene av kostnadsanalysen gjengitt.

2 GENERELT OM ANALYSEN

Kostnadsanalysen er gjennomført i henhold til kravene som Finansdepartementet stiller i forbindelse med utarbeidelse av sentralt styringsdokument. En prinsippskisse av modellen som er benyttet for estimering av kostander og usikkerhet er vist i figuren nedenfor:



I Figur 1 er en prinsippskisse av modellen vist.

Som det fremgår av figuren over, dekker Alternativ 3 kostander for støttefylling, tildekking, heving av last og miljøovervåkning i 5 år etter tiltaket er utført. I tillegg til dette inngår også kostnader for drift av prosjektorganisasjon. Nedenfor er forutsetninger og avgrensninger for analysen listet:

Forutsetninger:

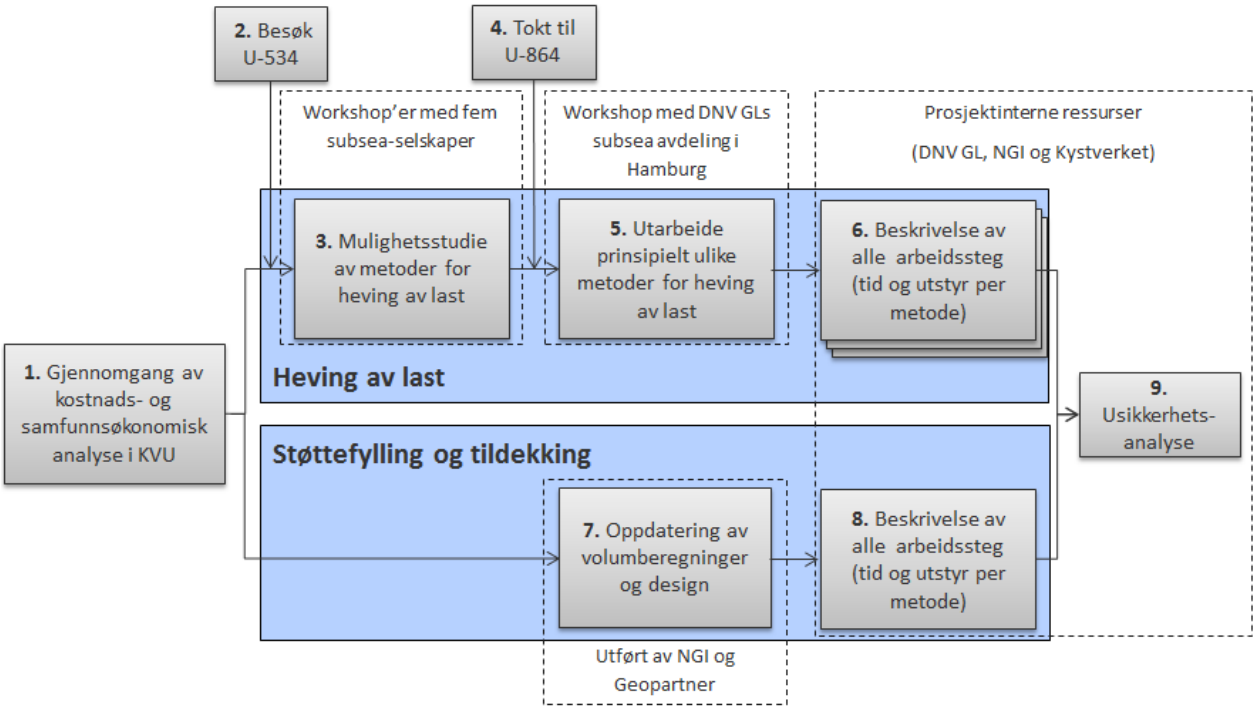
- Kostnadene dekker de aktiviteter som er beskrevet i kapittel 3.
- Alle kostander er i 2014 priser, fremtidige utgifter er ikke diskontert.
- Alle enkeltkostander er eks. merverdiavgift (MVA), men total MVA er beregnet og oppgitt.
- Eurokursen som er benyttet er 8,2 kr/Euro.
- Alle resultater som er oppgitt er forventede verdier, om ikke annet er oppgitt.

Avgrensninger:

- Gjennomføringstid for formelle beslutningsprosesser er ikke medregnet (kvalitetssikring med påfølgende behandling).
- Kostnader for prosjektet er regnet fra det tidspunktet Kystverket får i oppdrag om å starte tiltaket, og at prosjektets fremdrift deretter er som beskrevet i Vedlegg V3.01. Noe avvik fra dette er dekket av usikkerhetsanalysen, mens større utsettelser eller forsinkelser som vil kreve replanlegging av prosjektet er ikke kostnadsvurdert.
- Det er ikke tatt hensyn til om Staten vil ønske å sette noen tidsbegrensninger for hvor lenge en operasjon skal kunne vare. Alternativt om de vil ønske å legge inn muligheter for å kunne avbryte operasjonen tidligere enn forventet (redusere kostnader), dersom det viser seg svært vanskelig å gjennomføre operasjonen. Dette er forhold som får innvirkning på risikodelingen mellom Staten og utfører, og derav påvirker kostnadene. I kalkylen er derfor forventet varighet for å gjennomføre hele operasjonen lagt til grunn.

3 UTARBEIDELSE AV KOSTNADSANALYSEN

Kostnadsanalysen er utført av DNV GL AS, men i tett samarbeid med Kystverket, Norges Geotekniske Institutt (NGI) og andre samarbeidspartnere. Prosessen for å utarbeide grunnlaget for usikkerhetsanalysen er vist i figuren under:



Figur 1 Prosess for usikkerhetsanalyse av kostnader

Nedenfor gis en kort beskrivelse av hvert trinn i figuren over. Nummereringen i listen under viser til numrene i tekstboksene i figuren.

1. Oppdraget til Kystverket om utarbeidelse av sentralt styringsdokument (SSD) ble vurdert opp mot konklusjonen i den samfunnsøkonomiske analysen som ble gjennomført i konseptvalgutredningen (KVU) og KS1-rapporten. Dette for å se om det er vesentlige endringer til prosjektet som ville medført at den samfunnsøkonomiske analysen burde oppdateres. Det er ikke identifisert endringer eller ny informasjon om prosjektet og som kunne medført andre konklusjoner i KVUen. En oppdatering av den samfunnsøkonomiske analysen var derfor ikke nødvendig.

2. Prosjektet har besøkt den tyske ubåten U-534 som er utstilt i Liverpool. Hensikten med besøket var å vurdere konstruksjonen av kjølkassen der kvikksølvflaskene var stuet, for så å kunne vurdere gjennomføring og kostnader av en subseaoperasjon for å ta ut kvikksølvflaskene. For mer informasjon om dette besøket og informasjonen som ble innhentet, se Vedlegg V3.09.

3. For å vurdere mulige løsninger for hvordan heving av kvikksølvbeholderne kan gjennomføres, ble fem subseaselskaper invitert til å gjennomføre en to-dagers workshop med prosjektet. DNV GL ledet workshop'ene og har utarbeidet en rapport fra hver av de fem workshop'ene.

Aktivitetene i de foreslåtte operasjonene er delt inn i en generisk seks-trinns prosess (se Figur 2 på side 6). De foreslåtte løsningene er beskrevet i vedlegg V3.05.1-V3.05.5.

4. På oppdrag fra Kystverket gjennomførte DOF Subsea i januar 2014 et 10 dager langt tokt til U-864. Målet med toktet var blant annet å forsøke å åpne noen av kjølkassene i akterseksjonen for å innhente erfaringer om en slik operasjon. For mer informasjon om toktet, se SSD.

5. Hensikten med arbeidet var å sammenstille all innhentet informasjon (trinn 2 til 4 over, samt tidligere utredninger) om U-864 og mulige løsninger for heving av last, og derav utarbeide noen prinsipielt ulike løsninger for hvordan kvikksølvflaskene kan heves. I denne workshop’en deltok spesialister innen Trykk- og undervannssystemer fra DNV GLs kontor i Hamburg. Muligheter og utfordringer med de foreslåtte løsningene (trinn 3) ble diskutert og dokumentert. Utfallet av workshop’en og etterarbeid av denne, var tre prinsipielt forskjellige løsninger. Disse er lagt til grunn for kostnadsanalysen for heving av last. For mer detaljer om utvelgelsen av disse tre løsningene, se vedlegg V3.06.

   De tre ulike løsningene er:

   - **«Rulle»:** feste wire til trykkskroget, deretter vinsje vraket kontrollert over til sidene for å gi tilgang til kjølkassene.
   - **«Rigg»**: bruke en spesialdesignet rigg til å løfte fartøyet opp fra sjøbunnen for å få tilgang til kjølkassene.
   - **«Krybbe»:** Løfte vrakdelene så vidt over havbunnen (med fartøy fra overflaten) over i hver sine spesialtilpassede krybber på havbunnen for å gi tilgang til kjølkassene.

6. Det ble først utarbeidet en overordnet kostnadsnedbrytningsprosess for hele alternativ 3 (Figur 2 på side 6). Spesialister fra marine operasjoner i DNV GL beskrev deretter alle aktivitetene mer detaljert (utstyr og tid), slik at kostnader for hvert trinn kunne estimeres. Den detaljerte kostnadnedbrytningsstrukturen (CBS) er vist i tabellene i kapittel 4.2.

   For de løsningene der større stålkonstruksjoner inngår, er disse styrke- og kostnadsberegnet av ressurser med dette som fagfelt. For beregninger av festepunkter i trykkskroget på U-864, er disse beregnet på bakgrunn av stålprøver fra U-864. Disse stålprøvene er testet i DNV GLs laboratorier. For mer informasjon om stålkonstruksjonene og materialtestene, se hhv. Vedlegg V3.06 og V3.07.

   Spesialister innen miljøovervåkning fra NV GL og NGI har utarbeidet et miljøovervåknings-program som skal pågå mens alle offshoreoperasjoner pågår. Dette for å sikre at miljøkriteriene som er satt for prosjektet blir overholdt. For mer informasjon, se vedlegg V0.01.

7. Designet på tildekkingslaget (massetyper og tykkelser av disse) og volum på støttefylling og tildekkingslaget er oppdatert av hhv. NGI og Geopartner i samarbeid med geoteknikere hos DNV GL. Disse resultatene danner grunnlaget for kostnader for steinmasser, samt forventet utleggingstid av disse. For mer informasjon om dette, se vedlegg V0.02-V0.06.

8. Ressurser fra DNV GL og NGI har beskrevet aktivitetene i de hovedprosessene som omhandler utlegging av støttefylling og tildekking.

9. Gjennom flere workshop’er er det utarbeidet en usikkerhetsanalyse av alle arbeidssteg (tid/kost), forbruk av utstyr, prosjektorganisering, og nødvendige forundersøkelser som er fremkommet av trinn 6 og 8. Følgende fagfelt har vært involvert i disse prosessene: marine

operasjoner, geoteknikk, miljø, materialstyrke, modellerings- og investeringsanalyser, samt prosjekt- og kontraktstyring. Disse selskapene har vært representert: Kystverket, DNV GL AS, NGI, Handelshøyskolen BI og Kvale Advokatfirma AS. Resultater fra analysen er beskrevet i kapittel 5.

Det er også utarbeidet en egen modell for beregning av antall kvikksølvflasker man kan forvente å kunne heve under en operasjon. Resultatene av denne analysen er benyttet for å analysere varigheten til arbeidet med å tømme kjølkassene, som derfor både påvirker varighet og kostnadene av operasjonen. Modell og resultater av denne analysen er beskrevet i Vedlegg V3.01.

4 PROSESS OG AKTIVITETER

4.1 Overordnet prosessbeskrivelse

Som beskrevet i pkt. 5 i kapittel 3 er det laget en overordnet prosess for Alternativ 3. Hovedprosess 4 er videre nedbrutt i seks delprosesser. Se figur nedenfor:

Figur 2 Hovedprosesser og delprosesser for Alt. 3 «Heving av last»

Under hver hovedprosess/delprosess er det laget en CBS for hver enkelt aktivitet med tilhørende kostnadskode.

Det er gjennomført en estimering av kostnadspostene for hver av de tre identifiserte løsningene (jf. pkt. 5 i kapittel 3) beskrevet i delprosess 4.1 til 4.6 i Figur 2. Ved beregning av totalkostnad for prosjektet presenteres kun en kostnad. Denne består av en lik vekting ($^1/_3$ hver) mellom de tre løsningene. Bakgrunnen for dette er:

- Hvordan en evt. operasjon for heving av last vil bli gjennomført er ukjent. Det forventes at offshoreselskaper vil ønske å benytte teknologi/metodikk som de er kjent med. Derfor vil løsningen som benyttes kunne avhenge av hvilket selskap som tildeles et slikt oppdrag.
- Risikodeling mellom Kystverket og operatør, som vil kunne påvirke valg av teknologi/metode.
- Dersom Alternativ 3 blir valgt, vil operasjonen måtte gjennomgå en lengre fase med detaljert design. Gjennom en slik prosess kan det hende at endelig løsning ligner på en av de tre løsningene foreslått i SSD, en kombinasjon av disse, eller at helt nye ideer/muligheter er identifisert og som gjør at løsningen blir svært annerledes de som er foreslått her.

Ved å vekte kostnader for de tre løsningene med 1/3 hver i analysen[1], vil usikkerhetsbildet favne om det utfallsrommet som kostnadene for Alt. 3 representerer på det nåværende tidspunkt, siden løsning for heving av last ikke er valgt. For kostnader til hovedprosess 2, 3, 5, 6 og 7 er kostnadene for de tre løsningene identisk, mens det er noen mindre forskjeller for hovedprosess 1. Dette er kort beskrevet i kapittel 4.2.

[1] I simuleringen velges kostnader for hele løsninger i hver iterasjon, for at totalsummen så aggregeres til slutt. Dette for å sikre at usikkerhet ikke reduseres ved å benytte gjennomsnittsberegninger, men heller det motsatte at ytterpunkter av hver løsning kommer frem.

4.2 Beskrivelse av hver hoved- og delprosess

I det følgende presenteres en kort beskrivelse av innholdet i de forskjellige prossesstegene. For nærmere beskrivelse av estimatusikkerheter, hendelser og faktorer, se kapittel 6.

1. Prosjektering

Denne kostnadsposten dekker kostnader for prosjektering og utvikling av løsninger for tiltakene. I CBS-koden er det oppgitt en x som angir at det er en egen aktivitet for hhv. 1=tildekking, 2=«rulle», 3=«rigg» og 4=«krybbe».

CBS	Aktivitet
1.1	**Prosjektstyring** (styring av prosjektet, detaljert organisasjon beskrevet i kapittel 6.4)
1.1.x.1	Kystverkets ressurser
1.1.x.2	Innleide ressurser
1.2	**Engineering**
1.2.x.1	Engineering (videreutvikling av løsning for tildekking og heving av last)
1.3	**Forundersøkelser**
1.3.x.1	Forundersøkelser med fartøy (flere tester for tildekking/støttefylling og tiltak på vrak)
1.4	**Miljø**
1.4.1	Utarbeide kontroll- og overvåkningsplan for tiltaket

2. Forundersøkelser miljøovervåkning

Denne kostnadsposten dekker kostnader for etablering av baseline for miljøet før tiltakene starter.

CBS	Aktivitet
2.1	Overvåke parametere til baseline for langtidsovervåkningen
2.2	Personell, rapportering, analyse
2.3	Utsyr (måleutstyr som er nødvendig)
2.4	Leie av fartøy (sett ut og ta inn måleutstyr)
2.5	Mob-/Demobilisering av utstyr og fartøy
2.6	Analyse av porevann

3. Støttefylling

Denne kostnadsposten dekker kostnader for etablering av en støttefylling i dalen nedenfor forseksjonen samt overvåkning av miljø denne operasjonen.

CBS	Aktivitet
3.0	**Andre aktiviteter**
3.0.0	Samlet tidsbruk/kostnad for Support Vessel ifm mobilisering/demobilisering
3.0.0	Samlet tidsbruk/kostnad for Rock Dumper ifm mobilisering/demobilisering
3.0.99	Værvente (hendelse: forsinkelse pga. bølgehøyde)
3.0.1/3	Mob-/demobilisering Support vessel
3.0.2/4	Mob-/demobilisering Rock Dumper
3.1	**Miljøovervåkning**
3.1.0	Samlet tidsbruk/kostnad Support vessel ifm operasjoner angitt nedenfor
3.1.1	Personell (3 personer hele varigheten av toktet)
3.1.2	Utstyr (diverse måleutstyr)
3.1.3	Sette ut / ta inn utstyr (bruk av Support vessel)
3.1.4	Mob/Demob av utstyr (måleutstyr)
3.1.5	Backuputstyr (diverse måleutstyr)
3.1.6	Etterarbeid / rapportering (dokumentasjon av resultater)
3.2	**Legge ut støttefylling**

3.2.0	Samlet tidsbruk/kostnad for Support Vessel ifm operasjoner angitt nedenfor
3.2.0	Samlet tidsbruk/kostnad for Rock Dumper ifm operasjoner angitt nedenfor
3.2.99	Værventetid (hendelse: forsinkelse pga. bølgehøyde)
3.2.1	Masser (kostnad for stein fra pukkverk)
3.2.2	Døgn bruk av steindumpefartøy (tid for lasting, transitt og utlegging av stein på støttefylling)
3.2.3	Kontroll av masser på kai (kontroll at massene er korrekte og rene)
3.2.4	Optimering av tildekkingsmasser (utlegging av tildekking for kontroll av massetap)

4. Heving av last

Som beskrevet i pkt. 5 i kapittel 3 er det foreslått tre løsninger for heving av last. Disse tre løsningene har fått følgende CBS kode: 4A = Rulle, $4B_1$ = Rigg og $4B_2$ = Krybbe. Mange av aktivtetene er felles for alle løsninger, mens andre gjelder kun én eller to av disse. I tabellen nedenfor er det angitt med et «X» i kolonnene til høyre for de løsningene aktivitetene gjelder for:

CBS	Aktivitet	Rulle	Rigg	Krybbe
4x.0	**Andre aktiviteter**			
4x.0.0	Samlet tidsbruk/kostnad Medium Offshore construction vessel	X	X	X
4x.0.0	Samlet tidsbruk/kostnad Support vessel	X	X	X
4A1.0.0	Samlet tidsbruk/kostnad Anchor handling vessel	X		
4A1.0.0	Hopper dredger	X		
4x.0.0	Samlet tidsbruk Large Offshore construction vessel w/ ≥400 t crane		X	X
4x.0.99	Værventetid (hendelse: forsinkelse pga. bølgehøyde)	X	X	X
4x.0.x	Mob-/demobilisere Medium Offshore construction vessel	X	X	X
4x.0.x	Mob-/demobilisere support vessel	X	X	X
4A1.0.3/7	Mob-/demobilisere Anchor handling vessel	X		
4A1.0.4/8	Mob-/demobilisere Hopper Dredger	X		
4x.0.x	Mob-/demobilisere Large Offshore construction vessel w/ ≥400 t crane		X	X
4x.0.x	Diverse utstyr (utstyr som er nødvendig for gjennomføring)	X	X	X
4x.1.1	**Forberedende tiltak**			
4x.1.1.0	Samlet tidsbruk/kostnad Medium Offshore construction vessel	X	X	X
4x.1.1.0	Samlet tidsbruk/kostnad Support vessel	X	X	X
4A.1.1.0	Samlet tidsbruk/kostnad Anchor handling vessel	X		
4Bx.1.1.0	Large Offshore construction vessel w/ ≥400 t crane		X	X
4x.1.1.99	Værventetid (hendelse: forsinkelse pga. bølgehøyde)	X	X	X
4x.1.1.1	Fjerne deler på formskroget og feste ankre i skroget	X	X	X
4A.1.1.2	Installere bukker	X		
4A.1.1.3	Installere ankere (til vinsjer)	X		
4x.1.1.4	Installere vinsjer (subsea)	X	X	
4A.1.1.5	Stramme wire	X		
4B1.1.1.2	Forberede område for rigg		X	X
4B1.1.1.3	Installere rigg		X	
4B1.1.1.5	Installere oppdriftselementer		X	
4B1.1.1.6	Installere wire til skrog		X	
4B1.1.1.7	Injisere vann under skrog		X	X
4B2.1.1.2	Forberede område for krybber			X
4B2.1.1.3	Installere krybber			X
4B2.1.1.4	Feste wire fra løftefartøy til ankerene			X
4x.1.2	**Skaffe tilgang til kjøl**			
4x.1.2.0	Samlet tidsbruk/kostnad Medium Offshore construction vessel	X	X	X
4x.1.2.0	Samlet tidsbruk/kostnad Support vessel	X	X	X
4A.1.2.0	Samlet tidsbruk/kostnad Hopper Dredger	X		
4B1.2.2.0	Samlet tidsbruk/kostnad Large Offshore Construction vessel			X
4x.1.2.99	Værventetid (hendelse: forsinkelse pga. bølgehøyde)	X	X	X
4B2.1.2.99	Værventetid Large Offshore Construction vessel (hendelse:			X

CBS	Aktivitet	Rulle	Rigg	Krybbe
	forsinkelse pga. bølgehøyde)			
4A.1.2.1	Fjerne steiner og vrakrester med klo	X		
4A.1.2.2	Mudre langs kjølen	X		
4A.1.2.3	Mudre langs kjølen (motsatt side)	X		
4A.1.2.4	Rulle vraket over på siden	X		
4A.1.2.5	Mudre/fjerne vrakdeler for å gi ROV tilgang	X		
4A.1.2.7	Rengjøre kjølplater	X		
4A.1.2.8	Rulle vraket over på motsatt side	X		
4Bx.1.2.1	Løfte vraket (4B1: i rigg, 4B2: med overflatefartøy over i krybbe)		X	X
4Bx2.1.2	Fjerne steiner og vrakrester med klo/ROV langs kjøl		X	X
4Bx.1.2.3	Mudre/rense kjølen for sediment som er festet til kjøl		X	X
4x.1.2.4	Installere arbeidsrigg (hver side som arbeidsplatform)	X	X	X
4x.1.3	**Åpne kjøl**			
4x.1.3.0	Samlet tidsbruk/kostnad Medium Offshore construction vessel	X	X	X
4x.1.3.0	Samlet tidsbruk/kostnad Support vessel	X	X	X
4x.1.3.99	Værventetid (hendelse: forsinkelse pga. bølgehøyde)	X	X	X
4x.1.3.1	Borre/kutte sideplater	X	X	X
4x.1.3.2	Fjerne sideplater	X	X	X
4x.1.4	**Ta ut kvikksølvflasker**			
4X.1.4.0	Samlet tidsbruk/kostnad Medium Offshore construction vessel	X	X	X
4X.1.4.0	Samlet tidsbruk/kostnad Support vessel	X	X	X
4X.1.4.99	Værventetid (hendelse: forsinkelse pga. bølgehøyde)	X	X	X
4X.1.4.1	Ta ut løse flasker	X	X	X
4X.1.4.2	Ta ut flasker som har rustet sammen	X	X	X
4X.1.4.3	Fjerne flytende Hg	X	X	X
4X.1.4.4	Flytte Hg-flasker til våt-lager	X	X	X
4X.1.4.5	Flytte flytende Hg til våt-lager	X	X	X
4x.1.5	**Ta kvikksølvflasker opp til mellomlager**			
4x.1.5.0	Samlet tidsbruk Medium Offshore construction vessel	X	X	X
4x.1.5.0	Samlet tidsbruk Support vessel	X	X	X
4x.1.5.99	Værventetid (hendelse: forsinkelse pga. bølgehøyde)	X	X	X
4x.1.5.1	Heve flasker fra sub-sea lager (hendelse H3: forventes at denne kostnaden dekkes av post 5, da det er mest gunstig å la flaskene stå på et våtlager på sjøbunn frem til det skal flyttes til endelig destinasjon)	X	X	X
4x.1.6	**Ta kvikksølvflasker opp til mellomlager**			
4A.1.6.0	Samlet tidsbruk/kostnad Medium Offshore construction vessel	X	X	X
4A.1.6.0	Samlet tidsbruk/kostnad Support vessel	X	X	X
4B1.1.6.0	Samlet tidsbruk/kostnad Large Offshore construction vessel w/ ≥400 t crane		X	X
4B1.1.1.99	Værventetid (hendelse: forsinkelse pga. bølgehøyde)	X	X	X
4B1.1.1.99	Værventetid Large Offshore Construction vessel (hendelse: forsinkelse pga. bølgehøyde)			
4A.1.6.1	Flytte/fjerne sub-sea vinsjer	X		
4A.1.6.2	Flytte/fjerne, og rengjøre og transport	X		
4A.1.6.3	Flytte/fjerne ankre	X		
4B1.1.6.1	Flytte/fjerne oppdriftselementer		X	
4Bx.1.6.2	Flytte/fjerne sub-sea-vinsjer, rengjøre og transport		X	X
4B1.1.6.3	Flytte/fjerne rigg		X	
4B2.1.6.3	Flytte/fjerne krybber			X
4x.3	**Miljøovervåkning**			
4B1.3.1	Personell	X	X	X
4B1.3.2	Utsyr	X	X	X
4B1.3.3	Mob/Demob av utstyr	X	X	X
4B1.3.4	Backupustyr	X	X	X
4B1.3.5	Etterabeid / rapportering	X	X	X

5. Kvikksølv til godkjent mottak

Denne kostnadsposten dekker kostnader for transportere kvikksølvflaskene til godkjent mottak, bearbeiding av kvikksølvet før lagring samt lagring. I analysen er det lagt til grunn at bearbeiding og lagring skjer i et godkjent mottak Tyskland.

CBS	Aktivitet
5	**Kvikksølv til godkjent mottak**
5.1	Support vessel (transport fra Fedje til mottak)
5.2	Transport for behandling og til sluttdeponering
5.3	Stabilisering av avfall og sluttdeponering

6. Tildekking

Denne kostnadsposten dekker kostnader for å dekke til de forurensede sedimentene rundt vraket.

CBS	Aktivitet
6.1	**Miljøovervåkning**
6.1.0	Samlet tidsbruk/kostnad Support vessel ifm operasjoner angitt nedenfor
6.1.1	Personell (3 personer hele varigheten av toktet)
6.1.2	Utstyr (diverse måleutstyr)
6.1.3	Sette ut / ta inn utstyr (bruk av Support vessel)
6.1.4	Mob/Demob av utstyr (måleutstyr)
6.1.5	Backuputstyr (diverse måleutstyr)
6.1.6	Etterarbeid / rapportering (dokumentasjon av resultater)
6.2	**Legge ut tildekking**
6.2.0	Samlet tidsbruk/kostnad Support vessel
6.2.0	Samlet tidsbruk/kostnad Rock dumper
6.2.99	Værventetid (hendelse: forsinkelse pga. bølgehøyde)
6.2.1	Masser (kostnad for stein fra pukkverk)
6.2.2	Døgn bruk av steindumpefartøy (tid for lasting, transitt og utlegging av stein)
6.2.3	Kontroll av masser på kai (kontroll at massene er korrekte og rene)
6.2.4	Planlegging av oppmåling (forberedende tiltak)
6.2.5	Oppmåling av bunn m /bathymetri fra overflatefartøy (etter fylling av masser rundt vrak)
6.2.6	Etterarbeid / rapportering av oppmåling (utarbeide bathymetrisk rapport)
6.2.7	Produksjon og design av målestaver ink forsendelse
6.2.8	Utsetting, etterarbeid og kontroll av målestaver
6.2.9	Oppmåling bathymetri, av blandingslaget (kontroll etter at blandingslaget er lagt ut)
6.2.10	Sluttkontroll: Oppmåling bathymetri (av tildekkingslaget) og film m/ ROV
6.2.11	Sluttkontroll: Sedimentprøvetaking (skjer m/ klo fra ROV fartøy)

7. Miljøovervåkning (etter tiltak)

CBS	Aktivitet
7.0	**Andre kostnader**
6.0.0	Samlet tidsbruk/kostnad Support vessel
6.0.99	Værventetid (hendelse: forsinkelse pga. bølgehøyde)
6.0.1	Mobilisere support vessel
6.0.2	Demobilisere support vessel
6.1	**Miljøovervåkning**
7.1.0	Samlet tidsbruk/kostnad Support vessel
7.1.99	Værventetid (hendelse: forsinkelse pga. bølgehøyde)
7.1	NIFES miljøovervåkning (av biota)
7.2	Kontroll av tildekingslaget (at tildekkingen har korrekt geometri)
7.3	Etterarbeid / rapportering / analyser

4.3 Noen generelle kommentarer til modellen

Modellen som er utarbeidet har også tatt hensyn til følgende elementer:

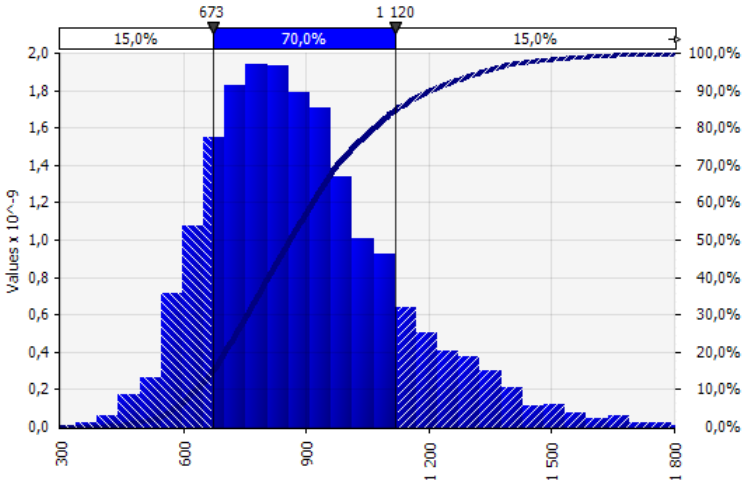
- **Værvente.** Området der U-864 ligger (Fedje) er værutsatt, og en del av fartøyene som brukes har krav til maksimal bølgehøyde under operasjon. Overstiges maksimal bølgehøyde under operasjonen, må hele eller deler av operasjonen vente til været bedres. Dette er ivaretatt i analysen. Det skilles mellom værvente for løftefartøy (Large offshore construction vessel) og de mindre offshore-fartøyene. For mer informasjon om modellering av værvente, se Vedlegg V3.01.
- **Parallellitet.** En del operasjoner kan gjennomføres i parallell.
- **Antall kvikksølvflasker som forventes å kunne heves.** Det er laget en egen modell som beregner forventet antall kvikksølvflasker som kan heves. Modellen og resultater er gjengitt i Vedlegg V3.01. Fordelingsfunksjonen (resultatene) fra denne analysen er brukt i kostnadsanalysen for å estimere hvor lang tid det vil ta å tømme kjølkassene (CBS 4.1.4). For kostnadsanalysen er det tatt utgangspunkt i at operasjonen ikke vil bli avsluttet ved de beslutningspunktene som er identifisert, men uansett fortsetter til alle kjølkasser er forsøkt tømt. Forventet antall flasker som vil kunne heves er derfor noe høyere for kostnadsanalysen enn som angitt i Vedlegg V3.01.

5 RESULTATER

Nedenfor presenteres resultatene fra analysen av Alternativ 3. Som beskrevet i kapittel 4.1 er resultatene fra kostnadsanalysen basert på en vektet analyse av de identifiserte tre metodene for heving av last: «rulle», «rigg» og «krybbe». Kostnadene som er analysert er totalkostnadene, samt kostnader for støttefylling, heving av last og tildekking. Disse er presentert i nedenfor.

5.1 Totalkostnader

Resultatene fra usikkerhetsanalysen av kostnader er presentert nedenfor. Påslag for usikkerhetsfaktorer og hendelser er inkludert:



Analyseresultater (eks. MVA)	
Forventet kostnad	890
p15-verdi	670
p50-verdi	860
p85-verdi	1 120
Standardavvik	230
Relativt standardavvik	26 %
MVA	210

Verdier i MNOK 2014 eks MVA, avrundet til MNOK 10.

Figur 3 Resultater av usikkerhetsanalysen for Alternativ 3.

Som det fremgår av resultatene over, så:

- er forventet kostnad for hele prosjektet MNOK 890.
- vil prosjektet med 70 % sannsynlighet ha en kostnad mellom MNOK 670 og MNOK 1 120.
- vil de totale kostnadene for MVA være MNOK 210.
- er relativt standardavvik 26 %.

Som det fremgår av usikkerhetsanalysen, så er det en stor usikkerhet knyttet til kostnadene. Dette skyldes i all hovedsak at en endelig løsning for heving av flasker ikke er utarbeidet, og at det fortsatt er svært mange usikkerheter knyttet til en operasjon for heving av last. De største usikkerhetsdriverne er nærmere beskrevet i kapittel 5.2.

Det er gjennomført en sensitivitetsanalyse av de usikkerhetsdriverne som har størst påvirkning på totalkostnadene. Resultatene av denne er presentert i 5.3.

Budsjettoppstilling:

I tabellen nedenfor er kostandene per delprosess listet. Hva som inngår i de enkelte postene er beskrevet kort i kapittel 4.2:

Tabell 1 Kostnader per underpost (MNOK 2014 eks. MVA)[2]

Heving av last [Kombinasjon]		
Totalkostnad ink. usikkerhetsfaktorer og hendelser eks. mva		**894**
Id	**Kostnadspost**	**757**
1	**Prosjektering**	**107**
1.1	**Prosjektstyring**	**49**
1.1.x	Prosjektstyring	49
1,2	**Engineering**	**38**
1.2.1	Tildekking	5
1.2.x	Heving av last	33
1.3	**Forundersøkelser**	**18**
1.3.1	Tildekking	5
1.3.x	Heving av last	13
1.4	**Miljø**	**2**
2	**Forundersøkelse miljøovervåkning**	**1**
3	**Støttefylling**	**107**
3.0	Andre kostnader	6
3.1	Miljøovervåkning	9
3.2	Legge ut støttefylling	92
4X	**Heving av last (kombinasjonsløsning)**	**304**
4X.0	**Andre kostnader**	**66**
4X.1	**Akterseksjon**	**126**
4X.1.1	Forberedende tiltak	65
4X.1.2	Skaffe tilgang til kjøl	34
4X.1.3	Åpne kjøl	2
4X.1.4	Ta ut Hg-flasker	7
4X.1.5	Ta Hg-flasker opp til mellomlager	-
4X.1.6	Stabilisere vraket før tildekking	18
4X.2	**Forseksjon**	**104**
4X.2.1	Forberedende tiltak	52
4X.2.2	Skaffe tilgang til kjøl	29
4X.2.3	Åpne kjøl	2
4X.2.4	Ta ut Hg-flasker	7
4X.2.5	Ta Hg-flasker opp til mellomlager	-
4X.2.6	Stabilisere vraket før tildekking	13
4X.3	**Miljøovervåkning**	**8**

[2] «X» indikerer at CBS-nummeret er en kombinasjon av de kostnadspostene som tilhører «Rulle, «Rigg» eller «Krybbe».

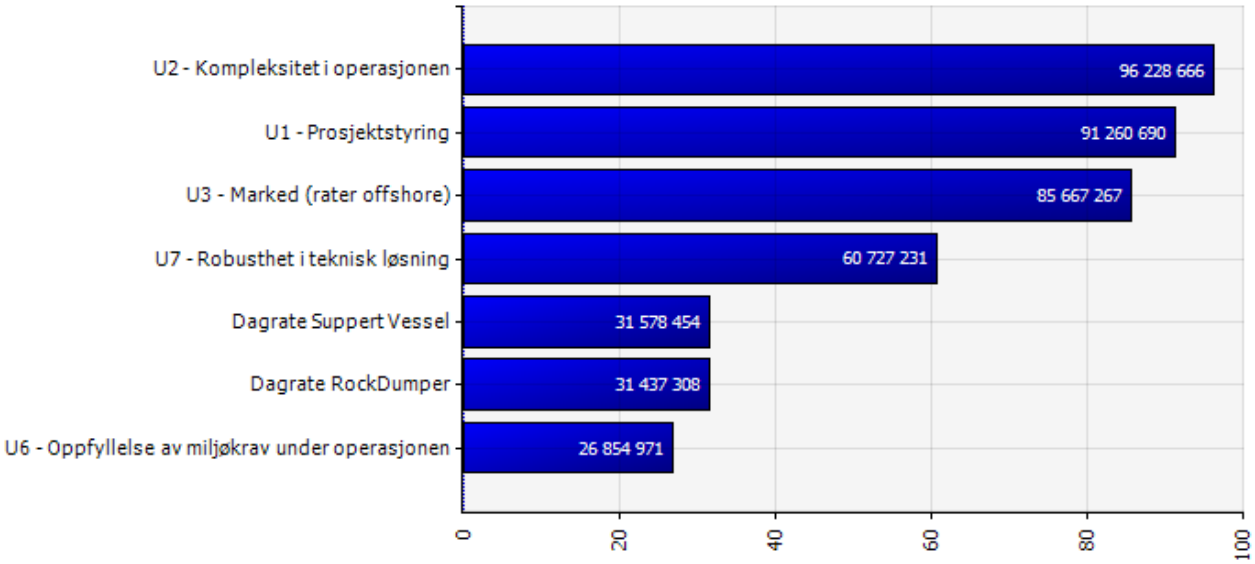
5	**Hg til godkjent mottak**	**4**

6	**Tildekking**	**213**
6.0	Andre kostnader	6
6.1	Miljøovervåkning	12
6.2	Legge ut tildekking	195
7	**Miljøovervåkning**	**19**
7.0	Andre kostnader	1
7.1	Miljøovervåkning	18
U	**Usikkerhetsfaktorer***	**130**
U1	Prosjektstyring	35
U2	Kompleksitet i operasjonen	53
U3	Marked (rater offshore)	0
U4	Marked (råvarer og konsulenttjenester)	0
U5	Vær	42
U6	Oppfyllelse av miljøkrav under operasjonen	0
U7	Robusthet i teknisk løsning	0
U8	Ambisjonsnivå for miljøovervåkning	1
H	**Hendelser**	**8**
H1	Tiltaksområde øker pga graving/mudring/arbeid	1
H2	Må hente steinmasser til tildekking i utenfor Bergens-regionen	7
H3	Mellomlager av HG på land	1
H4	Vrakene samlokaliseres (krybbe)	2
M	**MVA**	**209**

*) De usikkerhetsfaktorene som er angitt med «0» i forventet kostnad, så er det pga. symmetrisk usikkerhetsspenn for den respektive usikkerhetsfaktor. Se kapittel 6.2 for estimatusikkerheter.

5.2 Usikkerhetsdrivere

I tornadoplottet under er de variablene som bidrar med mest usikkerhet listet[3].



Figur 4 Tornadoplott for Alternativ 3[4]

Nedenfor er de fire variablene som bidrar med mest usikkerhetene beskrevet kort. For mer informasjon om de enkelte variablene, se kapittel 6. Variabler som starter med «U» er en usikkerhetsfaktor.

- **U2 Kompleksitet i operasjonen**. Dette er den variabelen som bidrar med mest usikkerhet, og representerer usikkerhet knyttet til antall arbeidssteg, nødvendighet av spesialutstyr og gjennomføring av forundersøkelser mv.
- **U1 Prosjektstyring**. Denne variabelen representerer prosjektets evne til å ta gode beslutninger under prosjektering og gjennomføring. Herunder valg av kontraktsform(er), etablere en prosjektorganisasjon som har tilstrekkelig med ressurser med rett kompetanse, og spesielt gjøre gode vurderinger underveis i tiltaket. En så kompleks operasjon som dette vil naturlig medføre mange utfordringer i gjennomførelsen, og særlig under hovedprosess 4 (heving av last), og som vil kreve gode beslutningsprosesser for å ta de beste avgjørelsene.
- **U3 Marked**. Kostnadene til støttefyllings-, tildekkings- og hevingsoperasjonen er i stor grad drevet av varigheten, og herunder leie av de fartøy som er nødvendig for å gjennomføre operasjonene. Markedet for fartøy kan variere mye, både fra år til år, og i løpet av et år (sesongvariasjon).
- **U7 Robusthet i teknisk løsning**. Valg av teknisk løsning for å gjennomføre en operasjon for heving av last vil i seg selv kunne øke eller redusere kostnadene betydelig ut fra 1) hvor lang tid operasjonen vil ta å gjennomføre, 2) hvor mye utstyr/spesialutstyr som kreves og 3) antall og type fartøy som er nødvendig. Videre vil robusthetene i løsningen innvirke på i hvor stor grad man er rustet til å møte uforutsette hindringer.

[3] Verdien angir hvor mye totalkostnaden vil øke dersom angitte variabel øker med ett standardavvik.

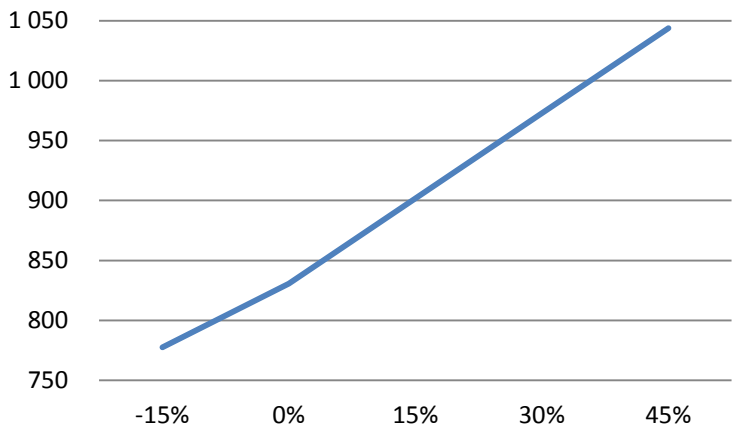
[4] Figuren viser de variablene som bidrar med størst usikkerhet på prosjektets totale kostander. Verdien angir hva totalkostnaden vil forventes å bli dersom respektive variabel øker med ett standardavvik. Tilsvarende reduksjon vil inntreffe dersom variabelen i stedet reduseres med ett standardavvik.

5.3 Sensitivitetsanalyse

Det er gjennomført en sensitivitetsanalyse for de tre variablene som bidrar med størst usikkerhet på totalkostnadene. Tornadoplottet (Figur 4) viser at dette er usikkerhetsfaktorene *U2 Kompleksitet i operasjonen, U1 Prosjektstyring* og *U3 Marked (rater offshore)*.

Nedenfor er påvirkningen usikkerhetsvariablene har på totalkostnadene for prosjektet vist, der inputverdien til variablene endres. Variasjonen for hver variabel er fra p10-verdien til p90-verdien, som er benyttet i estimatusikkerheten for disse. For mer informasjon om hva som kan føre til endringene som analyseres i sensitivitetsanalysen henvises det til kapittel 6.2.

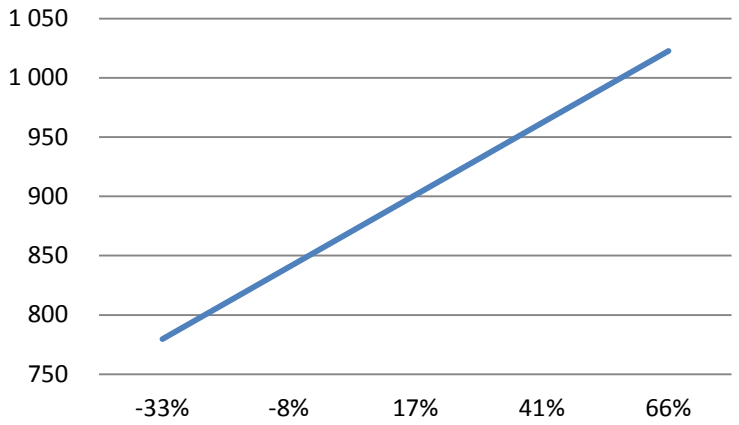
U2 Kompleksitet i operasjonen



Figur 5 Sensitivitetsanalyse av «U2 - Kompleksitet i operasjonen»

Denne usikkerhetsfaktoren varierer totalkostnadene fra ca. MNOK 770 til MNOK 1050 for hhv. p10-verdien og p-90-verdien.

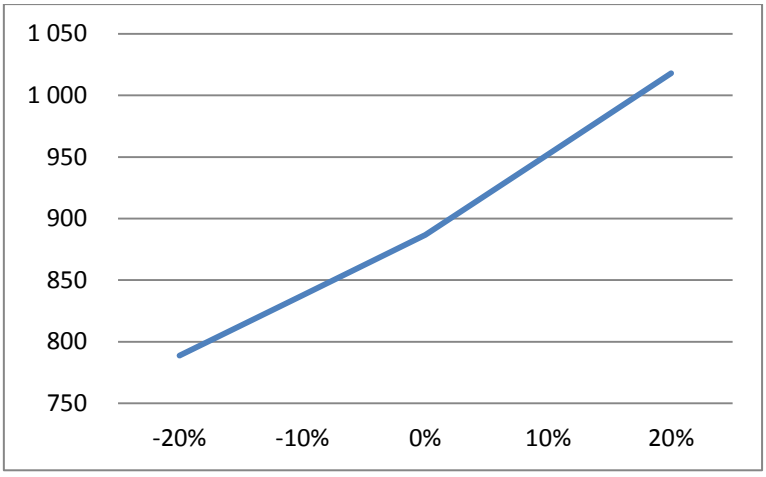
U1 Prosjektstyring



Figur 6 Sensitivitetsanalyse av «U2 - Kompleksitet i operasjonen»

Denne usikkerhetsfaktoren varierer totalkostnadene fra ca. MNOK 780 til MNOK 1020 for hhv. p10-verdien og p-90-verdien.

U3 Marked (rater offshore)



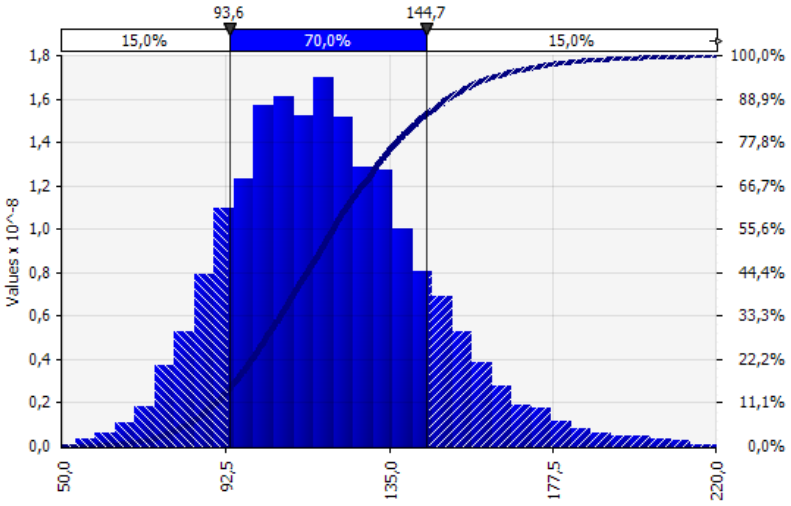
Figur 7 Sensitivitetsanalyse av «U3 – Marked (rater offshore)»

Denne usikkerhetsfaktoren varierer totalkostnadene fra ca. MNOK 790 til MNOK 1020 for hhv. p10-verdien og p-90-verdien.

5.4 Kostnader for utvalgte hovedprosesser

Nedenfor er resultatene av de tre største deloperasjonene gjengitt hver for seg: støttefylling, heving av last og tildekking. Påslag for usikkerhetsfaktorer og hendelser er inkludert:

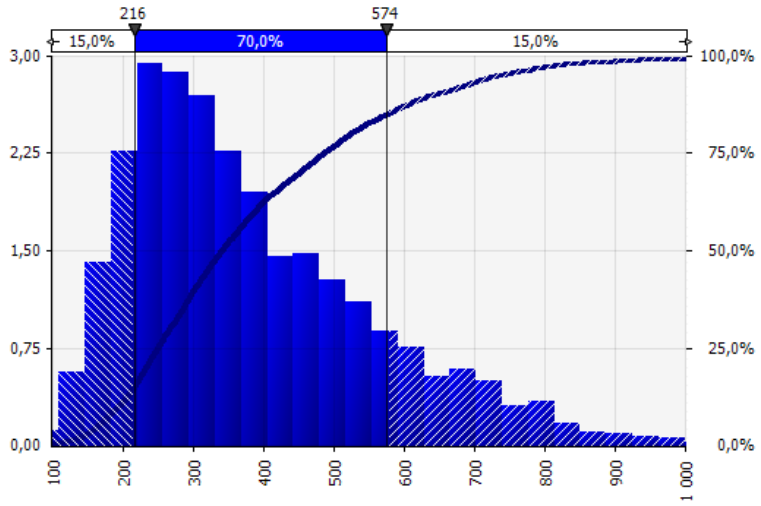
Støttefylling



Analyseresultater (eks. MVA)	
Forventet kostnad	119
p15-verdi	94
p50-verdi	117
p85-verdi	145
Standardavvik	17
Relativt standardavvik	21 %

Verdier i MNOK 2014 eks MVA

Heving av last (kombinasjonskonsept)

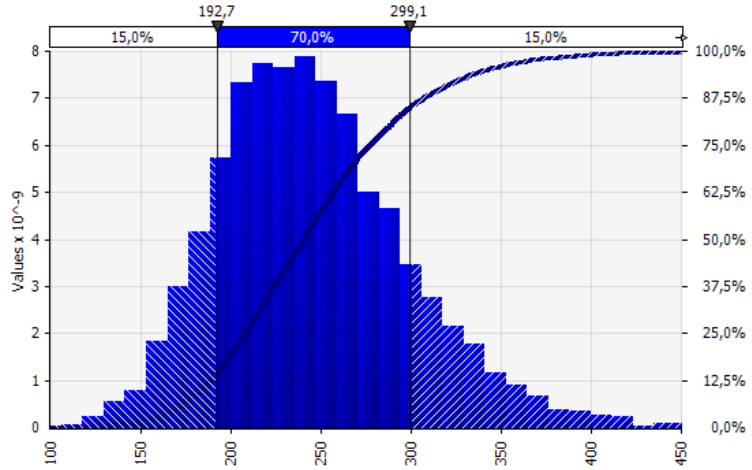


Analyseresultater (eks. MVA)	
Forventet kostnad	384
p15-verdi	216
p50-verdi	340
p85-verdi	574
Standardavvik	180
Relativt standardavvik	47 %

Verdier i MNOK 2014 eks MVA

Resultatene fra analysen gir naturlig svært høy usikkerhet fordi løsningen for hvordan evt. heving av last skal gjennomføres ikke er besluttet.

Tildekking



Analyseresultater (eks. MVA)	
Forventet kostnad	246
p15-verdi	193
p50-verdi	241
p85-verdi	299
Standardavvik	53
Relativt standardavvik	22 %

Verdier i MNOK 2014 eks MVA

5.5 Forslag til kutt

Det er identifisert noen mulige kutt i prosjektet, disse er:

Tabell 2 Kuttliste

K	Beskrivelse	25
K1	Optimering av tildekkingslag	10
K2	Redusere miljøovervåkning etter tiltak fra fem til to undersøkelser	12
K3	La vrakdelen stå i krybbene etter operasjonen	3

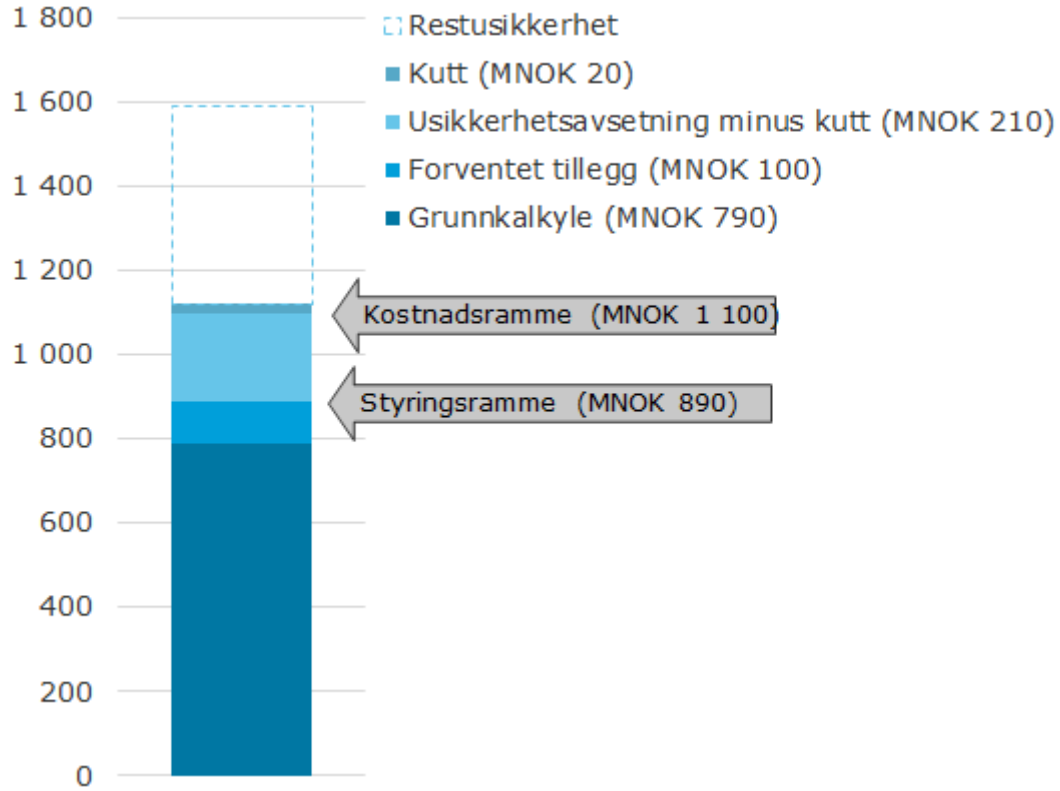
Her følger en kort beskrivelse av de identifiserte kuttene:

- **K1:** I forbindelse med utlegging av støttefyllingen (hovedprosess 3) er det lagt inn kostnader for å legge ut et tildekkingslag på ca. 6000 m^2 stort område. Hensikten med dette er å kunne analysere hvor mye av finmassene som evt. går tapt (forsvinner med strømmen) under tildekkingsoperasjonen. Ved å ha bedre kjennskap til dette kan de nødvendige volumene for tildekkingen estimeres bedre, evt. utleggingsmetodikk forbedres. Det er usikkert om testområdet blir innenfor eller utenfor tiltaksområdet, derfor er kostnadene for dette regnet som ekstrakostnader. Det foreslåtte kuttet innebærer at dette testforsøket ikke gjennomføres, eller gjennomført innenfor tiltaksområdet slik at det vil redusere omfanget av tildekkingen i hovedprosess 6.
- **K2:** Det er tatt høyde for en omfattende årlig kontroll av tildekkingen de påfølgende fem årene etter tiltaket (hovedprosess 7). Forslag til kutt er å redusere dette til to undersøkelser, f.eks. til to og fem år etter tiltaket. Basert på resultatene av kontrollen to år etter tiltaket vil det også kunne gjøres en god vurdering på om når neste kontroll bør gjennomføres.
- **K3:** Dersom løsning for heving av last blir som foreslått i «krybbe-alternativet», eller en annen lignende løsning, er det vurdert at det vil være kostnadsbesparende om man velger å la vrakdelene stå i krybbene etter tiltak. Det trenger ikke et større løftefartøy (delprosessteg 4x.1.6) å løfte vrakdelene ut igjen av krybbene etter endt tømming av kjølkassene. En slik løsning vil kreve noe mer stein til tildekkingen fordi høyden på vrakene i krybbene blir noe høyere enn om vrakdelene ligger på bunn.

Kuttlisten for prosjektet må oppdateres etter at løsning for heving av last er valgt. Valg av løsning for heving av last kan i seg selv ses på som et kutt, ved at man krever at løsningen som skal velges optimaliseres for lav gjennomføringstid og kostand, men gitt at miljøkravene overholdes.

5.6 Styringsramme

Prosjektets kostnads- og styringsramme er vist i figuren under.



Figur 8 Styringsrammer

Styrings- og kostnadsrammene over er kun veiledende. Årsaken til dette er at dersom det besluttes at Alternativ 3 skal gjennomføres, så vil dette medføre en betydelig designfase for å utvikle løsninger og en anbuds- og forhandlingsfase som til sammen vil ha stor innvirkning på den faktiske forventede kostnaden til prosjektet. Styrings- og kostnadsrammene må i et slikt tilfelle vurderes på nytt i lys av forhandlinger og detaljprosjektering.

6 BESKRIVELSE AV VARIABLER

I de etterfølgende kapitlene beskrives usikkerhetsvurderingen per variabel i kostnadsmodellen. Først beskrives estimatusikkerhetene for alle kostnadspostene i hovedprosessene, deretter vurderingene rundt de identifiserte usikkerhetsfaktorene og hendelsene.

For mange av aktivitetene er det varigheten på denne som avgjør kostnaden, herunder hvor lenge et/flere fartøy må leies. Beskrivelse og usikkerhetsanalyse av gjennomføringstid er presentert i Vedlegg V3.01.

6.1 Estimatusikkerhet for kostnadspostene

Nedenfor presenteres først estimatene for fartøysleie, deretter andre estimatusikkerheter som inngår per hovedprosess. Flere av aktivitetene som forbruker ressurser inngår i flere prosesser. Estimatusikkerhet for disse presenteres kun en gang. For mer beskrivelse av alle aktiviteter som inngår under hver hovedprosess, se tabeller i kapittel 4.2.

Rater for leie av fartøy (per døgn, ink. drivstoff)

CBS	Fartøy	P10	Mode	P90	Forventet
	Large Offshore construction vessel w/ ≥400 t crane	-20 %	1 350 000	20 %	1 350 000
	Medium Offshore construction vessel w/ ≥100 t crane	-20 %	940 000	20 %	940 000
	Support vessel	-20 %	630 000	20 %	630 000
	Hopper dredger	-20 %	1 500 000	20 %	1 500 000
	Rock Dumper (Euro)	-20 %	€ 175.000	20 %	Kr 1 435 000
Usikkerhetsfaktorer:		Kostnader for operasjonene er avhengig av hvor lenge disse fartøyene leies, og bidraget fra disse faktorene kommer derfor indirekte via analysen av gjennomføringstid.			

Delprosess 1: Prosjektering

Tabellen nedenfor lister de variablene som inngår i beregning av prosjektkostnader. I lønnskostnader for Kystverkets interne ressurser er det påregnet 40 % tillegg for diverse sosiale kostnader. Ett årsverk regnes som 1860 timer. Beløp er i MNOK 2014 om ikke annet er angitt.

CBS	Prosjektering	P10	Mode	P90	Forventet
1.1.x.1/1.1.x.2	Prosjektleder (KYV, kr/år)	-15 %	980 000	+15 %	980 000
1.1.x.1/1.1.x.2	Seniorressurs (KYV, kr/år)	-15 %	840 000	+15 %	840 000
1.1.x.1/1.1.x.2	Juniorressurs (KYV, kr/år)	-15 %	700 000	+15 %	700 000
1.1.x.1/1.1.x.2	Prosjektleder (Kons, kr/t)	-15 %	1 800	+15 %	1 800
1.1.x.1/1.1.x.2	Seniorressurs (Kons, kr/t)	-15 %	1 500	+15 %	1 500
1.1.x.1/1.1.x.2	Juniorressurs (Kons, kr/t)	-15 %	1 200	+15 %	1 200
Usikkerhetsvurdering		Generell usikkerhet for å ivareta variasjoner innenfor hver ressurskategori			
Usikkerhetsfaktorer (KYV):		U2 (¼), U7 (¼)			
Usikkerhetsfaktorer (KYV):		U2 (¼), U5, U7 (¼)			
1.2.1	Engineering (tildekking)	3,5	5	6,5	5

CBS	Prosjektering	P10	Mode	P90	Forventet
1.2.2	Engineering (rulle)	14	20	26	20
1.2.3	Engineering (rigg)	28	40	52	40
1.2.4	Engineering (krybbe)	28	40	52	40
Usikkerhetsvurdering		Generell usikkerhet for å ivareta variasjoner innenfor hver kategori			
Usikkerhetsfaktorer (KYV):		U2 (¼), U7 (¼)			
Usikkerhetsfaktorer (KYV):		U2 (¼), U5, U7 (¼)			
1.3.1	Forundersøkelser (rundsum)	3,5	5	6,5	5
Usikkerhetsvurdering		Generell usikkerhet for å ivareta variasjoner av mengde forundersøkelser som kan være nødvendig.			
Usikkerhetsfaktorer:		U4			
1.4.1	Miljø: Kontroll- og overvåkningsplan (ukesverk / kr/t for miljøkonsulent)	18 1 000	26 1 200	48 1 700	32 1 327
Usikkerhetsvurdering		Generell usikkerhet for å ivareta variasjoner av mengde forundersøkelser som kan være nødvendig.			
Usikkerhetsfaktorer:		U4			

Delprosess 3 og 6: Støttefylling og Tildekking

Tabellen nedenfor lister de variablene som inngår i beregning av støttefylling og tildekking, og som ikke er listet tidligere.

CBS	Støttefylling og tildekking	P10	Mode	P90	Forventet
3.1.1/6.1.1	Personell. Deltagelse under hele gjennomføringen. 12t betalt per døgn (kr/t for miljøkonsulent)	1 000	1 200	1 700	1 327
3.1.2/6.1.2	Utstyr, leie hele gjennomføringen. (kr/døgn)	-30 %	20 000	30 %	20 000
3.1.4/6.1.4	Mob-/demobilsere utstyr (forsendelse, klargjøring)	-30 %	100 000	30 %	100 000
3.1.5/6.1.5	Backuputstyr	-30 %	200 000	30 %	200 000
3.1.6/6.1.6	Etterarbeid/rapportering	-30 %	300 000	30 %	300 000
3.2.1	Masser til støttefylling (volum / kr/m^3)	-5 % 120	78 412 150	5 % 180	78 412 150
3.2.3	Kontroll av masser (RS)	-30 %	500 000	30 %	500 000
6.2.1	Masser til støttefylling (volum / kr/m^3)	-5 % 120	156 824 150	5 % 180	156 824 150
6.2.3	Kontroll av masser (RS)	-30 %	500 000	30 %	500 000
6.2.6	Etterarbeid / rapportering av oppmåling (RS)	-30 %	150 000	30 %	150 000
6.2.7	Produksjon og design av målestaver ink forsendelse	-30 %	630 000	30 %	630 000
Usikkerhetsvurdering		Generell usikkerhet for å ivareta variasjoner av mengde arbeid og utstyr som blir nødvendig.			
Usikkerhetsfaktorer:		Personell / masser / kontroll: U4 Utstyr: U2 (¼), U4, U7 (¼)			

Delprosess 4: Heving av last
Tabellen nedenfor lister de variablene som inngår i beregning av heving av last, og som ikke er listet tidligere.

CBS	Heving av last	P10	Mode	P90	Forventet
4.0 Andre kostnader					
4A.0.4	Mobilisere hopper dredger (RS)	-30 %	80 000	30 %	80 000
4x.0.7	Diverse utstyr	-40 %	20 000	40 %	20 000
Usikkerhetsvurdering		Generell usikkerhet for å ivareta variasjoner av mengde arbeid og utstyr som blir nødvendig.			
Usikkerhetsfaktorer:		Hopper dredger: U2 (¼), U4, U7 (¼) Utstyr: U2, U4, U7			
4.1.1 Forberedende tiltak					
4x.1.x	Ankre, til feste i skrog (antall og kr/stk)	-30 % 50 000	70 75 000	30 % 100 000	35 75 000
4A.1.x	Bukker (antall og kr/stk)	8 -30 %	8 1 000 000	8 30 %	8 1 000 000
4B.1.x	Rigg (tonn stål og kr/tonn). Trenger to stk, og kr/tonn er ink. engineering og sveis	-30 % -30 %	220 100	30 % 30 %	220 100
4A.1.x	Ankre, til å feste vinsjer (antall og kr/døgn)	8 -30 %	8 6 000	8 30 %	8 6 000
4B1.1.x	Oppdriftselemeneter (antall / kr døgn)	6 100 000	8 125 000	10 150 000	8 125 000
4B2.1.x	Krybber (tonn stål og kr/tonn)	-30 % -30 %	35 100	30 % 30 %	35 100
4A.1.x	Leie av vinsjer (kr/døgn)	-30 %	120 000	30 %	120 000
3.2.3	Kontroll av masser (RS)	-30 %	500 000	30 %	500 000
Usikkerhetsvurdering		Generell usikkerhet for å ivareta variasjoner av mengde arbeid og utstyr som blir nødvendig.			
Usikkerhetsfaktorer:		U2, U4, U7			
4.1.2 Skaffe tilgang til kjøl					
4x.1.x	Arbeidsrigg (MNOK)	2,5	5	10	6,1
Usikkerhetsvurdering		Generell usikkerhet for å ivareta variasjoner av mengde arbeid og utstyr som blir nødvendig.			
Usikkerhetsfaktorer:		U2, U4, U7			
4.1.3-6 (kun tidskostnader)					
4.3 Miljøovervåkning (tilsvarende som for 3.1.1 til 3.1.6)					
4x.3.4	Backuputstyr	-30 %	300 000	30 %	300 000
4x.3.1-3 og 4x.3.5	Som for hovedprosess 3				
Usikkerhetsvurdering		Generell usikkerhet for å ivareta variasjoner av mengde arbeid og utstyr som blir nødvendig.			
Usikkerhetsfaktorer:		U2, U4, U7, U8			

Delprosess 5: Kvikksølv til godkjent mottak
Tabellen nedenfor lister de variablene som inngår i beregning av

CBS	Etterbehandling av kvikksølv	P10	Mode	P90	Forventet
5.2	Transport for behandling og til sluttdeponering (MNOK)	1	2	3	2
5.3	Stabilisering av avfall og sluttdeponering (tonn/Euro per tonn. 1 € = 8,2 kr)	9 -20 %	40 2000	49 20 %	30 2000
Usikkerhetsvurdering		Generell usikkerhet for å ivareta variasjoner av mengde arbeid og utstyr som blir nødvendig.			
Usikkerhetsfaktorer:		Transport: U3, U7 ($^1/_2$) Stabilisering: U4			

Delprosess 7: Langtids miljøovervåkning
Tabellen nedenfor lister de variablene som inngår i beregning av

CBS	Langtids miljøovervåkning	P10	Mode	P90	Forventet
7.1	NIFES miljøovervåkning (kr/år)	400 000	500 000	600 000	500 000
7.3	Etterabeid / rapportering / analyser (RS)	-30 %	500 000	30 %	500 000
Usikkerhetsvurdering		Generell usikkerhet for å ivareta variasjoner av mengde arbeid og utstyr som blir nødvendig.			
Usikkerhetsfaktorer:		NIFES: U2 (¼), U4, U7, U8 Utstyr: U4			

6.2 Usikkerhetsfaktorer

U	Usikkerhetsfaktorer		Beskrivelse
U1	**Prosjektstyring**		*Prosjektets evne til å ta gode beslutninger. Denne modelleres slik at den gir påslag eller fradrag på de andre faktorene som prosjektressursene kan ha en innvirkning på kostnadene til.*
Lav	-33 %	Tilstrekkelig med svært kompetente ressurser	
Mode	0 %	Som forventet og som ligger til grunn i kostnadsanalysen	
Høy	66 %	Lavt bemanning organisasjon, og ikke med rett kompetanse	
U2	**Kompleksitet i operasjonen** *(omvendt korrelert med CBS 1.2)*		*Operasjonen mer eller mindre kompleks enn forventet. Antall arbeidssteg, bruk av spesial-utstyr, nødvendighet av forundersøkelser mv. «Plunder og heft».*
Lav	-15 %	Færre hindringer enn forventet medfører lavere forbruk av dyrt materiell og/eller at operasjonen tar kortere tid enn forventet.	
Mode	0 %	Som forventet og som ligger til grunn i kostnadsanalysen	
Høy	+45 %	Operasjonene møter på mange uforutsette hindringer som krever mer bruk av dyrt materiell og/eller medfører at operasjonen tar lengre tid. Tilstanden og forholdene til baugen er lite utforsket (grunnet ustabil skråning).	
U3	**Marked (rater offshore)**		*Endringer i markedet (konjunktur- eller sesongvariasjoner) for fartøy og maritimt utstyr. Rater på leie av fartøy. Det forutsettes at operasjonene gjennomføres i sommerhalvåret.*
Lav	-20 %	Lavkonjunktur og/eller at maritime operasjoner gjennomføres på et tidspunkt på sesongen som gir lave priser	
Mode	0 %	Som forventet og som ligger til grunn i kostnadsanalysen	
Høy	+20 %	Høykonjunktur og/eller at maritime operasjoner gjennomføres på et tidspunkt på sesongen som gir høye priser	
U4	**Marked (råvarer og konsulenttjenester)**		*Endringer i markedet for utstyr, råvarer og konsulenttjenester*
Lav	-10 %	Lavkonjunktur og/eller at ressursene som benyttes har en lavere kostpris enn det som er lagt til grunn. Lavere råvarepriser enn forventet.	
Mode	0 %	Som forventet og som ligger til grunn i kostnadsanalysen	
Høy	+10 %	Høykonjunktur og/eller at ressursene som benyttes har en høyere kostpris enn det som er lagt til grunn. Høyere råvarepriser enn forventet.	
U5	**Vær**		*Endringer i vær som øker gjennomføringstiden* *3m: 9% sannsynlig over* *4m:2% sannsynlig over*
Lav	0 %	Godt vær som ikke medfører noen utsettelser	
Mode	+5 %	Tidvis dårlig vær (høy sjø) som medfører noe forsinkelser	
Høy	+10 %	Dårlig vær (høy sjø) som medfører lengre forsinkelser	
U6	**Oppfyllelse av miljøkrav under operasjonen**		*Kravene til miljø ligger fast. Teknisk utførelse vil derimot kunne medføre et antall stopp i operasjonen som vil medføre ventekostnader.*
Lav	-20 %	God løsninger og kontroll med utførelse gir færre antall stopp i operasjonen enn forventet	
Mode	+0 %	Som lagt til grunn i kostnadsanalysen	
Høy	+20 %	Valgt gjennomføring og dårligere kontroll med utførelse gir flere antall stopp i operasjonen enn forventet.	

U7	**Robusthet i teknisk løsning** *(omvendt korrelert med CBS 1.2)*		*Valg av teknisk løsning reduserer eller øker kostnadene, og i hvor stor grad man er rustet til å møte uforutsette hindringer.*
Lav	-20 %	Gode tekniske løsninger som er robuste mot uforutsette hendelser som reduserer gjennomføringstid og kostnader.	
Mode	0 %	Som forventet og som ligger til grunn i kostnadsanalysen. Det er tatt høyde for en relativt tidkrevende operasjon, mens kostnadene som ikke er tidsavhengige er estimert på bakgrunn et normalt kostnadsbilde.	
Høy	+20 %	Mangelfulle/ensidige og kostbare tekniske løsninger og/eller som i liten grad håndterer uforutsette hendelser som øker gjennomføringstid.	
U8	**Ambisjonsnivå for miljøovervåkning**		*Økte eller reduserte krav til miljøovervåkning etter tiltak*
Lav	-10 %	Redusert ambisjon/nødvendighet for miljøovervåkningen etter tiltaket	
Mode	0 %	Som forventet og som ligger til grunn i kostnadsanalysen	
Høy	+30 %	Økt ønske/behov for miljøovervåkning etter tiltaket er gjennomført for å være sikre at tiltaket er godt nok gjennomført.	

6.3 Hendelser

Fire hendelser er tatt med i usikkerhetsanalysen av kostnader.

	Hendelse	p	P10	Mode	P90	Forventet
H1	Tiltaksområde øker pga graving/muddring/arbeid (MNOK)	20 %	6,1	12,2	24,4	14,8
	Beskrivelse (gjelder kun «Rulle»)	Denne løsningen vil kreve at store mengder masser fjernes med klo og/eller mudring. Dette kan medføre at oppvirvlede sedimenter spres utenfor tiltaksområder, som da øker i størrelse. Kostnadene for p10, mode og p90 gjenspeiler de totale økte kostnadene dersom rock dumper må ha hhv. 0,5 / 1 / 2 ekstra runder med stein.				
H2	Må hente steinmasser til tildekking i utenfor Bergens-regionen	50 %	1.05	1,08	1,16	1,1
	Beskrivelse	Dersom pukkverk i Bergen-regionen ikke har tilstrekkelig med kapasitet til å levere all stein, ivaretar denne hendelsen av steindumpefartøyet må transittere utenfor Bergens-regionen for masser. Verdiene over er en beregnet verdi for den andelen den totale transittiden øker med, dersom hhv. 10 %, 20 % eller 40 % av volumet må hentes i Stavanger-regionen. Det ar anslått at transitten øker med ca. 1 dag per tur pga. lengre transitt.				
H3	Mellomlager av kvikksølvflasker på land (MNOK)	25 %	0,5	1	2	1,2
	Beskrivelse	Dersom våtlageret med kvikksølvflasker kan transporteres direkte til lokasjon for lagring, så må dette hentes opp og midlertidig lagres på land.				

		Kostnadene er estimater for hva dette kan koste, men kostnader for henting av last i CBS 5.1 faller vekk. Forventningsverdi for denne hendelsen blir derfor MNOK 0,6.				
H4	Vrakene samlokaliseres (MNOK)	25 %	-26	-17	-9	-17
	Beskrivelse (gjelder kun «Krybbe»)	Dersom vrakene samlokaliseres på støttefyllingen vil volum av stein over vrakdelene kunne reduseres. Det er anslått at reduksjonen kan være 10.000/20.000/30.000 m^3 avhengig av plassering og design av overdekningen.				

6.4 Prosjektorganisering

I tabellen nedenfor er type ressurser og det respektive antall årsverk listet for hhv. «Rulle» og «Rigg/Krybbe». Gjennomføringstiden for “Rulle” er noe lenger enn for “Rigg/Krybbe”, derfor er også totalt antall årsverk noe høyere.

Ressurs	Intern/ekstern	Type ressurs	ÅV Rulle	ÅV Rigg/Krybbe
Prosjektleder	KYV	PL	3,08	3,00
Prosjektstyringskoordinator	KYV	PL	3,08	3,00
Kommunikasjonsansvarlig	KYV	Sr	3,08	3,00
Leder Kontraktsadministrasjon	Kons	SrKons	2,04	2,00
Leder Operasjon	Kons	SrKons	2,04	2,00
Leder Miljøovervåkning	KYV	Sr	3,07	3,00
Kontroller	KYV	Jr	2,05	2,00
Kvalitet/HMS	KYV	Sr	3,08	3,00
Fagrådgivning (Miljø/Geoteknikk/Marine Op.)	Kons	SrKons	8,25	8,00

Ved beregning av totalt antall årsverk er ressurspådraget fordelt ut i hele prosjektets varighet.

For mer informasjon om organisering, se Sentralt Styringsdokument.

About DNV GL

Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter and greener.til

Vedlegg V3.03

MILJØTILTAK VED VRAKET AV U-864

Kvalitativ risikoanalyse Alt. 3 “Heving av last”

DNV GL AS

Project name: Miljøtiltak ved vraket av U-864
Report title: Kvalitativ risikoanalyse Alt. 3 “Heving av last”

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Dato: 12.5.2014

Gjengivelse av deler av dette vedleggsdokument som kan føre til mistolkning er ikke tillatt

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1 INNLEDNING

Det er gjennomført en kvalitativ risikoanalyse av «Miljøtiltak ved vraket av U-864, Alternativ 3 Heving av last» (heretter kalt Alternativ 3). Resultatene fra denne analysen presenteres i dette vedlegget.

Det er også gjennomført en kvantitativ usikkerhetsanalyse av gjennomføringstid og kostnader. Resultatene fra disse analysene er presentert i hhv. Vedlegg V3.01 og V3.02.

2 GENERELT OM ANALYSEN

2.1 Bakgrunn:

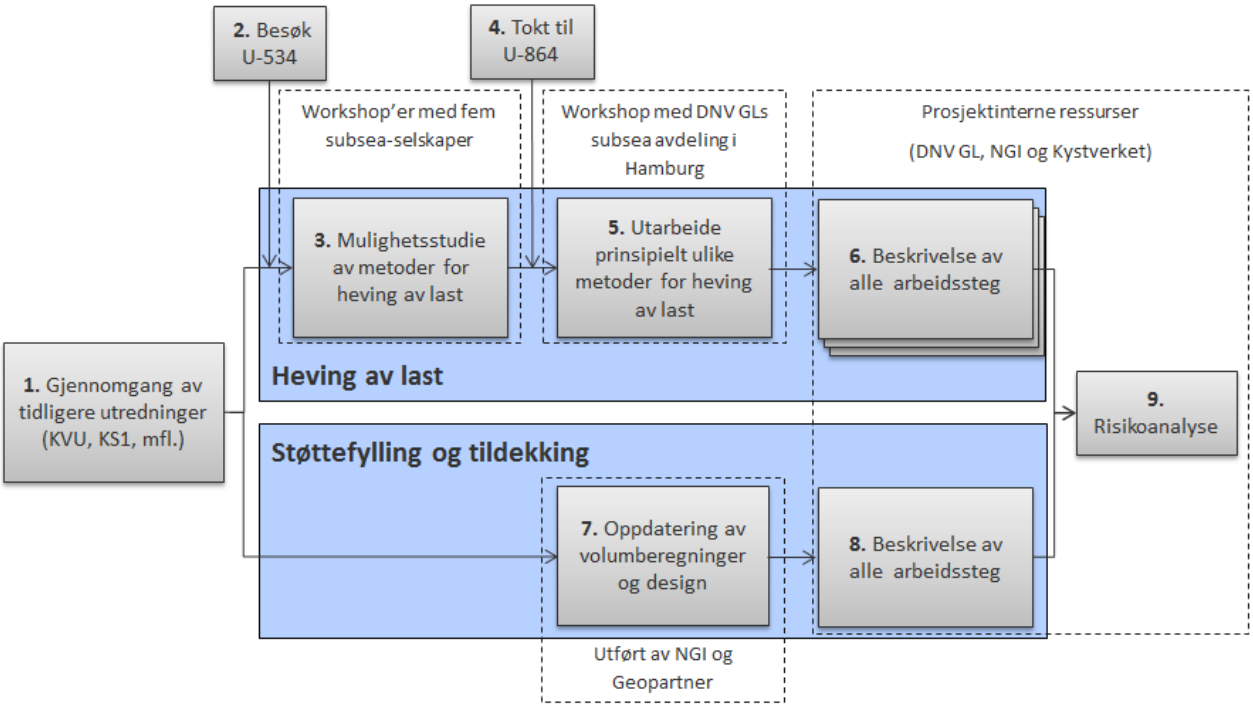
Hensikten med denne analysen er å fange opp de viktigste risikoene som kan redusere måloppnåelsen til prosjektet dersom de inntreffer. Målene som risikoene måles mot er

- Personellsikkerhet
- Miljø, kort sikt
- Miljø, lang sikt
- Operasjonell risiko

For nærmere beskrivelse av disse målene, samt definisjon av sannsynlighets- og konsekvensskalaen som er benyttet, se kapittel 3.

2.2 Metodikk:

Under utarbeidelse av Sentralt Styringsdokument (SSD) har det vært gjennomført mange arbeidsmøter og utarbeidet et større antall vedlegg/rapporter. I tillegg har tidligere utredninger vært gjennomgått. Underveis i dette arbeidet har prosjektet notert ned mulige hendelser som kan inntreffe underveis i operasjonene og som kan redusere måloppnåelsen til prosjektet. Disse hendelsene har blitt analysert opp mot etablering av støttefyllingen, de foreslåtte løsningene for heving av last, samt tildekking av forurensede masser. Risikoverktøyet EasyRisk Manager er benyttet i hele dette arbeidet. Figur 1 illustrerer hele denne prosessen:



Figur 1 Prosess for analyse av kvalitative risikoer

Hvert trinn i prosessen over har hatt ulike hovedfokus, men et gjennomgående tema i alle trinn har vært identifisering av risikoer. Hvert trinn er kort presentert nedenfor:

1. Gjennomgang av tidligere utredninger av U-864, spesielt DNV GLs eget risikoregister fra utredninger som DNV GL har utført.
2. Prosjektet har besøkt den tyske ubåten U-534 som er utstilt i Liverpool. Hensikten med besøket var å vurdere konstruksjonen av kjølkassen der kvikksølvflaskene var stuet, for så å kunne vurdere hvordan en subseaoperasjon for å ta ut kvikksølvflaskene kunne utføres. For mer informasjon om dette besøket og informasjonen som ble innhentet, se Vedlegg V3.09.
3. For å vurdere mulige løsninger for hvordan heving av kvikksølvbeholderne kan gjennomføres, ble fem subseaselskaper invitert til å gjennomføre en to-dagers workshop med prosjektet. DNV GL ledet workshop'ene og har utarbeidet en rapport fra hver av de fem workshop'ene (ref. Vedlegg V3.05.1-V3.05.5), der blant annet risikoer ble identifisert og dokumentert.
4. På vegne av Kystverket gjennomførte DOF Subsea i januar 2014 et 10 dager langt tokt til U-864. Målet med toktet var blant annet å forsøke å åpne noen av kjølkassene i akterseksjonen for å innhente erfaringer om en slik operasjon. For mer informasjon om toktet, se SSD.

5. Hensikten med arbeidet var å sammenstille all innhentet informasjon (trinn 2 til 4 over, samt tidligere utredninger) om U-864 og mulige løsninger for heving av last, og derav utarbeide noen prinsipielt ulike løsninger for hvordan kvikksølvflaskene kan heves. Risikoer er i prosessen videre analysert ift. disse tre løsningene.

   De tre ulike løsningene er:

   «Rulle»: feste wire til trykkskroget, deretter vinsje vraket kontrollert over til sidene for å gi tilgang til kjølkassene.

   «Rigg»: bruke en spesialdesignet rigg til å løfte fartøyet opp fra sjøbunnen for å få tilgang til kjølkassene.

   «Krybbe»: Løfte vrakdelene så vidt over havbunnen (med fartøy fra overflaten) over i hver sine spesialtilpassede krybber for å gi tilgang til kjølkassene.

   For mer detaljer om utvelgelsen av disse tre løsningene, se vedlegg V3.06.

6. Det ble utarbeidet en overordnet prosess for alternativ 3 (se Figur 2). Denne ble i risikoanalysen benyttet til å identifisere risikoer i hvert prossessteg, i grensesnittet mellom to prossessteg, samt overordnet for hele prosjektet.

Figur 2 Hovedprosesser og delprosesser for Alt. 3 «Heving av last»

7. Designet på tildekkingslaget (massetyper og tykkelser av disse) og volum på støttefylling og tildekkingslaget er oppdatert av hhv. NGI og Geopartner i samarbeid med geoteknikere hos DNV GL. Risikoer knyttet til design og volumer ble identifisert.

8. Ressurser fra DNV GL og NGI har beskrevet aktivitetene i de hovedprosessene som omhandler utlegging av støttefylling og tildekking, og risikoer ift. disse operasjonene ble identifisert.

9. Da utarbeidelsen av SSD og alle vedlegg nærmet seg ferdigstilt, ble det gjennomført flere workshops for å samle, sortere, beskrive og analysere alle de risikoene som hadde blitt identifisert. Resultatene av denne analysen er presentert i kapittel 4.

2.3 Forutsetninger og avgrensninger

Nedenfor er forutsetninger og avgrensninger for analysen listet:

Forutsetninger:

- Risikoene som er presentert (kapittel 3) beskriver risikobildet slik det fremstår når beste praksis for gjennomføring av aktuelle operasjoner er ivaretatt. I dette gjelder blant annet standard tiltak under offshore-operasjoner for å sikre helse, miljø og sikkerhet (HMS), og at risikoreduserende tiltak for operasjonene er vurdert og de tiltak som er funnet nødvendige er iverksatt. Risikobildet gjenspeiler derfor det iboende risikonivået for prosjektet når identifiserte problemstillinger er ivaretatt i designet av operasjonen.
- Alt personell som benyttes i prosjektet skal besitte nødvendig kunnskap om og erfaring fra andre relaterte prosjekter.
- Det er tilgjengelig og utprøvd teknologi som er lagt til grunn for bruk i offshore-operasjonene og som er analysert mht. risikoer og hensiktsmessige tiltak iverksatt.
- Ved vurderinger av risikoer som er knyttet til «Heving av last» så er disse vurdert mot hver av de tre foreslåtte løsningen (jf. trinn 5 i kapittel 2.2), samt at risikoen også er vurdert mot en generisk løsning. For analyse av sistnevnte er det vurderte risikonivået et vektet snitt av risikonivået for hver de tre løsningene. Høyeste risiko er ikke lagt til grunn som prinsipp.

Avgrensninger:

- Kun de foreslåtte løsninger som inngår i Alternativ 3 er vurdert og analysert (jf. kapittel 2.2 trinn 5 og 6).
- Vesentlig forsinket gjennomføring av prosjektet (jf. Vedlegg V3.01) som vil medføre endrede rammevilkår er ikke vurdert.

3 SANNSYNLIGHET- OG KONSEKVENSSKALA SOM ER BENYTTET I RISIKOVURDERINGENE

De følgende skalaene er benyttet for å tilordne en risiko henholdsvis sannsynlighet og konsekvens. Skalaen er på engelsk da samme formulering er benyttet av bergingsselskaper i deres egne risikovurderinger av de tilbudte hevingskonseptene, og i risikovurderingene som er foretatt av ekspertene i forbindelse med tilleggsutredninger, blant annet relatert til eksplosiver.

Bakgrunnen for å benytte en så fint inndelt skala er målsetningen om å kunne skille best mulig mellom de ulike alternativene og kunne adressere en rekke problemstillinger som er reist underveis i prosjektet uten at det skapes misforståelser eller feiltolkninger av risikobildet. I matrisene under er den norske betegnelsen benyttet.

Tabell 1 Skala som benyttes for å tilordne sannsynlighet

Veldig Høy	Må forventes i løpet av en operasjon av denne typen (p >50%)
Høy	Kan forventes i løpet av en operasjon av denne typen (10%< p <50%)
Middels	Kan inntreffe, men forventes ikke i løpet av en operasjon av denne typen (0,5%< p <10%)
Lav	Er mulig, men med svært lav sannsynlighet (0,01%< p <0,5%)
Veldig lav	Begrenset eller ingen erfaring med at dette har skjedd (0,0001%< p <0,01%)
Teoretisk mulig	Kun teoretisk mulig. Ingen erfaring med at dette har skjedd. (0,00001%< p <0,0001%)

Tabell 2 Skala som benyttes for å tilordne konsekvens til evalueringskriteriene (risikomålene) Personellsikkerhet (PSAFE) og Operasjonell sikkerhet og gjennomføring (OSAFE)

Veldig lav	Personell:	Personskade, men ingen legeerklæring
	Operasjonell:	Ingen vesentlig skade på utstyr. Kostnad mindre enn 500.000 NOK. Ingen forsinkelser
Lav	Personell:	Personskade med legeerklæring, men ingen permanente skader.
	Operasjonell:	Skade på utstyr: 500.000 < NOK < 5.000.000. Forsinkelse < 3 dager.
Middels	Personell:	Personskade med legeerklæring < 1 mnd, permanent skade. Situasjonene *kan resultere* i dette, men uten at det faktisk inntreffer.
	Operasjonell:	Skade på utstyr: 5 000.000 < NOK < 30.000.000. Forsinkelse < 2 uker.
Høy	Personell:	Alvorlig personskade og/eller død
	Operasjonell:	Tap av utstyr. Operasjonen avbrytes, vesentlig forsinkelse < 1 mnd. Behov for replanlegging.
Veldig høy	Personell:	Et større antall skadde og døde
	Operasjonell:	Tap av hovedutstyr/fartøy. Operasjonen mislykkes. Vesentlig forsinkelse. Replanlegging før ny oppstart av prosjektet.

Tabell 3 Skala som benyttes for å tilordne konsekvenser til evalueringskriteriene (risikomålene) Forurensning på kort sikt (ENVST) og lang sikt (ENVLT).

Veldig lav	Kort tid (Under operasjon)	Hendelsen medfører ingen spredning av kvikksølv utenfor planlagt tiltaksområde. Det er ingen målbare effekter på vann og/ eller sedimentkvalitet (for eksempel bakgrunnsverdier i sedimentfeller eller turbiditetsmålinger) Hendelsen medfører ingen negative akutte effekter på økosystemet. Dette kan sammenliknes med: • Ingen vannkonsentrasjoner er høyere enn klasse III , som tilsvarer maksimum 0,07 µg Hg/l.
	Lang tid	Hendelsen medfører ingen spredning av kvikksølv utenfor planlagt tiltaksområde. Det er ingen målbare effekter på og/vann- eller sedimentkvalitet (for eksempel bakgrunnsverdier i sedimentfeller eller turbiditetsmålinger) Hendelsen medfører ingen negative kroniske effekter på økosystemet. Dette kan sammenliknes med: • Ingen vannkonsentrasjoner er høyere enn klasse II, som tilsvarer maksimum 0,048 µg Hg/l.
Lav	Kort tid	Hendelsen medfører noe spredning av kvikksølv utenfor planlagt tiltaksområde. Det er kortvarige målbare effekter på vann og/eller sedimentkvalitet (for eksempel målt i sedimentfeller eller turbiditetsmålinger). Hendelsen medfører ingen negative akutte effekter på økosystemet. Dette kan sammenliknes med: • Ingen vannkonsentrasjoner er høyere enn klasse III, som tilsvarer maksimum 0,07 µg Hg/. • Ingen sedimentkonsentrasjoner er høyere enn klasse III, som tilsvarer maksimum 0,86 mg Hg/kg, over et større areal utenfor tiltaksområdet. Det forventes ingen negative effekter på human helse ved inntak av fisk eller skalldyr som kan ha tatt opp kvikksølv på grunn av hendelsen.
	Lang tid	Hendelsen medfører noe spredning av kvikksølv utover planlagt tiltaksområde. Det er langvarige målbare effekter på vann og/eller sedimentkvalitet (for eksempel målt i sedimentfeller eller turbiditetsmålinger). Hendelsen medfører ingen negative kroniske effekter på økosystemet. Dette kan sammenliknes med: • Ingen vannkonsentrasjoner er høyere enn klasse II, som tilsvarer maksimum 0,048 µg Hg/l. • Ingen sedimentkonsentrasjoner er høyere enn klasse II , som tilsvarer maksimum 0,63 mg Hg/kg, over et større areal utenfor tiltaksområdet. Det forventes ingen negative effekter på human helse ved inntak av fisk eller skalldyr som kan ha tatt opp kvikksølv på grunn av hendelsen.
Middels	Kort tid	Hendelsen medfører spredning av kvikksølv utover planlagt tiltaksområde. Det er kortvarige målbare effekter på vann og/eller sedimentkvalitet (for eksempel målt i sedimentfeller eller turbiditetsmålinger). Hendelsen medfører negative akutte effekter på økosystemet. Dette kan sammenliknes med: • Vannkonsentrasjoner er høyere i klasse IV, som tilsvarer maksimum 0,14 µg Hg/l. • Sedimentkonsentrasjoner i klasse IV, som tilsvarer maksimum 1,6 mg Hg/kg, over et betydelig areal utenfor tiltaksområdet (10 – 100% av tiltaksarealet på 47 000). Det forventes ingen negative effekter på human helse ved inntak av fisk eller skalldyr som kan ha tatt opp kvikksølv på grunn av hendelsen.

	Lang tid	Hendelsen medfører spredning av kvikksølv utover planlagt tiltaksområde. Det er langvarige målbare effekter på vann og/eller sedimentkvalitet (for eksempel målt i sedimentfeller eller turbiditetsmålinger). Hendelsen medfører negative kroniske effekter på økosystemet. Dette kan sammenliknes med: • Vannkonsentrasjoner i klasse III, som tilsvarer maksimum 0,071 µg Hg/l. • Sedimentkonsentrasjoner i klasse III, som tilsvarer maksimum 0,86 mg Hg/kg, over et betydelig areal utenfor tiltaksområdet (10 – 100% av tiltaksarealet på 47 000 m2). Det forventes ingen negative effekter på human helse ved inntak av fisk eller skalldyr som kan ha tatt opp kvikksølv på grunn av hendelsen.
Høy	Kort tid	Hendelsen medfører stor spredning av kvikksølv utover planlagt tiltaksområde. Det er langvarige målbare effekter på vann og/eller sedimentkvalitet (for eksempel målt i sedimentfeller eller turbiditetsmålinger). Det forventes negative akutte effekter på økosystemet. Dette kan sammenliknes med: • Vannkonsentrasjoner i klasse V, som tilsvarer > 0,14 µg Hg/l. • Sedimentkonsentrasjoner i klasse V, som tilsvarer >1,6 mg Hg/kg, over et betydelig areal utenfor tiltaksområdet (10 – 100% av tiltaksarealet på 47 000 m2). Det forventes ingen negative effekter på human helse ved inntak av fisk eller skalldyr som kan ha tatt opp kvikksølv på grunn av hendelsen.
	Lang tid	Hendelsen medfører stor spredning av kvikksølv utover planlagt tiltaksområde. Det er langvarige målbare effekter på vann og/eller sedimentkvalitet (for eksempel målt i sedimentfeller eller turbiditetsmålinger). Det forventes negative kroniske effekter på økosystemet. Dette kan sammenliknes med: • Vannkonsentrasjoner i klasse IV, som tilsvarer maksimum 0,14 µg Hg/l. • Sedimentkonsentrasjoner i klasse IV, som tilsvarer maksimum 1,6 mg Hg/kg, over et betydelig areal utenfor tiltaksområdet (10 – 100% av tiltaksarealet på 47 000 m2). Det forventes negative effekter på human helse ved inntak av fisk eller skalldyr som kan ha tatt opp kvikksølv på grunn av hendelsen.
Veldig høy	Kort tid	Hendelsen medfører stor spredning av kvikksølv utover planlagt tiltaksområde. Det er langvarige målbare effekter på vann og/eller sedimentkvalitet (for eksempel målt i sedimentfeller eller turbiditetsmålinger). Det forventes omfattende negative akutte effekter på økosystemet. Dette kan sammenliknes med: • Vannkonsentrasjoner som er 5 ganger eller høyere enn klasse V, som tilsvarer >= 0,7 µg Hg/l. • Sedimentkonsentrasjoner som er 5 ganger eller høyere enn klasse V, som tilsvarer >= 8 mg Hg/kg, over et betydelig areal utenfor tiltaksområdet (10 – 100% av tiltaksarealet på 47 000 m2). Eller spredning slik at et område større enn 47 000 m2 utenfor det eksisterende forurensede området foruenses med konsentrasjoner >0,86 mg Hg /kg. Det forventes negative effekter på human helse ved inntak av fisk eller skalldyr som kan ha tatt opp kvikksølv på grunn av hendelsen.

	Lang tid	Hendelsen medfører stor spredning av kvikksølv utover planlagt tiltaksområde. Det er langvarige målbare effekter på vann og/eller sedimentkvalitet (for eksempel målt i sedimentfeller eller turbiditetsmålinger). Det forventes omfattende negative kroniske effekter på økosystemet. Dette kan sammenliknes med: • Vannkonsentrasjonersom er 5 ganger eller høyere enn klasse V, som tilsvarer >= 0,7 µg Hg/l. • Sedimentkonsentrasjoner som 5 ganger eller høyere enn klasse V, som tilsvarer >= 8 mg Hg/kg, over et betydelig areal utenfor tiltaksområdet (10 – 100% av tiltaksarealet på 47 000 m2). Eller spredning slik at et område større enn 47 000 m2 utenfor det eksisterende forurensede området foruenses med konsentrasjoner >0,86 mg Hg /kg. Det forventes negative effekter på human helse ved inntak av fisk eller skalldyr som kan ha tatt opp kvikksølv på grunn av hendelsen.

4 RESULTATER

Nedenfor presenteres resultatene fra risikoanalysen av Alternativ 3. Først presenteres det totale risikobildet for hele Alternativ 3, deretter for enkelte av hovedprosessene og til slutt for hver av de tre foreslåtte løsningene for heving av last.

Hvert av numrene som vises i matrisene henviser til en konkret risiko. For komplett liste over alle risikoer (sorter på ID-nummer), se Tabell 4 i kapittel 4. Definisjon av skala for sannsynlighet og konsekvens er presentert i kapittel 3.3.

4.1 Overordnet risikobilde

I matrisen nedenfor er det totale risikobildet for Alternativ 3 presentert. Det er totalt identifisert 42 risikoer. Som beskrevet i kapittel 2.1 er risikoene analysert i forhold til de fire målene: 1) Personellsikkerhet, 2) Miljø, kort sikt, 3) Miljø, lang sikt og 4) Operasjonell risiko. En risiko kan medføre en konsekvens (dersom den inntreffer) for ett eller flere av disse målene. I matrisen (Tabell 1) nedenfor er nivået på risikoen som er angitt lik nivået for risikoen for det målet der risikoen er høyest. Risikoene fordelt per risikomål er vist i Tabell 2 til Tabell 5.

Tabell 4 Overordnet risikobilde for Alternativ 3

Veldig høy		269	288		279
Høy		273 278	265 275 284	283	
Middels		86	85 267 281 295	87 154 290	
Lav	231	205 207 236 240 282	90 291 293 294 296	96 228 297	
Veldig lav	2 4 206		72 214 232 241	289	
Teoretisk mulig		233	230	18	
Sanns. ↑ Kons. →	**Veldig Lav**	**Lav**	**Middels**	**Høy**	**Veldig høy**

Som det fremgår av matrisen over, er det totalt identifisert 42 risikoer, hvorav disse fordeler seg slik:

- Kritiske risikoer (røde): 10 stk
- Moderate risikoer (gule): 16 stk
- Lave risikoer (grønne): 16 stk

De kritiske risikoene er presentert nedenfor:

ID	***Navn***
R-0087	Tyngdepunkt/totalvekt faller utenfor toleranseområdet under løft ut av sjøbunn -> kapasitet eller stabilitetsproblemer under løft og overbelastning av løftesystem
R-0154	Dårligere værforhold enn planlagt for -> operasjonen blir vesentlig forsinket
R-0265	Prosjektorganisasjon fungerer ineffektivt => Økte kostnader, redusert måloppnåelse og/eller lengre prosjektgjennomføringstid
R-0269	Oppvirvling av forurensede sedimenter under operasjon på/ved vraket => forurensede sedimenter spres utover tiltaksområdet.
R-0275	Vrakdeler faller av vraket og skader ROV eller annet subseautstyr => materielle skader og/eller forsinkelser
R-0279	Problemer med å hente ut kvikksølvflaskene fra kjølkassene => det blir liggende igjen mer enn 30 tonn kvikksølv på havbunnen og tiltaket har ikke nådd målet for operasjonen
R-0283	Sedimentene rundt vraket inneholder mye stein og vrakdeler => tidkrevende å grave og/eller mudre og medfører store forsinkelser og spredning av forurensede sedimenter
R-0284	Utstyr som brukes på sjøbunnen blir forurenset av kvikksølv => utstyret kan ikke rengjøres og må derfor skrapes/erstattes
R-0288	Oppvirvling av sedimenter under arbeidet rundt vraket => begrenset sikt og medfører vesentlige forsinkelser
R-0290	Lykkes ikke å stabilisere vrak i installasjon på sjøbunn => Installasjonen siger på ett eller flere ben og får en vinkel som medfører at løfteoperasjonen må avbrytes og fundamentering utbedres

I tabellene nedenfor er risikoene fordelt per risikomål. Som det fremgår av matrisene, så er ikke alle risikoene gjeldene for alle mål.

Tabell 5 Personellrisiko

Veldig høy					
Høy		265			
Middels		267			
Lav	296	282 297	293		
Veldig lav					
Teoretisk mulig					
Sanns. ↑ Kons. →	**Veldig Lav**	**Lav**	**Mid-dels**	**Høy**	**Veldig høy**

Tabell 6 Operasjonell risiko

Veldig høy			288		279
Høy		273 278	265 275 284		
Middels		86	267 281 295	87 154 290	
Lav		207	90 291 293 294 296	96	
Veldig lav	2 4	72	214 241	289	
Teoretisk mulig				18	
Sanns. ↑ Kons. →	**Veldig Lav**	**Lav**	**Mid-dels**	**Høy**	**Veldig høy**

Tabell 7 Miljørisiko, kort sikt

Veldig høy	279		288		
Høy	273 278	265		283	
Middels	87	86 281	85 267 290		
Lav	90 96 293	205	294 296	228	
Veldig lav	2 4 241		72		
Teoretisk mulig				18	
Sanns. ↑ Kons. →	**Veldig Lav**	**Lav**	**Mid-dels**	**Høy**	**Veldig høy**

Tabell 8 Miljørisiko, lang sikt

Veldig høy	279 288	269			
Høy	273 283	265			
Middels	86 290	85 281	267		
Lav	205 231 294	236 240	228	297	
Veldig lav	2 4 72 206		232		
Teoretisk mulig		233	18 230		
Sanns. ↑ Kons. →	**Veldig Lav**	**Lav**	**Mid-dels**	**Høy**	**Veldig høy**

4.2 Risikobilde for hovedfaser

Nedenfor er risikomatrisene for Støttefylling/tildekking og Heving av last presentert. De risikoene som er felles for begge disse operasjonene er vist i begge matriser.

Støttefylling og tildekking:

Veldig høy					
Høy		265			
Middels		269	267 295		
Lav	207 231	205 236 240	96	154 228	
Veldig lav	2 4 206		72 214 232 241 293		
Teoretisk mulig		233	230	18	
Sanns. ↑ Kons. →	**Veldig Lav**	**Lav**	**Mid-dels**	**Høy**	**Veldig høy**

Som det fremgår av matrisen over, er det totalt identifisert 23 risikoer relatert til støttefylling- og tildekkingsoperasjonen, hvorav disse fordeler seg slik:

- Kritiske risikoer (røde): 0 stk
- Moderate risikoer (gule): 7 stk
- Lave risikoer (grønne): 16 stk

13 av de 23 identifiserte risikoene knyttet til støttefylling og tildekking vil også kunne inntreffe under hevingsoperasjonen, men vil i de fleste tilfeller ha en høyere kritikalitet enn for støttefylling og tildekking.

Heving av last:

Veldig høy		269	288		279
Høy		273 278	265 275 284	283	
Middels		86	85 267 281 295	87 154 290	
Lav		207 282	90 291 293 294 296	96 297	
Veldig lav	2 4		72 214	289	
Teoretisk mulig				18	
Sanns. ↑ **Kons.** →	**Veldig Lav**	**Lav**	**Mid-dels**	**Høy**	**Veldig høy**

Som det fremgår av matrisen over, er det totalt identifisert 33 risikoer som relatert til operasjonen for heving av last, hvorav disse fordeler seg slik:

- Kritiske risikoer (røde): 10 stk
- Moderate risikoer (gule): 15 stk
- Lave risikoer (grønne): 7 stk

4.3 Konklusjon

Risikoanalysen har identifisert totalt 42 risikoer for Alternativ 3. Analysen viser at det totale risikonivået er svært ulikt mellom operasjonene for å etablere støttefylling og tildekking, sammenlignet med heving av last. Risikonivået er betydelig høyere for operasjonen knyttet til heving av last, som har til sammen 10 kritiske risikoer, mens støttefylling og tildekking ikke har noen identifiserte kritiske risikoer. Analysen viser at risiko knyttet til operasjonell sikkerhet ved gjennomføring av en heving av lasten er betydelig. De fleste kritiske risikoene er knyttet til operasjonell sikkerhet (8 stk). Dette kommer i stor grad av usikkerhet knyttet til gjennomføring av operasjonene på havbunnen. Dette er en følge av plassering og tilstand på vraket, usikkerhet i kvikksølvflaskenes plassering og tilstand samt hensynet til miljø. Det er forutsatt at operasjonen designes for å minimere oppvirvling og spredning av forurensede sedimenter. Det forutsettes at operasjonen overvåkes nøye og stoppes ved vesentlig spredning av kvikksølv. Dette vil kunne medføre vesentlige forsinkelser i gjennomføring. Hele operasjonen forventes gjennomført i begrenset høyde over havbunnen. Dette begrenser potensiell spredning utover tiltaksområdet. Spredning av forurensede sedimenter må imidlertid forventes når man skal aksessere kjølkassene. Området vil tildekkes i etterkant av operasjonen. Størrelsen på området som tildekkes må justeres basert på spredning av forurensning under heving av last. Dette forventes å begrense antall kritiske risikoer knyttet til Miljø (2 stk). Analysen viser at det er få risikoer knyttet til personellsikkerhet (6 stk) og at ingen av disse er kritiske. Årsaken til dette er at personell i liten grad er direkte involvert i utførelsen av operasjonene. Dykkere inngår ikke i noen av de foreslåtte operasjonene. Personell fungerer kun som operatører fra fartøy, der bransjens HMS-krav legges til grunn og derfor forventes å medføre at personellsikkerheten er ivaretatt

5 RISIKOREGISTER

Nedenfor er alle risikoene listet. Følgende forkortelser gjelder: ENVLT = Miljø, lang sikt, ENVST = Miljø, kort sikt, OSAFE = Operasjonell sikkerhet, PSAFE = Personellsikkerhet. Grønn farge rundt forkortelsen indikerer at risikoen er LAV, Gul farge indikerer moderat risiko, og rød farge indikerer kritisk risiko. Risikoene er vist i forhold til nivået for 1) Tildekking (og støttefylling), 2) Heving av last («rulle»-løsningen), 3) Heving av last («rigg»-løsningen), 4) Heving av last («krybbe»-løsningen) og 5) Heving av last (kombinasjon, en samlet vurdering for alle hevingsløsningene).

Tabell 9 Liste over alle risikoer

ID	***Navn***	***Beskrivelse***	***Til-dekking***	***Heving Rulle***	***Heving Rigg***	***Heving Krybbe***	***Heving Komb.***
R-0002	Eksplosiver detonerer under eller etter operasjon => Materielle skader og forsinkelser	Eksplosiver (105mm, 20mm, patroner til håndvåpen mm) kan ligge spredt på sjøbunnen eller i vrakseksjonene. Disse kan detonere dersom de blir utsatt for svært store krefter, men det forventes å være svært lite sannsynlig. Risikoen er vurdert med bakgrunn i at HSM prosedyrer følges og at dersom eksplosiver oppdages vil disse bli håndtert av godkjent personell.	ENVLT ENVST OSAFE	ENVLT ENVST OSAFE	ENVLT ENVST OSAFE	ENVLT ENVST OSAFE	ENVLT ENVST OSAFE
R-0004	Ukontrollert utblåsning fra trykkluftbeholdere under etter operasjon => tildekkingslaget får en svakhet og/eller forsinkelse i operasjonen	Ubåten hadde store mengder trykkluft på flasker når den ble senket. Trykkluften brukes når fartøyet skal dykke opp etter neddykket operasjon. Det er lite sannsynlig at det fortsatt er trykksatte beholdere ombord. Disse vil mest sannsynlig ha bli tømt i det vraket delte seg, ved at trykkluftrørene da ble kappet/ødelagt. Vraket har også ligget i sjøen siden 1945 og korrosjon på ventiler og sveiser på trykkluftanlegget vil mest sannsynlig ha resultert i at evt. gjenværende etter torpederingen nå er lekket ut.	ENVLT ENVST OSAFE	ENVLT ENVST OSAFE	ENVLT ENVST OSAFE	ENVLT ENVST OSAFE	ENVLT ENVST OSAFE

ID	Navn	Beskrivelse	Til-dekking	Heving Rulle	Heving Rigg	Heving Krybbe	Heving Komb.
R-0018	Torpedoer eksploderer under eller etter operasjon => store mengder forurensede sedimenter spres, tildekkingslaget får en svakhet, utstyr ødelegges og/eller operasjonen forsinkes	Det kan være 27 torpedoer ombord. Disse er forventet at er ødelagt av korrosjon, mens hovedladningen nok er intakt. Det er vurdert kun teoretisk mulig at tenning, drivladning og hovedladning er i en slik tilstand at hovedladningen kan bli avsatt selv om ekstreme krefter påføres dette. Overvåkningsplanen er utarbeidet for å kontrollere at miljøtiltaket fortsatt har tilstrekkelig effekt. Skulle det bli en detonasjon, vil dette bli oppdaget og tiltak for å reparere skaden på tildekkingen gjennomføres.	ENVLT ENVST OSAFE	ENVLT ENVST OSAFE	ENVLT ENVST OSAFE	ENVLT ENVST OSAFE	ENVLT ENVST OSAFE
R-0072	Det blir stor sedimentutglidning under operasjon => oppvirvling av forurensede masser som spres utenfor tiltaksområdet	Støttefylling er lagt ut i forkant og som har tiltenkt effekt. Det vil derfor være svært lite sannsynlig at et globalt ras vil inntreffe.	ENVLT ENVST OSAFE	ENVLT ENVST OSAFE	ENVLT ENVST OSAFE	ENVLT ENVST OSAFE	ENVLT ENVST OSAFE
R-0085	Ras utløses som følge av at vraket løftes ut av sedimentene -> forurensede masser spres utover tiltaksområdet	Forutsettes sakte løft ut av sedimentene for å minimere sugkreftene.			ENVLT ENVST	ENVLT ENVST	ENVLT ENVST
R-0086	Sugkrefter mellom vrak og sjøbunn større enn forutsatt -> stor oppvirvling av forurensede masser og/eller skade på kjølkassen når vrak frigjøres	Omvendt bæreevnebrudd i sedimentene -> stor oppvirvling av forurensede masser. Manglende styrke i kobling mellom kjøl og skrog kan føre til at hele eller deler av kjølen løsner. Sveisene er forventet å være lite korrodert, hvilket innebærer at feste mellom kjøl og skrog er forventet å være tilstrekkelig til å motvirke at kjølen løsner.		ENVLT ENVST OSAFE	ENVLT ENVST OSAFE	ENVLT ENVST OSAFE	ENVLT ENVST OSAFE

ID	Navn	Beskrivelse	Til-dekking	Heving Rulle	Heving Rigg	Heving Krybbe	Heving Komb.
R-0087	Tyngdepunkt/totalvekt faller utenfor toleranseområdet under løft ut av sjøbunn -> kapasitet eller stabilitetsproblemer under løft og overbelastning av løftesystem	Kan forårsakes av: - utvasking av sedimenter eller at vrakrester faller ut. - Lokal eller global overbelastning av skroget - deformasjon og strukturfeil. - Ikke forventede luftlommer i vraket - Endring i vinkelen på vraket kan føre til at luft lekker ut og erstattes av vann. - Store mengder sedimenter kan være festet til vrak - Store mengder sedimenter i vrak Løftepunktene i hvert anker sjekkes i forkant av selve løftet, og man sjekker at disse løftepunktene overholdes i etterkant.		ENVST OSAFE	ENVST OSAFE	ENVST OSAFE	ENVST OSAFE
R-0090	Feil i posisjoneringssystemet eller maskineriet til løftefartøyet under løft ut av havbunnen -> mister evne til å holde posisjonen	Vraket dras sidelengs langs bunn -> sedimentoppvirvling og/eller sediment utglidning, skade på kjølen Vraket forskyves sideveis -> Kan føre til: - Kollisjon med stein, fjell eller vrakdeler -> Skader på kjøl eller profilskrog -> kvikksølv, kvikksølvbeholdere og/eller annen forurensning spres utenfor tiltaksområdet - Sedimentutglidning som frakter forurensning utenfor tiltaksområdet - Skade på utstyr/materiell			ENVST OSAFE	ENVST OSAFE	ENVST OSAFE
R-0096	Skade eller feil på utstyr under operasjon -> operasjonen stoppes og medfører vesentlig forsinkelse	Problemer under løft/rulle: - Feil i løfteutstyr - Feil i wire tromler - Større uventede bevegelser i løftefartøy - Problemer med hiv-kompensering Tildekking: - Skader eller feil på fall pipe utstyr kan medføre skader på personell. - Repetitive operasjoner kan medføre stor slitasje på utstyr. - Lang operasjonstid og press for å bli ferdige med operasjonen før en gitt dato kan medføre svikt i vedlikeholdsrutiner og utstyr skades/bryter sammen etc	ENVST OSAFE	ENVST OSAFE	ENVST OSAFE	ENVST OSAFE	ENVST OSAFE

ID	Navn	Beskrivelse	Til-dekking	Heving Rulle	Heving Rigg	Heving Krybbe	Heving Komb.
R-0154	Dårlige værforhold enn planlagt for -> operasjonen blir vesentlig forsinket	Lokasjonen utenfor Fedje er eksponert for vær og bølger. Operasjonen trenger et vesentlig værvindu for å kunne gjennomføres. Dårlige værforhold vil kreve at operasjonen stoppes midlertidig.	OSAFE	OSAFE	OSAFE	OSAFE	OSAFE
R-0205	Eksterne naturlige krefter (havstrøm eller jordskjelv) skaper svekkelse i capping lag -> spredning av kvikksølvforurensning	Det er sannsynlig at man vil registrere jordskjelv i dette området, derfor er dette tatt hensyn til i designet av tildekkingen. Materialet som er tenkt brukt som erosjonsbeskyttelse spesifiseres for å være stabilt under de faktiske hydrodynamiske påvirkningene. Forventet påvirkning fra jordskjelv: Fra GeoPartners rapport: "The permanent displacements during the 10-2 load event are negligible. For the 10-4 load event the permanent displacements are estimated to be less than 20 cm which are also considered to be hardly noticeable. The overall conclusion is that earthquake loading is not critical for the wreck encapsulation and seabed capping." Designet på capping tar hensyn til jordskjelv. Det er ikke forventet at et jordskjelv vil medføre en vesentlig reduksjon av effektiviteten i cappinglaget (ref Geopartner). Evt. skader vil fanges opp av planlagt miljøovervåkning og kan repareres.	ENVLT ENVST	ENVLT ENVST	ENVLT ENVST	ENVLT ENVST	ENVLT ENVST
R-0206	Unøyaktighet i vertikal og/eller horisontal fordeling av cappingmateiale -> capping gir ikke ønsket miljøbeskyttende effekt	Konsekvensen av dette kan være at cappinglaget blir tynnere enn spesifisert og derved ikke har den ønskede effekt og gir manglende beskyttelse mot kvikksølvlekkasje. Ikke forventet at strømmen i området vil påvirke presisjonen i vesentlig grad.	ENVLT	ENVLT	ENVLT	ENVLT	ENVLT

ID	Navn	Beskrivelse	Til-dekking	Heving Rulle	Heving Rigg	Heving Krybbe	Heving Komb.
R-0207	Strøm langs bunnen sterkere enn antatt -> Problemer i forbindelse med gjennomføring av ROV operasjoner og forsinkelser i gjennomføring	Dersom bunn- eller overflatestrøm er anderledes og/eller sterkere enn antatt. kan dette medføre at installasjonen av cappingmateriale vanskeliggjøres, og/eller ROV operasjoner på/ved vraket ifm heving av last. Cappingmaterialet kan være for finkornet til å kunne installeres presist dersom det er kraftig strøm. Krever at fall pipe er nær bunnen ved utlegging. Strømmen i området blir ikke vurdert til å være et problem hvis kjente capping teknikker anvendes. Erfaring fra tidligere liknende operasjoner indikerer at strømmen i området ikke er en hindring for ROV operasjoner. (Ref strømmålinger). Målinger gjennomført 3m over sjøbunnen viser en gjennomsnitts strømhastighet på 0,15 m/s og en maksimal hastighet på 0,9 m/s (ref Geoconsult).	OSAFE	OSAFE	OSAFE	OSAFE	OSAFE
R-0214	Kollisjon med andre fartøyer eller grunnstøting -> vesentlige skader på fartøy og forsinkelse av operasjonen	Potensiell kollisjon mellom fartøyer i området over U-864 eller ifm transitt fra lastehavn til installasjonsområde. Kollisjon kan være mellom fartøyer som er involvert i operasjonen eller tredjepart. Kan medføre større eller mindre skader i verste fall tap av menneskeliv. Risikoen vurderes ikke til at være større enn ved normal skipstrafikk	OSAFE	OSAFE	OSAFE	OSAFE	OSAFE
R-0228	Stort overflateras under etablering av støttefylling -> transport av forurensede masser utenfor tiltaksområdet	Forutsetter at man starter i dalbunn, og at det er høyt fokus på planlegging, i kravspesifikasjon og under oppfølging av utlegging. Feil gjennomføring, eller feil i design kan medføre at utglidning.	ENVLT ENVST	ENVLT ENVST	ENVLT ENVST	ENVLT ENVST	ENVLT ENVST

ID	Navn	Beskrivelse	Til-dekking	Heving Rulle	Heving Rigg	Heving Krybbe	Heving Komb.
R-0230	Grunnvannsstrømninger i bunnen -> Transport av forurenset porevann og vesentlig reduksjon i effekten av cappingen	Det forventes at porevann vil trenge inn i cappinglaget. Designet av cappingen må ta hensyn til dette. Det største poretrykket vil oppstå der en har størst fylling. Her vil det også være størst tykkelse på massene som vil begrense penetrering av cappingen.	ENVLT	ENVLT	ENVLT	ENVLT	ENVLT
R-0231	Tråling i området -> skade på cappinglag som krever reparasjon	Trålespor går sjelden mer enn 30 cm ned i sand, og mindre dypt i steinmasser.	ENVLT	PSAFE	PSAFE	PSAFE	ENVLT
R-0232	Nødankring av store fartøyer -> skade på cappinglag som krever reparasjoner	Ankere fra større fartøyer kan trenge dypt ned i cappinglaget og kan treffe ubåtvraket. Dette kan medføre skader på kvikksølvflaskene og oppvirvling av kvikksølvforurensning. Det kan også etterlate en åpning i cappinglaget. Cappingen kan designes slik at det kan tåle nødankring. Dette er dog meget kostbart og ligger ikke inne i beregnet volum av tildekkingsmasser.	ENVLT	ENVLT	ENVLT	ENVLT	ENVLT
R-0233	Fartøy synker i området -> skader cappingen	Det er lite sannsynlig, men skip kan synke og lande på tildekket ubåt. Det forventes at skade kan oppstå, men at dette blir lokalt og at skaden kan repareres med ny lokal tildekking dersom dette skjer	ENVLT	ENVLT	ENVLT	ENVLT	ENVLT
R-0236	Gassutvikling i de forurensede sedimentene => Dannelse av gassbobler som generer advektive prosesser som øker utlekkingsraten av kvikksølv	Åpninger i cappinglaget genereres av stigende gassbobler samt at boblene generer "strømninger" som øker transportraten av kvikksølv ut av sedimentet og til vannsøylen. Gassbobler kan genereres "naturlig i sedimentet" (eks metan).	ENVLT	ENVLT	ENVLT	ENVLT	ENVLT
R-0240	Tiltaksområdet er underestimert=> Andre områder som ikke er avdekket av de gjennomførte undersøkelsene vil medføre at kvikksølv fortsatt er tilgjengelig for utlekking og opptak i biota etter tiltak	Det kan være vanskelig å avgrense et tiltaksområde på grunn av flekkvis fordeling og/eller manglende kartlegging. Disse områdene kan utgjøre en miljørisiko hvis det ikke gjennomføres tiltak også i disse. Kan være relevant dersom kvikksølv har blitt frigjort under eksplosjonen og spredt. NIVA har målt klare gradienter i graden av forurensning på havbunnen hvilket taler imot dette.	ENVLT	ENVLT	ENVLT	ENVLT	ENVLT

ID	Navn	Beskrivelse	Til-dekking	Heving Rulle	Heving Rigg	Heving Krybbe	Heving Komb.
R-0241	Tildekkingsmassene er forurenset => Tilførsler av ny forurensning ved capping	Hvis ikke tildekkingsmaterialet sjekkes for forurensninger kan dette inntreffe	ENVST OSAFE	ENVST OSAFE	ENVST OSAFE	ENVST OSAFE	ENVST OSAFE
R-0265	Prosjektorganisasjon fungerer ineffektivt => Økte kostnader, redusert måloppnåelse og/eller lengre prosjektgjennomføringstid	Dersom ikke Kystverket får bemannet prosjektet med riktig kompetanse, samt får etablert en effektiv arbeidsprosess, vil dette kunne medføre økte kostnader (beslutninger fattes sent og/eller er gale/lite hensiktsmessige), dårligere måloppnåelse (dårlige og sene beslutninger medfører at tiltak på U-864 og/eller på havbunn ikke blir optimale) og/eller at prosjektet tar lenger tid å gjennomføre enn nødvendig. Dersom ikke Kystverkets prosjekt klarer å få til et effektivt samarbeid med: - Forsvaret (spesielt EOD-personell) - Sentrale underleverandører vil dette kunne medføre økte kostnader (beslutninger fattes sent og/eller er gale/lite hensiktsmessige), dårligere måloppnåelse (dårlige og sene beslutninger medfører at tiltak på U-864 og/eller på havbunn ikke blir optimale) og/eller at prosjektet tar lenger tid å gjennomføre enn nødvendig. Kostnadsanalysen viser at dette er den nest høyeste driveren av usikkerhet.	PSAFE ENVLT ENVST OSAFE	PSAFE ENVLT ENVST OSAFE	PSAFE ENVLT ENVST OSAFE	PSAFE ENVLT ENVST OSAFE	PSAFE ENVLT ENVST OSAFE
R-0267	Ikke tilstrekkelig tid til å detaljplanlegge prosjektet => Økte kostnader, redusert måloppnåelse og/eller lengre prosjektgjennomføringstid	Dårlig detaljplanlegging kan medføre at lite hensiktsmessige løsninger besluttes og/eller manglende/dårlig koordinering av medvirkende aktører. Dette kan inntreffe dersom gjennomføring av prosjektet besluttes (evt politisk) å gjennomføres før tilstrekkelig detaljplanlegging er gjennomført. Utlegging av støttefylling bør gjøres uansett og så raskt som mulig, og kan derfor medføre økt tidspress for å få gjennomført denne operasjonen.	PSAFE ENVLT ENVST OSAFE	PSAFE ENVLT ENVST OSAFE	PSAFE ENVLT ENVST OSAFE	PSAFE ENVLT ENVST OSAFE	PSAFE ENVLT ENVST OSAFE

ID	Navn	Beskrivelse	Til-dekking	Heving Rulle	Heving Rigg	Heving Krybbe	Heving Komb.
R-0269	Oppvirvling av forurensede sedimenter under operasjon på/ved vraket => forurensede sedimenter spres utover tiltaksområdet.	Dette gjelder kun under operasjon, og gjelder både bruk av ROV og annet utstyr. Dersom det blir spredning utover tiltaksområdet må dette utvides.	ENVLT	ENVLT	ENVLT	ENVLT	ENVLT
R-0273	Sedimenter raser inn i grop langs vraket => forsinkelser	Sedimentene har lav skjerstyrke.		ENVLT ENVST OSAFE			ENVLT ENVST OSAFE
R-0275	Vrakdeler faller av vraket og skader ROV eller annet subseautstyr => materielle skader og/eller forsinkelser	Profilskroget er sterkt korrodert og man har under operasjoner på vraket observert at deler fra profilskroget faller av.		OSAFE	OSAFE	OSAFE	OSAFE
R-0278	Kvikksølvflasker knuser når de hentes ut av kjølkassen => vesentlig etterarbeid for opprydding	Kvaliteten på kvikksølvflaskene i kjølkassene er ukjent. Det kan være at disse også er svært korrodert, slik som flaskene som er funnet i sedimentene, slik at disse kan knuses når ROVen tar tak i disse.		ENVST OSAFE	ENVST OSAFE	ENVST OSAFE	ENVST OSAFE
R-0279	Problemer med å hente ut kvikksølvflaskene fra kjølkassene => det blir liggende igjen mer enn 30 tonn kvikksølv på havbunnen og tiltaket har ikke nådd målet for operasjonen	Det er sannsynlig at mengden kvikksølv som kan forventes å bli hevet er lav, både pga. utfordringer med å hente i flaskene av kjølen SKRIV INN MER TEKST		ENVLT ENVST OSAFE	ENVLT ENVST OSAFE	ENVLT ENVST OSAFE	ENVLT ENVST OSAFE
R-0281	Kvikksølvflasker lekker under heving til overflaten => kvikksølv spres til sjøbunn utenfor tiltaksområdet	Kvikksølvflaskene kan være sterkt korrodert og ved heving kan ekspansjon (pga lavere trykk i omgivelsene) føre til at kvikksølv lekker ut. At forurensede masser faller ut av/fra miljøcontainer.		ENVLT ENVST OSAFE	ENVLT ENVST OSAFE	ENVLT ENVST OSAFE	ENVLT ENVST OSAFE
R-0282	Kvikksølvforurensning på utenfor "skitten sone" => kritisk eksponering for personell og omfattende rengjøring	Erfaring viser at utstyr som har vært i kontakt med sedimentene blir svært forurenset og vanskelig å rengjøre.		PSAFE	PSAFE	PSAFE	PSAFE

ID	Navn	Beskrivelse	Til-dekking	Heving Rulle	Heving Rigg	Heving Krybbe	Heving Komb.
R-0283	Sedimentene rundt vraket inneholder mye stein og vrakdeler => tidkrevende å grave og/eller mudre og medfører store forsinkelser og spredning av forurensede sedimenter	Basert på erfaringer fra graving og mudring på toktet i januar. Sedimentene inneholder mye stein, og for å kunne mudre må sedimentene "løses opp" ved å slå/skrape. For "Rulle" vil det kreves mye graving/mudring, mens for krybbe/rigg må det tilrettelegges for å plassere rigg/krybbe Erfaringer fra januar-toktet tilsier at graving/mudring er svært tidkrevende, og kan medføre at store mengder forurensede masser virvles opp.		ENVLT ENVST OSAFE	ENVLT ENVST OSAFE	ENVLT ENVST OSAFE	ENVLT ENVST
R-0284	Utstyr som brukes på sjøbunnen blir forurenset av kvikksølv => utstyret kan ikke rengjøres og må derfor skrapes/erstattes	Erfaring fra toktet i januar viser at rent kvikksølv blir liggende igjen på utstyret og vil kreve omfattende rensing i etterkant. Dette er sikkert, så hendelsen er at utstyret må erstattes i etterkant.		OSAFE	OSAFE	OSAFE	OSAFE
R-0288	Oppvirvling av sedimenter under arbeidet rundt vraket => begrenset sikt og medfører forsinkelser	Basert på erfaring virvles toppsedimentene mye opp under arbeid, og det blir lett så mye at ROV operatørene ikke kan se hva de skal gjøre. Da må man vente til sedimentene har lagt seg, noe som tar lang tid. Ved mye slike avbrudd øker gjennomføringstiden og/eller arbeidet som gjøres blir utført med mindre presisjon. For "Rulle" er dette en større utfordring da mye masser må fjernes.		ENVLT ENVST OSAFE	ENVLT ENVST OSAFE	ENVLT ENVST OSAFE	ENVLT ENVST OSAFE
R-0289	Vinsjer klarer ikke fordele løftekraft jevnt til alle ankre => wire ryker og/eller ankre løsner pga ujevn kraftfordeling og en ette en ryker så vraket ikke blir løftet	Ukjent fordeling av vekt i skrogene og/eller ikke synkronisert kraftoveføring mellom vinsjer på Rigg medfører at wire'e ryker. Dersom først en ryker, så øker sannsynligheten for at en/flere ryker en etter en. Dersom dette skjer, så må det vurderes om man skal lage flere festepunkter eller la gjeldene vrak ligge og prøve den andre vrakdelen.			OSAFE	OSAFE	OSAFE
R-0290	Lykkes ikke å stabilisere vrak i installasjon på sjøbunn => Installasjonen siger på ett eller flere ben og får en vinkel som medfører at løfteoperasjonen må avbrytes og fundamentering utbedres	Dersom ikke installasjonen får god fundamentering under føttene vil denne kunne sige skjevt under løft. Dersom den siger for mye, så kan operasjonen løftet måtte avbrytes, rigg flyttes og bedre fundamentering under føttene etableres. Dette vil medføre store forsinkelser. Installasjonen er forutsatt at er designet for at den skal kunne synke ned i massene under løft.		ENVLT ENVST OSAFE	ENVLT ENVST OSAFE	ENVLT ENVST OSAFE	ENVLT ENVST OSAFE

ID	Navn	Beskrivelse	Til-dekking	Heving Rulle	Heving Rigg	Heving Krybbe	Heving Komb.
R-0291	Sterkere strøm enn forventet påvirker løfteballongene => Ustabile og horisontale kraftkomponenter og/eller høy VIV (Vortex Induced Vibrations) gir komplikasjoner for løft slik at dette må utsettes	Strømmen langs bunn er normalt ikke veldig høy (ca 0,5 kn), men den varierer både i styrke og retning. VIV effekter kan medføre ustabilitet.			OSAFE		OSAFE
R-0293	Eksplosiver sitter fast i utstyr som er brukt på sjøbunn og detonerer på sjøbunn eller på dekk => materiell og eller personellskader	Eksplosiver fra vraket som ligger på sjøbunnen kan feste seg på utstyr som er benyttet under operasjoner på sjøbunnen.	PSAFE ENVST OSAFE	PSAFE ENVST OSAFE	PSAFE ENVST OSAFE	PSAFE ENVST	PSAFE ENVST OSAFE
R-0294	Problemer med sugeslange til Hopper Dredger => spredning av forurensede masser og/eller forsinkelser	"Rulle" må bruke Hopper Dredger for å redusere sprendingsfaser under tiltaket		ENVLT ENVST OSAFE			ENVLT ENVST OSAFE
R-0295	Aktivister interferer med operasjonen => operasjonen forsinkes og/eller skade på materiell	Prosjektet er omdiskutert og flere organisasjoner kan tenkes å aksjonere dersom de mener valgte løsning ikke møter deres ønsker.	OSAFE	OSAFE	OSAFE	OSAFE	OSAFE
R-0296	Ulykke inntreffer ifm transport fra Fedje til endelig lagring => forurensning av kvikksølv og som krever opprydning og rensning av materiell	Ulykke på fartøy eller lastebil/tog og hvor kvikksølv lekker ut og forurenser området der ulykken inntraff.		PSAFE ENVST OSAFE	PSAFE ENVST OSAFE	PSAFE ENVST OSAFE	PSAFE ENVST OSAFE
R-0297	Kvalitet på sluttbehandling/lagring utføres ikke iht regelverk => kvikksølvet kan forurense på endelig lokasjon	Kvikksølvet behandles og/eller lagres ikke slik det er avtalt, og hvor dette medfører at noe lekker ut til omgivelsene.		PSAFE ENVLT	PSAFE ENVLT	PSAFE ENVLT	PSAFE ENVLT

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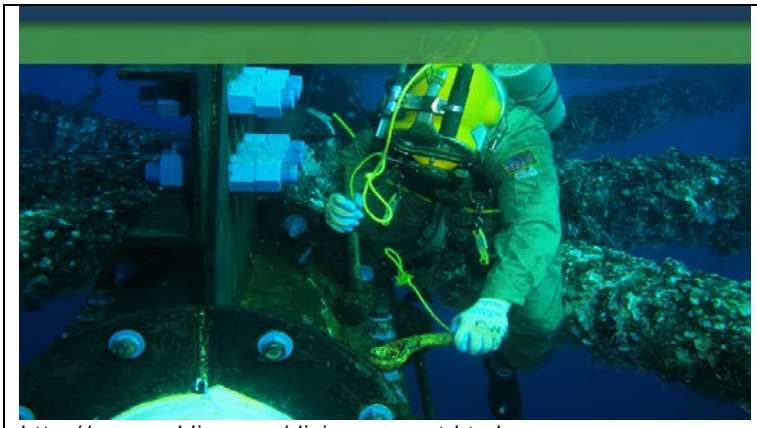
APPENDIX V3.04

ENVIRONMENTAL MEASURES FOR THE WRECK OF U-864

Use of divers to raise the mercury – Assessment of mercury exposure

DNV GL AS



http://www.caldive.com/diving-support.html

http://www.blue-bubbles.com/com_diving.html

Project name: Environmental measures for the wreck of U-864
Report title: Use of divers to raise the mercury – Assessment of mercury exposure

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Dato: 12.5.2014

Gjengivelse av deler av dette vedleggsdokument som kan føre til mistolkning er ikke tillatt

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1 INTRODUCTION

The German submarine U-864 was sunk by the British submarine Venturer on 9 February 1945, approximately 2 nautical miles west of the island Fedje in Hordaland, Norway. The submarine was on its way from Germany via Norway to Japan with war material and according to historical documents; U-864 was carrying about 67 metric ton of metallic (liquid) mercury, stored in 1 857 steel canisters in the keel (Figure 1). The U-864, which was broken into two main parts as a result of the torpedo hit, was found at 150-175 m depth by the Royal Norwegian Navy in March 2003. The Norwegian Costal Administration (NCA) has, on behalf of the Ministry of Fisheries and Coastal Affairs, been performing several studies on how the risk that the mercury load constitutes to the environment can be handled. In 2001 six different alternatives were studied for environmental measures at the wreck of U-864 on behalf of the Norwegian Government. In 2012 the Norwegian Government decided to continue with design and quality assurance for two of the alternatives; raising the cargo (mercury) (Alternative 3) and capping the wreck site (Alternative 1).

This memo presents an assessment on possible exposure to mercury if divers are used to raise the mercury cargo from U-864 (Alternative 3).

Figure 1: Mercury canister from U-864. Photo: Norwegian Coastal Administration

2 DESCRIPTION OF THE OPERATION

The alternative to raise the cargo is limited to bringing the mercury containers to the surface, while the remaining wreckage remains. After the cargo of mercury is raised, the wreck and contaminated sediments will be capped with clean sand/gravel. After the project is completed the situation in the area will be followed up with environmental monitoring.

Use of divers may be relevant in the following parts of the operation:

- Remove the steel plates on the sides of the keel to get the mercury canisters out (Figure 2).
- Place the mercury canisters in baskets (or similar) on the seabed before lifting them to the surface (Figure 3).

Figure 2: Photo showing a part of the keel of the U-534 submarine that is exhibited in Liverpool. U-534 is a type IXC/40 submarine very similar to U-864. The steel plate to the left is covering a keel compartment and to the right the steel plates covering the keel compartments have been removed. In U-864 the compartments in the keel were used for storing the ballast. The mercury containers were used as such ballast. Photo: DNV GL.

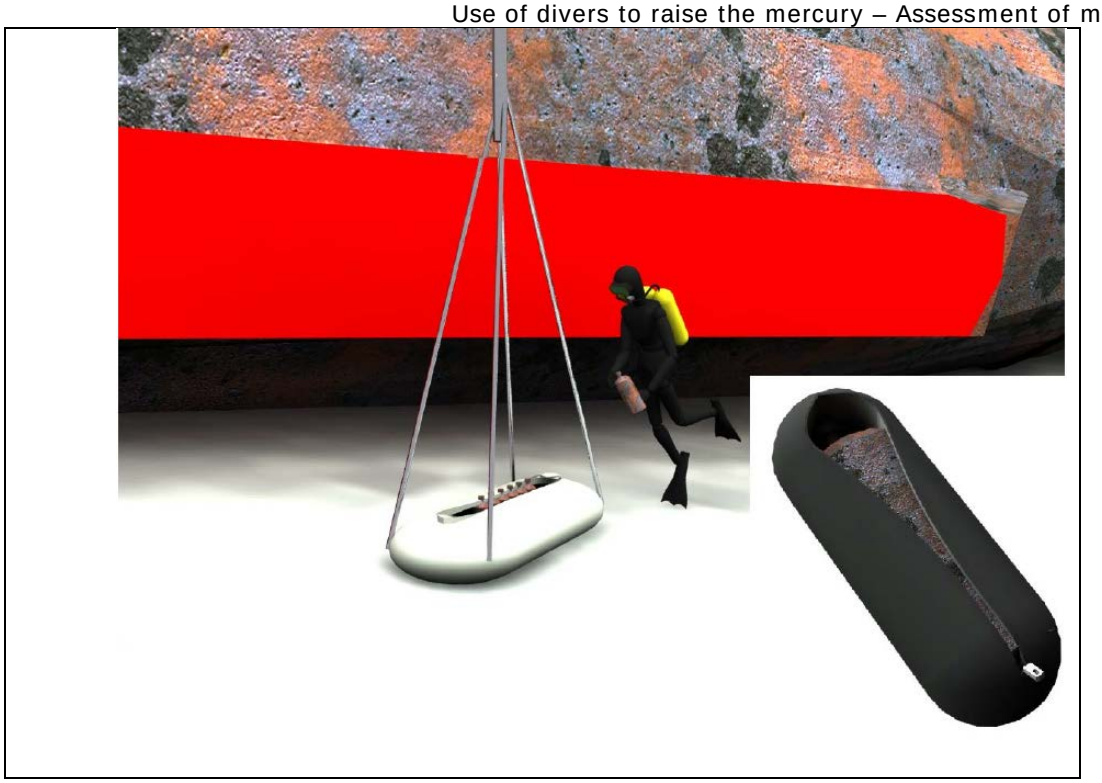

Figure 3: Placing the mercury canisters in baskets on the seabed to be lifted up on board the vessel (from NUI, 2011).

3 ABOUT SATURATION DIVING

Saturation diving involves divers at very large depths for a sustained duration. This results in a point in which no more gas, in particular nitrogen, is able to be dissolved into the tissues of the diver. This is where the term 'saturation' is derived. After the saturation point is reached the decompression time to rid the body of excess nitrogen is the maximum time needed. Therefore the diver can stay at large depths for a much longer period of time with the same decompression time needed. Typically, the commercial deep diving executed around the Norwegian coast involves working at depths around 100 – 150 meters. At these depths the total pressure that a diver can be subject to may be towards 1600 kPa (HSE).

The diving system used in saturation diving is composed of four main chambers known as the deck decompression chamber (DDC) or living chamber, the personal transfer chamber bell (PTC) or submersible decompression chamber (SDC), the recompression chamber (RC) and the transfer chamber (DTC). Attached to the DTC is the supply lock (SL), see Figure 4. Divers enter the environment through the PTC and when the work is completed the worker re-enters the PTC which is subsequently attached to the DDC via the DTC. Within the DDC the diver can start to decompress.

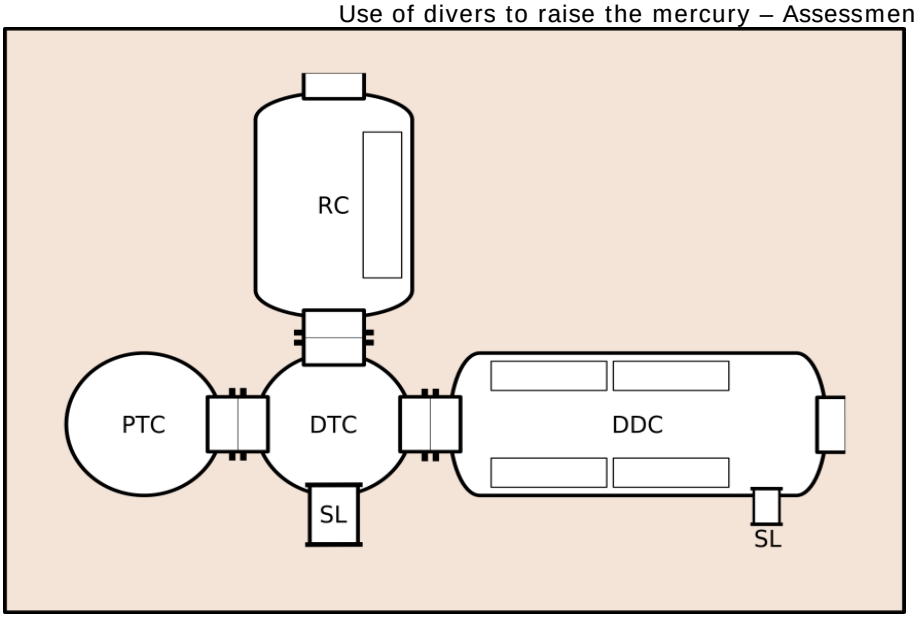

Figure 4: Simplified schematic plan of saturation dive system showing compartments used by saturation divers. Schematic plan of a simple saturation system showing the main pressure vessels for human occupation. DDC - Living chamber, DTC - Transfer chamber, PTC - Personnel transfer chamber (bell), RC - Recompression chamber, SL - Supply lock. (From Wikipedia).

4 NORWEGIAN GUIDELINES FOR MERCURY IN THE OIL AND GAS SECTOR

In Norway the Norwegian Oil and Gas Association (Norsk olje & gass) have issued a guideline with recommendations for handling mercury in the oil and gas sector.

The uptake of mercury in human beings can take place through inhalation, skin contact and by swallowing. The main uptake is through inhalation (75-80 %). For persons working in an area with mercury the administrative norm (recommended target value) is 0,02 mg/m^3 in air and for a 12 hour shift (exposure) it is 0,014 mg/m^3.

The guideline has no specific recommendations for diving in mercury contaminated areas.

In the guideline the level of risk control is divided into three levels depending on the amount of mercury. For installations with more than 100 ppb mercury concentration the highest level of risk control (level red) is required. Red level includes frequent measurements of mercury concentrations in the working atmosphere, personal air measurement devices and personal protection devices (mask, special clothing, gloves and shoes).

5 HAZARDS WHEN DIVING IN CONTAMINATED WATERS

IMCA (The International Marine Contractors Association) have issued the *International Code of Practice for Offshore Diving* (IMCA, 2007). In chapter 7.4.1.3 *Pollutants* the following is stated concerning diving in polluted areas:
"The presence of man-made and natural petroleum products around oil fields can cloud optical lenses and may damage plastic materials. Equally, gas can affect visibility, block sound transmission and cause sudden loss of buoyancy. Special precautions should be taken to protect the divers if pollutants are present and prevent these pollutants from entering the diving bell, as well as protecting personnel who may handle the divers or their equipment during launch/recovery and during maintenance ".

IMCA has also released a report that specifically concerns diving in polluted areas; *Diving in Contaminated Waters* (IMCA, 2004). The report identifies the following hazards that need to be considered when diving when there may be contamination in the water or on the seabed or because the diver is recovering contaminated materials:

- *direct contamination of the diver while working in the water;*
- *contamination of the diver's equipment causing hazards to the surface personnel or others that are required to handle it;*
- *contamination of the atmosphere of the diving bell or deck decompression chamber (DDC) either by the contaminant entering directly or else on the equipment of the diver after he returns.*

Concerning heavy metals the report concludes:
"Heavy metal contamination is normally encountered as a result of past industrial activity. Examples of such substances that may be encountered are mercury, cadmium and arsenic although other substances may also be found.

Heavy metals do not normally have acute (that is sudden) effects but tend toward chronic (that is long term) health effects. Skin contact will normally have to be repeated and prolonged to become a serious hazard and there usually be little or no toxic vapours given off that may contaminate, for example, the inside of a bell. The main risk is if the heavy metals are ingested which means that the risk to divers from heavy metals on their own is often relatively small".

The control measures for heavy metals are:
"levels of risks should normally be considered low/medium;

- *for lowest level risks, normal diving equipment with precautions such as those for drilling muds;*
- *for medium level risks, closed suits with fitted helmet may need to be used;*
- *particular care is needed that divers are not exposed to risk of ingestion;*
- *surface teams with adequate PPE[1] disinfecting/rinsing by washing down, showers, etc."*

6 SPECIFIC CRITICAL OPERATIONS FOR THE DIVERS WHEN WORKING WITH MERCURY AND MERCURY CONTAMINATED SEDIMENTS AT U-864

For divers working with the mercury canisters and mercury contaminated sediments on the seabed at U-864 there would be specific critical operations like:

- The divers have to stand on the seabed close to the wreck when working. Investigations have shown that there is pure mercury (droplets) in the sediments close to the wreck. The diving suit can be polluted by the mercury.
- When the divers have removed the steel plates and are going to remove the mercury canisters there could be free mercury in the keel compartment from broken/corroded canisters. Their gloves and diving suit could then be polluted by mercury.
- When the divers are moving the mercury canisters from the keel over to the baskets (or similar) to lift them to the vessel the canisters can leak or break and pollute the diving suit.
- When the diver after working on the seabed enters the diving bell mercury on the divers suit can enter the diving bell and can evaporate and go further into the pressure chamber system. The diver could then risk inhaling the mercury vapour in the diving bell.

[1] PPE = Personal Protective Equipment

7 AVERTING MEASURES FOR DIVERS WORKING WITH MERCURY AND MERCURY CONTAMINATED SEDIMENTS AT U-864

In the previous chapter different specific critical operations were identified for divers working with the mercury canisters and mercury contaminated sediments on the seabed at U-864.

The IMCA report *Diving in Contaminated Waters* (IMCA, 2004) has recommendations for measures to reduce the risk for divers working in polluted areas that are relevant for the U-864 mercury case.

The most important recommendation is that when the hazard cannot be controlled by elimination[2] the next best option is substitution. In this case it would be possible to substitute the need for divers by using one or several ROVs (remotely operated vehicle) to do the work.

In cases when the hazard is limited, engineering control[3] can be used. In this case it could be measures like:

- The divers could be equipped with a protective extra suit outside of the regular diving suit. This protective suit would be taken off before the diver enters the diving bell and remain on the outside of the diving bell. The protective suit is taken up separately and taken care of by the surface crew. The divers will wear a new clean protective suit for each dive they are doing.
- Fitting covers (similar to a hot water shroud) to the second stage of the helmet to help prevent ingress of mud/mercury through the demand valve.
- As mercury contaminated sediments could be brought back into the bell on the diver's umbilical, mainly in the twisted lay of the hoses, some form of cleaning brush could be fitted to the bell clump weight.
- Protecting the first (say) 40 metres of umbilical with some form of rubber (latex) sock. This would be easier to clean or remove by the divers in the water prior to entering the bell.
- When the diver comes into the bell there could be installed a washing facility in the transfer chamber to remove any mercury that has attached to the body.

8 CONCLUSION

In this case it is assessed that the use of divers to raise the mercury could constitute a substantial risk. Raising mercury by divers at 150 m depth in the North Sea has never been done before. The operation has parts that are a risk for the diver's health and safety where they can be exposed to mercury in very high concentrations.

It is possible to substitute the divers with unmanned ROVs and thereby not needing to use the divers.

For this operation it is therefore recommended to use ROVs and not divers.

[2] Wth elimination is meant that the hazardous activity is not performed. In this case it would mean not to dive.
[3] With engineering control is meant that the hazard is controlled or limited, normally by mechanical or physical means.

9 REFERENCES

/1/ IMCA (The International Marine Contractors Association), 2007. International Code of Practice for Offshore Diving. IMCA Report D 014 Rev. 1 – October 2007.

/2/ IMCA (The International Marine Contractors Association), 2004. Diving in Contaminated Waters. IMCA Report D 021 Rev. 1 – November 2004.

/3/ Norsk olje og gass, 2012. Anbefalte retningslinjer for Håndtering av kvikksølv. Nr. 132, etablert 10.09.2012.

/4/ NUI, 2011, Dykkebasert metode for opphenting av kvikksølv fra U-864. Rapport nr. 01.11. 04.01.2011.

/5/ Jan Risberg, Diving doctor at Haakonsvern naval base. Pers. comm.

/6/ Hansen, Arnfinn at DNV GL, Principal Engineer at the department for Offshore Equipment and Diving (MOANO374).

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Vedlegg V3.05.0

MILJØTILTAK VED VRAKET AV U-864

Mulighetsstudier av alternative metoder for heving av last

DNV GL AS

Project name: Miljøtiltak ved vraket av U-864
Report title: Mulighetsstudier av alternative metoder for heving av last

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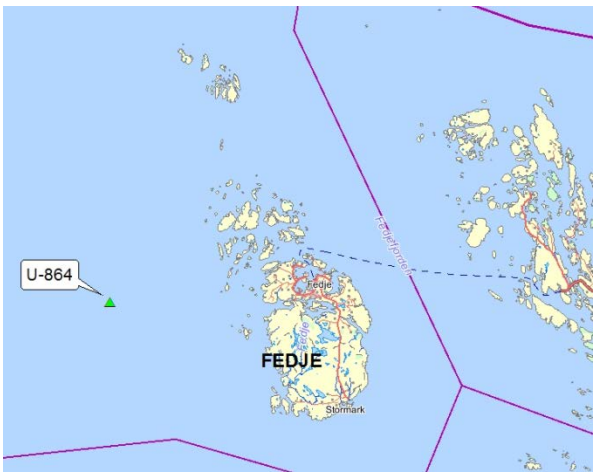
Dato: 12.5.2014

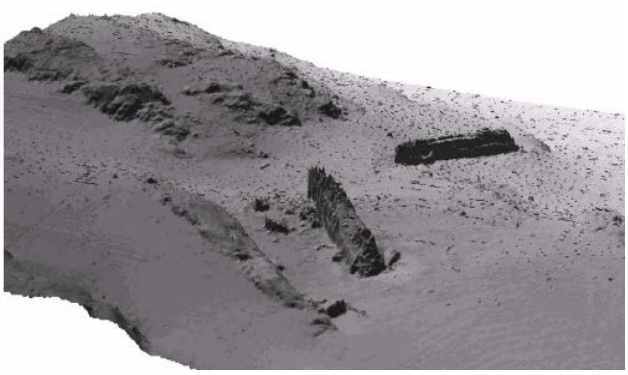
Gjengivelse av deler av dette vedleggsdokument som kan føre til mistolkning er ikke tillatt

1 INNLEDNING

Den tyske ubåten U-864 ble senket av den britiske ubåten HMS Venturer den 9. februar 1945, ca. 2 nautiske mil vest for øya Fedje i Hordaland (Figur 2-1). Ubåten var på vei fra Tyskland via Norge med krigsmateriell til Japan. I følge historiske dokumenter fraktet U-864 ca. 67 tonn metallisk kvikksølv (i væskeform) lagret i stålbeholdere i kjølen.

U-864 brakk i to hoveddeler som følge av torpedotreffet og ble funnet på 150-175 meters dyp av den Norske Marinen i mars 2003. Kystverket har, på vegne av Kyst og Fiskeridepartementet (FKD), utført en rekke studier for å avdekke hvordan miljørisikoen som utgjøres av kvikksølvlasten i U-864 skal håndteres.





Figur 1 Lokasjon (venstre), sonarbilde av vraket av U-864 på sjøbunnen (Geoconsult)

Konseptvalgutredningen (KVU) ble levert FKD i januar 2011 og har senere vært gjenstand for ekstern kvalitetssikring av konseptvalg (KS1). Regjeringen vedtok basert på rangeringen i KVU og KS1 å gå videre med to alternativer i et forprosjekt. I bestillingen fra FKD til Kystverket fremgår det at det skal gjennomføres forprosjektering av følgende alternative løsninger for miljøtiltak ved vraket av U-864:

- Tildekking av vrak og forurenset havbunn (jf. KVU Alternativ 1)
- Heving av last og tildekking av vrak og forurenset havbunn (jf. KVU Alternativ 3).

I 2013 ble DNV GL AS tildelt oppdraget med å bistå Kystverket i å utarbeide sentralt styringsdokument for forprosjektet.

2 BAKGRUNN FOR VEDLEGG V3.05.01-05

2.1 Mulighetsstudie av alternative hevingsmetoder (Alternativ 3)

For å kunne vurdere gjennomførbarhet, risiko og kostnader for en operasjon for heving av last fra kjølkassene til U-864 har prosjektet søkt bistand fra offshore industrien. Kystverket, med bistand fra DNV GL AS, gjennomførte en anskaffelsesprosess for gjennomføring av følgende oppdrag:

- Gjennomføre en to-dagers workshop (ledet av DNV GL AS) der det skal utarbeides et alternativ for å kunne hente ut flest mulig kvikksølvflasker av kjølkassene.
- I etterkant av workshop'en utarbeide enkle tegninger/skisser av foreslått alternativ.
- Sammenstilling av en rapport fra workshop'en vil bli gjennomført av DNV GL AS.

Følgende fem selskaper ble tilbud kontrakt for dette oppdraget: DOF Subsea, Oceaneering, Technip, Swire Seabed og Subsea7. I de følgende vedleggene (Vedlegg V3.05.1 til V3.05.5) er hvert selskaps foreslåtte løsning beskrevet. Kystverket og DNV GL AS vil berømme alle selskapene for den svært gode bistanden som har blitt gitt. Selskapene har på kort tid utarbeidet gode forslag til alternative metoder for heving av lasten i U-864.

2.2 Avgrensninger

Følgende momenter må det tas hensyn til ved vurdering av selskapenes løsninger:

- Alternativene har vært utarbeidet gjennom en to-dager lang workshop med hver leverandør. Workshopene ble gjennomført i oktober 2013.
- Hovedfokus i WSene var utarbeidelse av gjennomførbare løsninger for heving av last.
- De fleste av selskapene hadde begrenset kjennskap til vrakets tilstand og de miljømessige utfordringene knyttet til operasjon på vrakstedet før oppstart av workshopen.
- Det ble også gjennomført en overordnet risikoanalyse, men omfanget av denne var begrenset pga. tilgjengelig tid. Det totale risikobildet for Alternativ 3 er analysert separat (Vedlegg V3.03).
- I januar 2014 ble det utført en 11 dager lang operasjon på U-864 for å innhente mer kunnskap om gjennomførbarheten av en eventuell operasjon for heving av last. Denne operasjonen ble gjennomført av DOF Subsea. Mål for denne operasjonen var blant annet:
    - Flytte noen av vrakdelene som ligger tett inntil akterseksjonen noe lenger vekk
    - Grave eller mudre for å gi tilgang til de kjølkassene som er plassert lengst akterut på akterseksjonen på styrbord side. Dette er de kjølkassene som er lettest å grave frem.
    - Åpne en/flere kjølkasser. Dersom disse inneholder kvikksølvflasker, hente disse opp til overflaten.

  Denne operasjonen har tilført mye kunnskap til prosjektet som ikke de fem selskapene hadde tilgjengelig når deres alternativer ble utarbeidet. Denne informasjonen er tatt med i den overordnede risikoanalysen i Vedlegg V3.03.
- En endelig løsning for en evt. heving av last må gjennomgå detaljert design og vil kunne endres i større eller mindre grad for å redusere risiko og øke suksessrate. Løsning vil også avhenge av operatør som får tildelt oppdraget.

2.3 Metodikk for gjennomføring av WS

For å strukturere prosessen i risikoanalysene ble det utarbeidet en overordnet prosessbeskrivelse som ble lagt til grunn. Denne besto av følgende trinn:

1. Sikre vraket i en stabil posisjon
2. Få tilgang til kjølen
3. Åpne kjølen
4. Hente ut kvikksølvbeholdere fra kjølen til havbunnen
5. Bringe kvikksølvbeholdere og flytende kvikksølv fra havbunnen opp til overflaten
6. Stabilisere vraket før tildekking

En felles risikomatrise og skala ble benyttet i alle analysene for å sikre sammenlignbarhet mellom risikobildene i de ulike foreslåtte metodene. Et sett med generiske risikoer ble benyttet som inngang til analysen, i tillegg ble det åpnet for at hver enkelt leverandør kunne komme med risikovurderinger. Aktuelle tiltak for å redusere risiko ved operasjonen ble identifisert, og risikobildet justert basert på deres effekt på sannsynlighet og konsekvens for de ulike risikoene.

De foreslåtte metodene og resultatene av risikoanalysene er presentert i vedlegg V3.05.1 til V3.05.5.

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Appendix V3.05.1

ENVIRONMENTAL MEASURES FOR THE WRECK OF U-864

Feasibility study - Suggested method for U864 mercury cargo recovery: DOF Subsea

DNV GL AS

Project name: Environmental measures for the wreck of U-864

Report title: Feasibility study - Suggested method for U864 mercury cargo recovery: DOF Subsea

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Reference to part of this report which may lead to misinterpretation is not permissible.

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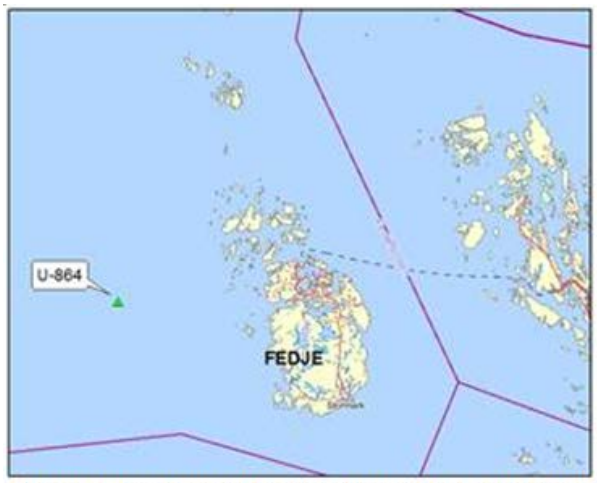
1 INTRODUCTION

The German submarine U-864 was torpedoed by the British submarine Venturer 9th of February 1945, approximately 2 nautical miles west of the Island Fedje in Hordaland. U-864 was on its way from Germany via Norway to Japan. The submarine was loaded with war material, and according to historical documents approximately 67 ton of floating metallic mercury in steel canisters stored in the keel. The torpedo split the submarine into two parts. The wreck parts were discovered by the Royal Norwegian Navy at a depth of approximately 150-175 m. Several studies have revealed feasible measures for pollution abatement. The risks related to these measures have been assessed and indicate the following:

- High mercury concentrations in the soil, especially around the wreck parts.
- The bow section is inclining and has a high risk of sliding downhill. (Geotechnical unstable)
- Torpedoes and ammunition in general.
- Oil in the wreck.
- The condition of the two wreck parts.
- The condition of the mercury canisters.

In 2013 DNV-GL was assigned by the Norwegian Coastal Administration to carry out a pre-project that will assess the possibility of recovering the mercury canisters from the wreck parts before capping the wreck parts and the polluted seabed-area. As part of the assignment, competent subsea companies have been invited to discuss feasible solutions and cost pertaining to the proposed solutions.



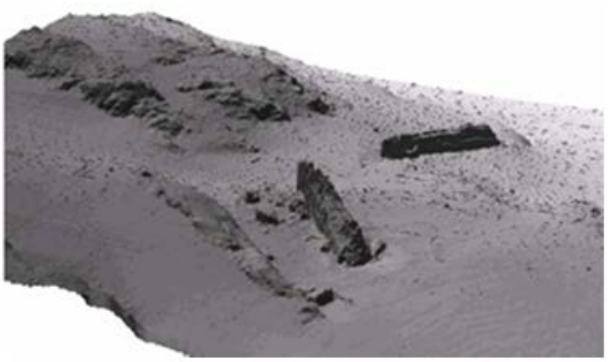


Figure 1.Loction of the wreck outside Fedje (left) and sonar image of bow and aft part of the wreck (right)

2 SUGGESTED METHOD TO RETRIEVE MERCURY CANISTERS

To avoid a global collapse of the seabed slope where the bow section resides, the valley to the North will be rock dumped with the purpose of stabilising the area prior to any intervention work on the wreck. This measure is valid for all the suggested methods from all companies participating in this RFI (Request for information).

For all companies the operation has been divided into 6 generic steps as presented in the table below. The suggested method by DOF Subsea for the retrieval of the mercury canisters from the keel of U-864 is presented briefly in the table below and more in detail in the succeeding sub-chapters:

No	Operational step	Brief description (company specific)
4.1	Preparations	Based on a geotechnical assessment a trench to be dredged in parallel and a few meters away from both wreck parts. Due to the soft seabed, the masses between the trench and the hull will collapse and the two wreck parts will naturally move into a stable position over to the side.
4.2	Get access to the keel	Excavate the sediments that cover the keel with a hose - and grab dredger.
4.3	Open the keel	Inspect the keel before opening the keel side plates with adequate cutting equipment.
4.4	Retrieve the Mercury canisters from keel to seabed	The canisters can either be removed from the keel through the use of a suction pad or a specially designed grabbing mechanism. To remove liquid Mercury, a suction pump will be used.
4.5	Recover Mercury canisters and free floating Mercury from seabed and bring this to the surface	At the seabed level the canisters will be moved from the keel to a container with a drain tube especially designed for this operation.
4.6	Stabilise wreck before capping	The wreck is expected to remain stable after the initial securing of the wreck in phase 4.1.

In the following chapters this method will be further elaborated with a focus on equipment and tools being used, and a risk assessment of the operation. The sketches included below are not accurate when it comes to dimensions; they are only included to better give the reader an understanding of the suggested concept.

In the risk assessment, possible events are rated with probability and consequence, with values according to the risk matrix in figure 2.

		Consequence				
		Minor	Low	Considerable	Large	Severe
Probability	Likely	Significant	Critical	Critical	Critical	Critical
	Reasonably prob	Significant	Significant	Critical	Critical	Critical
	Unlikely	Insignificant	Significant	Significant	Critical	Critical
	Remote	Insignificant	Insignificant	Significant	Significant	Critical
	Extremely remote	Insignificant	Insignificant	Insignificant	Significant	Significant
	Theoretically Possible	Insignificant	Insignificant	Insignificant	Insignificant	Significant

Figure 2: Risk matrix

Subsequently the mitigating actions that reduce the probability and/or the consequence of the event are identified. The new rating of probability and consequence for the event is then assessed.

One common set of risks and actions will be used as basis for all companies (see chapter 3) which has a numbering from R1 to R16 for risks and T1.x to T16.x for mitigating actions. For company and method specific risks the numbering will start with an abbreviation representing the company (D,SW,T,O,S7).

The abbreviations used in the risk assessment tables in this document are shown in the table below. The first four rows are abbreviations for different types of consequences. The five last rows are abbreviations for the magnitude of a particular type of consequence. Other abbreviations used are listed in the underlying table.

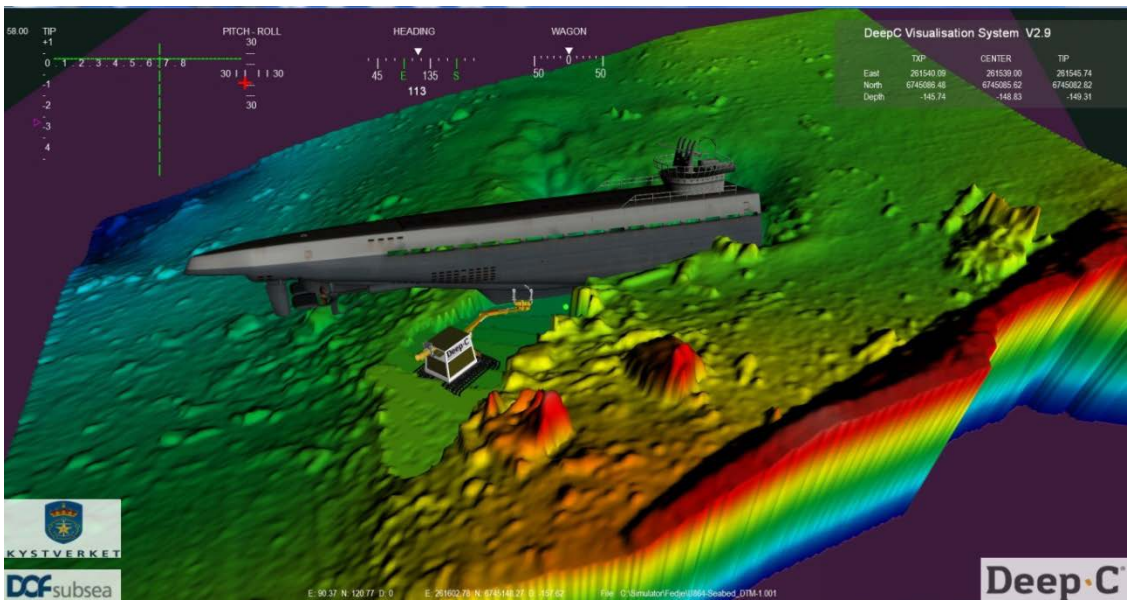
Abbreviation	Full text
ELT	Environment LONG Term
EST	Environment SHORT term
PS	Personnel SAFETY
OS	Operational SAFETY
M	Minor consequence
Lo	Low consequence
C	Considerable consequence
La	Large consequence
S	Severe consequence

2.1 Preparations

2.1.1 Operation

2.1.1.1 Dredge a trench

To secure the wreck DOF Subsea suggests dredging a trench in parallel and a few meters away from both parts of the wreck.



2.1.1.2 Wreck rolls into stable position

The masses between the trench and the hull will collapse and the wreck will naturally roll into a stable position on the side. The aft section should be rolled to the port side while the bow section should be rolled to its starboard side. Based on a previous experience form dredging at the port side of the aft

wreck part According to DOF Subsea expects this will not be a sudden movement but a slow and controllable operation.

2.1.1.3 Secure in stable position

When the two parts of the wreck has stabilised they should be secured by structures tailor made for this operation.

2.1.2 Equipment and tooling

DOF Subsea suggests using the following equipment and tooling:

No	Operational sub step	Equipment or tools applied
3.1.1.1	Dredging a trench	If environmentally acceptable, dredging should be done with a dredging hose which is able to move large amounts of sediments in a short time span.
3.1.1.2	Wreck rolls into stable position	Use ROV for monitoring
3.1.1.3	Secure wreck after roll	Struts, skirts, wires, saddles or ragbags

2.1.3 Risk assessment

2.1.3.1 Risk before mitigating actions

Risk	Sub step	Risk	Description	Probability	Consequence
R1	4.1.1.1	Spreading of mercury contaminated sediments	Spread contaminated sediments during suction dredging according to NIVA report 5279-2006.	Likely	ELT(Lo) EST(Lo)
R4	4.1.1.1	Uncontrolled movement of sediments surrounding the bow structure	The sediments surrounding the bow section are not stable and can be the cause of a massive slide. Polluted sediments will then be spread into the water column. If the bow section moves during the slide the keel can break up and lead to further contamination.	Likely	ELT(Lo) EST(Lo) OS(Lo)
R9	4.1.1.2	Damaged keel	When the hull rolls over the keel can be stuck in the sediments and therefore partly damaged. If more canisters rupture during this phase this might lead to further contamination of the sediments under the keel.	Reasonably probable	ELT(M) EST(M) OS(Lo)
R17	4.1.1.2	Air pockets in bow section	Bow section is expected to contain air pockets, and is therefore unstable. When excavating the trench, it is unknown what kind of roll the wreck will perform. The keel might not be accessible.	Reasonably probable	ELT(Lo) EST(M) OS(La)

2.1.3.2 Risk after mitigating actions

Action	Sub step	Mitigating action	Description of actions	Probability	Consequence

(Risk)				after action	after action
T1.1 (R1)	4.1.1.1	Develop new technology	For exhaust treatment, containerised system, or bags can be used. Today no subsea technology to filter out mercury from sediments or water exists. If this action is even possible is very uncertain and this will require more research and testing.	Reasonably probable	ELT(Lo) EST(Lo)
T1.2 (R1)	4.1.1.1	Use other forms of dredging	To remove the minimum amount of soil to get access to the keel by using mechanical dredging. Mechanical dredging will also spread contaminated sediments, but not in the same large amounts as suction dredging.	Reasonably probable	ELT(Lo) EST(Lo)
T1.3 (R1)	4.1.1.1	Analyse dredging method	Perform a detailed analysis on which dredging method should be used in the different areas and depths, depending on share strength and on the severity of the contamination.	Reasonably probable	ELT(Lo) EST(Lo)
T1.4 (R1)	4.1.1.1	Take core sample before operation	Take samples around the wreck parts and inside the keel, before and during the operation, to monitor the content of mercury in the sediments.	Reasonably probable	ELT(Lo) EST(Lo)
T4.2 (R4)	4.1.1.1	Monitor pitch and roll of wreck	Install monitoring equipment to the wreck to monitor pitch and roll.	Reasonably probable	ELT(Lo) EST(Lo) OS(Lo)
T4.3 (R4)	4.1.1.1	Wire supporting bow section	Support the bow structure by securing a wire from the bow to solid rock or a suction anchor.	Reasonably probable	ELT(M) EST(M) OS(Lo)
T4.4 (R4)	4.1.1.1	Planning	Geotechnical examinations	Reasonably probable	ELT(Lo) EST(Lo) OS(Lo)
T4.5 (R4)	4.1.1.1	Barrier	During the operation, sheet pile, sand bags etc. can be used to stabilize the sediments.	Reasonably probable	ELT(M) EST(M)
T9.1 (R9)	4.1.1.2	Monitor	Use Inclinometer to monitor the operation. A fast movement will increase the chances for a damaged keel	Unlikely	ELT(M) EST(M) OS(Lo)
T9.2 (R9)	4.1.1.2	Remove more sediments	If more sediment is removed around the keel before the hull is moved, the chance of damaging the keel is reduced.	Unlikely	ELT(M) EST(M) OS(Lo)

2.2 Get access to the keel

2.2.1 Operation

2.2.1.1 Excavate the keel

During the operation where the wreck rolls over onto the side the keel might not be exposed. The keel therefore has to be excavated in a way that secures that sediments do not slide back onto the keel.

2.2.2 Equipment and tooling

No	Operational sub step	Equipment or tools applied
3.2.1.1	Excavate the keel	Peel grab (7cubik meters). Dredging hose: Makes a close loop, can have some issues with regards to cleaning of the sediments. Containers are needed to collect the sediments. A mechanical grab with the possibility to push out sticky sediment from the grab.

2.2.3 Risk assessment

2.2.3.1 Risk before mitigating actions

Risk	Sub step	Risk	Description	Probability	Consequence
R1	4.2.1.1	Spreading of mercury contaminated sediments	Spread contaminated sediments during suction dredging according to NIVA report 5279-2006.	Likely	ELT(Lo) EST(Lo)
R5	4.2.1.1	Uncontrolled movement and back fill of sediments during dredging	The sediment has very low shear strength at approximately 5-10 KP. This makes it hard to stabilise.	Likely	ELT(Lo) EST(Lo)
DR18	4.2.1.1	Not able to operate excavator at bow section	Due to the 20° slope and the soft seabed at the bow section, it is not known if it is possible to operate the excavator for obtaining keel access.	Likely	ELT(M) EST(M)

2.2.3.2 Risk after mitigating actions

Action	Sub step	Mitigating action	Description of actin	Probability after action	Consequence after action
T1.1 (R1)	4.1.1.1	Develop new technology	For exhaust treatment, containerised system, or bags can be used. Today no subsea technology to filter out mercury from sediments or water exists. If this action is even possible is very uncertain and this will require more research and testing.	Reasonably probable	ELT(Lo) EST(Lo)
T1.2 (R1)	4.1.1.1	Use other forms of dredging	Remove sediments through the use of mechanical dredging or technology to freeze the sediment before removal.	Reasonably probable	ELT(Lo) EST(Lo)
T1.3 (R1)	4.2.1.1	Analyse dredging method	Perform a detailed analysis on which dredging method should be applied in the different areas.	Reasonably probable	ELT(Lo) EST(Lo)
T1.4 (R1)	4.2.1.1	Take core sample before operation	Take samples around the wreck parts and inside the keel, before and during the operation, to monitor the content of mercury in the sediments.	Reasonably probable	ELT(Lo) EST(Lo)

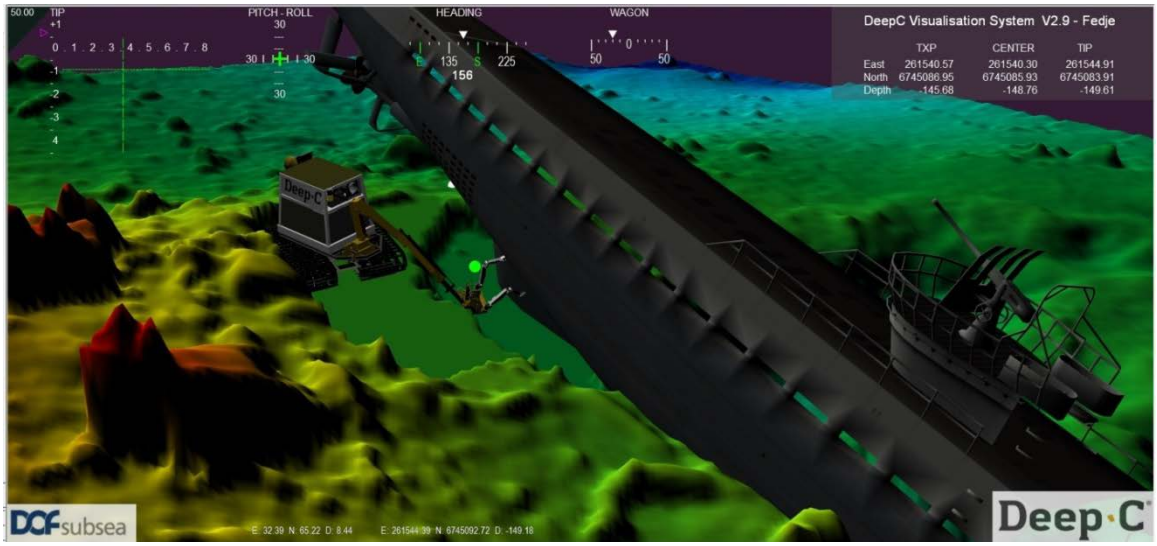
Action	Sub step	Mitigating action	Description of actin	Probability after action	Consequence after action
T1.5 (R1)	4.2.1.1	The use of a small suction pump	If free floating mercury is excavated a small suction pump that delivers the exhausts to a closed IBC container can be used.	Reasonably probable	ELT(Lo) EST(Lo)
T1.6 (R1)	4.2.1.1	The use of a smaller suction dredge	To reduce the flow from the exhaust, a smaller suction dredge can be used.	Reasonably probable	ELT(Lo) EST(Lo)
T5.1 (R5)	4.2.1.1	Geotechnical assessment	Assessment of soil conditions	Reasonably probable	ELT(Lo) EST(Lo)
T5.2 (R5)	4.2.1.1	Stabilising barrier	Sheet pile stabilisation or sand bags etc.	Reasonably probable	ELT(Lo) EST(Lo)

2.3 Open the keel

2.3.1 Operation

2.3.1.1 Drill or cut to open the keel

Drill or cut in the side plate to open the keel before the keel plates are removed. After removing the canisters and free floating mercury from the compartment, the other side of the keel must be accessed by cutting through the thick keel wall. In this operation it is essential that the cutting tool does not rupture the canisters in the opposite keel compartment.



2.3.2 Equipment and tooling

No	Operational sub step	Equipment or tools applied
4.3.1.1	Inspect compartments on the opposite side of the keel	ROV with tools to cut and drill Camera small enough to enter drilled hole
4.3.1.2	Drill or cut open the keel	ROV with tools to cut and drill

2.3.3 Risk assessment

2.3.3.1 Risk before mitigating actions

Risk	Sub step	Risk	Description	Probability	Consequence
R3	4.3.1.1 4.3.1.2	Spread contaminated sediments because of ROV operation	During the ROV operation the thrusting of the ROV or physical contact between ROV and the seabed can lead to spreading of contaminated sediments. This can also lead to reduced visibility and therefore delay the operation.	Likely	ELT(Lo) EST (C) OS (Lo)
R13	4.3.1.2	Access to other side of keel	When the wreck is stable and the keel is excavated, one side of the keel is easily accessible. It is uncertain how much effort is required to get access to the other side of the keel.	Likely	OS (C)

2.3.3.2 Risk after mitigating actions

Action	Sub step	Mitigating action	Description of action	Probability after action	Consequence after action
T3.1 (R3)	4.3.1.1 4.3.1.2	Cover the sediments	Cover the sediments with a mat or gravel.	Unlikely	ELT(Lo) EST(Lo) OS (M)
T3.2 (R3)	4.3.1.1 4.3.1.2	Optimal trim	Operate ROV with optimal trim.	Reasonably probable	ELT(Lo) EST(Lo) OS (M)
T3.3 (R3)	4.3.1.1 4.3.1.2	Experience and training	The ROV operator should be experienced and trained for the specific operation through simulation.	Reasonably probable	ELT(Lo) EST(Lo) OS (M)
T3.4 (R3)	4.3.1.1 4.3.1.2	ROV foundation	The ROV can use a magnet, a sticky foot, a platform and bags of sand or gravel as a foundation during the operation to reduce the thrusting of the ROV.	Reasonably probable	ELT(Lo) EST(Lo) OS (M)
T13.1 (R13)	4.3.1.2	Alterative equipment	Special designed equipment for this operation.	Unlikely	OS (C)
T13.2 (R13)	4.3.1.2	Inspection	Check the other side of the keel with a camera before starting the cut to prevent puncturing mercury canisters.	Unlikely	OS (C)
T13.3 (R13)	4.3.1.2	Testing/planning	Simulation and testing of method and equipment.	Unlikely	OS (C)

2.4 Retrieve the Mercury canisters from keel to seabed

2.4.1 Operation

2.4.1.1 Removal of mercury canisters from keel

The safest way to collect the bottles without destroying them is by using a suction pad. If the canisters are corroded together a specially designed lifting grab has to be used.

2.4.1.2 Removal of free floating mercury from keel

In the case where floating mercury is found the use of a suction pump is most efficient.

2.4.2 Equipment and tooling

No	Operational sub step	Equipment or tools applied
4.4.1.1	Removal of mercury canisters from keel	ROV with suction pad or designed lifting gear.
4.4.1.2	Removal of free floating mercury from keel	ROV with suction pump

2.4.3 Risk assessment

2.4.3.1 Risk before mitigating actions

Risk	Sub step	Risk	Description	Probability	Consequence
R11	4.4.1.1	Crush or drop canisters	The canisters are of various qualities. When extracting them from the keel it is very likely that some of them will be crushed. It is also very likely that some canisters may be dropped between the keel and the subsea basket.	Likely	ELT(La) EST(La) OS (La)

2.4.3.2 Risk after mitigating actions

Action	Sub step	Mitigating action	Description of action	Probability after action	Consequence after action
T11.1 (R11)	4.4.1.1.	“Vacuum cleaner”	To reduce the consequence of a mercury spill there should be access to a suction pump that can retrieve smaller amounts of floating mercury.	Likely	ELT(M) EST(M) OS (M)
T11.2 (R11)	4.4.1.1.	Design of receiving area	There should be a specially designated area next to the keel where the canisters are received. In this area the seabed should be designed so that any spill can easily be collected. This will not reduce the chance of crushing or dropping canisters, but the contamination will be limited.	Likely	ELT(M) EST(M) OS (M)
T11.3 (R11)	4.4.1.1.	Design of handling equipment	The handling equipment should be designed and tested with the aim to reduce number of canisters broken or dropped.	Likely	ELT(M) EST(M) OS (M)

2.5 Recover Mercury canisters and free floating Mercury from seabed to surface

2.5.1 Operation

2.5.1.1 Recover mercury canisters from seabed to surface

When the canisters are taken out of the keel they will be placed into a big container and brought up to the surface. DOF Subsea has designed a box where several canisters can be loaded and where spillage inside the box can be drained when the box is on deck.

2.5.1.2 Recover free floating mercury from seabed to surface

The free floating mercury will be collected with a suction pump into an IBC container bag.

2.5.1.3 Land and handle mercury on deck

When landing the subsea basket and other equipment that has been subsea there is a risk transferring contaminated sediments to the deck of the ship.

2.5.2 Equipment and tooling

No	Operational sub step	Equipment or tools applied
3.5.1.1	Bring mercury canisters from seabed to surface	Sealed box for several canisters at a time with a possibility to drain spillage.

2.5.3 Risk assessment

2.5.3.1 Risk before mitigating actions

Risk	Sub step	Risk	Description	Probability	Consequence
R14	4.5.1.1	Load falling	Uncontroll fall of basket when brought from surface to deck.	Extremely remote	ELT(La) EST(La) OS (Lo)
R15	4.5.1.1	Bottle crushed	Bottles crushed due to pressure difference.	Reasonably possible	ELT (La) EST (La)
R16	4.5.1.3	Spillage on deck	Spillage on deck due to contaminated equipment.	Likely	ELT (Lo) EST (Lo) PS (Lo)

2.5.3.2 Risk after mitigating actions

Action	Sub step	Mitigating action	Description of action	Probability after	Consequence

				action	after action
T14.1 (R14)	4.5.1.3	Procedure	The ROV checks that everything is closed and in place before lift.	Theoretically Possible	ELT(La) EST(La) OS (Lo)
T14.2 (R14)	4.5.1.3	Certified lifting equipment	For example closed offshore basket.	Theoretically Possible	ELT(La) EST(La) OS (Lo)
T15.1 (R15)	4.5.1.1	Sealed box	To avoid spillage because of this event it is important to use a sealed box.	Likely	ELT(M) EST(M)
T16.1 (R16)	4.5.1.3	Landing area	Predefined landing area on deck for subsea basket.	Unlikely	ELT(Lo) EST(Lo) PS (Lo)
T16.2 (R16)	4.5.1.3	Personal Protective gear	Gear to protect personnel handling the mercury and personnel located on deck.	Reasonably probable	ELT(Lo) EST(Lo) PS (Lo)
T16.3 (R16)	4.5.1.3	Cleaning of equipment under water	To reduce spillage on deck all equipment can be cleaned when submerged.	Unlikely	ELT(Lo) EST(Lo) PS (Lo)
T16.4 (R16)	4.5.1.3	Vessel heading	On DP the vessel heading will always be up-wind adjusted for the wave direction. If possible mercury evaporation is expected the vessel heading must be confirmed optimised to avoid any mercury gas exposure of the vessel superstructure.	Reasonably probable	ELT(Lo) EST(Lo) PS (Lo)
T16.5 (R16)	4.5.1.3	Experienced people	There has to be a crew of experienced people handling the mercury according to regulations.	Unlikely	ELT(Lo) EST(Lo) PS (Lo)
T16.6 (R16)	4.5.1.3	Adequate sealing of container	The box carrying the canister and free floating mercury has to have a robust and safe sealing mechanism.	Unlikely	ELT(Lo) EST(Lo) PS (Lo)

2.6 Stabilise wreck before capping

Before any wreck capping an “as-left” report must be prepared describing experience obtained and status of the two wreck parts. This report must be used as basis for the final recommended capping solution prepared by geotechnical expertise and other as required.

3 RISK ASSESSMENT

The risk assessment shows that all risk has been reduced to significant or due to the suggested mitigating actions.

Spreading of mercury contaminated sediments when stabilising the wreck and excavating the keel is a large risk but can be mitigated. Development of new technology could be more efficient in terms of reducing spreading of contamination but will require unknown recourses on research and testing

Mechanical dredging using a smaller suction dredge or a small suction pump can be used. Mechanical dredging will give moderate spreading but will increase the time of the operation.

4 LIST OF COMMON RISKS

No	Name	Description
R1	**Spreading of mercury contaminated sediments**	Spread contaminated sediments during suction dredging according to NIVA report 5279-2006.
R2	**Unwanted bodies around wreck or in the soil.**	Can be parts of wreck or stones that makes it difficult to place drag anchor, but can also make it difficult for the ROV to manoeuvre.
R3	**Spread contaminated sediments because of ROV operation**	During the ROV operation the thrusting of the ROV or physical contact between ROV and the sediments can lead to spreading of contaminated sediments. This can also lead to reduced visibility and therefor delay the operation.
R4	**Uncontrolled movement of sediments surrounding the bow structure**	The sediments surrounding the bow section are not stable and can be the cause of a massive slide. Polluted sediments will then be spread into the water column. If the bow section moves during the slide the keel can break up and lead to further contamination.
R5	**Uncontrolled movement and back fill of sediments during dredging**	The sediment has very low shear strength at approximately 5-10 KP. This makes it hard to stabilise.
R6	**Uncontrolled rotation**	
R7	**Access to pressure hull**	It might be difficult to get access to the pressure hull. The outer hull is very fragile and hull parts may for example fall of during ROV operation.
R8	**Excavation operation, mechanical dredging**	
R9	**Damaged keel**	When the hull rolls over the keel can be stuck in the sediments and therefore partly damaged. If the more canisters rupture during this phase this might lead to further contamination of the of the sediments under the keel.
R11	**Crush or drop canisters**	The canisters are of various qualities. When extracting them from the keel it is very likely that some of them will be crushed. It is also very likely that some canisters can be dropped between the keel and the subsea basket.
R13	**Access to other side of keel**	When the wreck is stable and the keel is excavated, one side of the keel is easily accessible. It is uncertain how much effort is required to get access to the other side of the keel.
R14	**Load falling**	Uncontrollable fall of basket when brought from surface to deck.
R15	**Bottles crushed**	Bottles crushed due to pressure difference.
R16	**Spillage on deck**	Spillage on deck due to contaminated equipment.
R17	**Air pockets in bow section**	Bow section might still contain air pockets, and is therefore unstable.
DR18	**Not able to operate excavator at bow section**	Due to the 20° slope and the soft seabed at the bow section, it is not known if it is possible to operate the excavator for obtaining keel access.

About DNV GL

Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter and greener.

Appendix V3.05.2

ENVIRONMENTAL MEASURES FOR THE WRECK OF U-864

Feasibility study - Suggested method for U864 mercury cargo recovery: Oceaneering

DNV GL AS

Project name:	Environmental measures for the wreck of U-864	DNV GL AS
Report title:	Feasibility study - Suggested method for U864 mercury cargo recovery: Oceaneering	Project Management & Technical Services Program P.O.Box 300 1322 Høvik Norway Tel: +47 67 57 99 00

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Dato: 12.5.2014

Reference to part of this report which may lead to misinterpretation is not permissible.

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1 INTRODUCTION

The German submarine U-864 was torpedoed by the British submarine Venturer 9th of February 1945, approximately 2 nautical miles west of the Island Fedje in Hordaland. U-864 was on its way from Germany via Norway to Japan. The submarine was loaded with war material, and according to historical documents approximately 67 ton of floating metallic mercury in steel canisters stored in the keel. The torpedo split the submarine into two parts. The wreck parts were discovered by the Royal Norwegian Navy at a depth of approximately 150-175 m. Several studies have revealed feasible measures for pollution abatement. The risks related to these measures have been assessed and indicate the following:

- High mercury concentrations in the soil, especially around the wreck parts.
- The bow section is inclining and has a high risk of sliding downhill. (Geotechnical unstable)
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- Oil in the wreck.
- The condition of the two wreck parts.
- The condition of the mercury canisters.

In 2013 DNV-GL was assigned by the Norwegian Coastal Administration to carry out a pre-project that will assess the possibility of recovering the mercury canisters from the wreck parts before capping the wreck parts and the polluted seabed-area. As part of the assignment, competent subsea companies have been invited to discuss feasible solutions and cost pertaining to the proposed solutions.

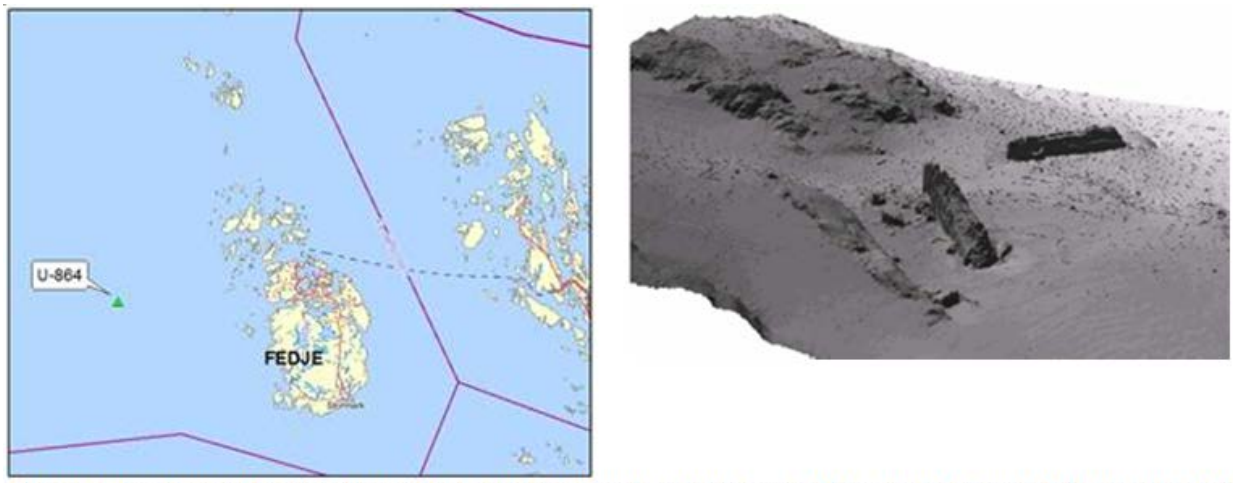


Figure 1.Loction of the wreck outside Fedje (left) and sonar image of bow and aft part of the wreck (right)

2 SUGGESTED METHOD TO RETRIEVE MERCURY CANISTERS

To avoid a global collapse of the seabed slope where the bow section resides, the valley to the North will be rock dumped with the purpose of stabilising the area prior to any intervention work on the wreck. This measure is valid for all the suggested methods from all companies participating in this RFI (Request for information).

For all companies the operation has been divided into 6 generic steps as presented in the table below. The suggested method by Oceaneering for the retrieval of the mercury canisters from the keel of U-864 is presented briefly in the table below and more in detail in the succeeding sub-chapters:

No	Operational step	Brief description (company specific)
4.1	Preparations	Secure the Bow section with wires and fill the section with water. Place one lifting frame on suction anchors surrounding each part of the wreck. Cut holes in the hull for fastening anchoring screws. Place hydraulic winches on the frame and a wire from the anchoring screws on the hull to the winch. Tighten the wires to secure the wreck.
4.2	Get access to the keel	Lift both parts of the wreck in parallel with the seabed where the lowest part of the keel should be lifted first to release the suction between the sediments and the keel. Roll out a plastic cover under the wreck as soon as possible to collect any canister or free floating mercury that could fall out of the keel.
4.3	Open the keel	Make a hole into the side plate of the keel and use suction to remove any free floating mercury or very contaminated sediments in the keel. Then use the same hole to inspect the keel with a camera. Secure the keel plate before a cut is made around the keel plate screws to loosen them from the keel.
4.4	Retrieve the Mercury canisters from keel to seabed	The canisters can either be withdrawn from the keel through the use of a suction pad, magnet or a specially designed grabbing mechanism. To remove liquid Mercury, a suction pump can be used. The canisters will be placed in a box with a size depending on how many canisters are stuck together due to corrosion.
4.5	Bring Mercury canisters and free floating Mercury from seabed to surface	The boxes will be places in a standard offshore basket that will bring them to the surface. They will be landed in a dedicated area and handled by expert.
4.6	Stabilise wreck before capping	After retrieving the canisters and free floating mercury the hull will be placed back on the seabed. The frame will then be removed but the suction anchors will be left to avoid spreading

of contaminated sediments. Both parts of the wreck will then be stable and ready for capping.

In the following chapters this method will be further elaborated with a focus on equipment and tools being used, and a risk assessment of the operation. The sketches included below are not accurate when it comes to dimensions, they are only included to give the reader a better understanding of the suggested concept. More sketches are included in chapter 4.

In the risk assessment possible event are rated with probability and consequence with values according to the risk matrix in figure 2.

		Consequence				
		Minor	Low	Considerable	Large	Severe
Probability	Likely	Significant	Critical	Critical	Critical	Critical
	Reasonably prob	Significant	Significant	Critical	Critical	Critical
	Unlikely	Insignificant	Significant	Significant	Critical	Critical
	Remote	Insignificant	Insignificant	Significant	Significant	Critical
	Extremely remote	Insignificant	Insignificant	Insignificant	Significant	Significant
	Theoretically Possible	Insignificant	Insignificant	Insignificant	Insignificant	Significant

Figure 2: Risk matrix

Subsequently the mitigating actions that reduce the probability and/or the consequence of the event are identified. The new rating of probability and consequence for the event is then assessed.

One common set of risks and actions will be used as basis for all companies (See chapter 3) which has a numbering from R1 to R16 for risks and T1.x to T16.x for Mitigating actions. For company and method specific risks the numbering will start with an abbreviation representing the company (D,SW,T,O,S7).

The abbreviations used in the risk assessment tables in this document are shown in the table below. The first four rows are abbreviations for different types of consequences. The five last rows are abbreviations for the magnitude of a particular type of consequence. Other abbreviations used are listed in the underlying table.

Abbreviation	Full text
ELT	Environment LONG Term
EST	Environment SHORT term
PS	Personnel SAFETY
OS	Operational SAFETY
M	Minor consequence
Lo	Low consequence
C	Considerable consequence
La	Large consequence
S	Severe consequence

2.1 Preparations

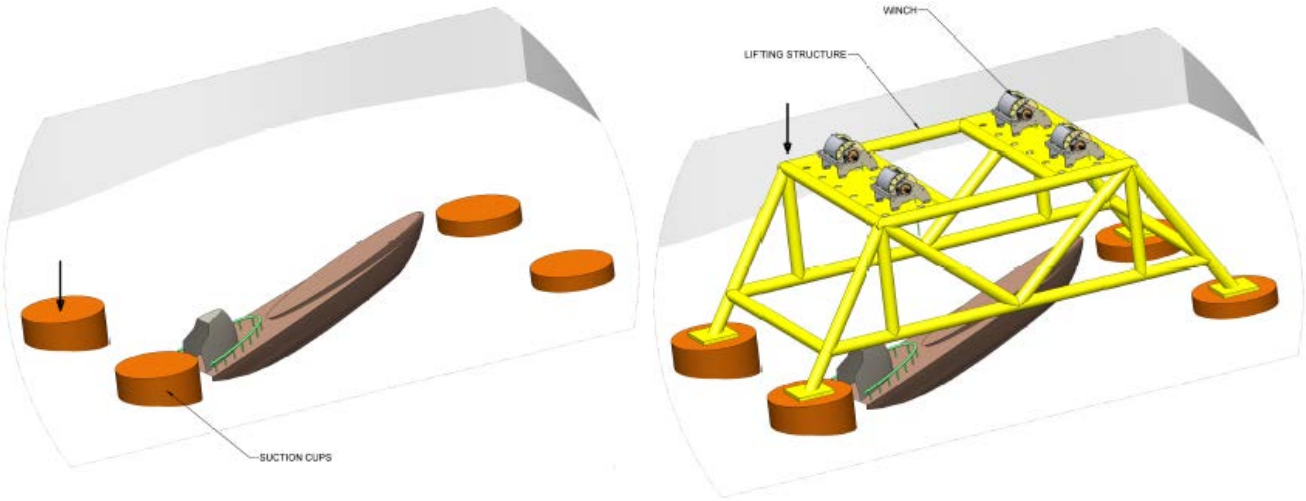
2.1.1 Operation

2.1.1.1 Secure the bow section

Secure the Bow section with wires and fill the section with water to further stabilise the wreck.

2.1.1.2 Place lifting frame into position

Place lifting frames in position on suction anchors surrounding each part of the wreck.



2.1.1.3 Fasten wire arrangement and secure in position

Cut holes in the hull for fastening anchoring screws. Then place hydraulic winches on the frame and a wire from the anchoring screws on the hull to the winch. Tighten the wires to secure the wreck.

2.1.2 Equipment and tooling

Oceaneering suggests using the following equipment and tooling:

No	Operational sub step	Equipment or tools applied
4.1.1.1	Secure the bow section	Wire, winch, ROV. Bolts and equipment to fasten bolts to solid rock.
4.1.1.2	Positioning of a lifting frame	Lifting frame, crane, suction anchors, ROV
4.1.1.3	Fasten wire arrangement and secure in position	Drilling equipment, wires, hydraulic winches, anchor Screws, ROV etc.

2.1.3 Risk assessment

2.1.3.1 Risk before mitigating actions

Risk	Sub step	Risk	Description	Probability	Consequence
OR1	4.1.1.2	Destabilising sediments	Because of the pressure from the lifting frame and the use of suction anchors the sediments can slide in the hill surrounding the bow section.	Likely	ELT(La) EST(La)
R2	4.1.1.2	Unwanted bodies around wreck or in the soil.	Wreck parts or stones can make it difficult to place suction anchor, but can also make it difficult for the ROV to operate.	Likely	OS(Lo)

2.1.3.2 Risk after mitigating actions

Action (Risk)	Sub step	Mitigating action	Description of action	Probability after action	Consequence after action
OT1.1 (OR1)	4.1.1.2	Geotechnical	Further geotechnical surveys in the hill where the bow structure is situated.	Remote	ELT(La) EST(La)
OT1.2 (OR1)	4.1.1.2	Buoyancy balloon.	Apply buoyancy balloons to the wrecks to reduce the pressure on the sediments in the unstable hill.	Remote	ELT(La) EST(La)
OT1.3 (OR1)	4.1.1.2	Foundation in solid rock	Make a foundation for the lifting frame that is anchored into solid rock	Remote	ELT(La) EST(La)
T2.1 (R2)	4.1.1.2	Geotechnical examination	With further examinations it will be easier to plan the placement of the anchors.	Unlikely	OS(Lo)
T2.2 (R2)	4.1.1.2	Alternative anchor on seabed	If placing the suction anchor becomes problematic and if solid bedrock is available it may be an alternative to place the anchor in solid rock.	Reasonable probable	OS(Lo)
T2.3 (R2)	4.1.1.2	Remove	Have a selection of equipment available to remove unwanted bodies.	Reasonable probable	OS(M)

2.2 Get access to the keel

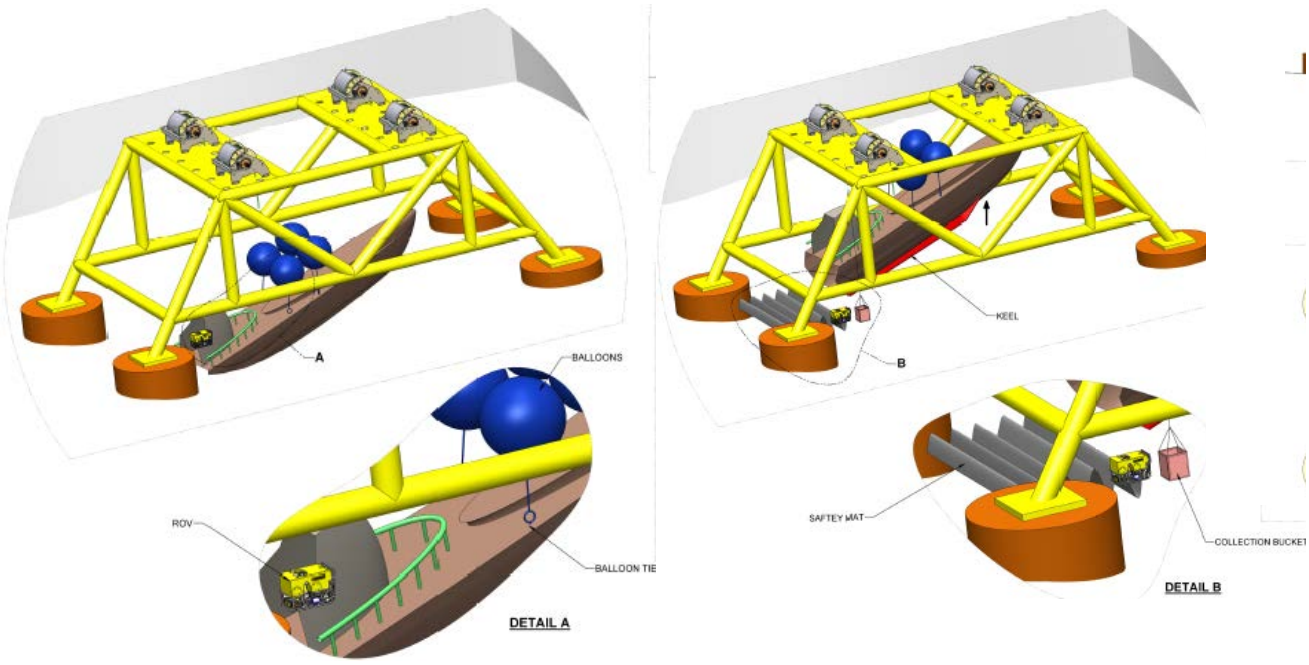
2.2.1 Operation

2.2.1.1 Lift wreck

Lift both parts of the wreck in parallel with the seabed where the lowest part of the keel should be lifted first to release the suction between the sediments and the keel. All the winches doing the lift will be synchronised and can pull at a very low speed.

Fill the buoyancy balloons on the frame for the bow section, to relieve some of the weight and avoid the sediments sliding.

Roll out a plastic cover under the wreck as soon as possible to collect any canister or free floating mercury that could fall out of the keel.



2.2.2 Equipment and tooling

No	Operational sub step	Equipment or tools applied
4.2.1.1	Lift wreck	ROV to operate the winches and one ROV to monitor the operation.

2.2.3 Risk assessment

2.2.3.1 Risk before mitigating actions

Risk	Sub step	Risk	Description	Probability	Consequence
OR2	4.2.1.1	Current puts pressure on buoyancy balloons	Strong current can make the balloons vibrate and pull in a slight non vertical direction. Could lead to challenges with the lift and the unstable sediments in the hill.	Remote	OS(L)
OR3	4.2.1.1	Wreck falls down to seabed	Because of malfunctioning anchoring screw the wreck falls down to the seabed.	Remote	OS(S)
OR4	4.2.1.1	Keel falls of partly during lift	Because of suction between keel and sediments and/or a damaged keel the keel falls of partly during lift.	Remote	ELT(M) EST(Lo) OS(C)
OR5	4.2.1.1	Side plates falls off the keel and content falls out.	Because of corrosion the side plates might fall off when the wreck is lifted and then the content can fall out.	Likely	ELT(M) EST(Lo) OS(Lo)

2.2.3.2 Risk after mitigating actions

Action	Sub step	Mitigating action	Description of action	Probability after action	Consequence after action
OT2.1 (OR2)	4.2.1.1	Perform analysis	Perform an analysis to optimise the design to handle the currents in the area.	Extremely Remote	OS(L)
OT3.1 (OR3)	4.2.1.1	Analyse condition of hull.	Thorough testing of several parts of the hull, determine how well the hull can manage the lift with anchoring screws.	Extremely Remote	OS(S)
OT3.2 (OR3)	4.2.1.1	Design anchoring screws	Do research into the optimal design of the hull anchoring screws for this operation.	Extremely Remote	OS(S)
OT4.1 (OR3)	4.2.1.1	Design lifting operation	Design the lifting operation to minimise the suction between the area under the keel and the sediments.	Extremely Remote	ELT(M) EST(Lo) OS(C)
OT5.1 (OR5)	4.2.1.1	Design lifting operation	Design a lifting operation where all movement are smooth and the keel is horizontal through the entire operation.	Reasonably probable	ELT(M) EST(Lo) OS(Lo)
OT5.2 (OR5)	4.2.1.1	Roll out a cover under the wreck	By rolling out a cover under the consequence of anything falling out of the keel will be reduced	Likely	ELT(M) EST(M) OS(Lo)

2.3 Open the keel

2.3.1 Operation

2.3.1.1 Drain and inspect the keel

Make a hole into the side plate of the keel and use suction to remove any free floating mercury or very contaminated sediments in the keel. Then use the same hole to inspect the keel with a camera.

2.3.1.2 Open the keel

This method allows an access to both sides of the keel. Secure the keel plate before a cut is made around the keel plate screws to loosen the side plate from the keel.

2.3.2 Equipment and tooling

No	Operational sub step	Equipment or tools applied
4.3.1.1	Drain and inspect the keel	Cutting equipment, suction unit, inspection camera
4.3.1.2	Open the keel	ROV with tools to secure and cut around the bolts in the side plates on the keel.

2.3.3 Risk assessment

2.3.3.1 Risk before mitigating actions

Risk	Sub step	Risk	Description	Probability	Consequence
R3	4.3.1.1 4.3.1.2	Spread contaminated sediments because of ROV operation	During the ROV operation the thrusting of the ROV or physical contact between ROV and the sediments can lead to spreading of contaminated sediments. This can also lead to reduced visibility and therefore delay the operation.	Likely	ELT(Lo) EST (C) OS (Lo)

2.3.3.2 Risk after mitigating actions

Action	Sub step	Mitigating action	Description	Probability	Consequence
T3.1 (R3)	4.3.1.1 4.3.1.2	Cover the sediments	Cover the sediments with a mat or gravel.	Unlikely	ELT(Lo) EST(Lo) OS (M)
T3.2 (R3)	4.3.1.1 4.3.1.2	Optimal trim	Operate ROV with optimal trim.	Reasonably probable	ELT(Lo) EST(Lo) OS (M)
T3.3 (R3)	4.3.1.1 4.3.1.2	Experience and training	The ROV operator should be experienced and trained for the specific operation through simulation.	Reasonably probable	ELT(Lo) EST(Lo) OS (M)
T3.4 (R3)	4.3.1.1 4.3.1.2	ROV foundation	The ROV can use a magnet, a sticky foot, a platform and bags of sand or gravel as a foundation during the operation	Reasonably probable	ELT(Lo) EST(Lo) OS (M)

Action	Sub step	Mitigating action	Description	Probability	Consequence
			to reduce the thrusting of the ROV.		

2.4 Retrieve the Mercury canisters from keel to seabed

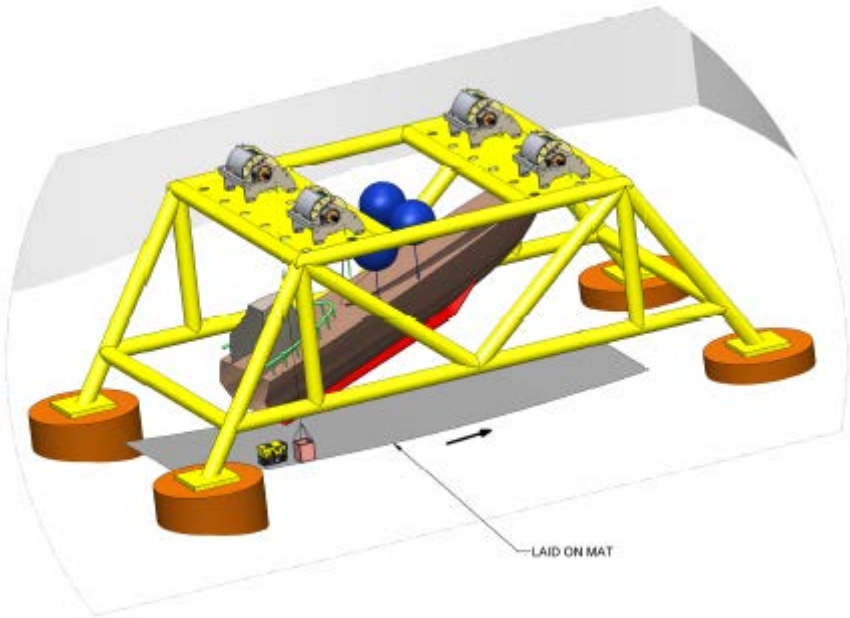
2.4.1 Operation

2.4.1.1 Removal of mercury canisters from keel

The canisters can either be withdrawn from the keel through the use of a suction pad, magnet or a specially designed grabbing mechanism. The canisters will be placed in boxes with different sizes depending on how many canisters are corroded together.

2.4.1.2 Removal of free floating mercury from keel

In the case where floating mercury is found, the use of a suction pump is most efficient.



2.4.2 Equipment and tooling

No	Operational sub step	Equipment or tools applied
4.4.1.1	Removal of mercury canisters from keel	ROV with suction pad, magnet or a specially designed grabbing mechanism.
4.4.1.2	Removal of free floating mercury from keel	ROV with suction pump

2.4.3 Risk assessment

2.4.3.1 Risk before mitigating actions

Risk	Sub step	Risk	Description	Probability	Consequence
R11	4.4.1.1	Crush or drop canisters	The canisters are of various qualities. When extracting them from the keel it is likely that some of them will be crushed.	Likely	ELT(M) EST(M) OS (M)

2.4.3.2 Risk after mitigating actions

Action	Sub step	Mitigating action	Description	Probability	Consequence
T11.1 (R11)	4.4.1.1.	"Vacuum cleaner"	To reduce the consequence of a mercury spill a suction pump should be available to retrieve smaller amounts of floating mercury.	Likely	ELT(M) EST(M) OS (M)
T11.2 (R11)	4.4.1.1.	Design of receiving area	There should be a specially prepared designated area next to the keel where the canisters are received. In this area the sea bed should be designed so that any spill can easily be collected. This will not reduce the chance of crushing or dropping canisters, but the contamination will be limited.	Likely	ELT(M) EST(M) OS (M)
T11.3 (R11)	4.4.1.1.	Design of handling equipment	The handling equipment should be designed and tested with the aim to reduce number of canisters broken or dropped.	Likely	ELT(M) EST(M) OS (M)

2.5 Bring Mercury canisters and free floating Mercury from seabed to surface

2.5.1 Operation

2.5.1.1 Bring mercury canisters from seabed to surface

The boxes will be placed in a standard offshore basket that will bring them to the surface.

2.5.1.2 Land and handle mercury on deck

When landing the subsea basket and other equipment that has been subsea, there is a risk transferring contaminated sediments to the deck of the ship. On the ship there will be a defined landing area for the subsea basket and all the equipment used subsea. The mercury will be handled by dedicated experts.

2.5.2 Equipment and tooling

No	Operational sub step	Equipment or tools applied
4.5.1.1	Bring mercury canisters from seabed to surface	Sealed box with room for several canisters with a capability to drain spillage. This box will be placed in a standard subsea basket.

2.5.3 Risk assessment

2.5.3.1 Risk before mitigating actions

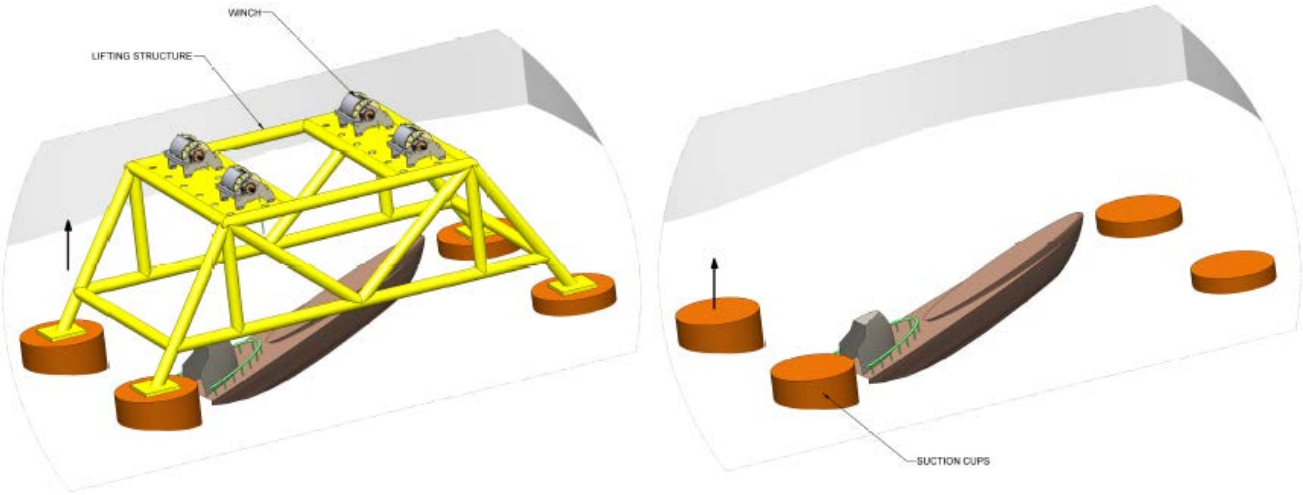
Risk	Sub step	Risk	Description	Probability	Consequence
R14	4.5.1.1	Load falling	Uncontrollable fall of basket when brought from surface to deck.	Extremely remote	ELT(La) EST(La) OS (Lo)
R15	4.5.1.1	Bottle crushed	Bottles crushed due to pressure difference.	Reasonably probable	ELT (La) EST (La)
R16	4.5.1.3	Spillage on deck	Spillage on deck due to contaminated equipment.	Likely	ELT (Lo) EST (Lo) PS (Lo)

2.5.3.2 Risk after mitigating actions

Action	Sub step	Mitigating action	Description of action	Probability after action	Consequence after action
T14.1 (R14)	4.5.1.3	Procedure	The ROV checks that everything is closed and in place before lift.	Theoretically Possible	ELT(La) EST(La) OS (Lo)
T14.2 (R14)	4.5.1.3	Certified lifting equipment.	For example closed offshore basket.	Theoretically Possible	ELT(La) EST(La) OS (Lo)
T15.1 (R15)	4.5.1.1	Sealed box	Use sealed box to avoid spillage.	Likely	ELT(M) EST(M)
T16.1 (R16)	4.5.1.3	Landing area	Predefined landing area on deck for subsea basket.	Unlikely	ELT(Lo) EST(Lo) PS (Lo)
T16.2 (R16)	4.5.1.3	Personal Protective gear	Gear to protect personnel handling the mercury and personnel located on deck.	Reasonably probable	ELT(Lo) EST(Lo) PS (Lo)
T16.3 (R16)	4.5.1.3	Cleaning of equipment under water	To reduce spillage on deck all equipment can be cleaned when submerged.	Unlikely	ELT(Lo) EST(Lo) PS (Lo)
T16.4 (R16)	4.5.1.3	Face the vessel with regards to the weather situation	Avoid evaporation from the mercury by facing the vessel against the wind so that the potential gas is led away from the deck in the most efficient way avoiding crew areas.	Reasonably probable	ELT(Lo) EST(Lo) PS (Lo)
T16.5 (R16)	4.5.1.3	Experienced people	The crew has to be experienced with handling of mercury and know procedures to manage the mercury according to regulations.	Unlikely	ELT(Lo) EST(Lo) PS (Lo)
T16.6 (R16)	4.5.1.3	Adequate sealing of container	The box carrying the canister and free floating mercury has to have a robust and safe sealing mechanism.	Unlikely	ELT(Lo) EST(Lo) PS (Lo)

2.6 Stabilise wreck before capping

After retrieving the canisters and free floating mercury the hull will be placed back on the seabed. The frame will then be removed. The suction anchors will be left in place to avoid spreading of contaminated sediments. Both parts of the wreck will then be stable and ready for capping.



3 RISK ASSESSMENT

The risk assessment shows that the overall risk picture is reduced, but there are still some risks that are critical after implementing mitigating actions.

4 LIST OF COMMON RISKS

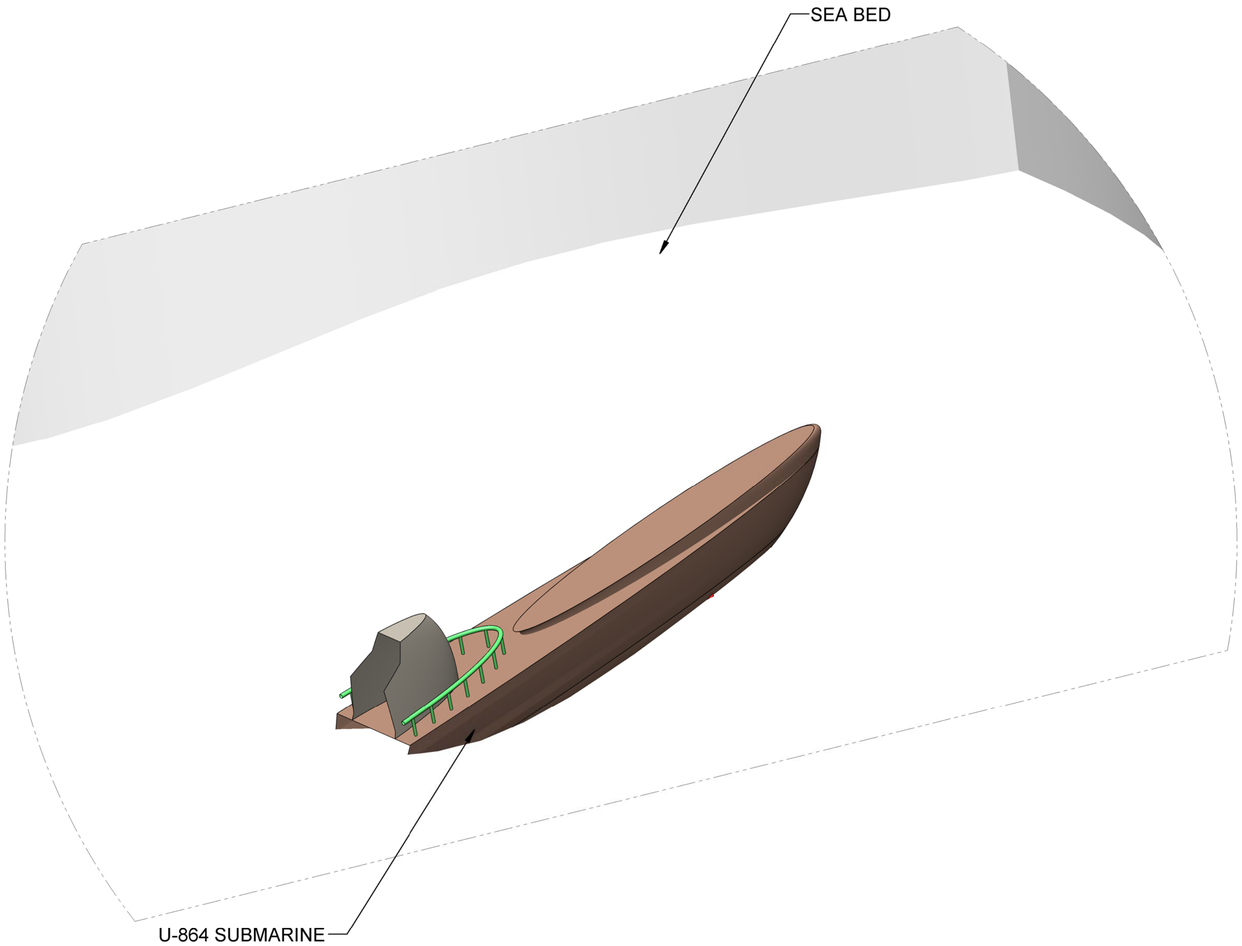
No	Name	Description
R1	**Spreading of mercury contaminated sediments**	Spread contaminated sediments during suction dredging according to NIVA report 5279-2006.
R2	**Unwanted bodies around wreck or in the soil.**	Can be parts of wreck or stones that makes it difficult to place drag anchor, but can also make it difficult for the ROV to manoeuvre.
R3	**Spread contaminated sediments because of ROV operation**	During the ROV operation the thrusting of the ROV or physical contact between ROV and the sediments can lead to spreading of contaminated sediments. This can also lead to reduced visibility and therefor delay the operation.
R4	**Uncontrolled movement of sediments surrounding the bow structure**	The sediments surrounding the bow section are not stable and can be the cause of a massive slide. Polluted sediments will then be spread into the water column. If the bow section moves during the slide the keel can break up and lead to further contamination.
R5	**Uncontrolled movement and back fill of sediments during dredging**	The sediment has very low shear strength at approximately 5-10 KP. This makes it hard to stabilise.
R6	**Uncontrolled rotation**	
R7	**Access to pressure hull**	It might be difficult to get access to the pressure hull. The outer hull is very fragile and hull parts may for example fall of during ROV operation.
R8	**Excavation operation, mechanical dredging**	
R9	**Damaged keel**	When the hull rolls over the keel can be stuck in the sediments and therefore partly damaged. If the more canisters rupture during this phase this might lead to further contamination of the of the sediments under the keel.
R11	**Crush or drop canisters**	The canisters are of various qualities. When extracting them from the keel it is very likely that some of them will be crushed. It is also very likely that some canisters can be dropped between the keel and the subsea basket.
R13	**Access to other side of keel**	When the wreck is stable and the keel is excavated, one side of the keel is easily accessible. It is uncertain how much effort is required to get access to the other side of the keel.
R14	**Load falling**	Uncontrollable fall of basket when brought from surface to deck.
R15	**Bottles crushed**	Bottles crushed due to pressure difference.
R16	**Spillage on deck**	Spillage on deck due to contaminated equipment.
R17	**Air pockets in bow section**	Bow section might still contain air pockets, and is therefore unstable.

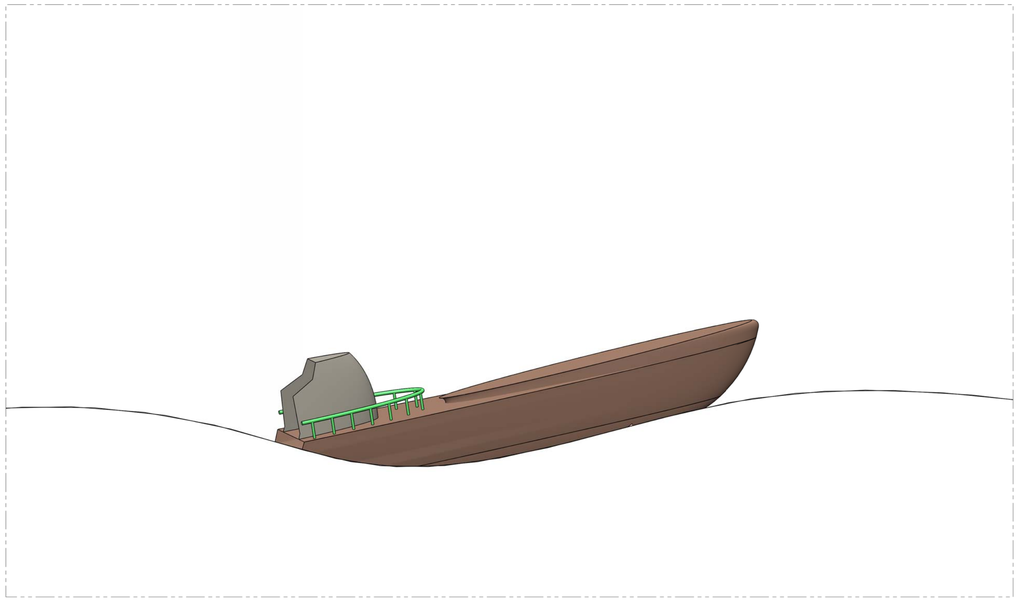
5 SKETCHES OF SUGGESTED METHOD

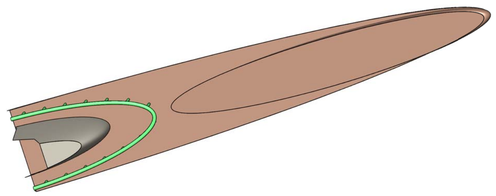
A complete set of sketches of the suggested method to retrieve mercury canisters follows:

U-864 RECOVERY PROCEDURE

INSPECTING CURRENT POSITION OF THE SUBMARINE ON SEABED.







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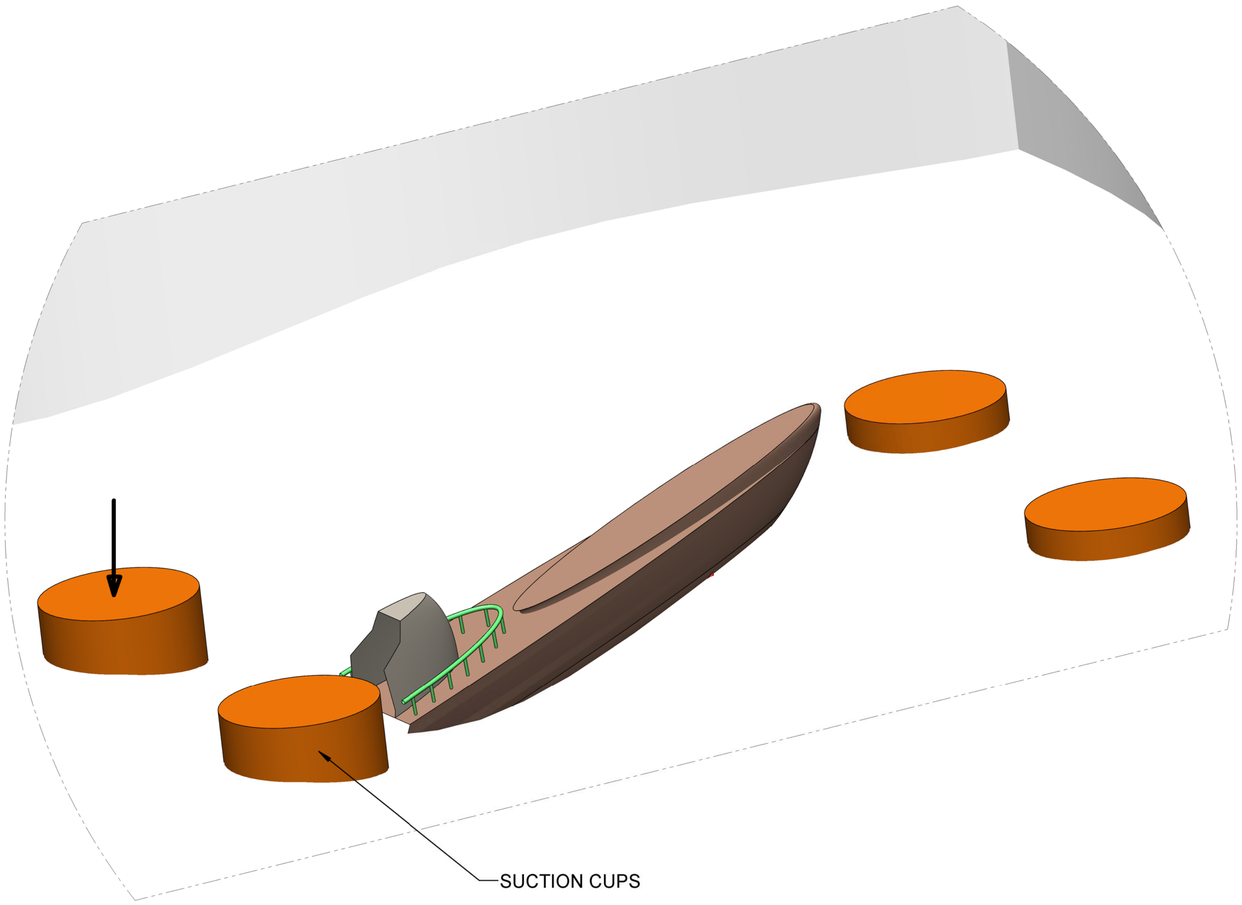
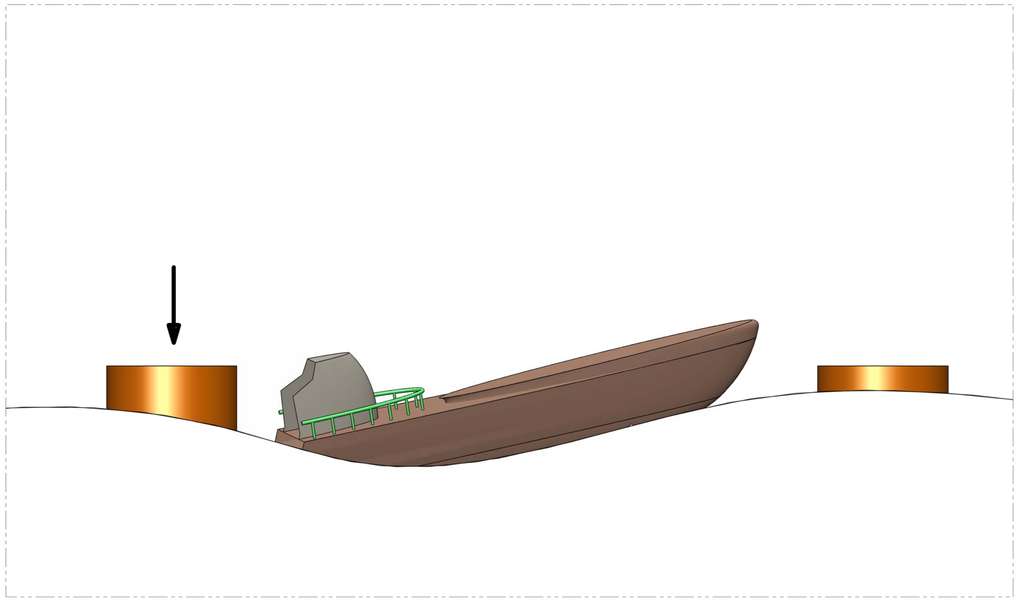
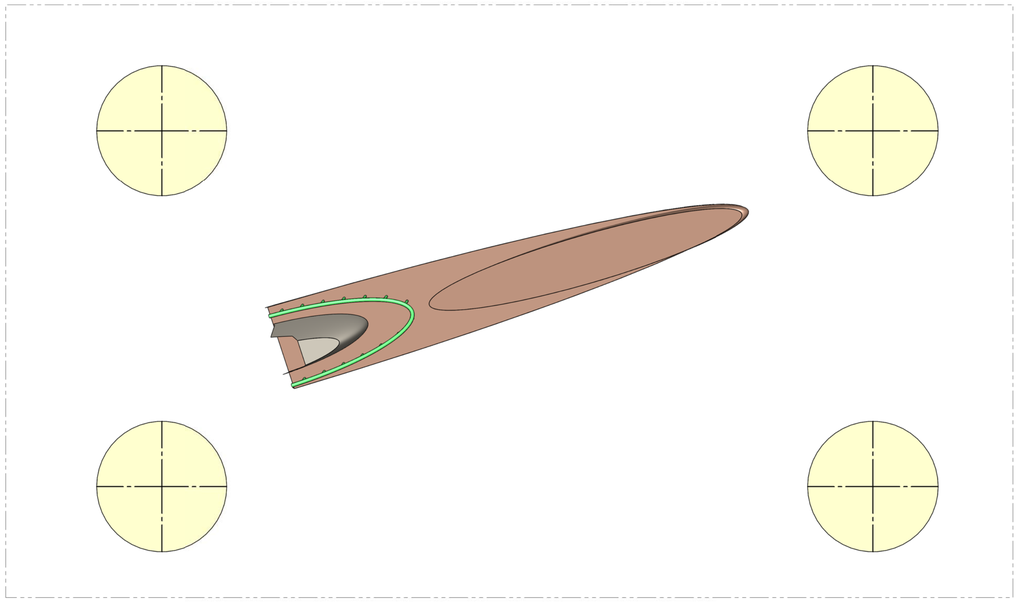
SOLIDWORKS

FORM F1366, REV. A

STEP - 1 : INSERTING THE SUCTION CUPS AROUND THE U-864.







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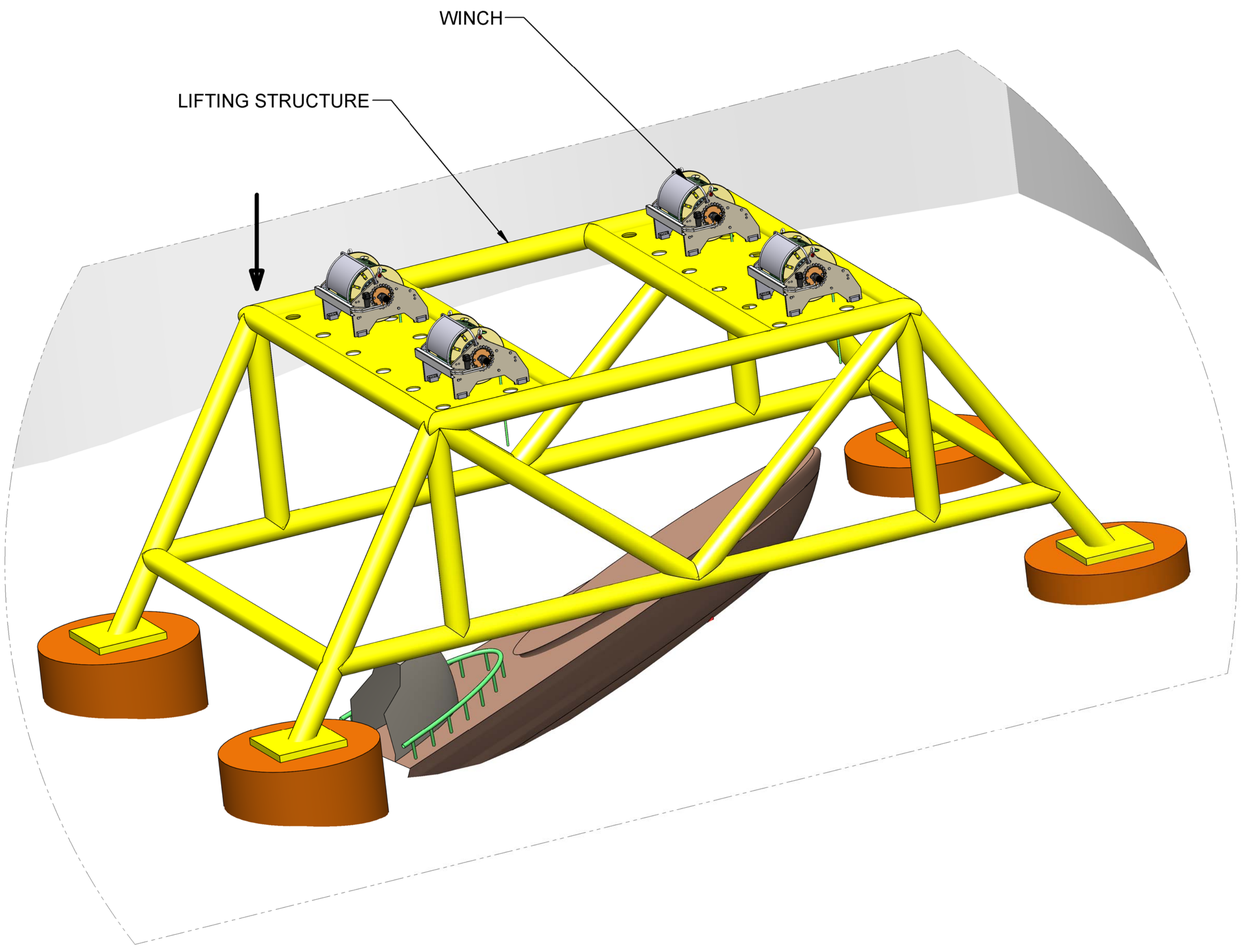
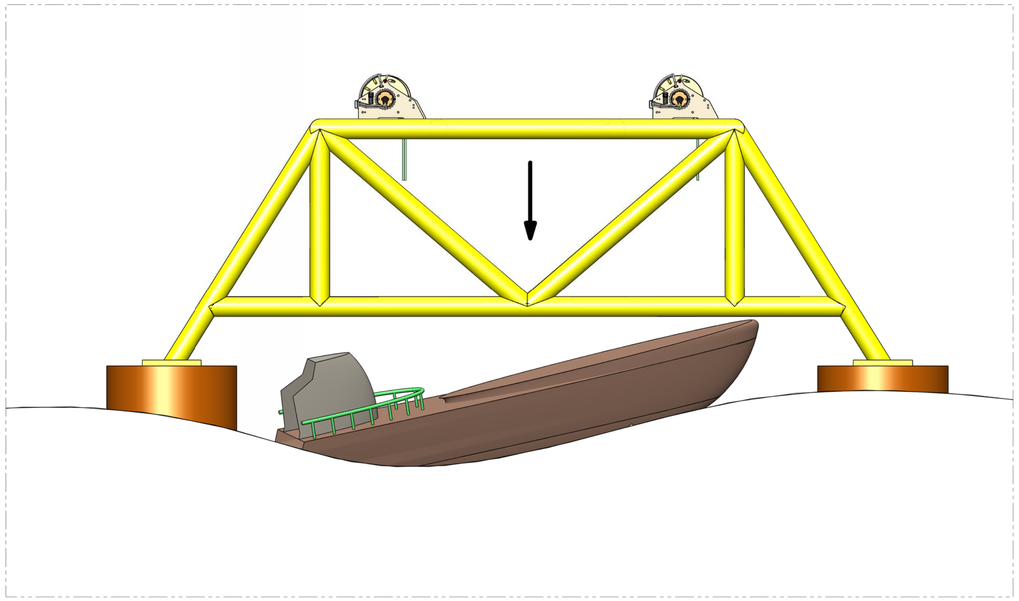
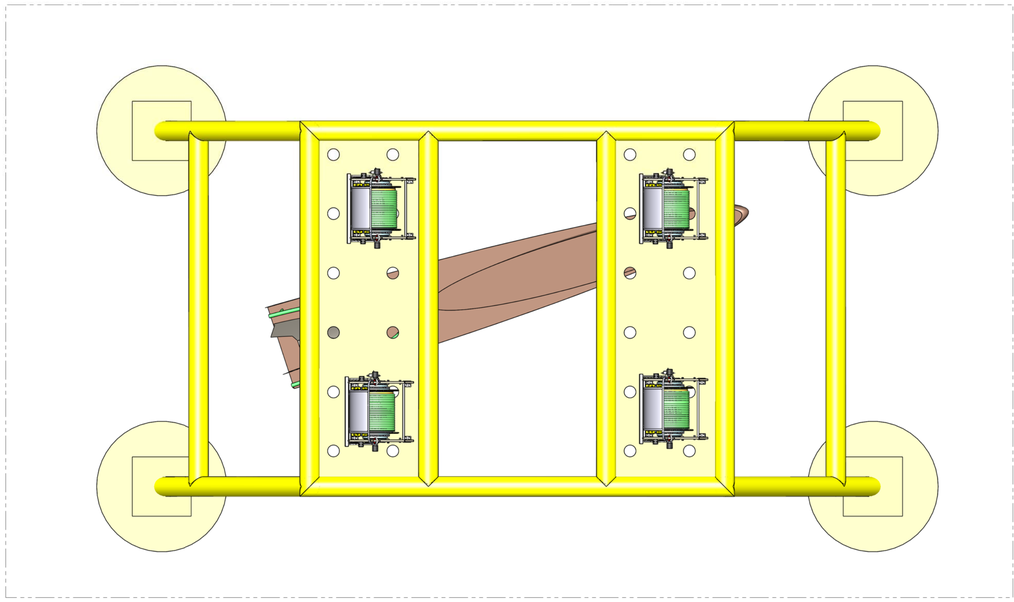
SOLIDWORKS

FORM F1366, REV. A

STEP - 2 : LOWERING DOWN THE TEMPLATE STRUCTURE WITH WINCHES ON.







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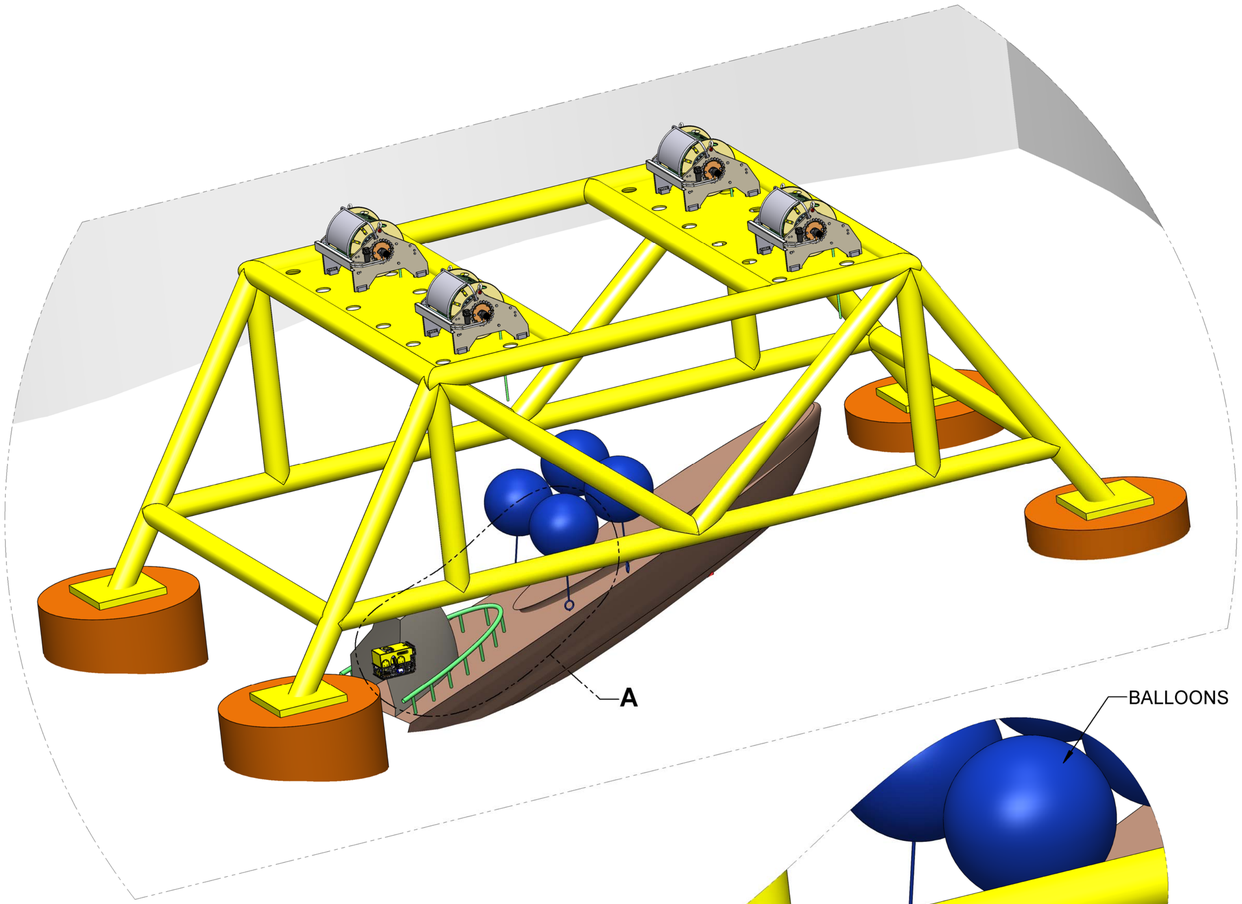
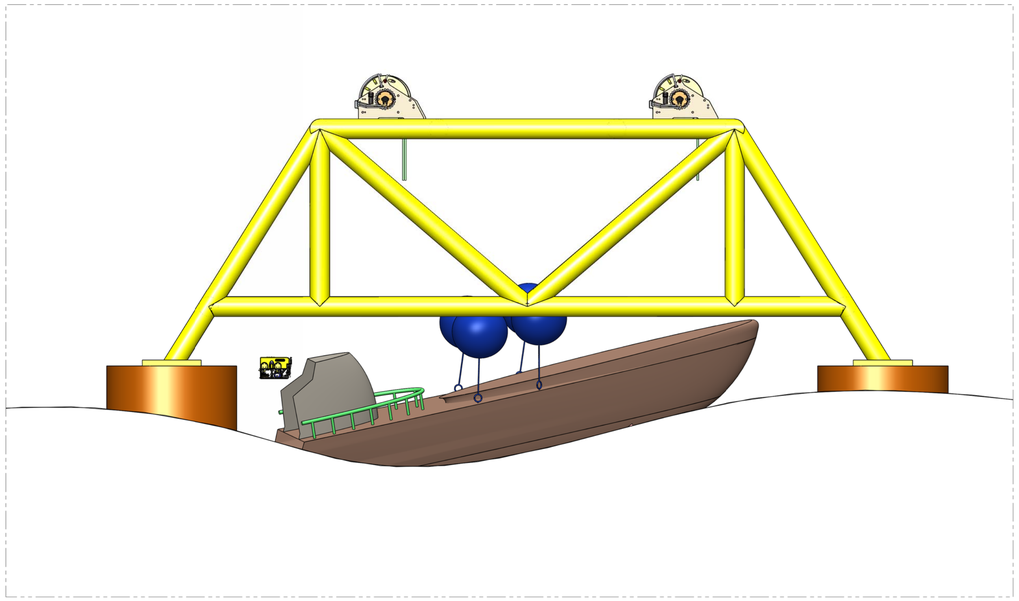
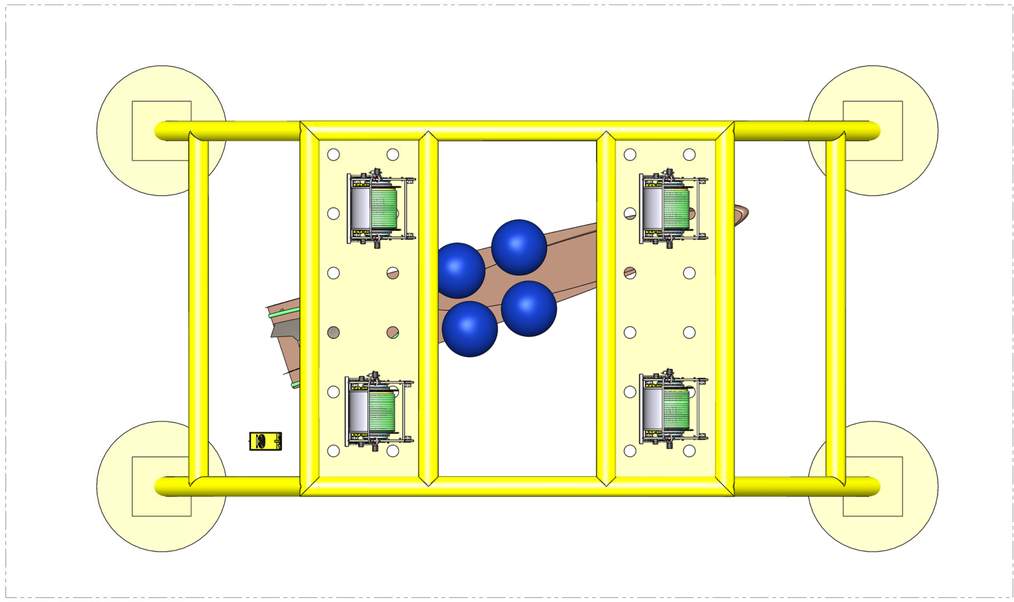
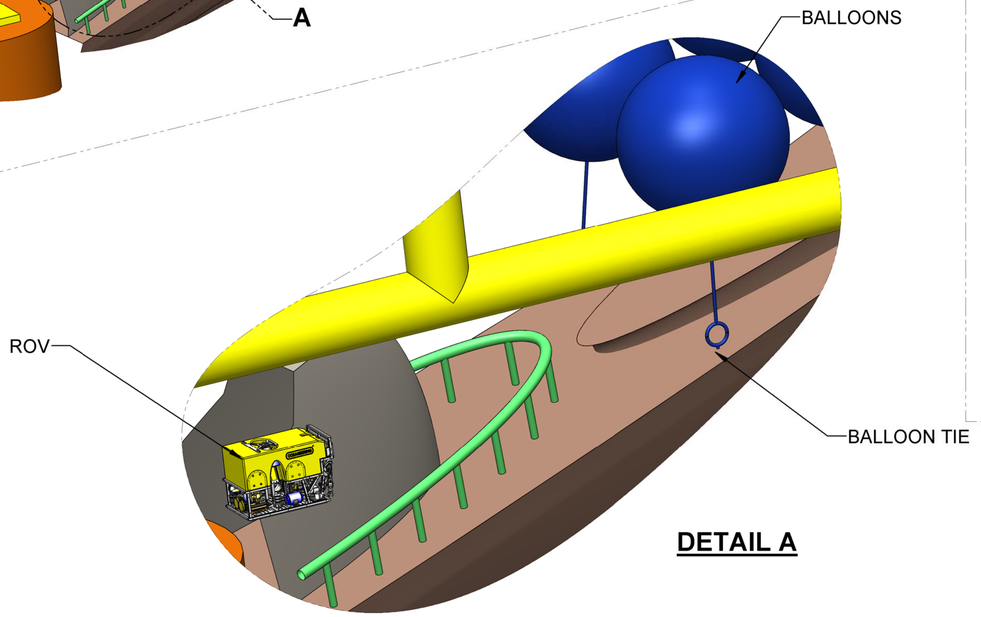
STEP - 2.1 : DRILL HOLES AND FASTEN THE TIE RODS ON TO THE SURFACE OF THE U-864 FOR THE BALLOONS AND WINCH CONNECTIONS WITH HELP OF ROV.









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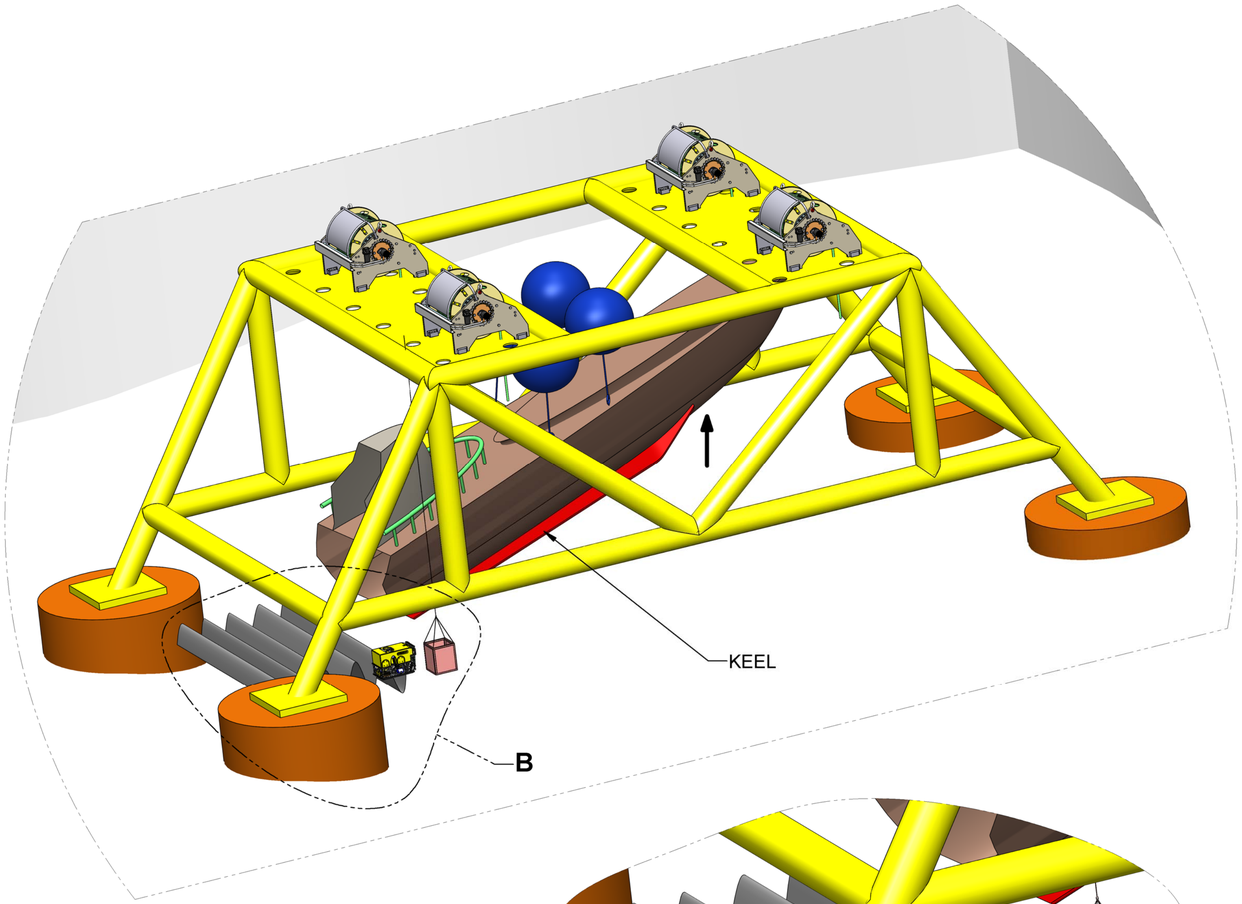
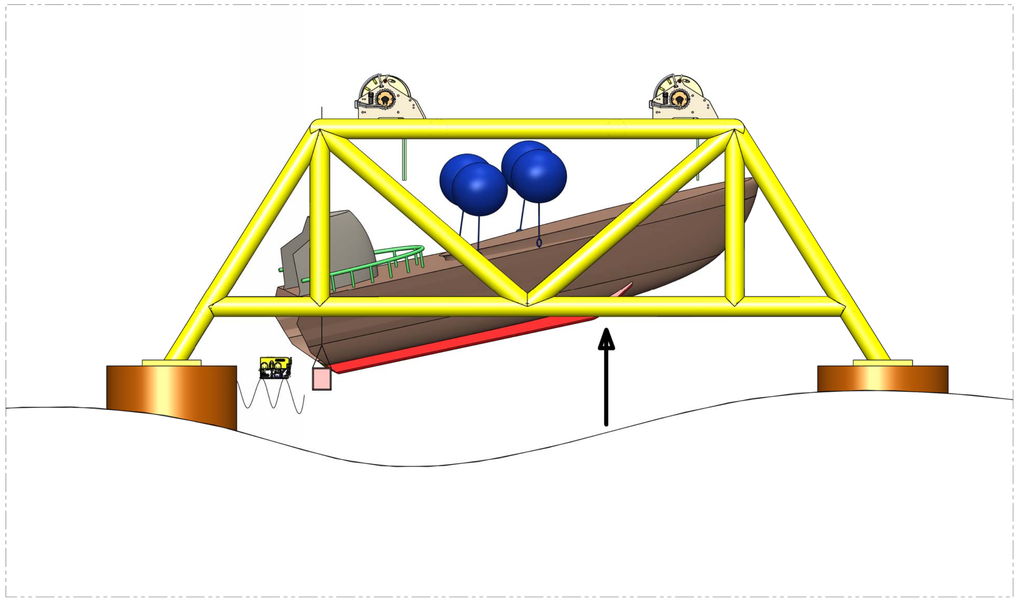
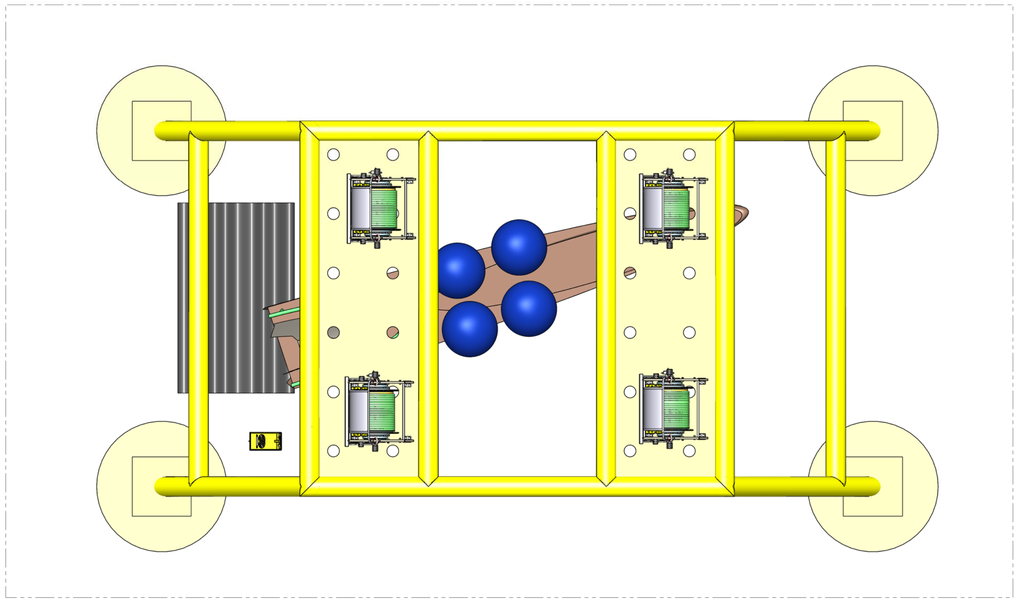
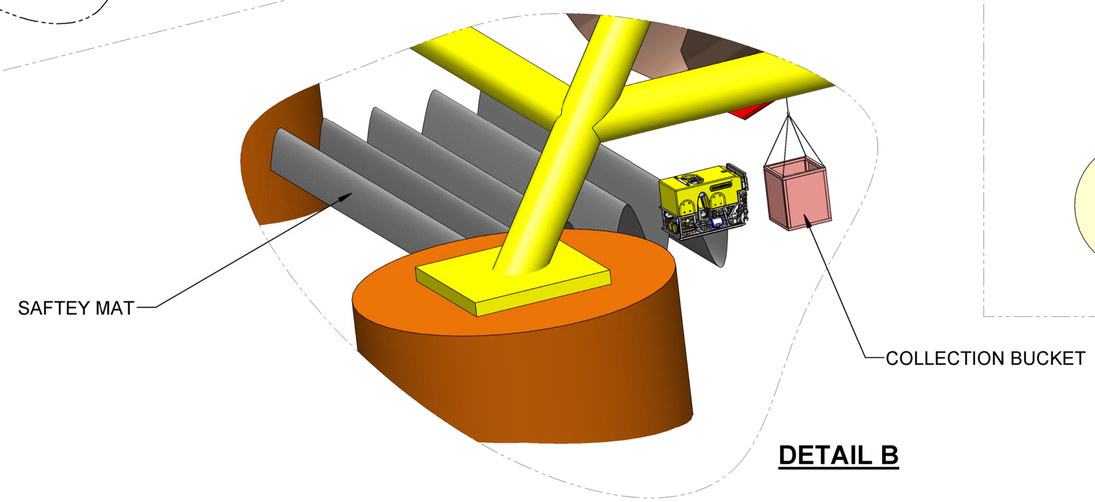
STEP - 2.2 : LIFTING THE U-864 UP OUT OF THE MUD AND LAY DOWN THE SAFETY MAT.









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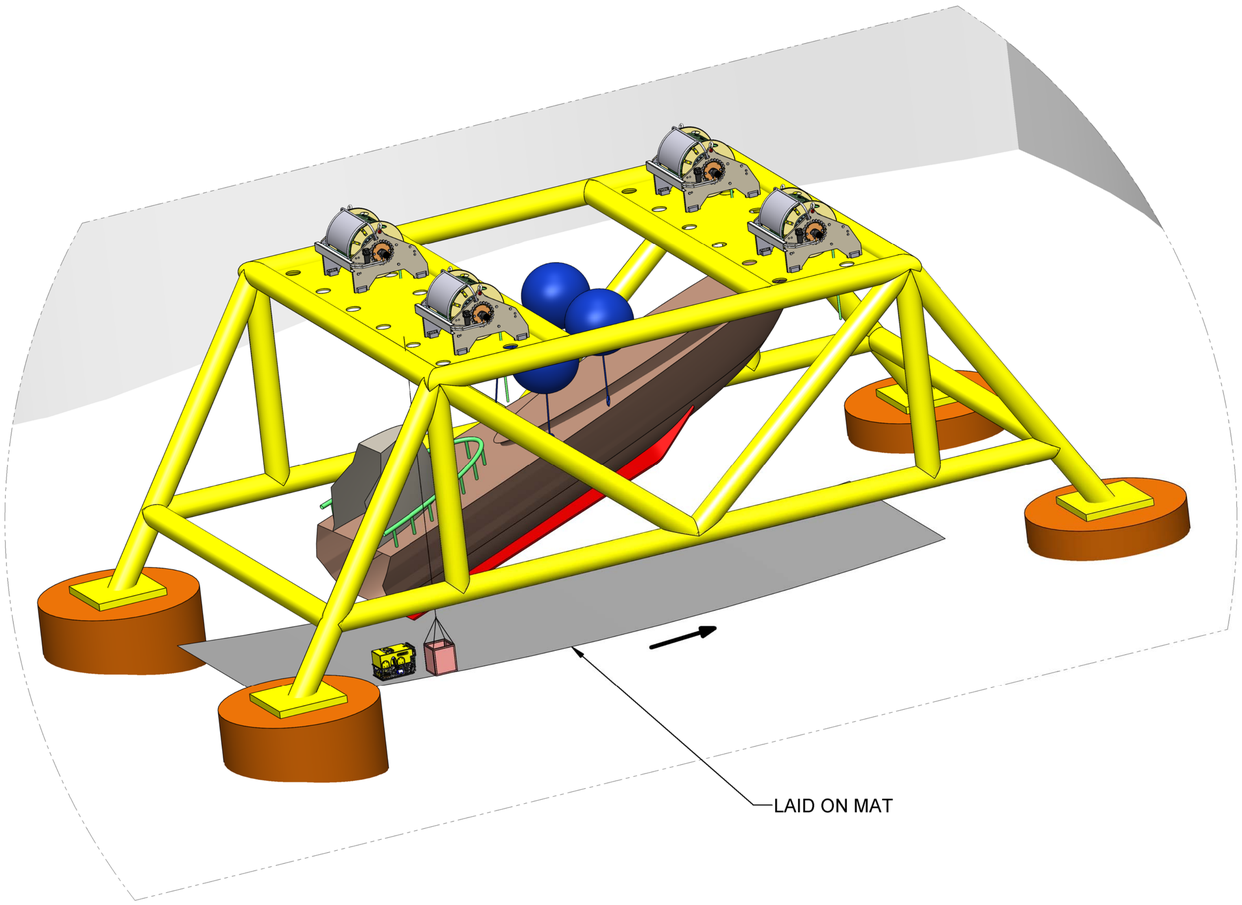
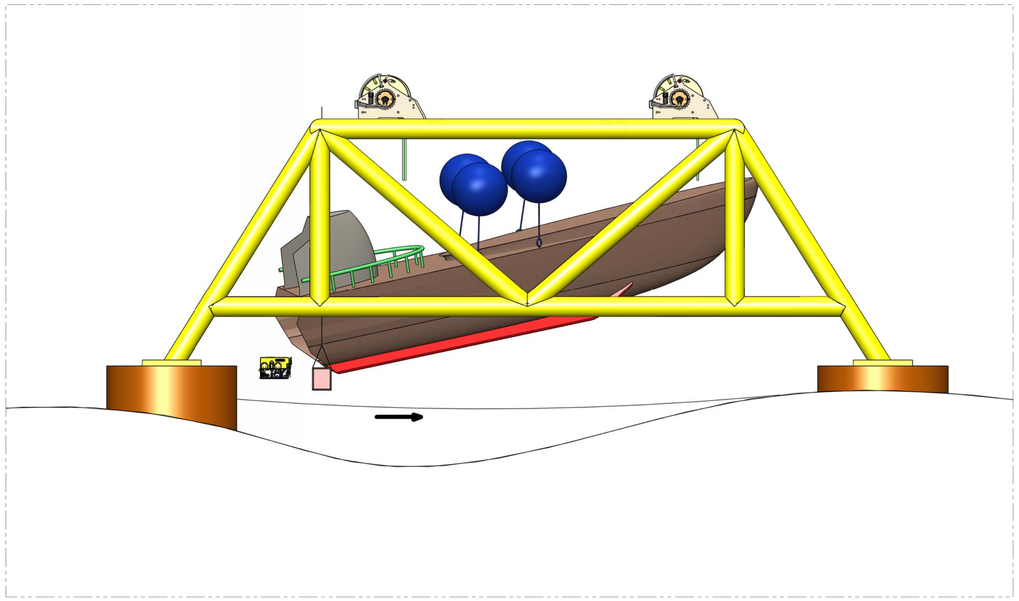
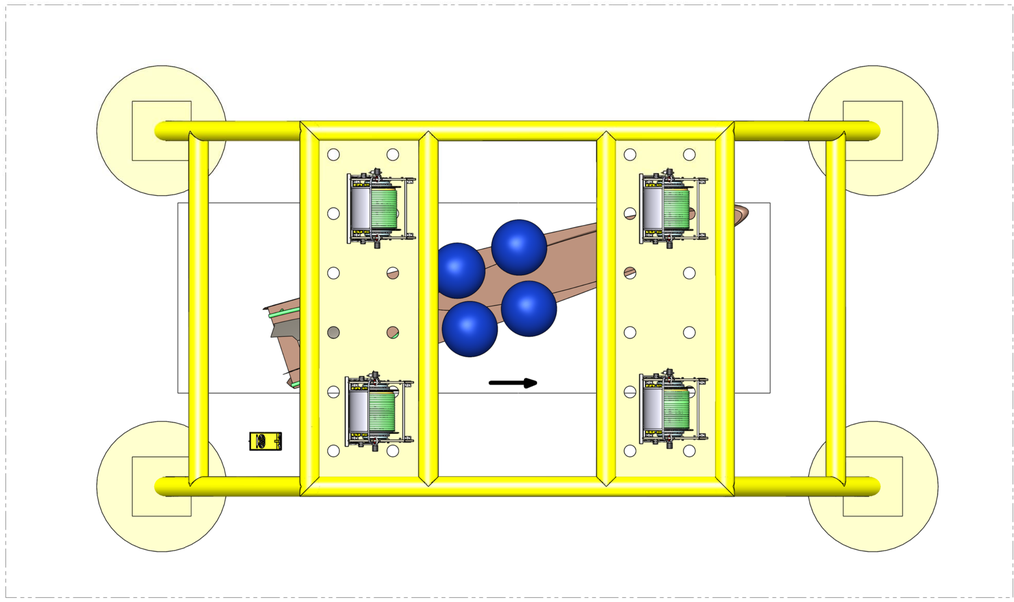
STEP - 2.3 : EXTRACT THE MERCURY CANINSTERS IN THE COLLECTION BUCKET WITH THE HELP OF ROV.







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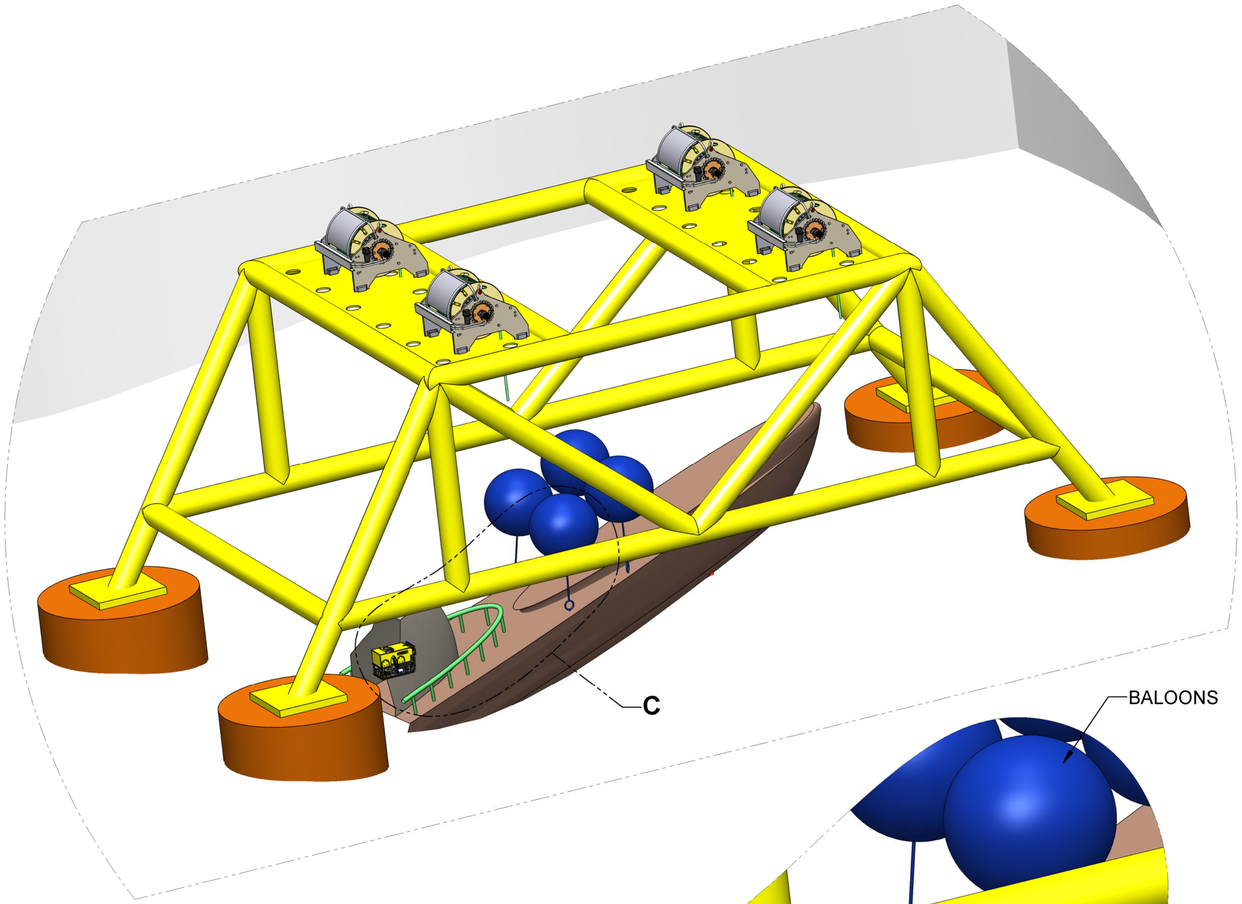
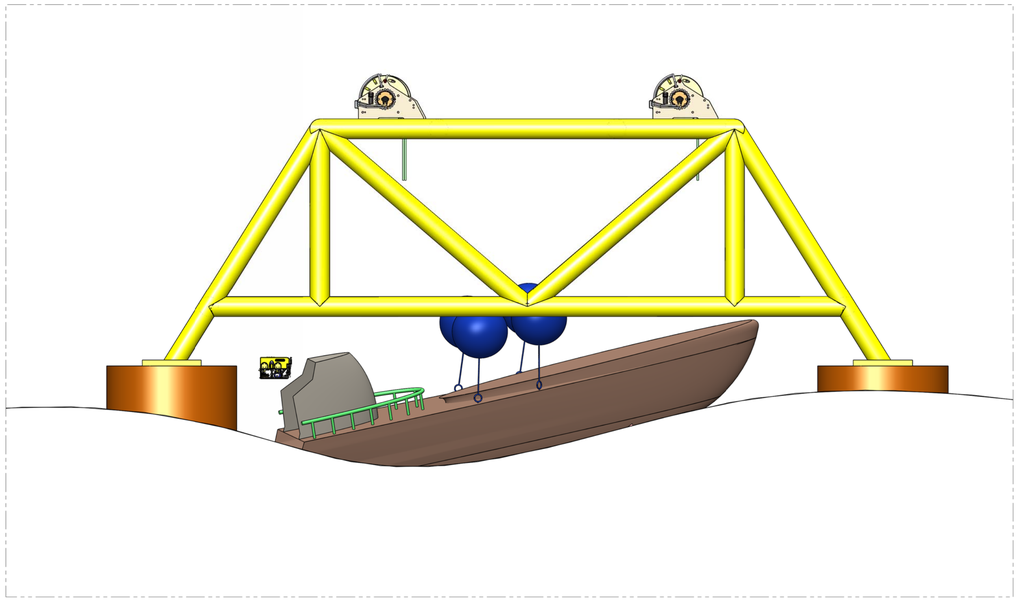
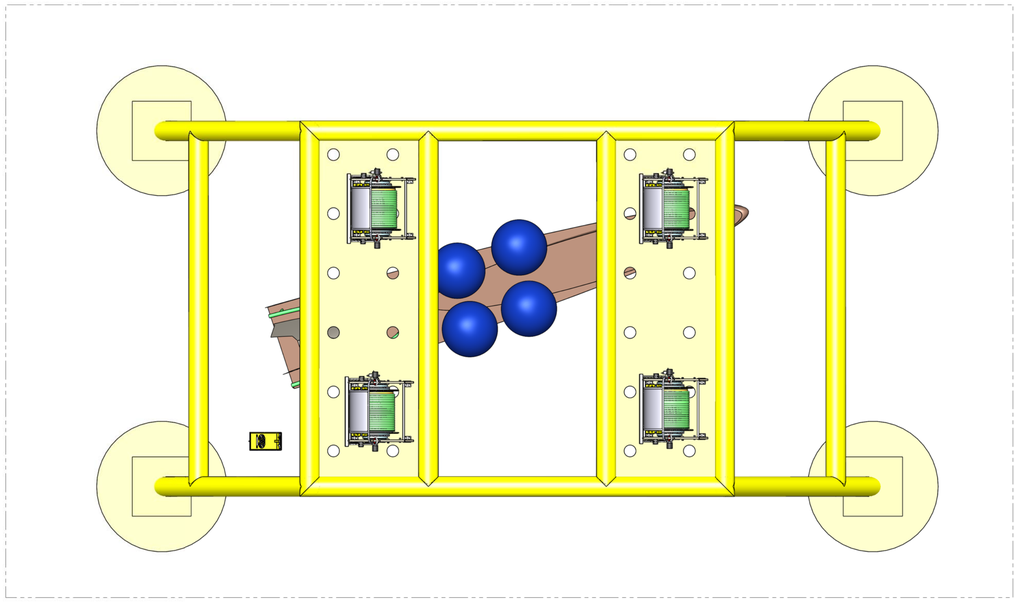
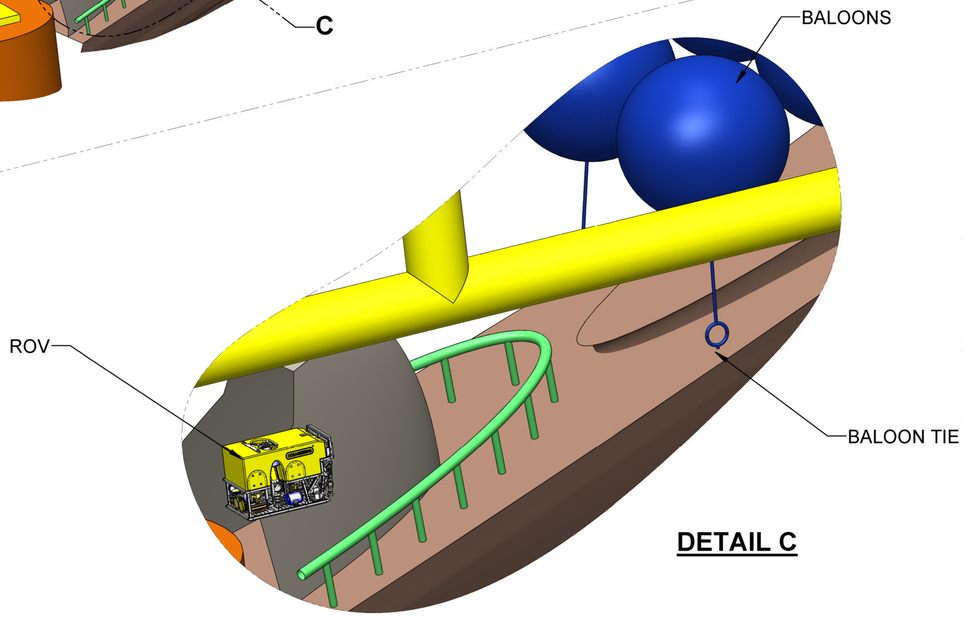
STEP - 3 : REMOVE THE BALOONS AND WINCH CONNECTIONS.









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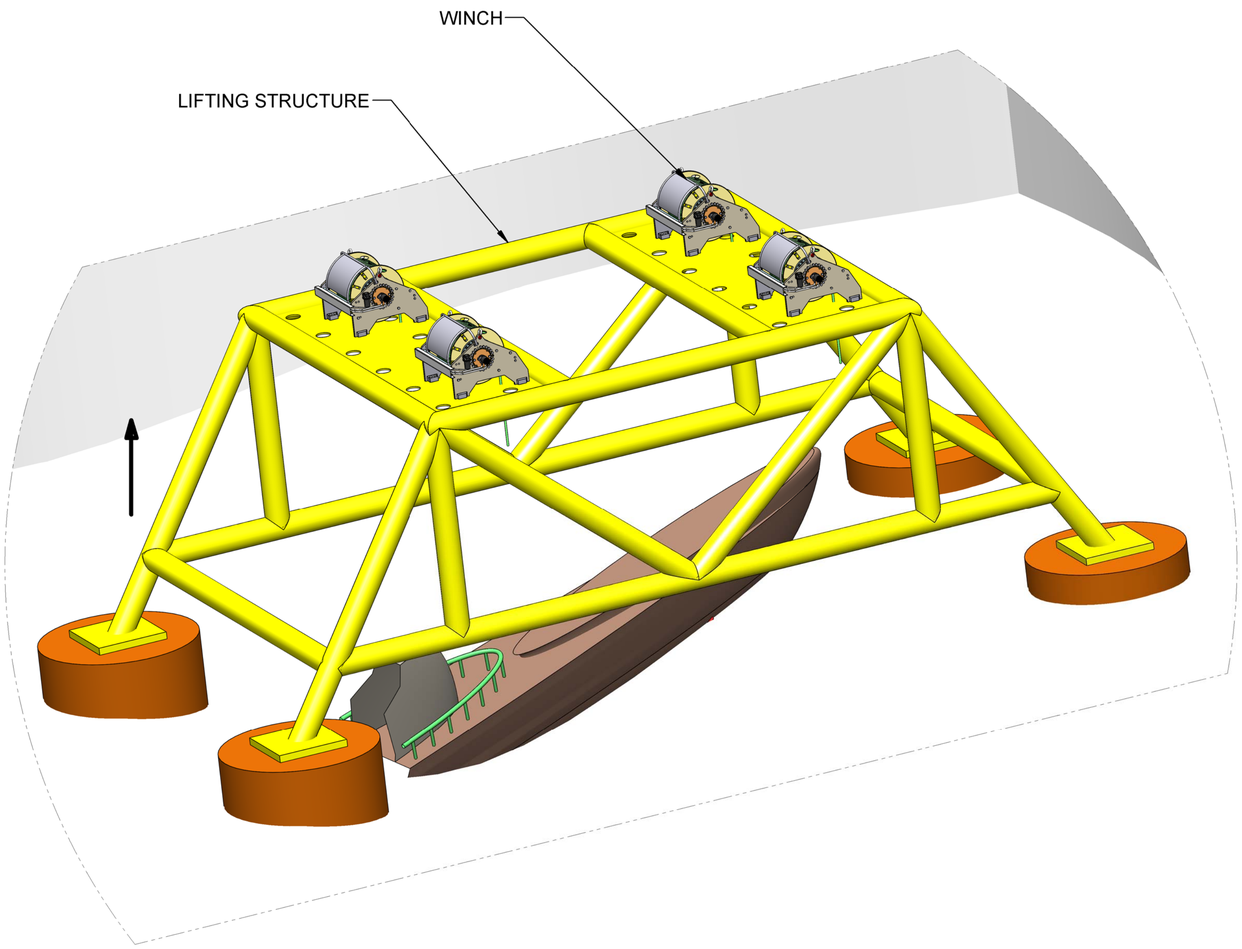
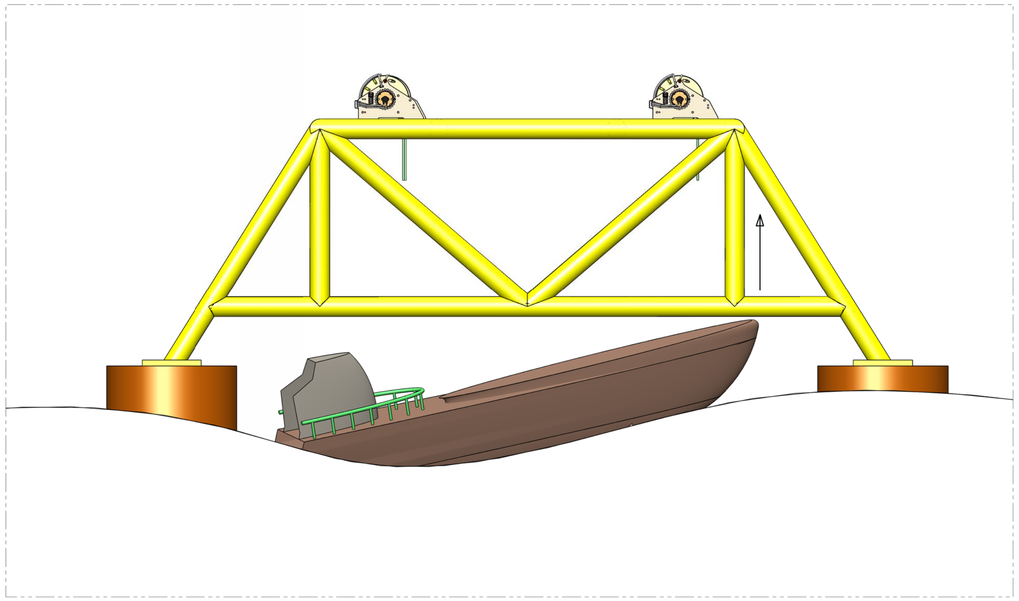
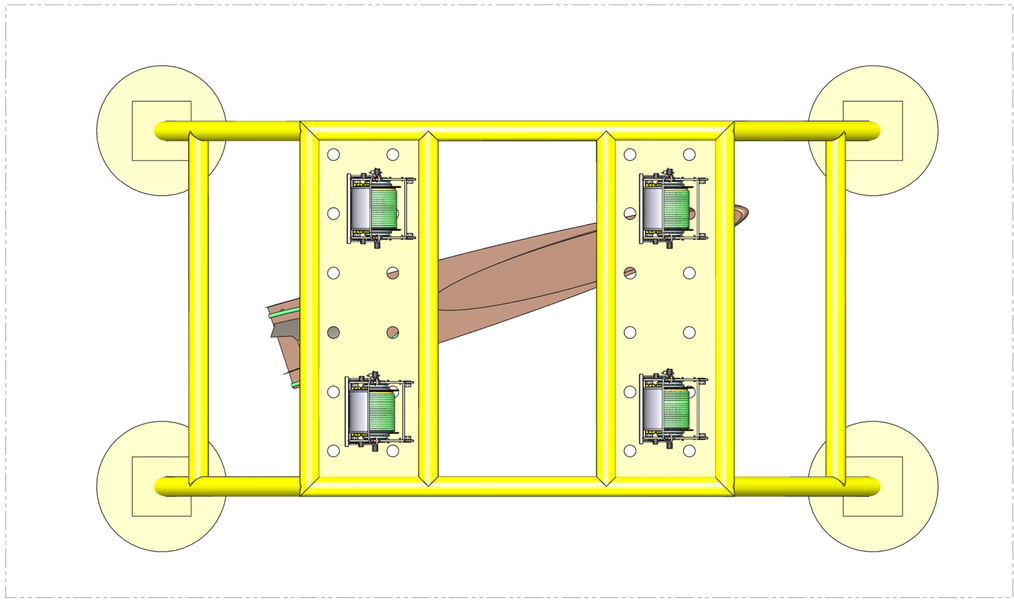
STEP - 3.1 : LIFT THE WHOLE STRUCTURE UP.







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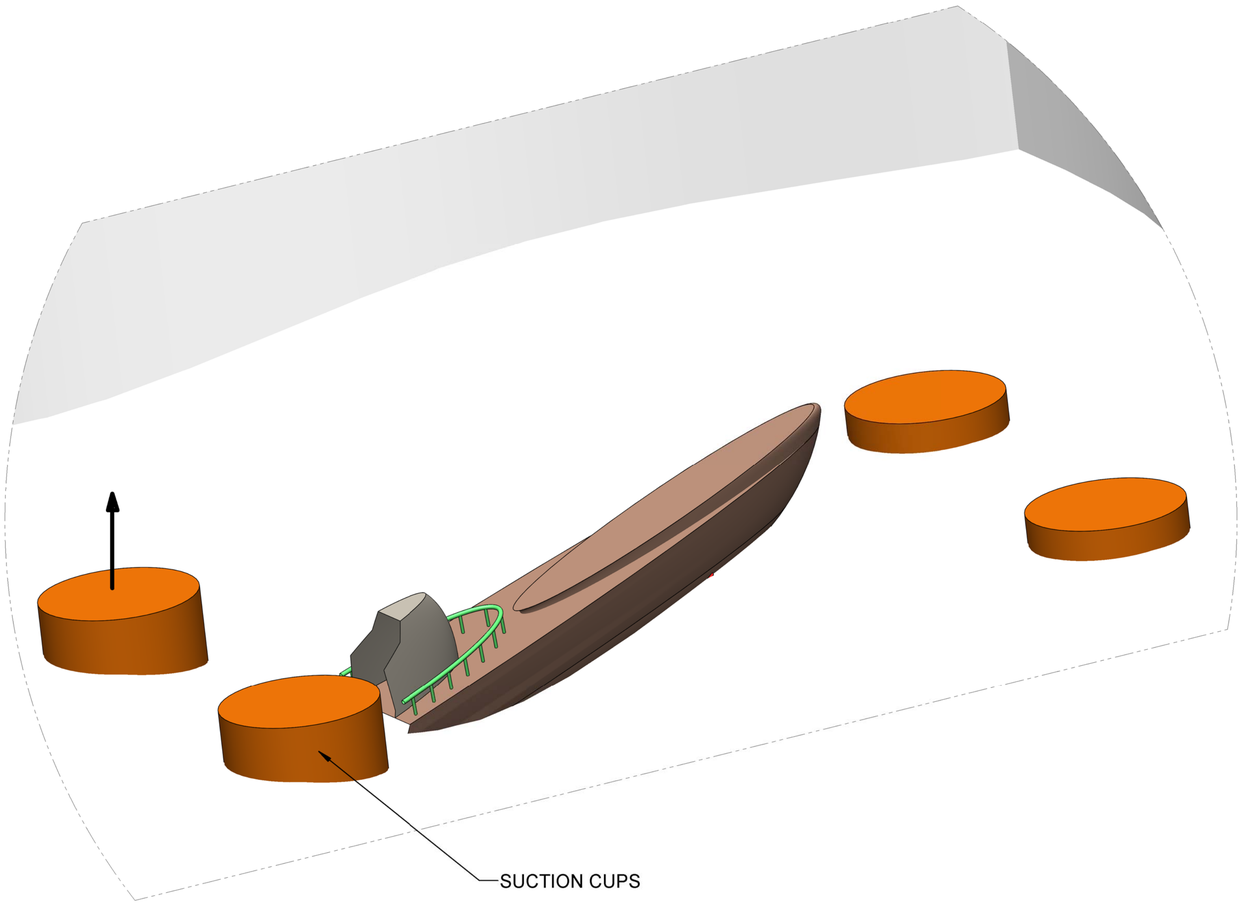
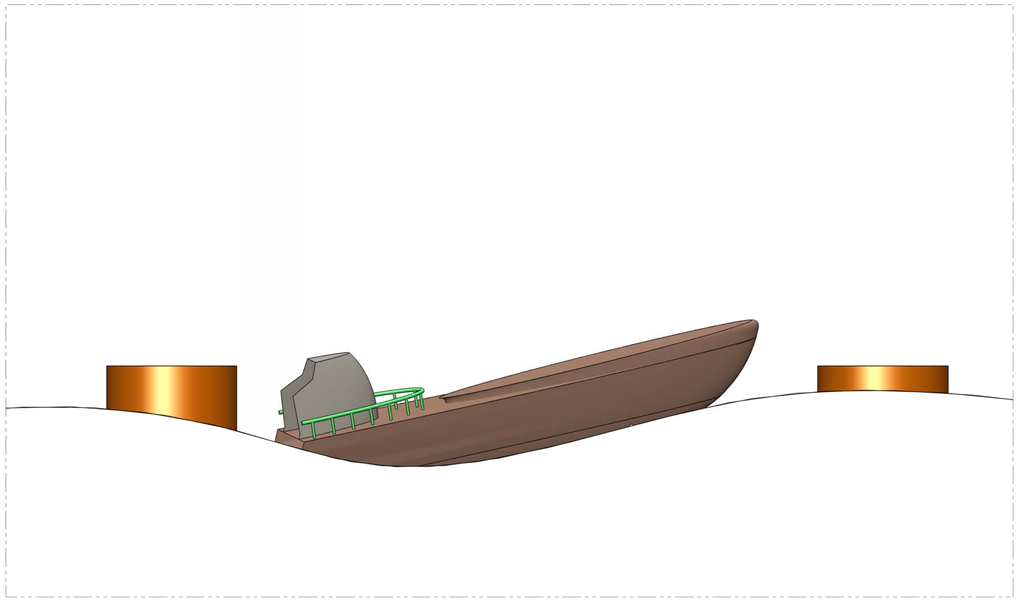
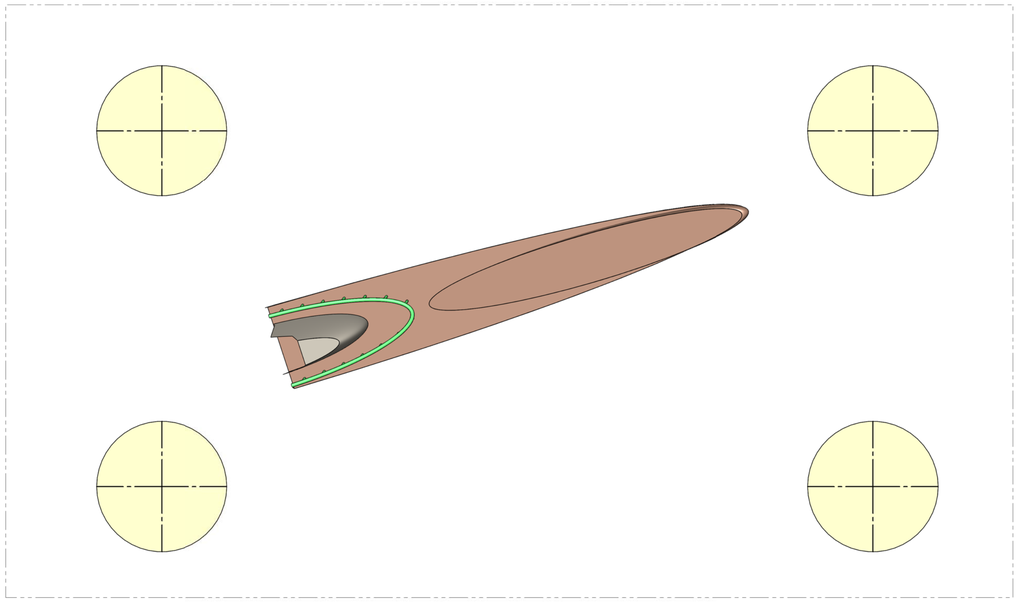
STEP - 3.2 : TAKE THE SUCTION CUPS OUT.







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Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter and greener.

Appendix V3.05.3

ENVIRONMENTAL MEASURES FOR THE WRECK OF U-864

Feasibility study - Suggested method for U864 mercury cargo recovery: Technip

DNV GL AS

Project name:	Environmental measures for the wreck of U-864	DNV GL AS
Report title:	Feasibility study - Suggested method for U864 mercury cargo recovery: Technip	Project Management & Technical Services Program P.O.Box 300 1322 Høvik Norway Tel: +47 67 57 99 00

Prepared by:
Andrew Junge (DNV GL AS)
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Technip

Verified by:
Carl Erik Høy-Petersen (DNV GL AS)

Dato: 12.5.2014

Reference to part of this report which may lead to misinterpretation is not permissible.

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1 INTRODUCTION

The German submarine U-864 was torpedoed by the British submarine Venturer 9th of February 1945, approximately 2 nautical miles west of the Island Fedje in Hordaland. U-864 was on its way from Germany via Norway to Japan. The submarine had a cargo of war material, and according to historical documents approximately 67 ton of liquid metallic mercury in steel canisters stored in the keel. The torpedo split the submarine into two parts. The wreck parts were discovered by the Royal Norwegian Navy at a depth of approximately 150-175 m. Several studies have revealed feasible measures for pollution abatement. The risks related to these measures have been assessed and indicate the following:

- High mercury concentrations in the soil, especially around the wreck parts.
- The bow section is inclining and has a high risk of sliding downhill. (Geotechnical unstable)
- Torpedoes and ammunition in general.
- Oil in the wreck.
- The condition of the two wreck parts.
- The condition of the mercury canisters.

In 2013 DNV-GL was assigned by the Norwegian Coastal Administration to carry out a pre-project that will assess the possibility of recovering the mercury canisters from the wreck parts before capping the wreck parts and the polluted seabed-area. As part of the assignment, competent subsea companies have been invited to discuss feasible solutions and cost pertaining to the proposed solutions.

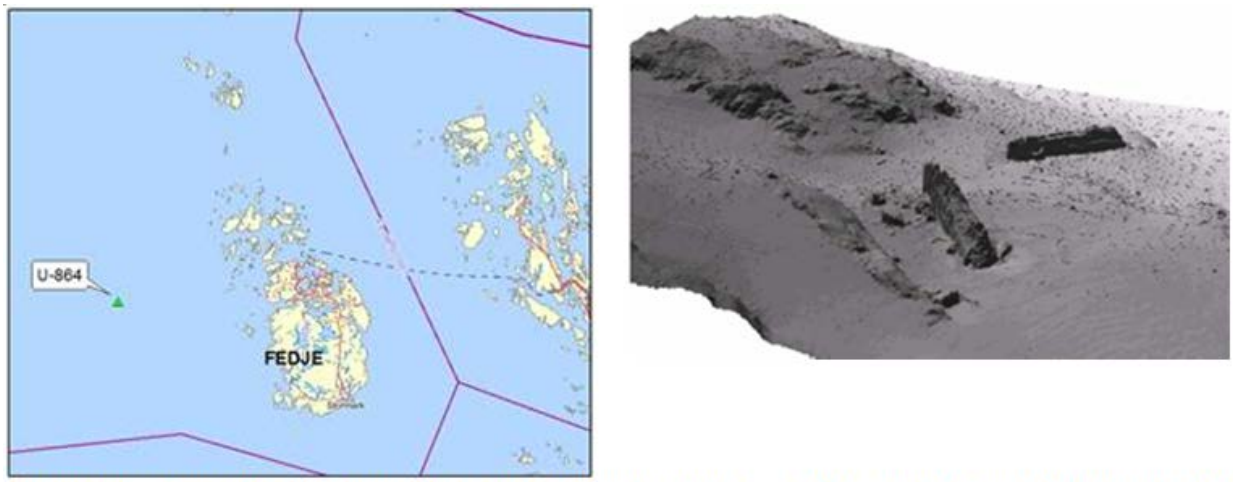


Figure 1.Loction of the wreck outside Fedje (left) and sonar image of bow and aft part of the wreck (right)

2 SUGGESTED METHOD TO RETRIEVE MERCURY CANISTERS

To avoid a global collapse of the seabed slope where the bow section resides, the valley to the North will be rock dumped with the purpose of stabilising the area prior to any intervention work on the wreck. This measure is valid for all the suggested methods from all companies participating in this RFI (Request for information).

For all companies the operation has been divided into 6 generic steps as presented in the table below. The suggested method by Technip for the retrieval of the mercury canisters from the keel of U-864 is presented briefly in the table below and more in detail in the succeeding sub-chapters:

No	Operational step	Brief description (company specific)
4.1	Preparations	First the bow section will be secured with a wire from the front rudder to solid rock. The metal bail will be fastened to the hull, kept in place by friction from huge hydraulic bolts that will be tightened just below the middle of the submarine. On top of the bail there are long arms with buoyancy balloons fastened at the ends. This will initially stabilise the wreck. Sediment then has to be removed from one side of the wreck to be able to rotate the structures, from the port side for the aft section and on the starboard side for the bow section. The wreck parts are then rotated with the help of the buoyancy balloons.
4.2	Get access to the keel	After the wreck has been rolled to the side the remaining sediments will be removed to reveal the keel.
4.3	Open the keel	A jig that will hold the cutting equipment will be installed alongside the keel. The jig and cutting equipment will be manoeuvred by an ROV. If possible the keel will be opened from underneath.
4.4	Retrieve the Mercury canisters from keel to seabed	To retrieve the canisters from the keel, divers will be used. The advantage with divers is that they have a more sensitive grip than an ROV, with less chance of rupturing the canisters. They are also more flexible in their use of tools and cause less spreading of contaminated sediments so that the operation will be performed faster.
4.5	Bring Mercury canisters and free floating Mercury from seabed to surface	The container used to collect the canisters on the seabed will be transferred to the surface in a standard subsea basket, hosed down on deck and then sent to a depot. The container will not be opened on deck and this will reduce the need for personnel and equipment to handle the mercury on board.
4.6	Stabilise wreck before capping	The wreck is stabilised on the side in the first phase. The metal bail will be removed before capping.

In the following chapters this method will be further elaborated with a focus on equipment and tools being used, and a risk assessment of the operation. The sketches included below are not accurate when it comes to dimensions, they are only included to give the reader a better understanding of the suggested concept.

In the risk assessment possible events are rated with probability and consequence with values according to the risk matrix in figure 2.

		Consequence				
		Minor	Low	Considerable	Large	Severe
Probability	Likely	Significant	Critical	Critical	Critical	Critical
	Reasonably prob	Significant	Significant	Critical	Critical	Critical
	Unlikely	Insignificant	Significant	Significant	Critical	Critical
	Remote	Insignificant	Insignificant	Significant	Significant	Critical
	Extremely remote	Insignificant	Insignificant	Insignificant	Significant	Significant
	Theoretically Possible	Insignificant	Insignificant	Insignificant	Insignificant	Significant

Figure 2: Risk matrix

Subsequently the mitigating actions that reduce the probability and/or the consequence of the event are identified. The new rating of probability and consequence for the event is then assessed.

One common set of risks and actions will be used as basis for all companies (See chapter 3) which has a numbering from R1 to R16 for risks and T1.x to T16.x for Mitigating actions. For company and method specific risks the numbering will start with an abbreviation representing the company (D,SW,T,O,S7).

The abbreviations used in the risk assessment tables in this document are shown in the table below. The first four rows are abbreviations for different types of consequences. The five last rows are abbreviations for the magnitude of a particular type of consequence. Other abbreviations used are listed in the underlying table.

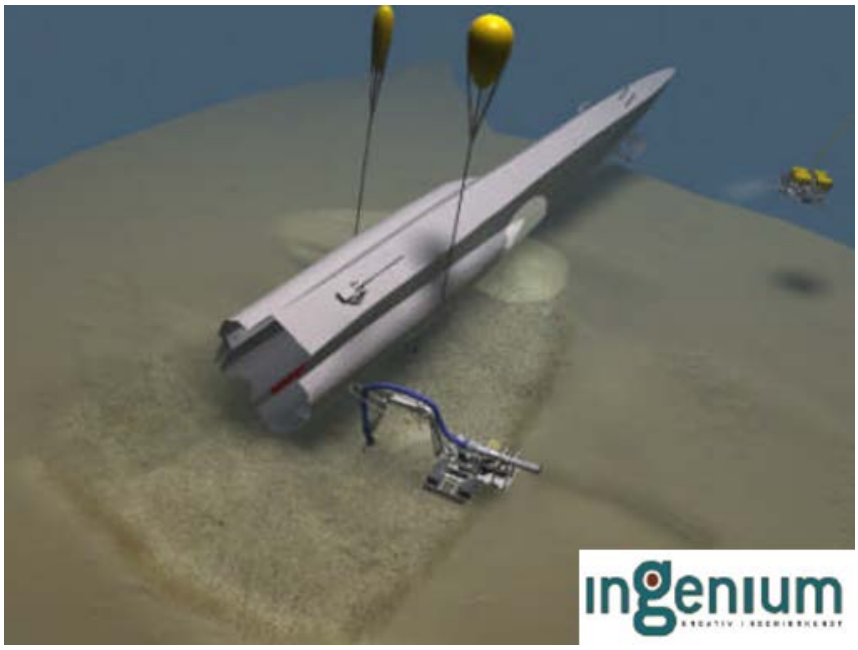
Abbreviation	Full text
ELT	Environment LONG Term
EST	Environment SHORT term
PS	Personnel SAFETY
OS	Operational SAFETY
M	Minor consequence
Lo	Low consequence
C	Considerable consequence
La	Large consequence
S	Severe consequence

2.1 Preparations

2.1.1 Operation

2.1.1.1 Secure in stable position

Several metal bails will be fastened to the hull, kept in place by friction from hydraulic bolts on each side of the bails that will be tightened just below the middle of the submarine. On top of the bail long arms with buoyancy balloons fastened at the ends. The ROV will first fill enough air in the balloons to stabilise the wreck.



2.1.1.2 Remove sediments alongside wreck

Sediment is removed from one side of the wreck to be able to rotate the structures. The aft section will be rotated to the port side. The bow section will be rotated to the starboard side. Suction dredging will be used together with a water jet to loosen the harder sediments.

2.1.1.3 Rotate wreck

The wreck parts are rotated with the help of the buoyancy balloons. The wreck is expected to be stable when lying on the side after the rotation.

2.1.2 Equipment and tooling

Technip suggests using the following equipment and tooling:

No	Operational sub step	Equipment or tools applied
4.1.1.1	Secure in stable position	Metal bails, buoyancy balloons, ROV
4.1.1.2	Remove sediments alongside wreck	Suction dredger, water jet/cutter, mechanical dredger.
4.1.1.3	Rotate wreck	Metal bails, buoyancy balloons, ROV

2.1.3

2.1.4 Risk assessment

2.1.4.1 Risk before mitigating actions

Risk	Sub step	Risk	Description	Probability	Consequence
R1	4.1.1.2	Spreading of mercury contaminated sediments	Spread contaminated sediments during suction dredging according to NIVA report 5279-2006.	Likely	ELT(Lo) EST(Lo)
R4	4.1.1.2	Uncontrolled movement of	The sediments surrounding the bow section are not stable and	Likely	ELT(Lo) EST(Lo)

Risk	Sub step	Risk	Description	Probability	Consequence
		sediments surrounding the bow structure	can be the cause of a massive slide. Polluted sediments will then be spread into the water column. If the bow section moves during the slide the keel can break up and lead to further contamination.		OS(Lo)
R9	4.1.1.3	Damaged keel	When the hull rolls over, the keel can be stuck in the sediments and therefore partly damaged. If canisters rupture during this phase this might lead to further contamination of the sediments under the keel.	Reasonably probable	ELT(M) EST(M) OS(Lo)
TR2	4.1.1.3	The canisters push outside plates on keel.	When rotating the keel the weight of the canisters and free floating mercury can push out the side plates facing downwards.	Reasonably probable	OS(Lo)

2.1.4.2

2.1.4.3 Risk after mitigating actions

Action (Risk)	Sub step	Mitigating action	Description of action	Probability after action	Consequence after action
T1.1 (R1)	4.1.1.1	Develop new technology	For example exhaust treatment, containerised system, or bags can be filled up. Today no subsea technology to filter out mercury from sediments or water exist . It is therefore very uncertain if this action is possible. This will require more research and testing.	Reasonably probable	ELT(Lo) EST(Lo)
T1.2 (R1)	4.1.1.1	Use other forms of dredging	Use mechanical dredging to remove the minimum amount of soil to get access to the keel. Mechanical dredging will also spread contaminated sediments, but not in such large amounts as suction dredging.	Reasonably probable	ELT(Lo) EST(Lo)
T1.3 (R1)	4.1.1.1	Analyse dredging method	Perform a detailed analysis on which dredging method should be applied in the different areas and depths, depending on share strength and on the severity of the contamination.	Reasonably probable	ELT(Lo) EST(Lo)
T1.4 (R1)	4.1.1.1	Take core sample before operation	Take samples around the wreck parts and inside the keel, before and during the operation, to monitor the content of mercury in the sediments.	Reasonably probable	ELT(Lo) EST(Lo)
T4.2 (R4)	4.1.1.1	Monitor pitch and roll of wreck	Fasten monitoring equipment to the wreck to monitor pitch and roll.	Reasonably probable	ELT(Lo) EST(Lo) OS(Lo)

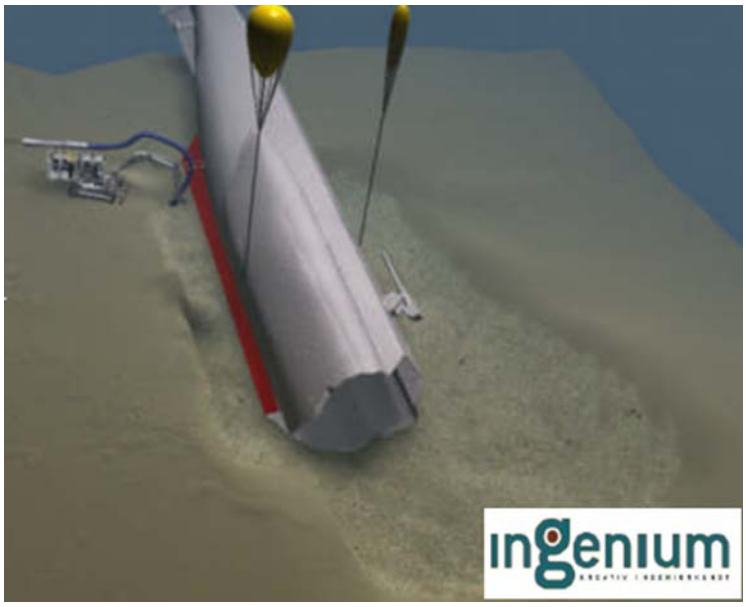
Action (Risk)	Sub step	Mitigating action	Description of action	Probability after action	Consequence after action
T4.3 (R4)	4.1.1.1	Wire supporting bow section	Support the bow structure by securing a wire from the bow to solid rock or a suction anchor.	Reasonably probable	ELT(M) EST(M) OS(Lo)
T4.4 (R4)	4.1.1.1	Planning	Geotechnical examinations	Reasonably probable	ELT(Lo) EST(Lo) OS(Lo)
T4.5 (R4)	4.1.1.1	Barrier	During the operation, sheet pile, sand bags etc. can be used to stabilize the sediments.	Reasonably probable	ELT(M) EST(M) OS(Lo)
T9.1 (R9)	4.1.1.2	Monitor	Use Inclinometer to monitor the operation. Reduce speed since too fast movement will increase the chances of further damage to the keel	Unlikely	ELT(M) EST(M) OS(Lo)
T9.2 (R9)	4.1.1.2	Remove more sediments	If more sediment is removed around the keel before the hull is moved, the chance of damaging the keel is reduced.	Unlikely	ELT(M) EST(M) OS(Lo)
TT 2.1 (TR2)		Inflatable elements	Place inflatable elements under keel before rolling the wreck to the side.		

2.2 Get access to the keel

2.2.1 Operation

2.2.1.1 Excavate the keel

After the operation where the wreck is rolled roll over onto the side, the keel might not be sufficiently exposed. The keel therefore has to be excavated in a way that secures that sediments do not slide back onto the keel.



2.2.2 Equipment and tooling

No	Operational sub step	Equipment or tools applied
4.2.1.1	Excavate the keel	Dredging hose: Makes a closed loop, can provide some issues with regards to cleaning of the sediments. Containers are needed to collect the sediments. Suction dredger, water jet/cutter, mechanical dredger.

2.2.3 Risk assessment

2.2.3.1 Risk before mitigating actions

Risk	Sub step	Risk	Description	Probability	Consequence
R1	4.2.1.1	Spreading of mercury contaminated sediments	Spread contaminated sediments during suction dredging according to NIVA report 5279-2006.	Likely	ELT(Lo) EST(Lo)
R5	4.2.1.1	Uncontrolled movement and back fill of sediments during dredging	The sediment has very low shear strength at approximately 5-10 KP. This makes it hard to stabilise.	Likely	ELT(Lo) EST(Lo)

2.2.3.2 Risk after mitigating actions

Action	Sub step	Mitigating action	Description of action	Probability after action	Consequence after action
T1.1 (R1)	4.1.1.1	Develop new technology	For example exhaust treatment, containerised system, or bags can be filled up. Today no subsea technology to filter out mercury from sediments or water exists. It is therefore very uncertain if this action is possible. This will require more research and testing.	Reasonably probable	ELT(Lo) EST(Lo)
T1.2 (R1)	4.1.1.1	Use other forms of dredging	Remove sediments through the use of mechanical dredging or technology to freeze the sediment before removal.	Reasonably probable	ELT(Lo) EST(Lo)
T1.3 (R1)	4.2.1.1	Analyse dredging method	Perform a detailed analysis on which dredging method should be applied in the different areas.	Reasonably probable	ELT(Lo) EST(Lo)
T1.4 (R1)	4.2.1.1	Take core sample before operation	Take samples around the wrecks and inside the keel, before and during the operation, to monitor the content of mercury in the sediments.	Reasonably probable	ELT(Lo) EST(Lo)
T1.5 (R1)	4.2.1.1	The use of a small suction pump	If free floating mercury is excavated a small suction	Reasonably probable	ELT(Lo) EST(Lo)

Action	Sub step	Mitigating action	Description of action	Probability after action	Consequence after action
			pump that delivers the exhausts to a closed bag can be used.		
T1.6 (R1)	4.2.1.1	The use of a smaller suction dredge	To reduce the flow from the exhaust a smaller suction dredge can be used.	Reasonably probable	ELT(Lo) EST(Lo)
T5.1 (R5)	4.2.1.1	Geotechnical assessment	Assessment of soil conditions	Reasonably probable	ELT(Lo) EST(Lo)
T5.2 (R5)	4.2.1.1	Stabilising barrier	Sheet pile stabilisation or sand bags etc.	Reasonably probable	ELT(Lo) EST(Lo)

2.3 Open the keel

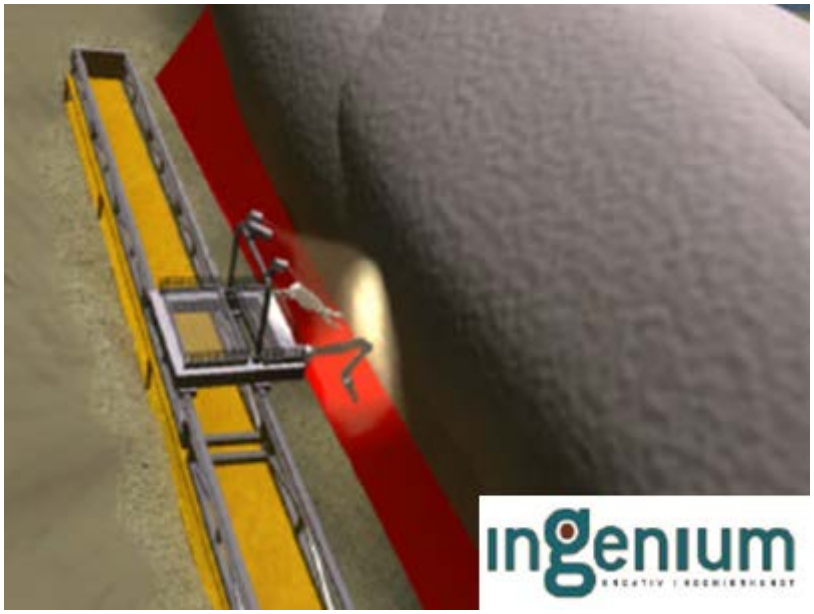
2.3.1 Operation

2.3.1.1 Inspect the inside of keel

Before opening the keel it is recommended to inspect each compartment on both sides of the keel with a camera.

2.3.1.2 Drill or cut to open the keel

A jig that will hold the cutting equipment will be installed alongside the keel. The jig and cutting equipment can drill, cut and remove steel and will be manoeuvred by an ROV. If the wreck can be rotated far enough the keel will be opened from underneath. The main plan is to open through the side plate and then cut through the mid-section.



2.3.2 Equipment and tooling

No	Operational sub step	Equipment or tools applied
4.3.1.1	Inspect the inside of the keel	ROV and jig with tools to cut and drill Camera small enough to enter drilled hole
4.3.1.2	Drill or cut open the keel	ROV with tools to cut and drill, a water jet or mechanical saw will be used to get through the side plate and the mid-section.

2.3.3 Risk assessment

2.3.3.1 Risk before mitigating actions

Risk	Sub step	Risk	Description	Probability	Consequence
R3	4.3.1.1 4.3.1.2	Spread contaminated sediments because of ROV operation	During the ROV operation the thrusting of the ROV or physical contact between ROV and the sediments can lead to spreading of contaminated sediments. This can also lead to reduced visibility and therefore delay the operation.	Likely	ELT(Lo) EST (C) OS (Lo)
R13	4.3.1.2	Access to other side of keel	When the wreck is stable and the keel is excavated, one side of the keel is easily accessible. It is uncertain how much effort is required to get access to the other side of the keel.	Likely	OS (C)

2.3.3.2 Risk after mitigating actions

Action	Sub step	Mitigating action	Description	Probability	Consequence
T3.1 (R3)	4.3.1.1 4.3.1.2	Cover the sediments	Cover the sediments with a mat or gravel.	Unlikely	ELT(Lo) EST(Lo) OS (M)
T3.2 (R3)	4.3.1.1 4.3.1.2	Optimal trim	Operate ROV with optimal trim.	Reasonably probable	ELT(Lo) EST(Lo) OS (M)
T3.3 (R3)	4.3.1.1 4.3.1.2	Experience and training	The ROV operator should be experienced and trained for the specific operation through simulation.	Reasonably probable	ELT(Lo) EST(Lo) OS (M)
T3.4 (R3)	4.3.1.1 4.3.1.2	ROV foundation	The ROV can use a magnet, a sticky foot, a platform and bags of sand or gravel as a foundation during the operation to reduce the thrusting of the ROV.	Reasonably probable	ELT(Lo) EST(Lo) OS (M)
T13.1 (R13)	4.3.1.2	Alterative equipment	Special designed equipment for this operation.	Unlikely	OS (C)
T13.2 (R13)	4.3.1.2	Inspection	Check the other side of the keel with a camera before starting the cut to prevent puncturing mercury canisters.	Unlikely	OS (C)

Action	Sub step	Mitigating action	Description	Probability	Consequence
T13.3 (R13)	4.3.1.2	Testing/planning	Simulation and testing of method and equipment.	Unlikely	OS (C)

2.4 Retrieve the Mercury canisters from keel to seabed

2.4.1 Operation

2.4.1.1 Removal of mercury canisters from keel

Divers will be used to retrieve the canisters from the keel. The advantage with divers is that they have a more sensitive grip than an ROV, with less chance of rupturing the canisters. They are also more flexible in their use of tools and cause less spreading of contaminated sediments so that the operation can be performed faster.

2.4.1.2 Removal of free floating mercury from keel

In the case where floating mercury is found the use of a suction pump is most efficient. This suction pump will be operated by a diver.

2.4.2 Equipment and tooling

No	Operational sub step	Equipment or tools applied
4.4.1.1	Removal of mercury canisters from keel	Tool to extract the bottles from the keel. Lifting gear to help with heavy lifts.
4.4.1.2	Removal of free floating mercury from keel	Suction pump that can be operated by diver.

2.4.3 Risk assessment

2.4.3.1 Risk before mitigating actions

Risk	Sub step	Risk	Description	Probability	Consequence
R11	4.4.1.1	Crush or drop canisters	The canisters are of various qualities. When extracting them from the keel it is likely that some of them will be crushed. It is also likely that some canisters can be dropped between the keel and the subsea basket.	Likely	ELT(La) EST(La) OS (La)
TR1	4.4.1.1 4.4.1.2	Mercury into bathysphere	The divers will have sediments containing mercury on their suits. The mercury will vaporise due to the pressure inside the bathysphere and into the ventilation system.	Likely	PS(C)

2.4.3.2 Risk after mitigating actions

Action	Sub step	Mitigating action	Description of actions	Probability after action	Consequence after action
T11.1 (R11)	4.4.1.1.	“Vacuum cleaner”	To reduce the consequence of a mercury spill a suction pump should be available to retrieve	Likely	ELT(M) EST(M) OS (M)

Action	Sub step	Mitigating action	Description of actions	Probability after action	Consequence after action
			smaller amounts of floating mercury.		
T11.2 (R11)	4.4.1.1.	Design of receiving area	There should be a specially designated area next to the keel where the canisters can be received. In this area the seabed should be designed so that any spill is easily collected. This will not reduce the chance of crushing or dropping canisters, but the contamination will be limited.	Likely	ELT(M) EST(M) OS (M)
T11.3 (R11)	4.4.1.1.	Design of handling equipment	The handling equipment should be designed and tested with the aim to reduce number of canisters broken or dropped.	Likely	ELT(M) EST(M) OS (M)
TT1.1 (TR1)	4.4.1.1.	Wash before entering the bathysphere	Wash the divers outside the bathysphere before entering.	Reasonable probable	PS(C)
TT1.2 (TR1)	4.4.1.1.	Alternative fabric in diving suit	The fabric in the diving suit should be of a material that sediments do not easily stick to.	Reasonable probable	PS(C)
TT1.3 (TR1)	4.4.1.1.	Monitoring the bathysphere	Monitor the ventilation system in the bathysphere for any signs of mercury gas.	Reasonable probable	PS(C)

2.5 Recover mercury canisters and free floating Mercury from seabed to surface

2.5.1 Operation

2.5.1.1 Bring mercury canisters from seabed to surface

The container used to collect the canisters on the seabed will be transferred to the surface in a standard subsea basket, hosed down on deck and then sent to a depot. The container will not be opened on deck and this will reduce the need for personnel and equipment to handle the mercury on board.

2.5.1.2 Bring free floating mercury from seabed to surface

The free floating mercury will be collected with a suction pump into a sealed bag. This bag will be put into the same type of sealed container.

2.5.1.3 Land and handle mercury on deck

When landing the subsea basket and other equipment that has been subsea there is a risk transferring contaminated sediments to the deck of the ship.

2.5.2 Equipment and tooling

No	Operational sub step	Equipment or tools applied
4.5.1.1	Bring mercury canisters from seabed to surface	Sealed container with room for several canisters. This box will be placed in a standard subsea basket.

2.5.3 Risk assessment

2.5.3.1 Risk before mitigating actions

Risk	Sub step	Risk	Description	Probability	Consequence
R14	4.5.1.1	Load falling	Uncontrolled fall of basket when brought from surface to deck.	Extremely remote	ELT(La) EST(La) OS (Lo)
R15	4.5.1.1	Bottle crushed	Bottles expand and break due to pressure difference.	Reasonably possible	ELT (La) EST (La)
R16	4.5.1.3	Spillage on deck	Spillage on deck due to contaminated equipment.	Likely	ELT (Lo) EST (Lo) PS (Lo)

2.5.3.2 Risk after mitigating actions

Action	Sub step	Mitigating action	Description of acton	Probability after action	Consequence after action
T14.1 (R14)	4.5.1.3	Procedure	The ROV checks that everything is closed and in place before lift.	Theoretically Possible	ELT(La) EST(La) OS (Lo)
T14.2 (R14)	4.5.1.3	Certified lifting equipment	For example closed offshore basket.	Theoretically Possible	ELT(La) EST(La) OS (Lo)
T15.1 (R15)	4.5.1.1	Sealed box	A sealed box will minimize/avoid spillage of mercury	Likely	ELT(M) EST(M)
T16.1 (R16)	4.5.1.3	Landing area	Predefined landing area on deck for subsea basket.	Unlikely	ELT(Lo) EST(Lo) PS (Lo)
T16.2 (R16)	4.5.1.3	Personal Protective gear	Gear to protect personnel handling the mercury and personnel located on deck.	Reasonably probable	ELT(Lo) EST(Lo) PS (Lo)
T16.3 (R16)	4.5.1.3	Cleaning of equipment under water	To reduce spillage on deck all equipment can be cleaned when submerged.	Unlikely	ELT(Lo) EST(Lo) PS (Lo)
T16.4 (R16)	4.5.1.3	Face the vessel with regards to the weather situation	Due to evaporation from the mercury it could help to face the vessel against the wind so that the potential gas is led away from the deck as fast as possible.	Reasonably probable	ELT(Lo) EST(Lo) PS (Lo)
T16.5	4.5.1.3	Experienced people	There crew of handling the	Unlikely	ELT(Lo)

(R16)			mercury must have experience with this and procedures to ensure that it is managed according to regulations.		EST(Lo) PS (Lo)
T16.6 (R16)	4.5.1.3	Adequate sealing of container	The box carrying the canister and free floating mercury has to have a robust and safe sealing mechanism.	Unlikely	ELT(Lo) EST(Lo) PS (Lo)

2.6 Stabilise wreck before capping

The wreck is stabilised on the side during the first phase of the operation. The metal bail and buoyancy will be removed before capping.

3 RISK ASSESSMENT

The risk assessment shows that the risk of getting mercury into the bathysphere is critical even after mitigating actions.

All other risk has been reduced to significant or insignificant due to the suggested mitigating actions.

Spreading of mercury contaminated sediments when stabilising the wreck and excavating the keel is a significant risk but can be mitigated. Development of new technology may be most efficient mitigation but will require unknown recourses on research and testing.

Mechanical dredging using a smaller suction dredge or a small suction pump can be an option. Mechanical dredging will give moderate spreading but will increase the time of the operation.

4 LIST OF COMMON RISKS

No	Name	Description
R1	**Spreading of mercury contaminated sediments**	Spread contaminated sediments during suction dredging according to NIVA report 5279-2006.
R2	**Unwanted bodies around wreck or in the soil.**	Can be parts of wreck or stones that makes it difficult to place drag anchor, but can also make it difficult for the ROV to manoeuvre.
R3	**Spread contaminated sediments because of ROV operation**	During the ROV operation the thrusting of the ROV or physical contact between ROV and the sediments can lead to spreading of contaminated sediments. This can also lead to reduced visibility and therefor delay the operation.
R4	**Uncontrolled movement of sediments surrounding the bow structure**	The sediments surrounding the bow section are not stable and can be the cause of a massive slide. Polluted sediments will then be spread into the water column. If the bow section moves during the slide the keel can break up and lead to further contamination.
R5	**Uncontrolled movement and back fill of sediments during dredging**	The sediment has very low shear strength at approximately 5-10 KP. This makes it hard to stabilise.
R6	**Uncontrolled rotation**	
R7	**Access to pressure hull**	It might be difficult to get access to the pressure hull. The outer hull is very fragile and hull parts may for example fall of during ROV operation.
R8	**Excavation operation, mechanical dredging**	
R9	**Damaged keel**	When the hull rolls over the keel can be stuck in the sediments and therefore partly damaged. If the more canisters rupture during this phase this might lead to further contamination of the of the sediments under the keel.
R11	**Crush or drop canisters**	The canisters are of various qualities. When extracting them from the keel it is very likely that some of them will be crushed. It is also very likely that some canisters can be dropped between the keel and the subsea basket.
R13	**Access to other side of keel**	When the wreck is stable and the keel is excavated, one side of the keel is easily accessible. It is uncertain how much effort is required to get access to the other side of the keel.
R14	**Load falling**	Uncontrollable fall of basket when brought from surface to deck.
R15	**Bottles crushed**	Bottles crushed due to pressure difference.
R16	**Spillage on deck**	Spillage on deck due to contaminated equipment.
R17	**Air pockets in bow section**	Bow section might still contain air pockets, and is therefore unstable.

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Appendix V3.05.4

ENVIRONMENTAL MEASURES FOR THE WRECK OF U-864

Feasibility study - Suggested method for U864 mercury cargo recovery: Swire Seabed

DNV GL AS

Project name: Environmental measures for the wreck of U-864

Report title: Feasibility study - Suggested method for U864 mercury cargo recovery: Swire Seabed

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Reference to part of this report which may lead to misinterpretation is not permissible.

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1 INTRODUCTION

The German submarine U-864 was torpedoed by the British submarine Venturer 9th of February 1945, approximately 2 nautical miles west of the Island Fedje in Hordaland. U-864 was on its way from Germany via Norway to Japan. The submarine was loaded with war material, and according to historical documents approximately 67 ton of floating metallic mercury in steel canisters stored in the keel. The torpedo split the submarine into two parts. The wreck parts were discovered by the Royal Norwegian Navy at a depth of approximately 150-175 m. Several studies have revealed feasible measures for pollution abatement. The risks related to these measures have been assessed and indicate the following:

- High mercury concentrations in the soil, especially around the wreck parts.
- The bow section is inclining and has a high risk of sliding downhill. (Geotechnical unstable)
- Torpedoes and ammunition in general.
- Oil in the wreck.
- The condition of the two wreck parts.
- The condition of the mercury canisters.

In 2013 DNV-GL was assigned by the Norwegian Coastal Administration to carry out a pre-project that will assess the possibility of recovering the mercury canisters from the wreck parts before capping the wreck parts and the polluted seabed-area. As part of the assignment, competent subsea companies have been invited to discuss feasible solutions and cost pertaining to the proposed solutions.

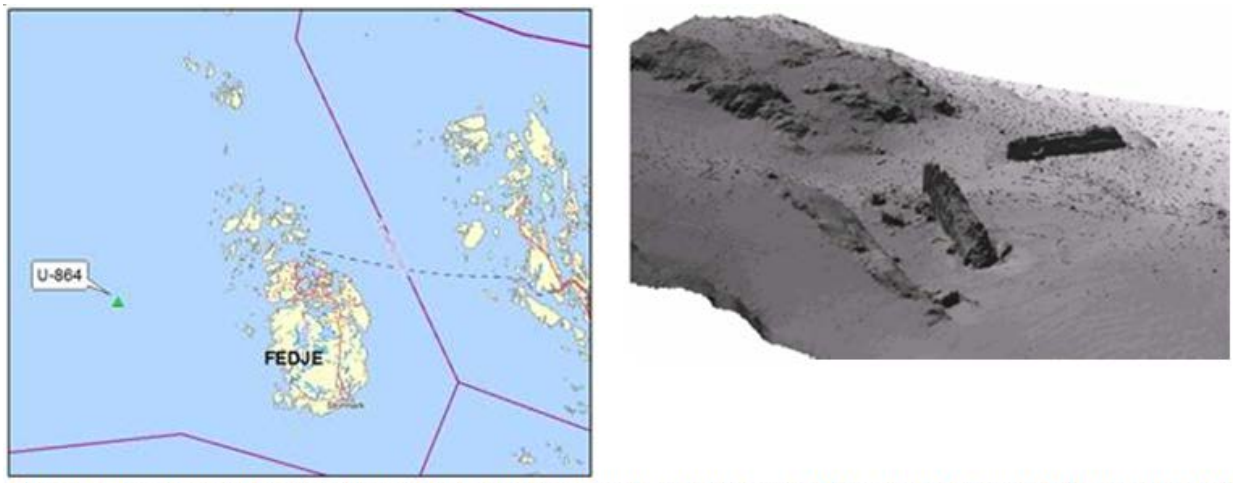


Figure 1.Loction of the wreck outside Fedje (left) and sonar image of bow and aft part of the wreck (right)

2 SUGGESTED METHOD TO RETRIEVE MERCURY CANISTERS

To avoid a global collapse of the seabed slope where the bow section resides, the valley to the North will be rock dumped with the purpose of stabilising the area prior to any intervention work on the wreck. This measure is valid for all the suggested methods from all companies participating in this RFI (Request for information).

For all companies the operation has been divided into 6 generic steps as presented in the table below. The suggested method by Swire Seabed for the retrieval of the mercury canisters from the keel of U-864 is presented briefly in the table below and more in detail in the succeeding sub-chapters:

No	Operational step	Brief description (company specific)
4.1	Preparations	Start the operation by laying down a thin layer of gravel to avoid movement of sediments when using the ROV. To decrease the use of thrust by the ROV and make access to the top of the wreck, platforms are made for the ROV next to the wreck. The wreck will be secured by wires fastened from the pressure hull of the wreck to the seabed using subsea winches connected to suction anchors or directly to solid rock.
4.2	Get access to the keel	Initially sediment has to be removed from one side of the wreck, from the port side for the aft section, from the starboard side for the bow section. One suggested method of removing sediments is through the use of freezing technology the sediments before removal another is traditional suction dredging. With subsea winches the wreck will be pulled/rotated over to the side until the keel is exposed.
4.3	Open the keel	If possible the easiest access to the keel would be from underneath the keel box. If this is not possible the keel must be accessed through the side plate and the centre plate separating the starboard and port side of the keel.
4.4	Retrieve the Mercury canisters from keel to seabed	The canisters can either be withdrawn from the keel through the use of a suction pad, magnet or a specially designed grabbing mechanism. To remove liquid Mercury, a suction pump can be used.
4.5	Bring Mercury canisters and free floating Mercury from seabed to surface	The canisters will be placed in a sealed container with a drain tube especially designed for this operation. The purpose built container will be installed in a standard subsea basket.
4.6	Stabilise wreck before capping	The wires and subsea winches will secure the wreck also after the operation has ended. To avoid any hydraulic oil spill, the hydraulic motors on the subsea winches will be removed. The subsea winches and wires will remain in place when capping, ensuring stability during capping.

In the following chapters this method will be further elaborated with a focus on equipment and tools being used, and a risk assessment of the operation. The sketches included below are not accurate when it comes to dimensions, they are only included to give the reader a better understanding of the suggested concept. More sketches are included in chapter 4.

In the risk assessment possible events are rated with probability and consequence with values according to the risk matrix in figure 2.

		Consequence				
		Minor	Low	Considerable	Large	Severe
Probability	Likely	Significant	Critical	Critical	Critical	Critical
	Reasonably prob	Significant	Significant	Critical	Critical	Critical
	Unlikely	Insignificant	Significant	Significant	Critical	Critical
	Remote	Insignificant	Insignificant	Significant	Significant	Critical
	Extremely remote	Insignificant	Insignificant	Insignificant	Significant	Significant
	Theoretically Possible	Insignificant	Insignificant	Insignificant	Insignificant	Significant

Figure 2: Risk matrix

Subsequently the mitigating actions that reduce the probability and/or the consequence of the event are identified. The new rating of probability and consequence for the event is then assessed.

One common set of risks and actions will be used as basis for all companies (See appendix A) which has a numbering from R1 to R16 for risks and T1.x to T16.x for Mitigating actions. For company and method specific risks the numbering will start with an abbreviation representing the company (D,SW,T,O,S7).

The abbreviations used in the risk assessment tables in this document are shown in the table below. The first four rows are abbreviations for different types of consequences. The five last rows are abbreviations for the magnitude of a particular type of consequence. Other abbreviations used are listed in the underlying table.

Abbreviation	Full text
ELT	Environment LONG Term
EST	Environment SHORT term
PS	Personnel SAFETY
OS	Operational SAFETY
M	Minor consequence
Lo	Low consequence
C	Considerable consequence
La	Large consequence
S	Severe consequence

2.1 Preparations

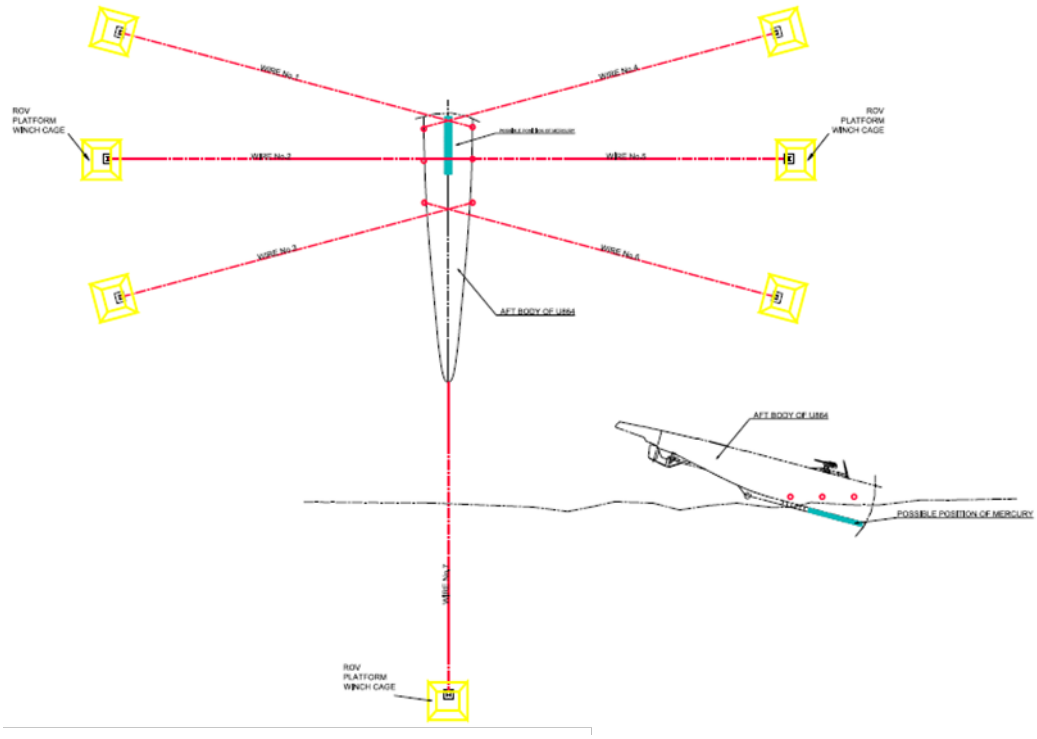
2.1.1 Operation

2.1.1.1 Build platform to support ROV

To create a more stable access to the top of the wreck and decrease ROV thrusting, a platform is built on both sides of both wreck parts.

2.1.1.2 Fasten wire arrangement and secure in position

To fasten anchoring screws and the wire to the hull several holes are drilled. On the seabed the wires will be fastened either to suction anchors in the mud or directly to solid rock. The wires will be tightened by hydraulic winches.



2.1.2 Equipment and tooling

Swire Seabed suggests using the following equipment and tooling:

No	Operational sub step	Equipment or tools applied
4.1.1.1	Build platform to support ROV.	Light weight building block to construct ROV platform.
4.1.1.2	Fasten wire arrangement and secure the wreck in current position.	Drilling equipment, Wires, hydraulic winches, anchor screws, mud anchor, Screws for solid rock, ROV etc.

2.1.3 Risk assessment

2.1.3.1 Risk before mitigating actions

Risk	Sub step	Risk	Description	Probability	Consequence
SR1	4.1.1.2	Whirl up of contaminated sediments.	The wires might touch the seabed during this operation, which again will lead to limited spreading of contaminated sediments.	Likely	ELT(Lo) EST(Lo) OS(Lo)
SR2	4.1.1.2	Breakage of parts	The anchoring bolt on the hull can break or loosen and the wire can be torn because of sharp edges on the wreck. This can happen through several steps during the operation.	Remote	ELT(Lo) EST(Lo) OS(Lo)
R2	4.1.1.2	Unwanted bodies around wreck or in the soil.	Can be parts of wreck or stones that makes it difficult to place drag anchor, but can also make it difficult for the ROV	Likely	OS(Lo)

2.1.3.2 Risk after mitigating actions

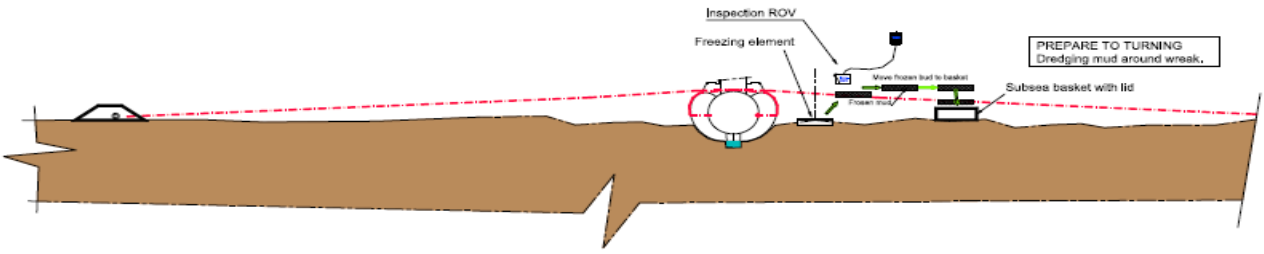
Action (Risk)	Sub step	Mitigating action	Description of action	Probability after action	Consequence after action
ST1.1 (SR 1)	4.1.1.2	Thin layer of gravel	Lay a thin layer of gravel in the area were the wire can touch the seabed before the operation.	Unlikely	ELT(Lo) EST(Lo) OS(Lo)
ST1.2 (SR 1)	4.1.1.2	Extra ROV	Use an extra ROV to hold the wire to prevent it from touching the seabed	Unlikely	ELT(Lo) EST(Lo) OS(Lo)
ST1.3 (SR 1)	4.1.1.2	Buoyancy on wire	Attach buoyancy elements to the wires to avoid them touching the seabed.	Unlikely	ELT(Lo) EST(Lo) OS(Lo)
ST2.1 (SR2)	4.1.1.2	Design of anchoring bolt	Flexible design of anchoring bolts that that will hold the hull even with an inaccurate entering point.	Extremely remote	ELT(I) EST(I) OS(I)
ST2.2 (SR2)	4.1.1.2	Protection cover	Use a protective cover on the wire the first meters from the hull.	Extremely remote	ELT(I) EST(I) OS(I)
T2.1 (R2)	4.1.1.2	Geotechnical examination	With further examinations it will be easier to plan the placement of the anchors.	Unlikely	OS(Lo)
T2.2 (R2)	4.1.1.2	Alternative anchor on seabed	It may a better alternative to place the anchor in solid rock if it is possible and if a suction anchor becomes a challenge.	Reasonable possible	OS(Lo)
T2.3 (R2)	4.1.1.2	Remove	Have a selection of equipment available to remove unwanted bodies.	Reasonable possible	OS(M)

2.2 Get access to the keel

2.2.1 Operation

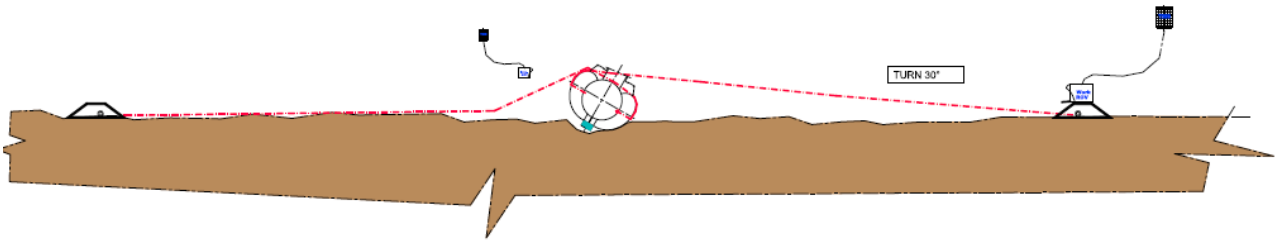
2.2.1.1 Remove sediments

To reduce pressure on the keel and the hull when pulling the wreck into position some sediment needs to be removed along the side of the wreck. The sediments will be removed from the port side for the aft section and on the starboard side for the bow section. One suggested method for removing sediments is by using freezing technology, then the sediments are frozen into blocks before removal, another option is traditional suction dredging.



2.2.1.2 Winch the wreck into position

With hydraulic winches the wreck will be pulled over to the side. The wreck will be pulled with a slow, controlled movement until the keel is exposed.



2.2.2 Equipment and tooling

No	Operational sub step	Equipment or tools applied
4.2.1.1	Remove sediments	Equipment to freeze and lift sediments Suction dredger and ROV
4.2.1.2	Winch the wreck into position	Hydraulic winches and ROV

2.2.3 Risk assessment

2.2.3.1 Risk before mitigating actions

Risk	Sub step	Risk	Description	Probability	Consequence
SR3	4.2.1.1	Uncontrolled pull by winches	If the winches pull the keel too fast, the keel can be damaged further and the fastening to the hull could be pulled off.	Unlikely	ELT(Lo) EST(Lo) OS(Lo)
R1	3.2.1.1	Spreading of mercury contaminated sediments	Spread contaminated sediments during suction dredging according to NIVA report 5279-2006.	Likely	ELT(Lo) EST(Lo)
R5	3.2.1.1	Uncontrolled movement and back fill of sediments during dredging	The sediment has very low shear strength at approximately 5-10 KP. This makes it hard to stabilise.	Likely	ELT(Lo) EST(Lo)

2.2.3.2 Risk after mitigating actions

Action	Sub step	Mitigating action	Description of action	Probability after action	Consequence after action
ST3.1 (SR3)	4.2.1.1	Use inclinometer	To monitor the movement an inclinometer will be fastened to the wreck.	Unlikely	ELT(Lo) EST(Lo) OS(Lo)
T1.1 (R1)	3.1.1.1	Develop new technology	For example exhaust treatment, containerised system, or bags can be filled up. Today no subsea technology to filter out mercury from sediments or water exist. It is therefore very uncertain if this action is possible. This will require more research and	Reasonably probable	ELT(Lo) EST(Lo)

Action	Sub step	Mitigating action	Description of action	Probability after action	Consequence after action
			testing.		
T1.2 (R1)	3.1.1.1	Use other forms of dredging	Use mechanical dredging to remove the minimum amount of soil to get access to the keel. Mechanical dredging will also spread contaminated sediments, but not in such large amounts as suction dredging.	Reasonably probable	ELT(Lo) EST(Lo)
T1.3 (R1)	3.2.1.1	Analyse dredging method	Perform a detailed analysis on which dredging method should be used in the different areas and depths, depending on share strength and on the severity of the contamination.	Reasonably probable	ELT(Lo) EST(Lo)
T1.4 (R1)	3.2.1.1	Take core sample before operation	Take samples around the wreck parts and inside the keel, before and during the operation, to monitor the content of mercury in the sediments.	Reasonably probable	ELT(Lo)
T1.5 (R1)	3.2.1.1	The use of a small suction pump	If free floating mercury is excavated a small suction pump that delivers the exhausts to a closed bag can be used.	Reasonably probable	ELT(Lo) EST(Lo)
T1.6 (R1)	3.2.1.1	The use of a smaller suction dredge	To reduce the flow from the exhaust a smaller suction dredge can be used.	Reasonably probable	ELT(Lo) EST(Lo)
T5.1 (R5)	3.2.1.1	Geotechnical assessment	Assessment of soil conditions	Reasonably probable	ELT(Lo) EST(Lo)
T5.2 (R5)	3.2.1.1	Stabilising barrier	Sheet pile stabilisation or sand bags etc.	Reasonably probable	ELT(Lo) EST(Lo)

2.3

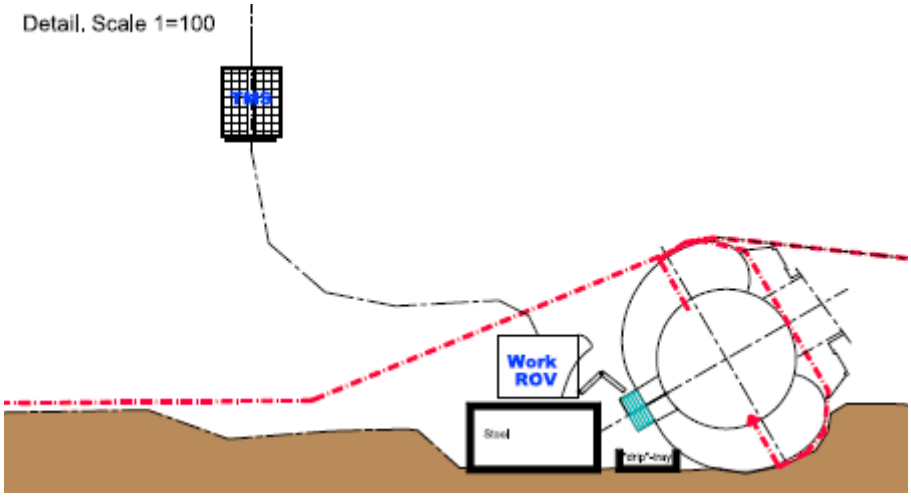
2.4 Open the keel

2.4.1 Operation

2.4.1.1 Drill or cut to open the keel

If possible the easiest access to the keel may be from underneath the keel box. If this is not possible the keel must be accessed through the side plate and the plate separating the starboard and port side of the keel. After removing the canisters and free floating mercury from one compartment, the other side of the keel must be approached.

In all phases of this operation it is essential that the cutting tool does not rupture the canisters.



2.4.2 Equipment and tooling

No	Operational sub step	Equipment or tools applied
3.3.1.2	Drill or cut open the keel	ROV with tools to cut and drill, a water cutter with grit could be used.

2.4.3 Risk assessment

2.4.3.1 Risk before mitigating actions

Risk	Sub step	Risk	Description	Probability	Consequence
R3	4.3.1.1 4.3.1.2	Spread contaminated sediments because of ROV operation	During the ROV operation the thrusting of the ROV or physical contact between ROV and the sediments can lead to spreading of contaminated sediments. This can also lead to reduced visibility and therefor delay the operation.	Likely	ELT(Lo) EST (C) OS (Lo)
R13	4.3.1.2	Access to other side of keel	When the wreck is stable and the keel is excavated, one side of the keel is easily accessible. It is uncertain how much effort is required to get access to the other side of the keel.	Likely	OS (C)

2.4.3.2 Risk after mitigating actions

Action	Sub step	Mitigating action	Description of action	Probability after action	Consequence after action
T3.1 (R3)	4.3.1.1 4.3.1.2	Cover the sediments	Cover the sediments with a mat or gravel.	Unlikely	ELT(Lo) EST(Lo) OS (M)
T3.2 (R3)	4.3.1.1 4.3.1.2	Optimal trim	Operate ROV with optimal trim.	Reasonably probable	ELT(Lo) EST(Lo) OS (M)
T3.3 (R3)	4.3.1.1 4.3.1.2	Experience and training	The ROV operator should be experienced and trained for the specific operation through simulation.	Reasonably probable	ELT(Lo) EST(Lo) OS (M)
T3.4 (R3)	4.3.1.1 4.3.1.2	ROV foundation	The ROV can use a magnet, a sticky foot, a platform and bags of sand or gravel as a foundation during the operation to reduce the thrusting of the ROV.	Reasonably probable	ELT(Lo) EST(Lo) OS (M)
T13.1 (R13)	4.3.1.2	Alterative equipment	Special designed equipment for this operation.	Unlikely	OS (C)
T13.2 (R13)	4.3.1.2	Inspection	Check the other side of the keel with a camera before starting the cut to prevent puncturing mercury canisters.	Unlikely	OS (C)
T13.3 (R13)	4.3.1.2	Testing/planning	Simulation and testing of method and equipment.	Unlikely	OS (C)

2.5 Retrieve the Mercury canisters from keel to seabed

2.5.1 Operation

2.5.1.1 Removal of mercury canisters from keel

The canisters can either be withdrawn from the keel through the use of a suction pad, magnet or a specially designed grabbing mechanism.

2.5.1.2 Removal of free floating mercury from keel

In the case where floating mercury is found, the use of a suction pump is most efficient. To capture free floating mercury, a tray will be placed under the keel.

2.5.2 Equipment and tooling

No	Operational sub step	Equipment or tools applied
4.4.1.1	Removal of mercury canisters from keel	ROV with suction pad, magnet or a specially designed grabbing mechanism.
4.4.1.2	Removal of free floating mercury from keel	ROV with suction pump

2.5.3 Risk assessment

2.5.3.1 Risk before mitigating actions

Risk	Sub step	Risk	Description	Probability	Consequence
R11	4.4.1.1	Crush or drop canisters	The canisters are of various qualities. When extracting them from the keel it is likely that some of them will be crushed.	Likely	ELT(M) EST(M) OS (M)

2.5.3.2 Risk after mitigating actions

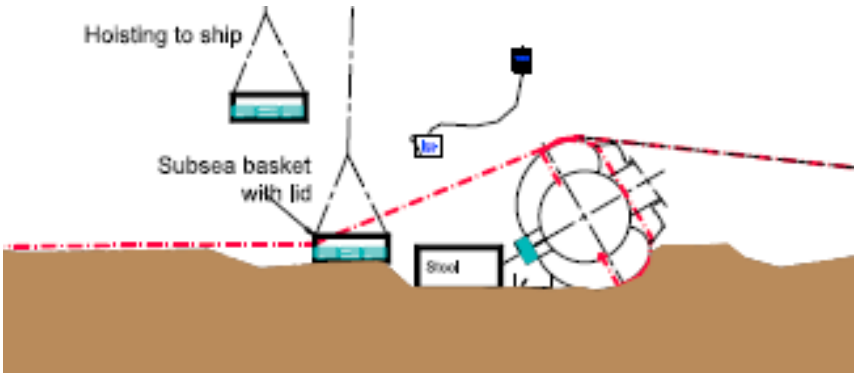
Action	Sub step	Mitigating action	Description	Probability	Consequence
T11.1 (R11)	4.4.1.1.	"Vacuum cleaner"	To reduce the consequence of a mercury spill a suction pump should be available to retrieve smaller amounts of floating mercury.	Likely	ELT(M) EST(M) OS (M)
T11.2 (R11)	4.4.1.1.	Design of receiving area	There should be a specially designated area next to the keel where the canisters can be received. In this area the seabed should be designed so that any spill is easily collected. This will not reduce the chance of crushing or dropping canisters, but the contamination will be limited.	Likely	ELT(M) EST(M) OS (M)
T11.3 (R11)	4.4.1.1.	Design of handling equipment	The handling equipment should be designed and tested with the aim to reduce number of canisters broken or dropped.	Likely	ELT(M) EST(M) OS (M)

2.6 Bring Mercury canisters and free floating Mercury from seabed to surface

2.6.1 Operation

2.6.1.1 Bring mercury canisters from seabed to surface

When the canisters are taken out of the keel they will be placed into a big container and brought up to the surface. Swire Seabed suggests designing a box where several canisters can be loaded and where spillage inside the box can be drained when the box is on deck.



2.6.1.2 Bring free floating mercury from seabed to surface

The free floating mercury will be collected with a suction pump into a sealed bag. This bag will be put into the same box designed by Swire Seabed.

2.6.1.3 Land and handle mercury on deck

When landing the subsea basket and other equipment that has been subsea there is a risk of transferring contaminated sediments to the deck of the ship. On the ship there should be a defined landing area for the subsea basket and all the equipment used subsea.

2.6.2 Equipment and tooling

No	Operational sub step	Equipment or tools applied
3.5.1.1	Bring mercury canisters from seabed to surface	Sealed box with room for several canisters with a possibility to drain spillage. This box will be placed in a standard subsea basket.

2.6.3 Risk assessment

2.6.3.1 Risk before mitigating actions

Risk	Sub step	Risk	Description	Probability	Consequence
R14	4.5.1.1	Load falling	Uncontrolled fall of basket when brought from surface to deck.	Extremely remote	ELT(La) EST(La) OS (Lo)
R15	4.5.1.1	Bottle crushed	Bottles crushed due to pressure difference.	Reasonably possible	ELT (La) EST (La)
R16	4.5.1.3	Spillage on deck	Spillage on deck due to contaminated equipment.	Likely	ELT (Lo) EST (Lo) PS (Lo)

2.6.3.2 Risk after mitigating actions

Action	Sub step	Mitigating action	Description	Probability	Consequence
T14.1 (R14)	4.5.1.3	Procedure	The ROV checks that everything is closed and in place before lift.	Theoretically Possible	ELT(La) EST(La) OS (Lo)
T14.2 (R14)	4.5.1.3	Certified lifting equipment.	For example closed offshore basket.	Theoretically Possible	ELT(La) EST(La) OS (Lo)
T15.1 (R15)	4.5.1.1	Sealed box	A sealed box will minimize/avoid spillage of mercury	Likely	ELT(M) EST(M)
T16.1 (R16)	4.5.1.3	Landing area	Predefined landing area on deck for subsea basket.	Unlikely	ELT(Lo) EST(Lo) PS (Lo)
T16.2 (R16)	4.5.1.3	Personal Protective gear	Gear to protect personnel handling the mercury and personnel located on deck.	Reasonably probable	ELT(Lo) EST(Lo) PS (Lo)

T16.3 (R16)	4.5.1.3	Cleaning of equipment under water	To reduce spillage on deck all equipment can be cleaned when submerged.	Unlikely	ELT(Lo) EST(Lo) PS (Lo)
T16.4 (R16)	4.5.1.3	Face the vessel with regards to the weather situation	Due to evaporation from the mercury it could help to face the vessel against the wind so that the potential gas is led away from the deck and crew areas as fast as possible.	Reasonably probable	ELT(Lo) EST(Lo) PS (Lo)
T16.5 (R16)	4.5.1.3	Experienced people	There crew of handling the mercury must have experience with this and procedures to ensure that it is managed according to regulations.	Unlikely	ELT(Lo) EST(Lo) PS (Lo)
T16.6 (R16)	4.5.1.3	Adequate sealing of container	The box carrying the canister and free floating mercury has to have a robust and safe sealing mechanism.	Unlikely	ELT(Lo) EST(Lo) PS (Lo)

2.7 Stabilise wreck before capping

Before capping, the winches will be removed but the wires will still be in place. Both wires and the wire anchoring will be left on the seabed and covered during the capping process to minimize spreading of contaminated sediments. There are no further operations needed to stabilise the wreck before capping.

3 RISK ASSESSMENT

The risk assessment shows that all risk has been reduced to significant or insignificant due to the suggested mitigating actions.

Spreading of mercury contaminated sediments when stabilising the wreck and excavating the keel is a critical risk but can be mitigated. Development of new technology could be the most efficient mitigation but will require unknown recourses on research and testing.

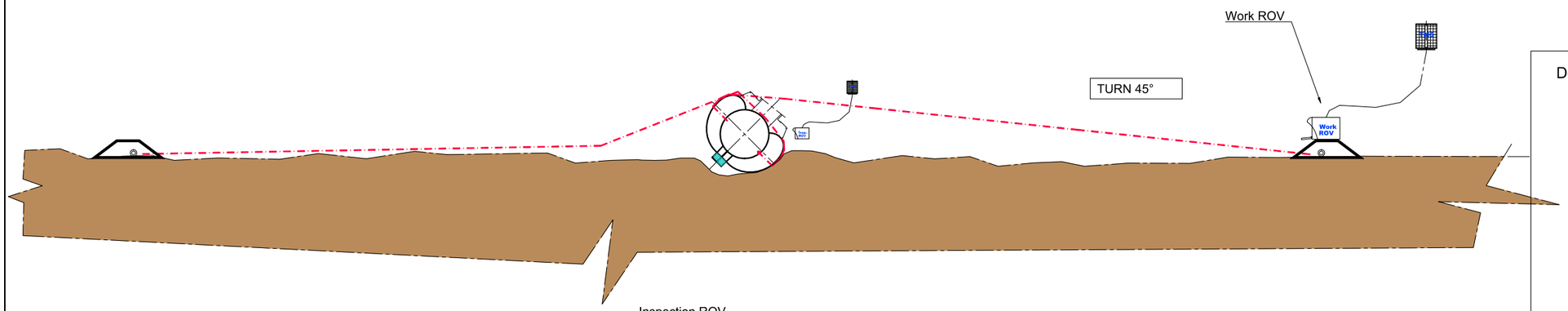
Mechanical dredging using a smaller suction dredge or a small suction pump can be used. Mechanical dredging will give moderate spreading but will increase the time of the operation.

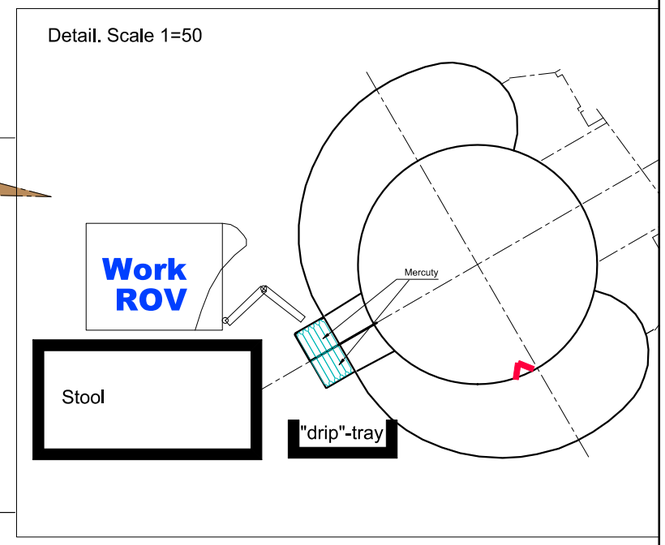
4 LIST OF COMMON RISKS

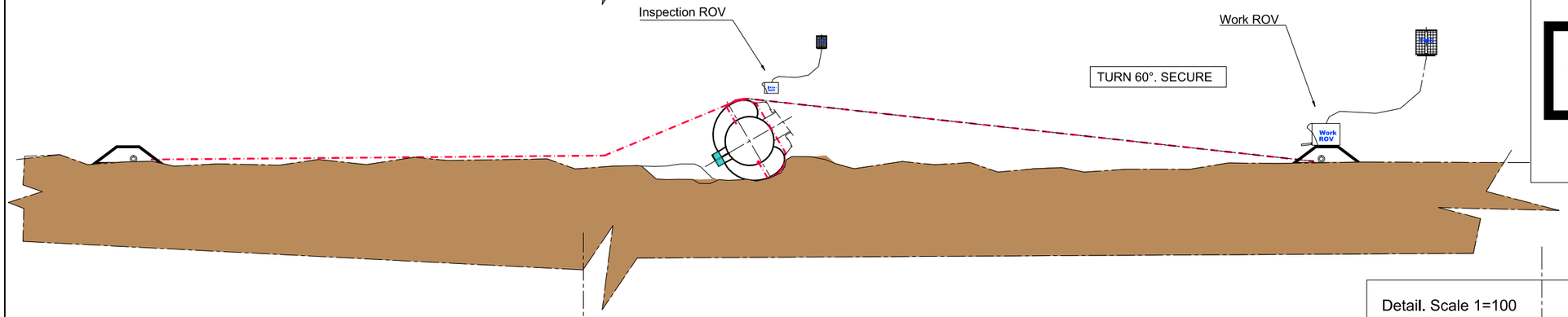
No	Name	Description
R1	**Spreading of mercury contaminated sediments**	Spread contaminated sediments during suction dredging according to NIVA report 5279-2006.
R2	**Unwanted bodies around wreck or in the soil.**	Can be parts of wreck or stones that makes it difficult to place drag anchor, but can also make it difficult for the ROV to manoeuvre.
R3	**Spread contaminated sediments because of ROV operation**	During the ROV operation the thrusting of the ROV or physical contact between ROV and the sediments can lead to spreading of contaminated sediments. This can also lead to reduced visibility and therefor delay the operation.
R4	**Uncontrolled movement of sediments surrounding the bow structure**	The sediments surrounding the bow section are not stable and can be the cause of a massive slide. Polluted sediments will then be spread into the water column. If the bow section moves during the slide the keel can break up and lead to further contamination.
R5	**Uncontrolled movement and back fill of sediments during dredging**	The sediment has very low shear strength at approximately 5-10 KP. This makes it hard to stabilise.
R6	**Uncontrolled rotation**	
R7	**Access to pressure hull**	It might be difficult to get access to the pressure hull. The outer hull is very fragile and hull parts may for example fall of during ROV operation.
R8	**Excavation operation, mechanical dredging**	
R9	**Damaged keel**	When the hull rolls over the keel can be stuck in the sediments and therefore partly damaged. If the more canisters rupture during this phase this might lead to further contamination of the of the sediments under the keel.
R11	**Crush or drop canisters**	The canisters are of various qualities. When extracting them from the keel it is very likely that some of them will be crushed. It is also very likely that some canisters can be dropped between the keel and the subsea basket.
R13	**Access to other side of keel**	When the wreck is stable and the keel is excavated, one side of the keel is easily accessible. It is uncertain how much effort is required to get access to the other side of the keel.
R14	**Load falling**	Uncontrollable fall of basket when brought from surface to deck.
R15	**Bottles crushed**	Bottles crushed due to pressure difference.
R16	**Spillage on deck**	Spillage on deck due to contaminated equipment.
R17	**Air pockets in bow section**	Bow section might still contain air pockets, and is therefore unstable.

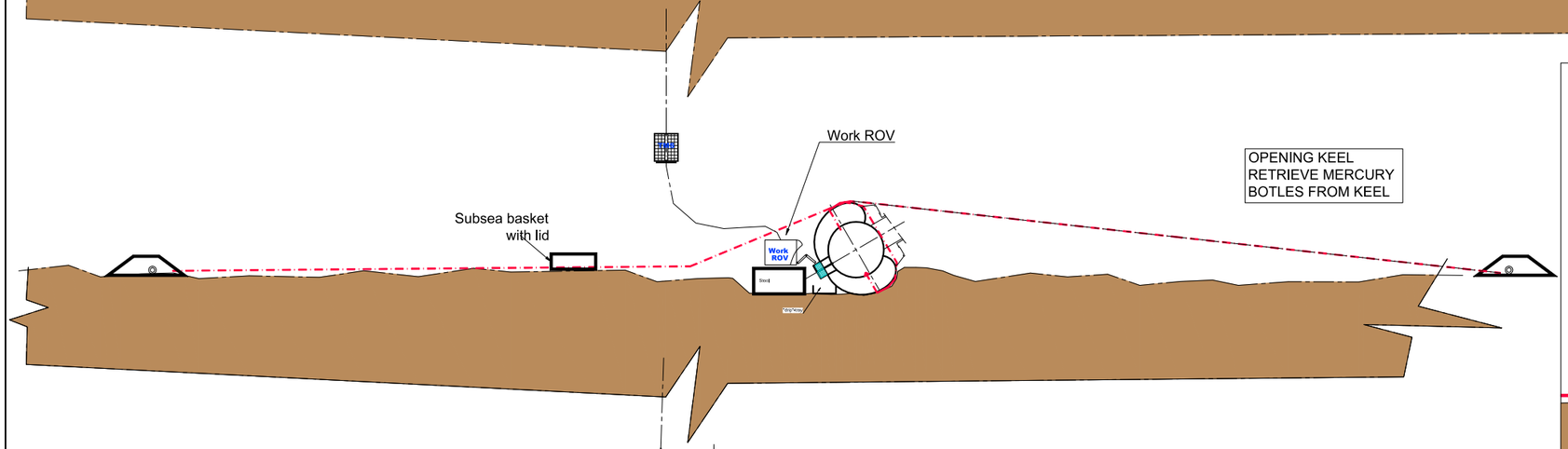
5 SKETCHES OF SUGGESTED METHOD

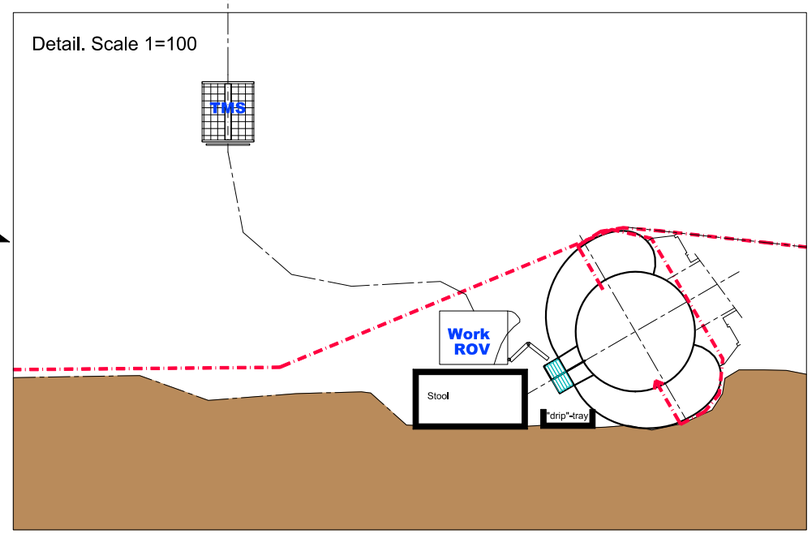
A complete set of sketches of the suggested method to retrieve mercury canisters follows:

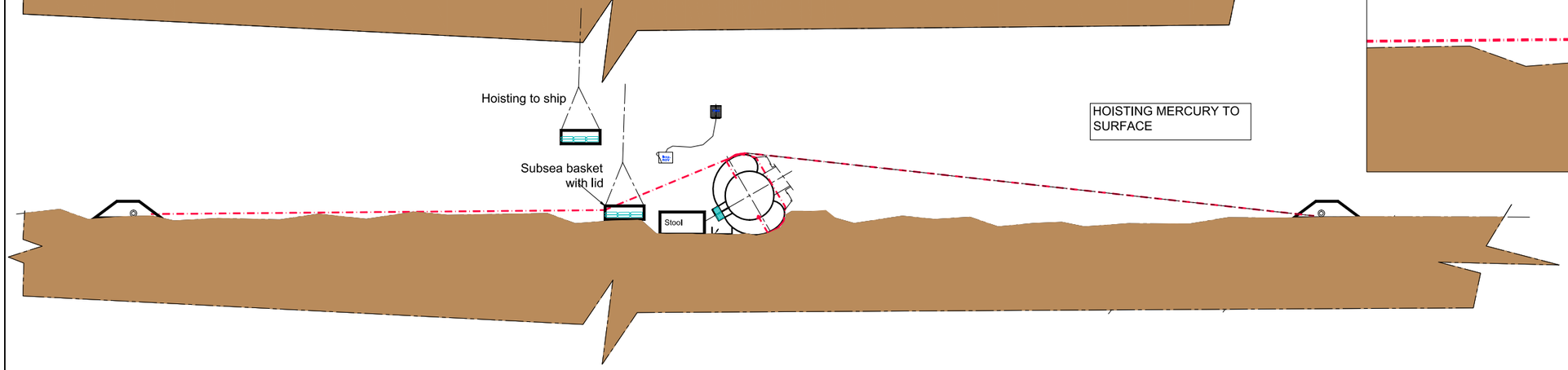












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SHEET	REV	DRAWN	DATE
3 OF 3	–	MaKi	27.01.2014
PROJECT NUMBER		CHECKED	DATE
1053 – U864		ABa	28.01.2014
DRAWING NUMBER		SCALE	FORMAT
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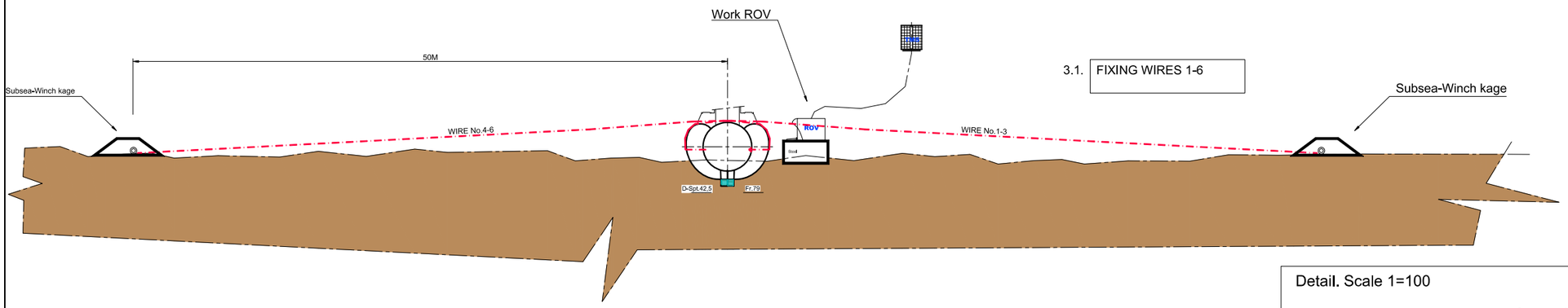
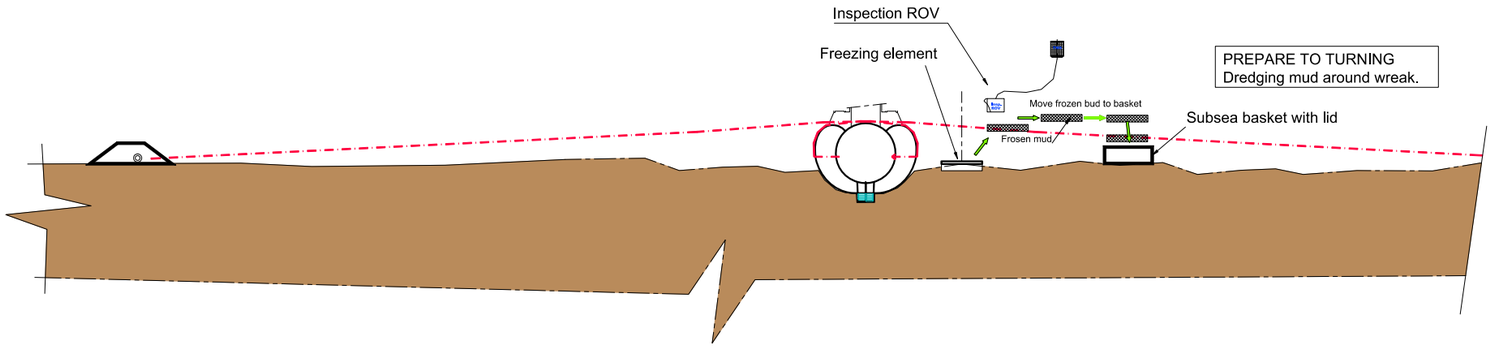
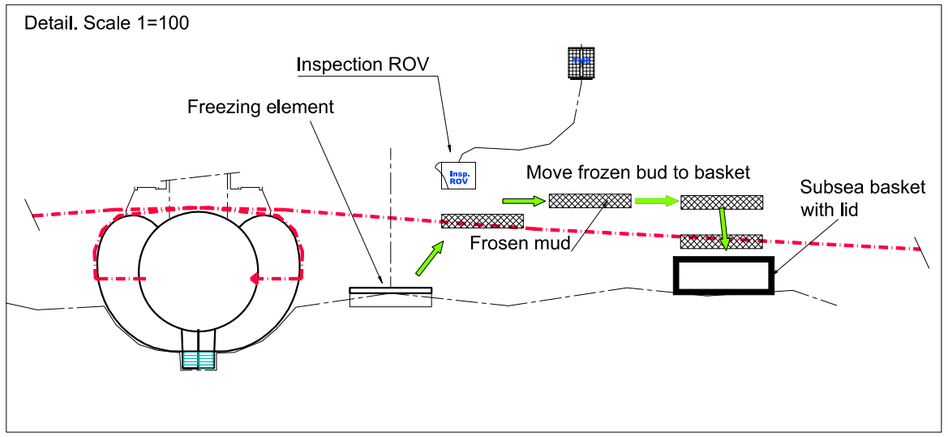
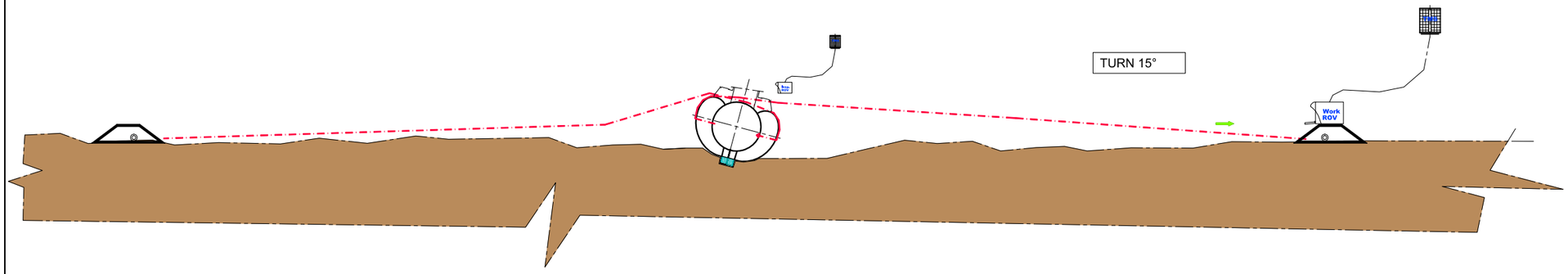


3.1. FIXING WIRES 1-6

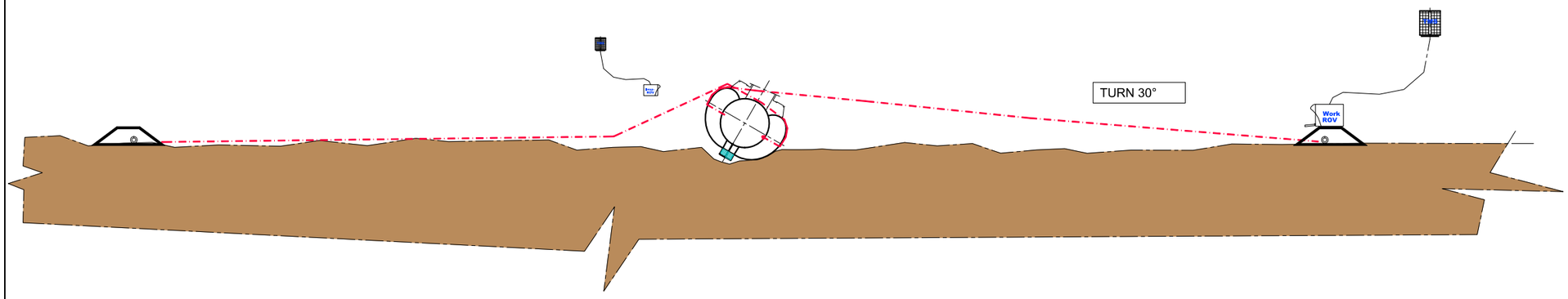


PREPARE TO TURNING
Dredging mud around wreak.





TURN 15°



TURN 30°

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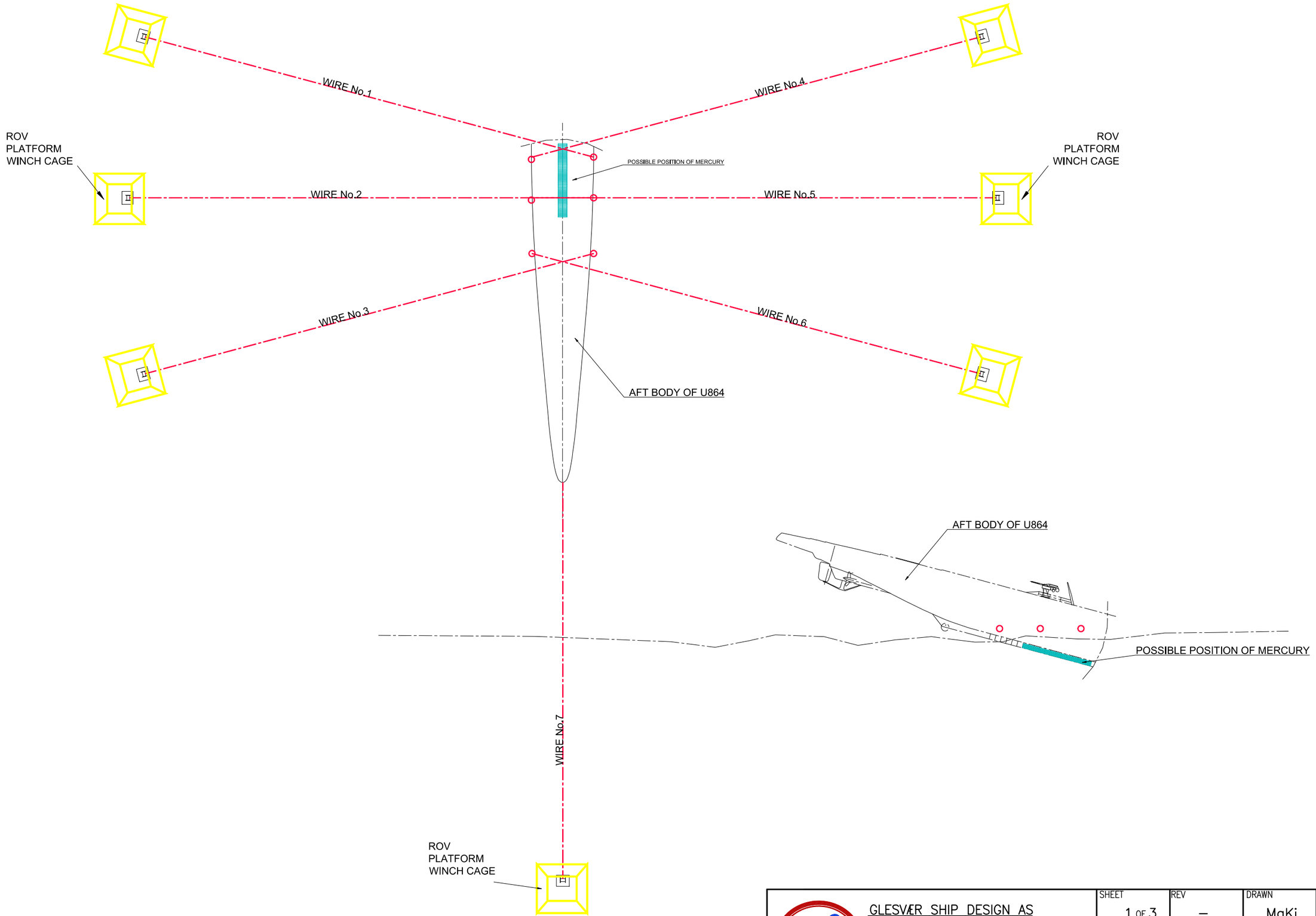

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ENVIRONMENTAL MEASURES FOR THE WRECK OF U-864

Feasibility study - Suggested method for U864 mercury cargo recovery: Subsea 7

DNV GL AS

Project name: Environmental measures for the wreck of U-864

Report title: Feasibility study - Suggested method for U864 mercury cargo recovery:
Subsea 7

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Dato: 12.5.2014

Reference to part of this report which may lead to misinterpretation is not permissible.

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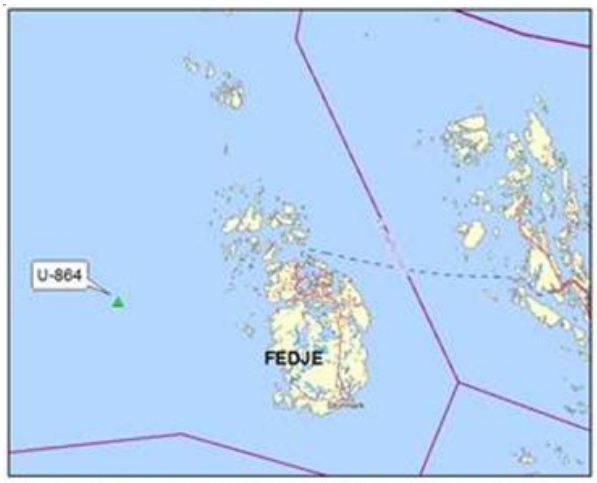
1 INTRODUCTION

The German submarine U-864 was torpedoed by the British submarine Venturer 9th of February 1945, approximately 2 nautical miles west of the Island Fedje in Hordaland. U-864 was on its way from Germany via Norway to Japan. The submarine was loaded with war material, and according to historical documents approximately 67 ton of floating metallic mercury in steel canisters stored in the keel. The torpedo split the submarine into two parts. The wreck parts were discovered by the Royal Norwegian Navy at a depth of approximately 150-175 m. Several studies have revealed feasible measures for pollution abatement. The risks related to these measures have been assessed and indicate the following:

- High mercury concentrations in the soil, especially around the wreck parts.
- The bow section is inclining and has a high risk of sliding downhill. (Geotechnical unstable)
- Torpedoes and ammunition in general.
- Oil in the wreck.
- The condition of the two wreck parts.
- The condition of the mercury canisters.

In 2013 DNV-GL was assigned by the Norwegian Coastal Administration to carry out a pre-project that will assess the possibility of recovering the mercury canisters from the wreck parts before capping the wreck parts and the polluted seabed-area. As part of the assignment, competent subsea companies have been invited to discuss feasible solutions and cost pertaining to the proposed solutions.



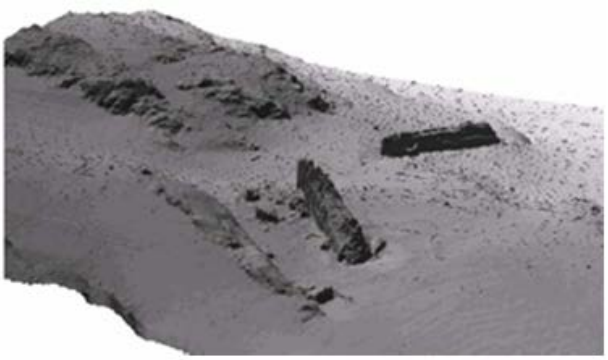


Figure 1.Loction of the wreck outside Fedje (left) and sonar image of bow and aft part of the wreck (right)

2 SUGGESTED METHOD TO RETRIEVE MERCURY CANISTERS

To avoid a global collapse of the seabed slope where the bow section resides, the valley to the North will be rock dumped with the purpose of stabilising the area prior to any intervention work on the wreck. This measure is valid for all the suggested methods from all companies participating in this RFI (Request for information).

For all companies the operation has been divided into 6 generic steps as presented in the table below. The suggested method Subsea 7 for the retrieval of the mercury canisters from the keel of U-864 is presented briefly in the table below and more in detail in the succeeding sub-chapters:

No	Operational step	Brief description (company specific)
4.1	Preparations	Start the operation by clearing debris surrounding the wreck. The bow section will initially be secured to avoid any movement. Both sections will then be secured by wires fastened from both sides of the hull to the seabed, either by the use of suction anchors or directly to solid rock.
4.2	Get access to the keel	Initially sediments have to be removed from one side of the wreck, from the port side for the aft section and from the starboard side for the bow section. To move the sediments a peel grab, mechanical digger and a suction dredger will be used. The suction dredger will be used closer to the wreck together with a smaller mechanical digger. The wreck will then be pulled over to the side with hydraulic winches until the keel is exposed. When the wreck is in the right position it will be secured by a supporting structure.
4.3	Open the keel	The keel will be accessed through the side plate and the plate separating starboard and port side of the keel. Before cutting through the middle plate an inspection hole will be made and a camera will be used to inspect the keel to avoid puncturing any canisters.
4.4	Retrieve the Mercury canisters from keel to seabed	The canisters can either be withdrawn from the keel through the use of a suction pad, magnet or a specially designed grabbing mechanism. To remove liquid Mercury, a suction pump can be used, and which will be a closed system.
4.5	Bring Mercury canisters and free floating Mercury from seabed to surface	The canisters will be placed in a watertight bag before they are put in a standard subsea basket. The liquid mercury will be pumped into a closed bag and also transported in the same basket. The basket will not be opened on deck but instead sent directly to a handling point on shore.
4.6	Stabilise wreck before capping	The wires will secure the wreck also after the operation has ended. The hydraulic winches can be retrieved without removing the wires.

In the following chapters this method will be further elaborated with a focus on equipment and tools being used, and a risk assessment of the operation. The sketches included below are not accurate when it comes to dimensions; they are only included to better give the reader an understanding of the concept suggested. More sketches are included at the end of this report.

In the risk assessment possible events are rated with probability and consequence with values according to the risk matrix in figure 2.

		Consequence				
		Minor	Low	Considerable	Large	Severe
Probability	Likely	Significant	Critical	Critical	Critical	Critical
	Reasonably prob	Significant	Significant	Critical	Critical	Critical
	Unlikely	Insignificant	Significant	Significant	Critical	Critical
	Remote	Insignificant	Insignificant	Significant	Significant	Critical
	Extremely remote	Insignificant	Insignificant	Insignificant	Significant	Significant
	Theoretically Possible	Insignificant	Insignificant	Insignificant	Insignificant	Significant

Figure 2: Risk matrix

Subsequently the mitigating actions that reduce the probability and/or the consequence of the event are identified. The new rating of probability and consequence for the event is then assessed.

One common set of risks and actions will be used as basis for all companies (see chapter 3) which has a numbering from R1 to R16 for risks and T1.x to T16.x for mitigating actions. For company and method specific risks the numbering will start with an abbreviation representing the company (D,SW,T,O,S7).

In the risk assessment tables in this document abbreviations are used. These abbreviations are shown in the table below where the first four rows are abbreviations for different types of consequences and the five last are abbreviations for the magnitude of a particular type of consequence. Other abbreviations used are listed in the underlying table.

Abbreviation	Full text
ELT	Environment LONG Term
EST	Environment SHORT term
PS	Personnel SAFETY
OS	Operational SAFETY
M	Minor consequence
Lo	Low consequence
C	Considerable consequence
La	Large consequence
S	Severe consequence

2.1 Preparations

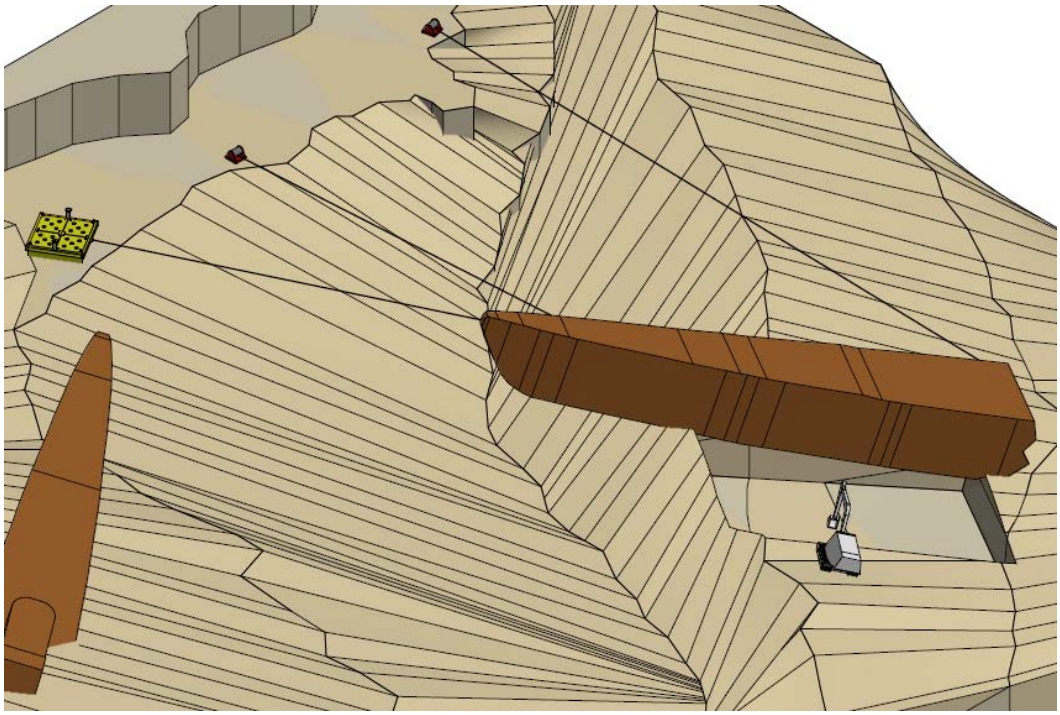
2.1.1 Operation

2.1.1.1 Clear debris and secure bow section

Clear debris surrounding the wreck before the bow section is secured to avoid any movement.

2.1.1.2 Fasten wire arrangement and secure in position

To fasten anchoring screws and the wire to the hull, several holes are drilled. On the seabed the wires will be fastened either to suction anchors in the mud or directly to solid rock. The wires will be tightened by hydraulic winches.



2.1.2 Equipment and tooling

Subsea7 suggests using the following equipment and tooling:

No	Operational sub step	Equipment or tools applied
4.1.1.1	Clear debris and secure bow section	ROV and crane Drilling equipment, wires, hydraulic winches, anchor screws, suction anchor, screws for solid rock, ROV etc.
4.1.1.2	Fasten wire arrangement and secure the wreck in current position.	Drilling equipment, wires, hydraulic winches, anchor screws, suction anchor, screws for solid rock, ROV etc.

2.1.3

2.1.4 Risk assessment

2.1.4.1 Risk before mitigating actions

Risk	Sub step	Risk	Description	Probability	Consequence
R2	4.1.1.2	Unwanted debris around wreck or in the soil.	Can be parts of wreck or stones that make it difficult to place drag anchor, but can also make it difficult for the ROV to manoeuvre.	Likely	OS(Lo)

2.1.4.2 Risk after mitigating actions

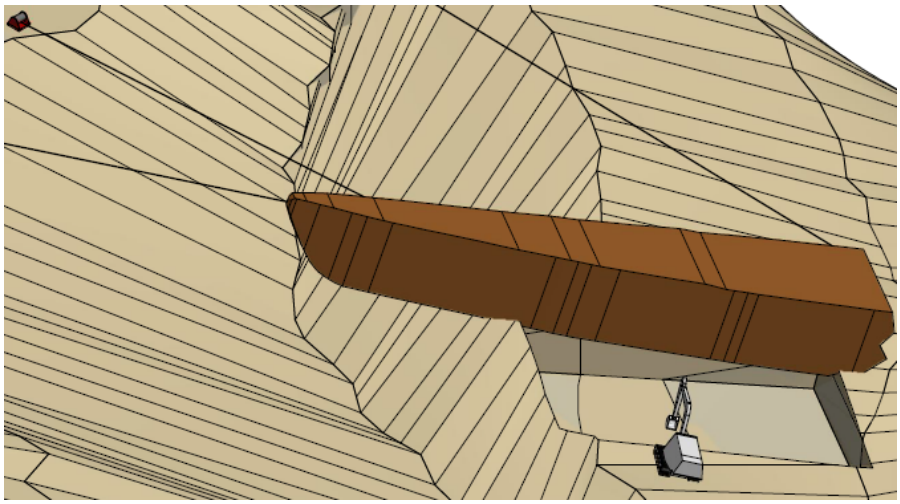
Action (Risk)	Sub step	Mitigating action	Description of action	Probability after action	Consequence after action
T2.1 (R2)	4.1.1.2	Geotechnical assessment	With further assessment it will be easier to plan the placement of the anchors.	Unlikely	OS(Lo)
T2.2 (R2)	4.1.1.2	Alternative anchor on seabed	It may be a better alternative to place the anchor in solid rock if it is possible and if a suction anchor becomes a challenge.	Reasonable possible	OS(Lo)
T2.3 (R2)	4.1.1.2	Alternative equipment	Have a selection of equipment available to remove unwanted bodies.	Reasonable possible	OS(M)

2.2 Get access to the keel

2.2.1 Operation

2.2.1.1 Remove sediments

To reduce pressure on the keel and the hull when pulling the wreck into position some sediment along the side of the wreck needs to be removed. The sediments will be removed from the port side for the aft section and from the starboard side for the bow section. To move the sediments a peel grab, mechanical digger and a suction dredger will be used. The suction dredger will be used closer to the wreck together with a smaller mechanical digger.



2.2.1.2 Winch the wreck into position

The wreck will be pulled over to the side with hydraulic winches. The wreck will be pulled with a controlled and slow movement until the keel is exposed. When the wreck is in the right position it will be secured by a supporting structure.

2.2.2 Equipment and tooling

No	Operational sub step	Equipment or tools applied
4.2.1.1	Remove sediments	Peel grab, mechanical digger, suction dredger and ROV
4.2.1.2	Winch the wreck into position	Hydraulic winches, ROV and supporting structure

2.2.3 Risk assessment

2.2.3.1 Risk before mitigating actions

Risk	Sub step	Risk	Description	Probability	Consequence
R1	4.2.1.1	Spreading of mercury contaminated sediments	Spread contaminated sediments during suction dredging according to NIVA report 5279-2006.	Likely	ELT(Lo) EST(Lo)
R5	4.2.1.1	Uncontrolled movement and back fill of sediments during dredging	The sediment has very low shear strength at approximately 5-10 KP. This makes it hard to stabilise.	Likely	ELT(Lo) EST(Lo)
S7R1	4.2.1.1	Destabilising wreck	The wreck might be destabilised when dredging alongside.	Likely	ELT(C) EST(C) OS(S)

2.2.3.2 Risk after mitigating actions

Action	Sub step	Mitigating action	Description of action	Probability after action	Consequence after action
T1.1 (R1)	4.1.1.1	Develop new technology	For example exhaust treatment, containerised system, or bags can be filled up. Today no subsea technology to filter out mercury from sediments or water exists.	Reasonably probable	ELT(Lo) EST(Lo)
T1.2 (R1)	4.1.1.1	Use other forms of dredging	Remove sediments through the use of mechanical dredging or technology to freeze the sediment before removal.	Reasonably probable	ELT(Lo) EST(Lo)
T1.3 (R1)	4.2.1.1	Analyse dredging method	Perform a detailed analysis on which dredging method should be used in the different areas.	Reasonably probable	ELT(Lo) EST(Lo)
T1.4 (R1)	4.2.1.1	Take core sample before operation	Take samples around the wreck parts and inside the keel, before and during the operation, to monitor the content of mercury in the sediments.	Reasonably probable	ELT(Lo) EST(Lo)

Action	Sub step	Mitigating action	Description of action	Probability after action	Consequence after action
T1.5 (R1)	4.2.1.1	The use of a small suction pump	If free floating mercury is excavated a small suction pump that delivers the exhausts to a closed bag can be used.	Reasonably probable	ELT(Lo) EST(Lo)
T1.6 (R1)	4.2.1.1	The use of a smaller suction dredge	To reduce the flow from the exhaust a smaller suction dredge can be used.	Reasonably probable	ELT(Lo) EST(Lo)
T5.1 (R5)	4.2.1.1	Geotechnical assessment	Assessment of soil conditions	Reasonably probable	ELT(Lo) EST(Lo)
T5.2 (R5)	4.2.1.1	Stabilising barrier	Sheet pile stabilisation or sand bags etc.	Reasonably probable	ELT(Lo) EST(Lo)
S7T1.1 (S7R1)	4.2.1.1	Wires on both sides of wreck	By placing wires on both sides to be able to both pull and hold, the wreck will be stable when dredging alongside.	Remote	ELT(C) EST(C) OS(S)

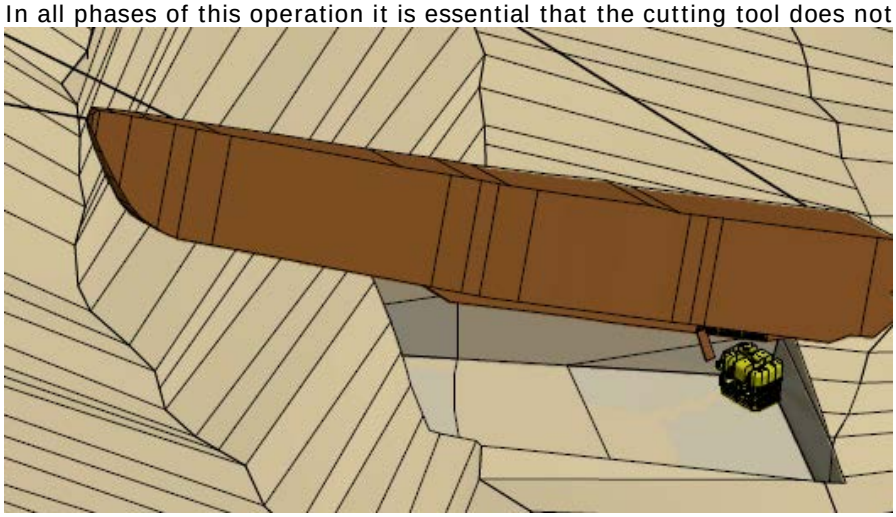
2.3 Open the keel

2.3.1 Operation

2.3.1.1 Drill or cut to open the keel

The keel will be accessed through the side plate and the plate separating starboard and port side of the keel. Before cutting through the middle plate an inspection hole will be made and a camera will be used to inspect the keel to avoid puncturing any canisters. If detailed analysis reveals that the integrity of the keel is at risk by cutting it, the keel could be filled by epoxy or cement after the removal of the mercury cargo.

In all phases of this operation it is essential that the cutting tool does not rupture the canisters.



2.3.2 Equipment and tooling

No	Operational sub step	Equipment or tools applied
4.3.1.2	Drill or cut open the keel	ROV with tools to cut and drill, a grinder could be used to cut between the starboard and port side of the keel.

2.3.3 Risk assessment

2.3.3.1 Risk before mitigating actions

Risk	Sub step	Risk	Description	Probability	Consequence
R3	4.3.1.1 4.3.1.2	Spread contaminated sediments because of ROV operation	During the ROV operation the thrusting of the ROV or physical contact between ROV and the sediments can lead to spreading of contaminated sediments. This can also lead to reduced visibility and therefor delay the operation.	Likely	ELT(Lo) EST (C) OS (Lo)
R13	4.3.1.2	Access to other side of keel	When the wreck is stable and the keel is excavated, one side of the keel is easily accessible. It is uncertain how much effort is required to get access to the other side of the keel.	Likely	OS (C)

2.3.3.2 Risk after mitigating actions

Action	Sub step	Mitigating action	Description of actions	Probability after action	Consequence after action
T3.1 (R3)	4.3.1.1 4.3.1.2	Cover the sediments	Cover the sediments with a mat or gravel.	Unlikely	ELT(Lo) EST(Lo) OS (M)
T3.2 (R3)	4.3.1.1 4.3.1.2	Optimal trim	Operate ROV with optimal trim.	Reasonably probable	ELT(Lo) EST(Lo) OS (M)
T3.3 (R3)	4.3.1.1 4.3.1.2	Experience and training	The ROV operator should be experienced and trained for the specific operation through simulation.	Reasonably probable	ELT(Lo) EST(Lo) OS (M)
T3.4 (R3)	4.3.1.1 4.3.1.2	ROV foundation	The ROV can use a magnet, a sticky foot, a platform and bags of sand or gravel as a foundation during the operation to reduce the thrusting of the ROV.	Reasonably probable	ELT(Lo) EST(Lo) OS (M)
T13.1 (R13)	4.3.1.2	Alternative equipment	Specially designed equipment for this operation.	Unlikely	OS (C)
T13.2 (R13)	4.3.1.2	Inspection	Check the other side of the keel with a camera before starting the cut to prevent puncturing mercury canisters.	Unlikely	OS (C)
T13.3 (R13)	4.3.1.2	Testing/ planning	Simulation and testing of method and equipment.	Unlikely	OS (C)

2.4

2.5 Retrieve the Mercury canisters from keel to seabed

2.5.1 Operation

2.5.1.1 Removal of mercury canisters from keel

The safest way to collect the bottles without destroying them is by using a suction pad. If the canisters are corroded together a specially designed lifting grab has to be used.

2.5.1.2 Removal of free floating mercury from keel

In the case where floating mercury is found, the use of a suction pump is most efficient.

2.5.2 Equipment and tooling

No	Operational sub step	Equipment or tools applied
4.4.1.1	Removal of mercury canisters from keel	ROV with suction pad, magnet or a specially designed grabbing mechanism.
4.4.1.2	Removal of free floating mercury from keel	ROV with suction pump

2.5.3 Risk assessment

2.5.3.1 Risk before mitigating actions

Risk	Sub step	Risk	Description	Probability	Consequence
R11	4.4.1.1	Crush or drop canisters	The canisters are of various qualities. When extracting them from the keel it is very likely that some of them will be crushed. It is also very likely that some canisters may be dropped between the keel and the subsea basket.	Likely	ELT(La) EST(La) OS (La)

2.5.3.2 Risk after mitigating actions

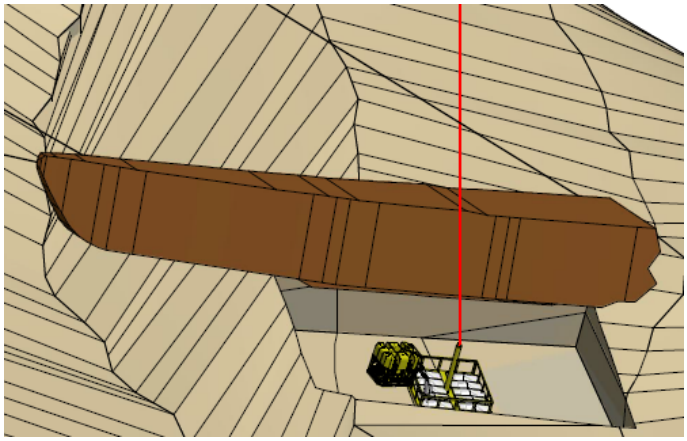
Action	Sub step	Mitigating action	Description of action	Probability after action	Consequence after action
T11.1 (R11)	4.4.1.1.	"Vacuum cleaner"	To reduce the consequence of a mercury spill there should be access to a suction pump that can retrieve smaller amounts of floating mercury.	Likely	ELT(M) EST(M) OS (M)
T11.2 (R11)	4.4.1.1.	Design of receiving area	There should be a specially designated area next to the keel where the canisters are received. In this area the seabed should be designed so that any spill can easily be collected. This will not reduce the chance of crushing or dropping canisters, but the contamination will be limited.	Likely	ELT(M) EST(M) OS (M)
T11.3 (R11)	4.4.1.1.	Design of handling equipment	The handling equipment should be designed and tested with the aim to reduce number of canisters broken or dropped.	Likely	ELT(M) EST(M) OS (M)

2.6 Bring Mercury canisters and free floating Mercury from seabed to surface

2.6.1 Operation

2.6.1.1 Bring mercury canisters from seabed to surface

The canisters will be placed in a watertight bag before they are put in a standard subsea basket.



2.6.1.2 Bring free floating mercury from seabed to surface

The liquid mercury will be pumped into a closed bag and also transported in the same basket.

2.6.1.3 Land and handle mercury on deck

When landing the subsea basket and other equipment that has been subsea there is a risk of transferring contaminated sediments to the deck of the ship. On the ship there should be a defined landing area for the subsea basket and all the equipment used subsea. The basket will not be opened on deck but instead sent directly to a handling point on shore.

2.6.2 Equipment and tooling

No	Operational sub step	Equipment or tools applied
3.5.1.1	Bring mercury canisters from seabed to surface	Sealed bag for each canister. This bag will be placed in a standard subsea basket.
3.5.1.2	Bring free floating mercury from seabed to surface	Closed bag that will be place in a standard subsea basket.

2.6.3 Risk assessment

2.6.3.1 Risk before mitigating actions

Risk	Sub step	Risk	Description	Probability	Consequence
R14	4.5.1.1	Load falling	Uncontrolled fall of basket when brought from surface to deck.	Extremely remote	ELT(La) EST(La) OS (Lo)
R15	4.5.1.1	Bottle crushed	Bottles crushed due to pressure difference.	Reasonably possible	ELT (La) EST (La)
R16	4.5.1.3	Spillage on deck	Spillage on deck due to contaminated equipment.	Likely	ELT (Lo) EST (Lo) PS (Lo)

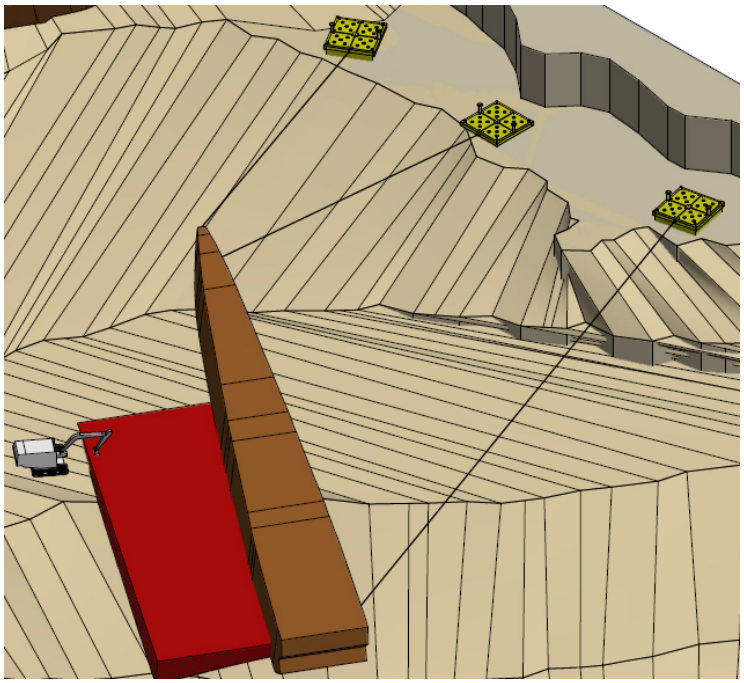
2.6.3.2 Risk after mitigating actions

Action	Sub step	Mitigating action	Description of action	Probability after action	Consequence after action
T14.1 (R14)	4.5.1.3	Procedure	The ROV checks that everything is closed and in place before lift.	Theoretically Possible	ELT(La) EST(La) OS (Lo)
T14.2 (R14)	4.5.1.3	Certified lifting equipment	For example closed offshore basket.	Theoretically Possible	ELT(La) EST(La) OS (Lo)
T15.1 (R15)	4.5.1.1	Sealed box	To avoid spillage because of this event it is important to use a sealed box.	Likely	ELT(M) EST(M)
T16.1 (R16)	4.5.1.3	Landing area	Predefined landing area on deck for subsea basket.	Unlikely	ELT(Lo) EST(Lo) PS (Lo)
T16.2 (R16)	4.5.1.3	Personal Protective gear	Gear to protect personnel handling the mercury and personnel located on deck.	Reasonably probable	ELT(Lo) EST(Lo) PS (Lo)
T16.3 (R16)	4.5.1.3	Cleaning of equipment under water	To reduce spillage on deck all equipment can be cleaned when submerged.	Unlikely	ELT(Lo) EST(Lo) PS (Lo)
T16.4 (R16)	4.5.1.3	Face the vessel with regards to the weather situation	Due to evaporation from the mercury it could help to face the vessel against the wind so that the potential gas is led away from the deck as fast as possible.	Reasonably probable	ELT(Lo) EST(Lo) PS (Lo)
T16.5 (R16)	4.5.1.3	Experienced people	There has to be a crew of experienced people handling the mercury according to regulations.	Unlikely	ELT(Lo) EST(Lo) PS (Lo)
T16.6 (R16)	4.5.1.3	Adequate sealing of container	The box carrying the canister and free floating mercury has to have a robust and safe sealing mechanism.	Unlikely	ELT(Lo) EST(Lo) PS (Lo)

2.7

2.8 Stabilise wreck before capping

Before capping the winches will be removed but the wires will still be in place. Both wires and the wire anchoring will be covered during the capping process. There are no further operations needed to stabilise the wreck before capping.



3 RISK ASSESSMENT

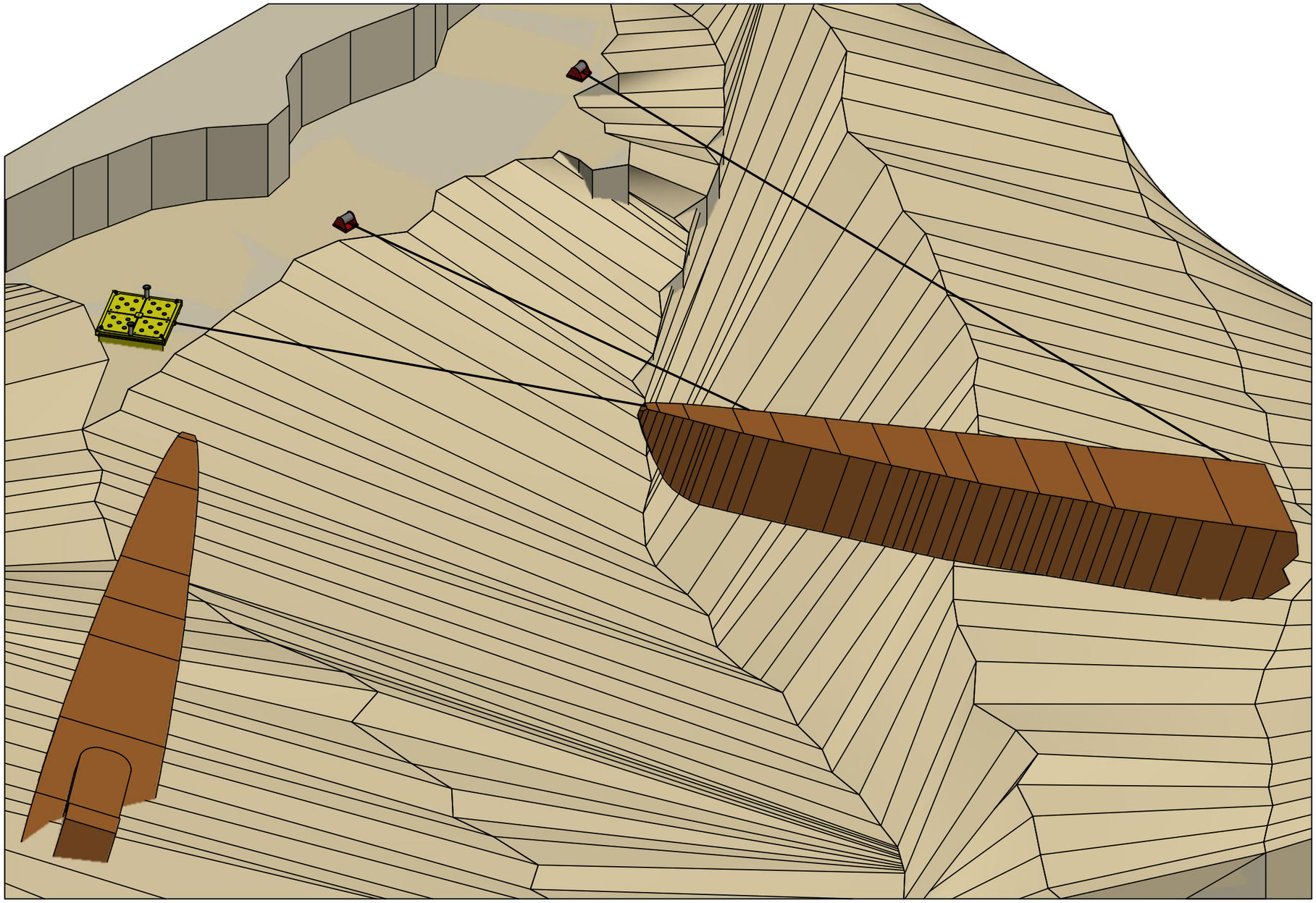
The risk assessment shows that all risk has been reduced to considerable or low due to the suggested mitigating actions.

Spreading of mercury contaminated sediments when stabilising the wreck and excavating the keel is a large risk but can be mitigated. Development of new technology would be most efficient but will require unknown resources on research and testing

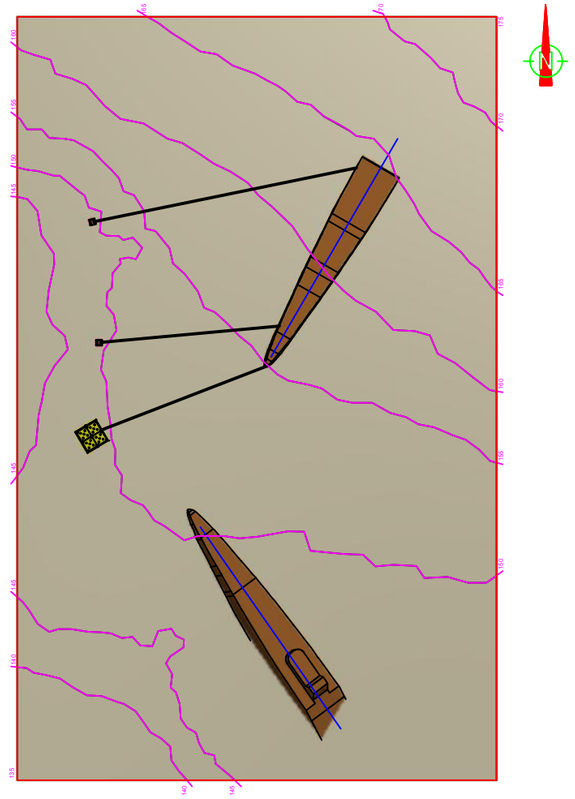
Mechanical dredging, a smaller suction dredge or a small suction pump can be used. Mechanical dredging will give more moderate spreading but will increase the time of the operation.

4 SKETCHES OF SUGGESTED METHOD

A complete set of sketches of the suggested method to retrieve mercury canisters follows:

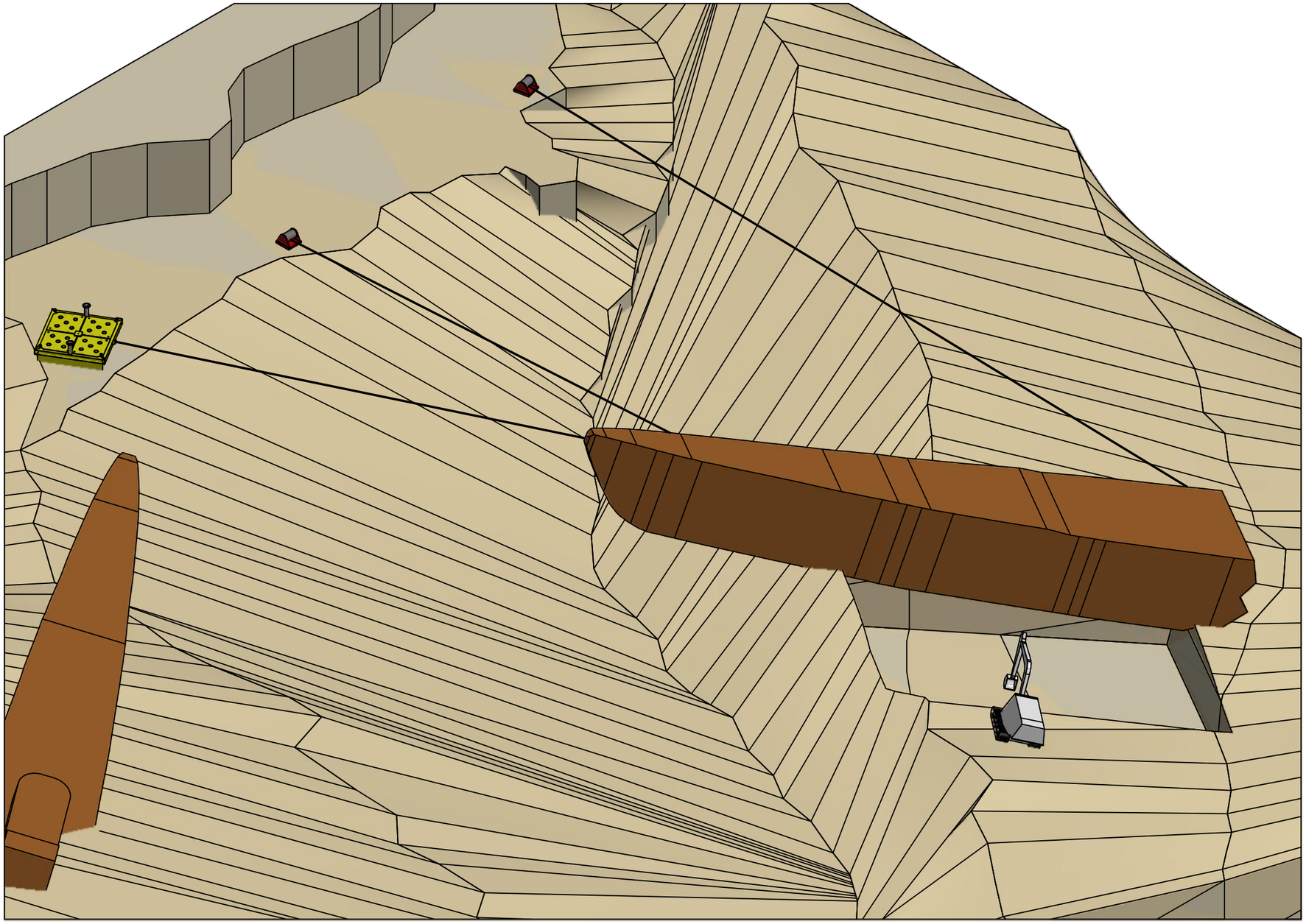


ISOMETRIC - SECURE THE WRECK

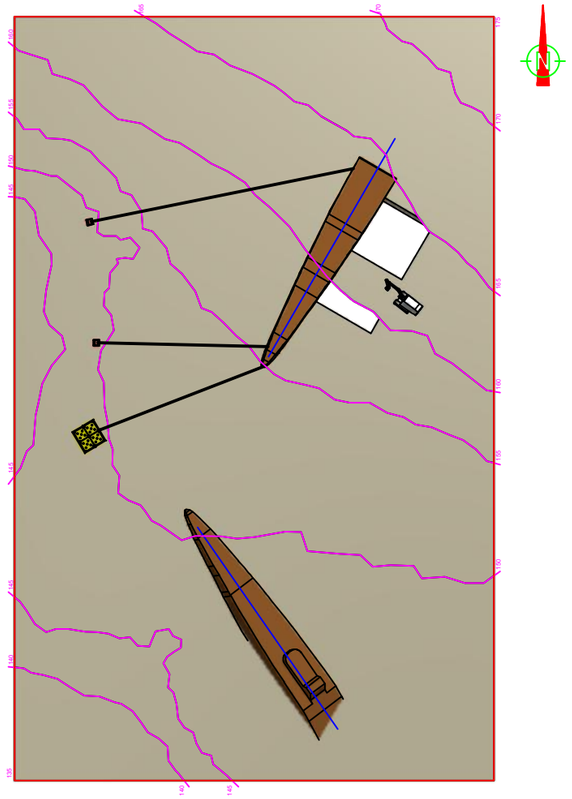


PLAN - STEP 1

Project	SS7_U-864 Hg RETRIEVAL OPERATION	Client	DNV GL	subsea 7	
Title	SS7_U-864 Hg RETRIEVAL OPERATION SKETCHES STEP 1 - SECURE THE WRECK	NOT TO SCALE FOR ILLUSTRATION ONLY		Kanalsletta 9, 4052 Røyneberg - P.O Box 205, 4056 Stavanger Tel: +47 51725000 Fax: +47 51725001	
		Drawn by: DDM	Date Drawn: 26.01.2014	Checked By: SHJ	Last Rev Date: 26.01.2014	Sketch No.: **Step 1**

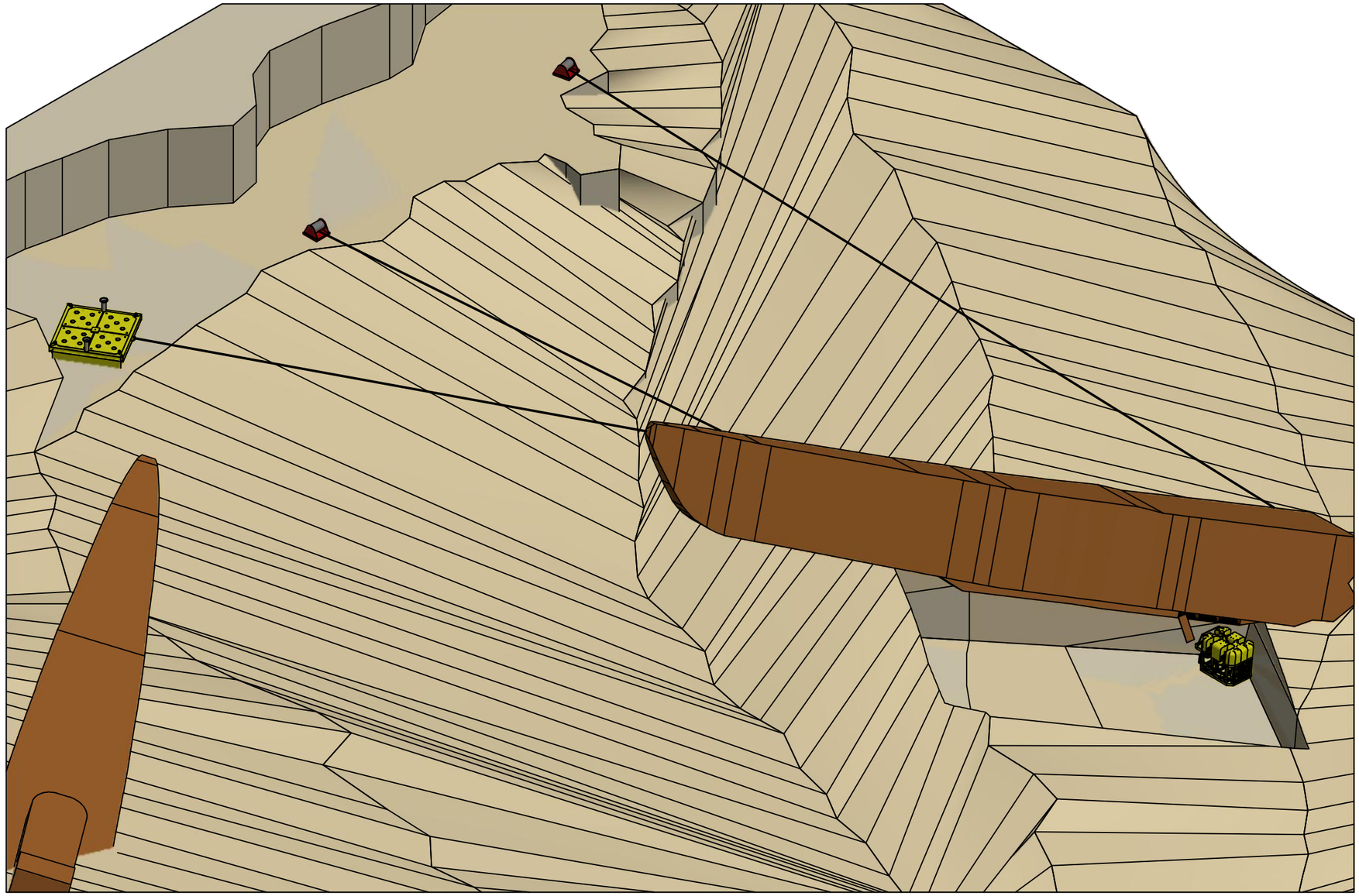


ISOMETRIC - WRECK IS ROLLED TOWARDS WEST USING SUBSEA WINCHES
AND KEEL IS EXPOSED USING SUBSEA EXCAVATOR

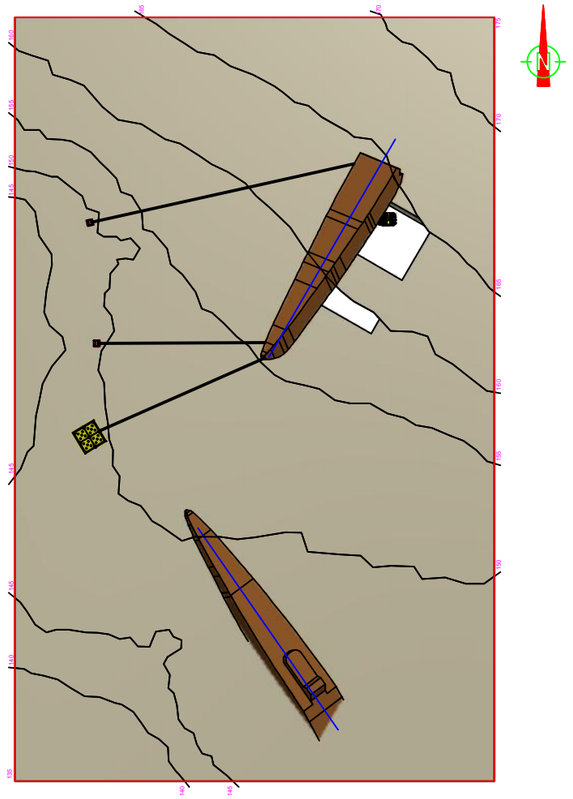


PLAN - STEP 2

Project	SS7_U-864 Hg RETRIEVAL OPERATION	Client	DNV GL	subsea 7	
Title	SS7_U-864 Hg RETRIEVAL OPERATION SKETCHES STEP 2 - GAIN ACCESS TO KEEL	NOT TO SCALE FOR ILLUSTRATION ONLY		Kanalsletta 9, 4052 Røyneberg - P.O Box 205, 4056 Stavanger Tel: +47 51725000 Fax: +47 51725001	
		Drawn by: DDM	Date Drawn: 26.01.2014	Checked By: SHJ	Last Rev Date: 26.01.2014	Sketch No.: **Step 2**

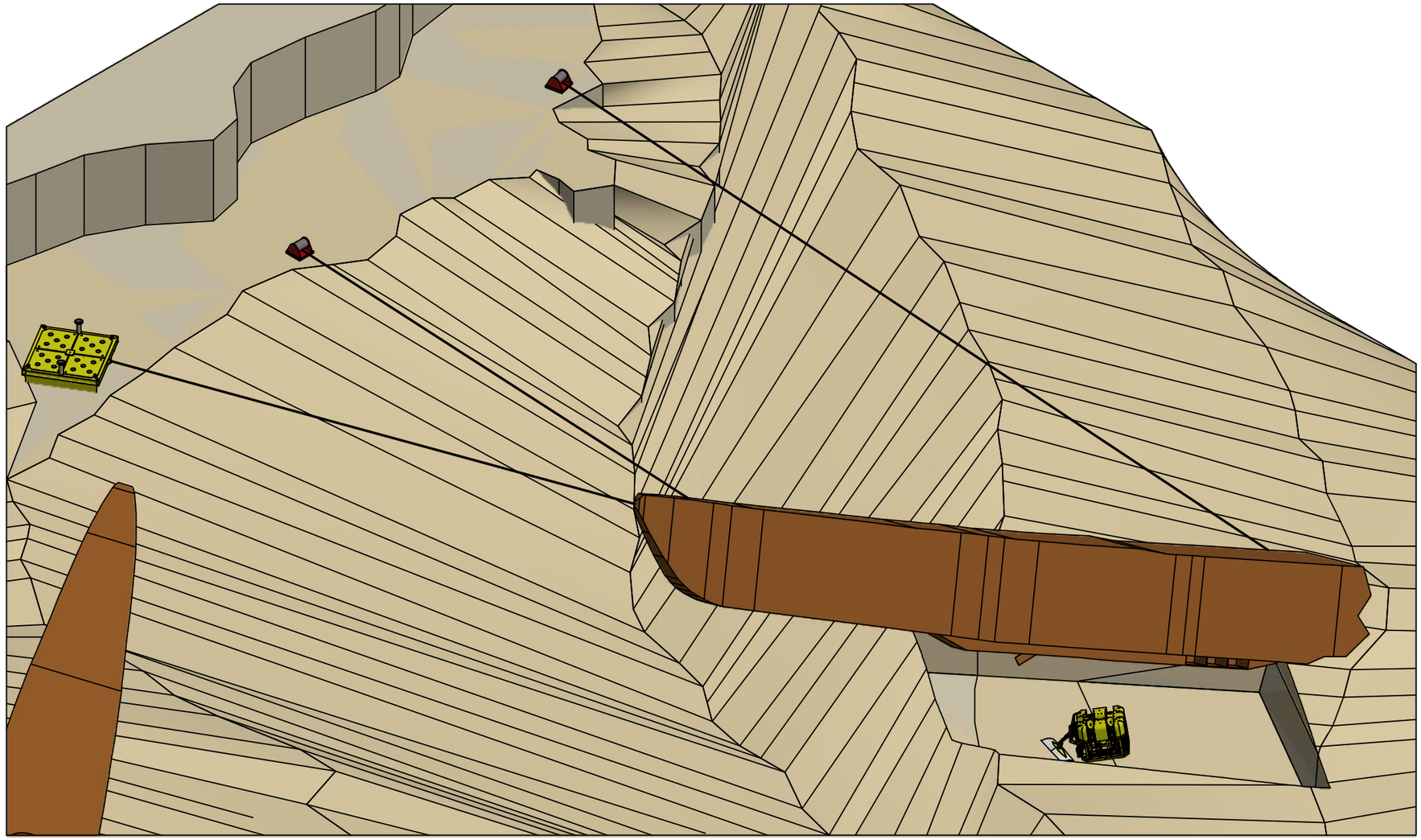


ISOMETRIC - ROV OPENS EXPOSED KEEL CARGO HOLDS WITH GRINDER

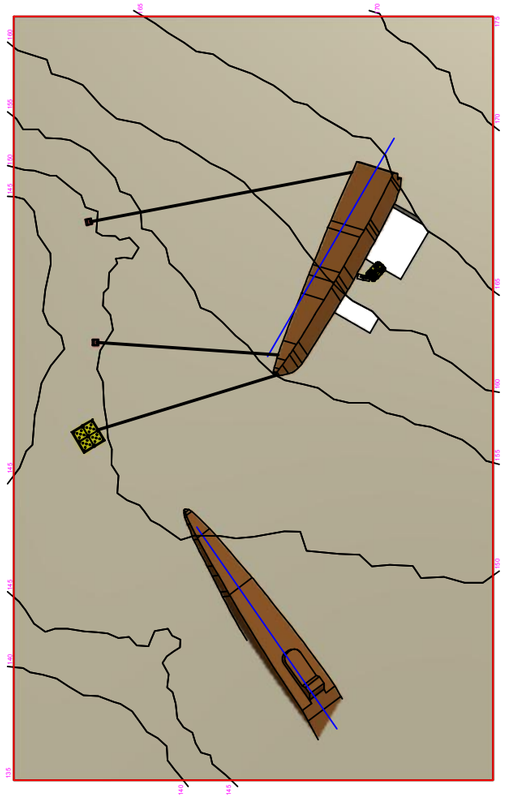


PLAN - STEP 3

Project	SS7_U-864 Hg RETRIVAL OPERATION	Client	DNV GL	subsea 7		
Title	SS7_U-864 Hg RETRIVAL OPERATION SKETCHES STEP 3 - OPENING THE KEEL	NOT TO SCALE FOR ILLUSTRATION ONLY		Kanalsletta 9, 4052 Røyneberg - P.O Box 205, 4056 Stavanger Tel: +47 51725000 Fax: +47 51725001		
		Drawn by	Date Drawn	Checked By	Last Rev Date	Sketch No.
		DDM	26.01.2014	SHJ	26.01.2014	**Step 3**

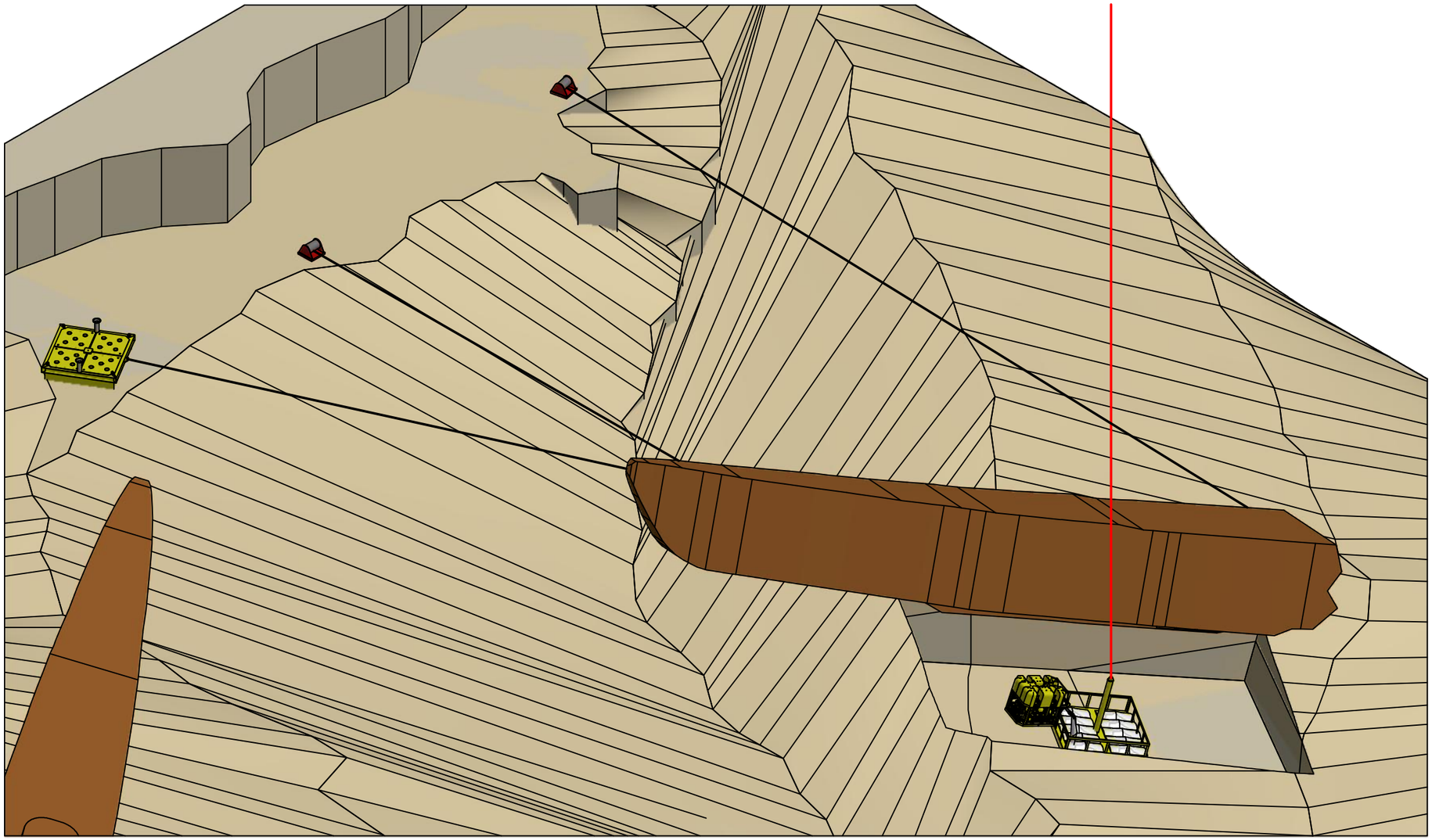


ISOMETRIC - ROV PLACES FLASKS INTO INDIVIDUAL SEALABLE BAGS

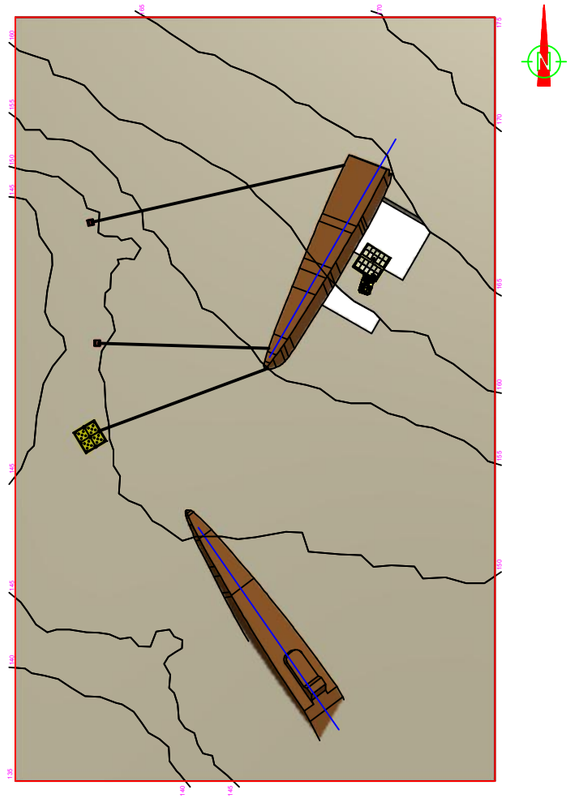


PLAN - STEP 4

Project	SS7_U-864 Hg RETRIVAL OPERATION	Client	DNV GL	subsea 7		
Title	SS7_U-864 Hg RETRIVAL OPERATION SKETCHES STEP 4 - RETRIVAL OF MERCURY CONTAINERS FROM KEEL TO SEABED	NOT TO SCALE FOR ILLUSTRATION ONLY		Kanalsletta 9, 4052 Røyneberg - P.O Box 205, 4056 Stavanger Tel: +47 51725000 Fax: +47 51725001		
		Drawn by	Date Drawn	Checked By	Last Rev Date	Sketch No.
		DDM	26.01.2014	SHJ	26.01.2014	**Step 4**

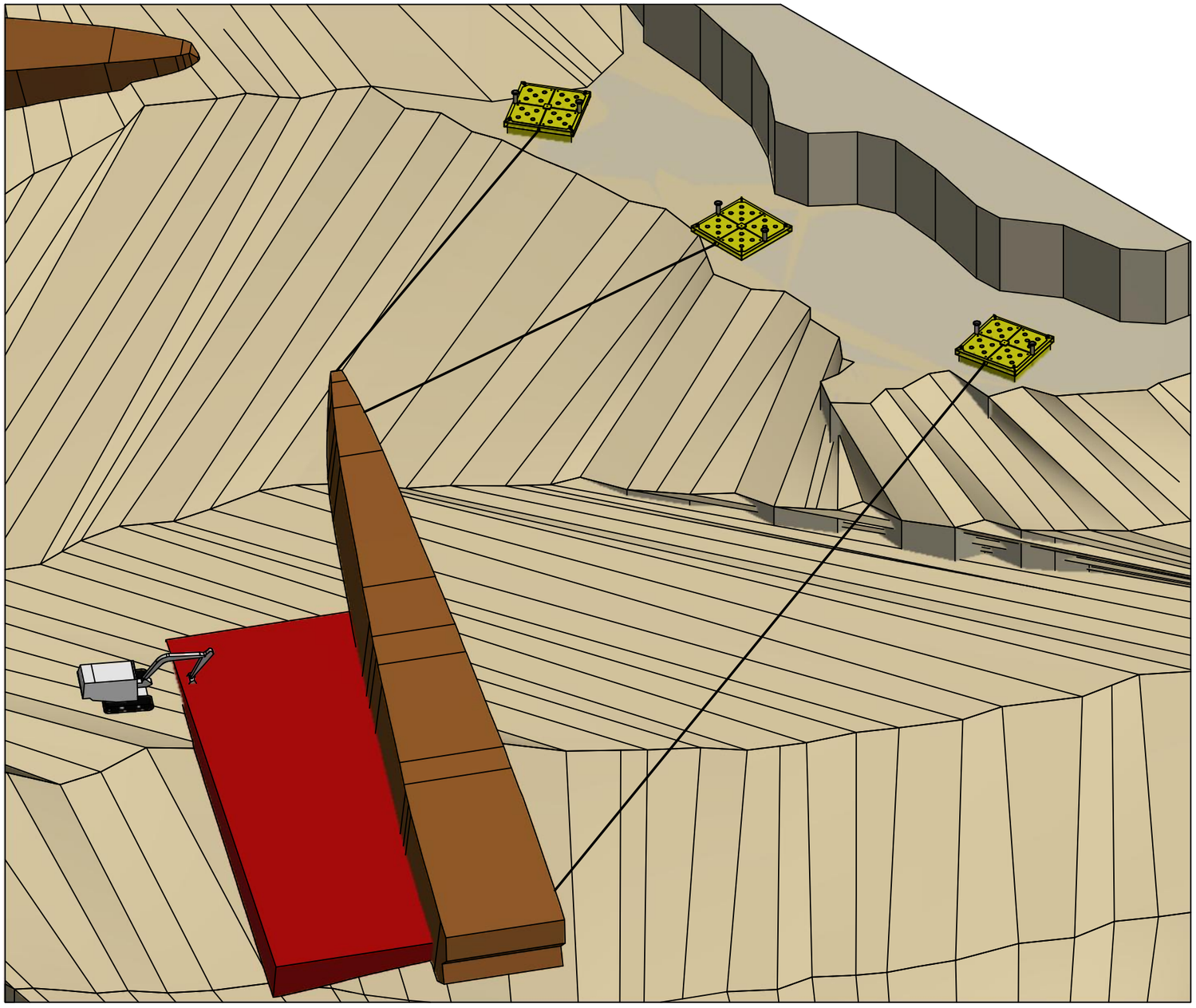


ISOMETRIC - FLASKS IN SEALED BAGS LOADED INTO
AN ROV BASKET FOR RETRIVAL TO SURFACE

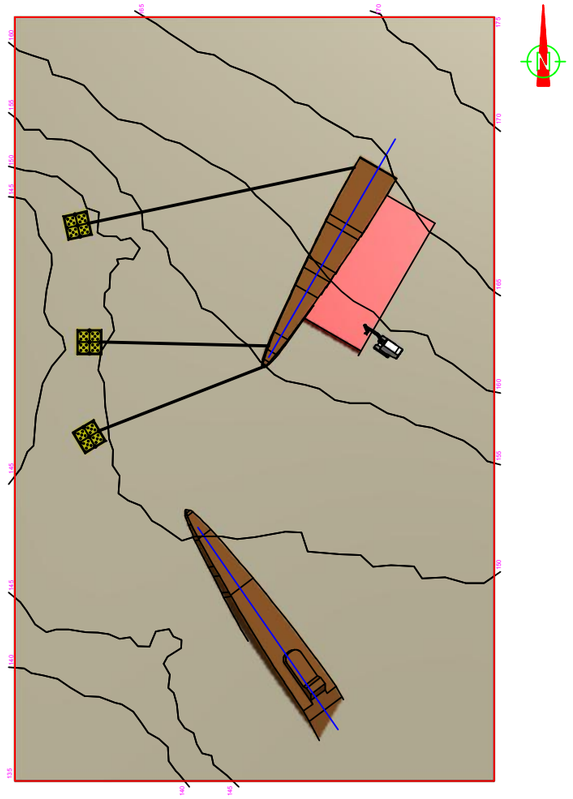


PLAN - STEP 5

Project	SS7_U-864 Hg RETRIVAL OPERATION	Client	DNV GL	subsea 7	
Title	SS7_U-864 Hg RETRIVAL OPERATION SKETCHES STEP 5 - REMOVAL OF MERCURY FROM SEABED TO SURFACE	NOT TO SCALE FOR ILLUSTRATION ONLY		Kanalsletta 9, 4052 Røyneberg - P.O Box 205, 4056 Stavanger Tel: +47 51725000 Fax: +47 51725001	
		Drawn by: DDM	Date Drawn: 26.01.2014	Checked By: SHJ	Last Rev Date: 26.01.2014	Sketch No.: **Step 5**



ISOMETRIC - KEEL TRENCH IS BACKFILLED & SUBSEA WINCHES ARE REMOVED AFTER THEIR WIRES ARE ANCHORED TO SEABED.



PLAN - STEP 6

Project	SS7_U-864 Hg RETRIVAL OPERATION	Client	DNV GL	subsea 7	
Title	SS7_U-864 Hg RETRIVAL OPERATION SKETCHES STEP - 6 STABILISE WRECK PRIOR TO CAPPING	NOT TO SCALE FOR ILLUSTRATION ONLY		Kanalsletta 9, 4052 Røyneberg - P.O Box 205, 4056 Stavanger Tel: +47 51725000 Fax: +47 51725001	
		Drawn by: DDM	Date Drawn: 26.01.2014	Checked By: SHJ	Last Rev Date: 26.01.2014	Sketch No.: **Step 6**

About DNV GL

Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter and greener.

Vedlegg V3.06

MILJØTILTAK VED VRAKET AV U-864

Mulige tiltak for heving av last

DNV GL AS

Project name: Miljøtiltak ved vraket av U-864
Report title: Mulige tiltak for heving av last

DNV GL AS
Project Management & Technical Services Program
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Håvard Nyseth

Dato: 12.5.2014

Gjengivelse av deler av dette vedleggsdokument som kan føre til mistolkning er ikke tillatt

Innholdsfortegnelse

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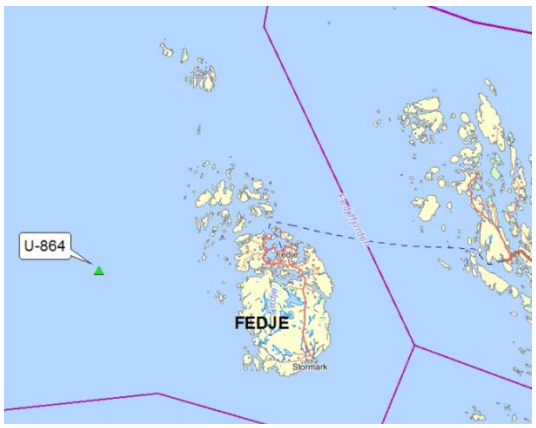
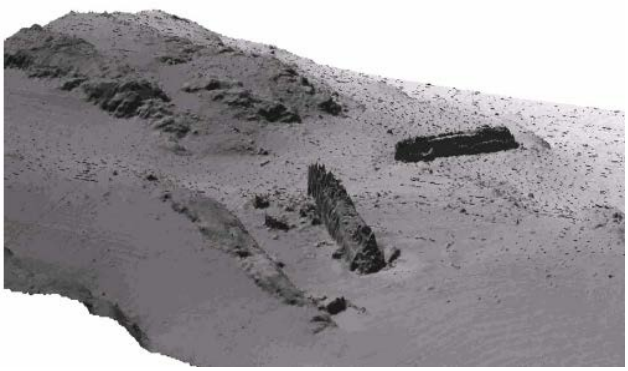
1 INNLEDNING

Den tyske ubåten U-864 ble senket av den britiske ubåten HMS Venturer den 9. februar 1945, ca. 2 nautiske mil vest for øya Fedje i Hordaland (Figur 1). Ubåten var på vei fra Tyskland via Norge med krigsmateriell til Japan. I følge historiske dokumenter fraktet U-864 ca. 67 tonn metallisk kvikksølv (i væskeform) lagret i stålbeholdere i kjølen.

U-864 brakk i to hoveddeler som følge av torpedotreffet og ble funnet på 150-175 meters dyp av den Norske Marinen i mars 2003. Kystverket har, på vegne av Kyst og Fiskeridepartementet (FKD), utført en rekke studier for å avdekke hvordan miljørisikoen som utgjøres av kvikksølvlasten i U-864 skal håndteres.





Figur 1 Lokasjon (venstre), sonarbilde av vraket av U-864 på sjøbunnen (Geoconsult)

Konseptvalgutredningen (KVU) ble levert FKD i januar 2011 og har senere vært gjenstand for ekstern kvalitetssikring av konseptvalg (KS1). Regjeringen vedtok basert på rangeringen i KVU og KS1 å gå videre med to alternativer i et forprosjekt. I bestillingen fra FKD til Kystverket fremgår det at det skal gjennomføres forprosjektering av følgende alternative løsninger for miljøtiltak ved vraket av U-864:

- Tildekking av vrak og forurenset havbunn (jf. KVU Alternativ 1)
- Heving av last og tildekking av vrak og forurenset havbunn (jf. KVU Alternativ 3).

I 2013 ble DNV GL tildelt oppdraget med å bistå Kystverket i å utarbeide sentralt styringsdokument (SSD) for forprosjektet.

SSD skal blant annet inneholde en analyse av kostander, fremdrift og risiko for aktuelle tiltak. For Alternativ 3 er løsning for å heve lasten ikke utarbeidet. Dette er forventet å være svært krevende operasjon, og det kan være mange ulike løsninger for å utføre dette.

Dette vedlegget beskriver prosessen som har vært gjennomført for å utarbeide noen prinsipielt forskjellige løsninger for heving av last, og som har vært lagt til grunn for analyse av kostander, fremdrift og risiko for deloperasjonen «heving av last» i Alternativ 3. Bakgrunnen for at det har vært søkt å finne flere aktuelle løsninger er for å bedre fange opp usikkerheten som er på det nåværende tidspunkt i prosjektet.

2 BESKRIVELSE AV PROSESSEN

Prosjektet «Miljøtiltak ved vraket av U-864» har pågått siden 2006. I perioden frem til forprosjekt og utarbeidelse av SSD (og dette vedlegget) det har vært gjennomført mange utredninger og undersøkelser på vraket for å sikre best mulig informasjon om vraket og geologien på vrakstedet. Ved gjennomføring av forprosjektet har de tidligere utredningene blitt supplert med ny nye undersøkelser der dette har vært funnet nødvendig, og praktisk gjennomførbart, for å bedre kunne vurdere muligheter og utfordringer for en operasjon for heving av last.

Følgende rapporter og undersøkelser vil i dette vedlegget legges til grunn for å utarbeide noen prinsipielt ulike løsninger for heving av last:

1. KVU (januar 2011) /D01/
2. KS1 av KVU (november 2011) /D02/
3. Tokt 3a til U-864. Grunnundersøkelser på vrakstedet til U-864 (januar 2013) (jf. Vedlegg V0.07)
4. Materialtesting av stålplate fra trykkskroget (april 2013) (jf. Vedlegg V3.07)
5. Studietur til U-534 (september 2013) (jf. Vedlegg V3.09)
6. Mulighetsstudie for heving av last. Workshops gjennomført med fem offshore selskaper hvor tiltak for heving av last ble utredet (oktober 2013) (jf. Vedlegg V3.05.00-3.05.06)
7. Tokt 3b til U-864. Uttesting av graving og mudring ved U-864s akterseksjon, åpning av to kjølkasser, samt uttesting av sanntids miljøovervåkningsprogram på U-864 (januar 2014) (jf. Vedlegg V0.12)
8. Materialtesting av stålplater fra kjølkasser (februar 2014) (jf. Vedlegg 3.08)
9. Miljømål og akseptkriterier for tiltak på U-864 (februar 2014) (jf. Vedlegg 3.01)
10. Use of divers to raise the mercury (april 2014) (jf. Vedlegg 3.04)

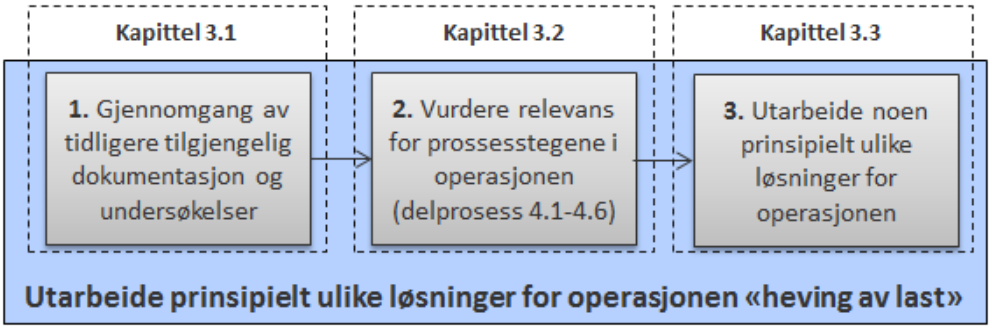
Det laget en overordnet prosess for Alternativ 3. Hovedprosess 4, som er delprosessen som omhandles i dette vedlegget, er videre nedbrutt i seks delprosesser, som vist i figuren nedenfor:

Figur 2 Hovedprosesser og delprosesser for Alt. 3 «Heving av last»

Under følger en kort beskrivelse av typiske oppgaver som inngår i hvert steg:

- **4.1: Forberedelser:** Gjør vraket klar for å kunne bevege/løfte dette og installere nødvendig på eller rundt vraket.
- **4.2: Etablere tilgang til kjøl:** Gjøre kjølkassene tilgjengelige for at ROV og/eller dykkere kan arbeide mot kjølkassen.
- **4.3: Åpne kjølkassene:** Fjerne sideplatene på kjølkassene slik at evt. innhold i kjølkassen blir tilgjengeliggjort.
- **4.4: Ta ut Hg-flasker:** Hente ut kvikksølvflasker av de kjølkassene som er lastet med dette, og samt fjerne evt. flytende kvikksølv som har lekket ut av flaskene.
- **4.5: Ta opp Hg-flasker til mellomlager:** Hente kvikksølvflasker til overflaten og transportere disse til et mellomlager. Videre transport til endelig deponi når dette kan ta imot flaskene.
- **4.6: Stabilisere vraket før tildekking:** Fjerne evt. utstyr fra sjøbunnen og sikre vraket slik at dette ligger i en stabil posisjon når tildekkingen starter.

I Figur 3 er prosessen for å utarbeide noen prinsipielt forskjellige løsninger basert på de listede rapportene og undersøkelsene, samt angitt i hvilket kapittel de respektive stegene er behandlet.



Figur 3 Prosess for utarbeidelse av løsninger for heving av last

Nedenfor er hvert av de tre stegene i Figur 3 kort beskrevet:

1. Gjennomgang av tidligere utredninger, og der hovedfokus vil være funn som kan være relevante for operasjonen. Følgende momenter vil bli vurdert:
   - Kort redegjørelse for studien
   - Aktuelle problemstillinger ift. heving av last, vurdert per operasjonssteg (jf. Figur 2)
   - Største risikoer
   - Utfordringer som må løses / behov for videre undersøkelser
2. For hvert enkelt steg i delprosessen for heving av last (delprosess 4.1-4.6), vurdere relevansen for informasjon i pkt. 1.
3. På bakgrunn av informasjonen i pkt. 2, utarbeide noen prinsipielt forskjellige løsninger for heving av last. Lage en overordnet beskrivelse av hvert steg i delprosessen 4.1 til 4.6 for hver foreslåtte løsning.

3 LØSNINGER FOR HEVING AV LAST

I de etterfølgende kapitlene gjennomgås hvert steg i prosessen som skissert i Figur 3.

3.1 Gjennomgang av tilgjengelig informasjon

I de etterfølgende ni kapitlene vurderes i korthet innholdet i de ni grunnlagsdokumentene som listet i kapittel 2 mht. relevans for heving av last. I tabellene som benyttes vises det til relevans ift. de seks prossesstegene. For ytterligere detaljer, se de respektive dokumenter.

3.1.1 #1: Konseptvalgutredningen (KVU) /1/

Kort beskrivelse av grunnlagsdokumentet	
Forstudie (KVU) om håndtering av U-864, der følgende fire alternativer skulle utredes: Nullalternativet, Alt.1: Tildekking av vraket og forurensede sedimenter, Alt.2: Heving av hele vraket og tildekking av sedimenter og Alt.3: Heving av last (kvikksølvbeholdere) og tildekking av forurensede sedimenter [1]	
Prosess	**Funn / observasjon**
4.1	• Alt.2/3: Arbeid på bunnen gir fare for utglidning av skråning. • Alt.2: Fare for at forberedelser til heving av last vil resultere i betydelig spredning av kvikksølv, pga. nødvendig arbeid på og i havbunnen
4.2	• Alt.2: Arbeid på bunnen gir fare for utglidning av skråning. • Alt.2: Fare for at fritt kvikksølv renner ut, sedimenter eller kvikksølvbeholdere faller ut av skroget under løfting. • Alt.2: Fare for at forberedelser til heving vil resultere i betydelig spredning av kvikksølv, pga. nødvendig arbeid på og i havbunnen. • Alt. 2: Risiko for detonasjon av sprenglegemer. • Alt.3: Skaffe tilgang til kjøl vil medføre mudring og rotasjon av vraket, som er forventet å gi medføre betydelig spredning av forurensede sedimenter i vannmassene, og utover tiltaksområdet.
4.5	• De som jobber med håndtering av kvikksølvflaskene (transport og deponering) vil kunne eksponeres for kvikksølvdamp.
Største risikoer	
4.1	• Utglidning av sedimenter • Forberedelser vil resultere i betydelig spredning av kvikksølv pga. nødvendig arbeid på og i havbunnen.
4.2	• Utglidning av sedimenter • Skaffe tilgang til kjøl er forventet å medføre betydelig spredning av forurensede sedimenter i vannmassene, og utover tiltaksområdet.
4.5	• At personell eksponeres for kvikksølvdamp.
Utfordringer som må løses	
• Redusere faren for utglidning av sedimenter. Dette gjelder spesielt forseksjon som ligger i en skråning. • Redusere oppvirvling av sedimenter under arbeidet på vraket. • Redusere faren for personell under håndtering av kvikksølv etter at dette er hentet opp.	

I dette tilfellet er det kun funnet relevant informasjon i KVU som kan benyttes i prossessteg 4.1, 4.2, 4.5, og altså ikke noe relevant informasjon om prossessteg 4.3, 4.4 og 4.6. Disse er derfor ikke listet i tabellen over. Tilsvarende systematikk er benyttet i etterfølgende tabeller.

[1] I forbindelse med KS1 ble det også utarbeidet alternativer (Alternativ 4) der forurensede sedimenter skulle fjernes ved hjelp av mudring.

3.1.2 #2: Ekstern kvalitetssikring (KS1)

4.1. Forberedelser → 4.2. Etabl. tilgang til kjøl → 4.3. Åpne kjøl → 4.4. Ta ut Hg-flasker → 4.5. Ta Hg-flasker opp til mellomlager → 4.6. Stabilisere vraket før tildekking

Kort beskrivelse av grunnlagsdokumentet	
Ekstern kvalitetssikring (KS1) av KVU, gjennomført av Metier og Møreforskning Molde AS (heretter kalt EKS). Følgende seks alternativer er kvalitetssikret: Nullalternativet, Alt.1: Tildekking av vraket og forurensede sedimenter, Alt.2: Heving av hele vraket, tildekking og landdeponi, Alt.3: Heving av last, tildekking og landdeponi, Alt.4A: Heving av hele vraket, storskala mudring og landdeponi, og Alt.4B: Heving av last (kvikksølvbeholdere), storskala mudring og landdeponi.	
Prosess	**Funn / observasjon**
4.1	• Alt.4A/4B: Behov for stabiliserende tiltak i skråningen før tiltaket startes.
4.2	• Alt.2:Hevingsoperasjon gir tilkomst til kjøl med mindre mudret masse enn Alt. 3. • Alt.3/4B: Krever mudring i de mest forurensede massene for å gi tilkomst til kjølen, minimum på den ene siden av kjølen. Dette forventes å gi betydelig oppvirvling av sedimenter og som kan medføre spredning utover tiltaksområdet. • Alt.3: Dersom tilkomst til kjøl oppnås ved å løfte opp seksjonene, vil anslått mengde som må mudres bli redusert.
Største risikoer	
4.1	• Utglidning av sedimenter
4.2	• Forberedelser vil resultere i betydelig spredning av kvikksølv pga. nødvendig arbeid på og i havbunnen.
Utfordringer som må løses	
• Redusere faren for utglidning av sedimenter. Dette gjelder spesielt forseksjon som ligger i en skråning. • Redusere oppvirvling av sedimenter under arbeidet på vraket.	

3.1.3 #3: Grunnundersøkelser på vrakstedet til U-864

4.1. Forberedelser → 4.2. Etabl. tilgang til kjøl → 4.3. Åpne kjøl → 4.4. Ta ut Hg-flasker → 4.5. Ta Hg-flasker opp til mellomlager → 4.6. Stabilisere vraket før tildekking

Kort beskrivelse av grunnlagsdokumentet	
I januar 2013 ble det gjennomført et tokt til U-864 for å: identifisere vrakdeler, ta sedimentprøver, ta kjerneprøver av sjøbunn for å beregne styrkeprofiler og tømme vraket for olje fra ballasttankene.	
Prosess	**Funn / observasjon**
4.1	• Vraket er tømt for olje. Det ingen indikasjoner på at det er mer ballast igjen i tankene. • Sveiser i formskroget for tankene er i svært dårlig forfatning/tilstand. • For- og akterseksjon, samt vrakdelene som ligger spredt rundt vrakene, utgjør hele vraket av U-864. Det er ingen andre vrakdeler på andre lokasjoner. • Sterk korrosjon har medført utlekking av dieselolje fra bunkerstankene over mange år og at dette ble først detektert under oljetømmingsoperasjonen.
4.2 / 4.3 / 4.4 / 4.6	• Sveiser i formskroget for tankene er i svært dårlig forfatning/tilstand. • Plater falt av når skroget ble børstet rent for marin groe forut for innsetting av ventiler for ventilering/tømming av olje.
Største risikoer	
4.1-4.4 / 4.6	• Sveiser i formskroget for tankene er i svært dårlig forfatning/tilstand, slik at plater kan falle av under arbeid.
Utfordringer som må løses	
• Ved arbeid ved under vraket (sadeltankene) er det behov for å sikre at deler av formskroget, evt. andre deler av vraket, ikke faller ned og ødelegger utstyr. Dette er spesielt viktig dersom dykkere skal brukes i arbeid med å åpne kjølkassene og ta ut kvikksølvflasker.	

3.1.4 #4: Materialtesting av stålplate fra trykkskroget

4.1. Forberedelser → 4.2. Etabl. tilgang til kjøl → 4.3. Åpne kjøl → 4.4. Ta ut Hg-flasker → 4.5. Ta Hg-flasker opp til mellomlager → 4.6. Stabilisere vraket før tildekking

Kort beskrivelse av grunnlagsdokumentet	
En stålprøve fra trykkskroget er testet i DNV GLs materiallaboratorie. Resultatet av testen kan si noe om hvor stor belastning trykkskroget kan tåle ved et evt. løft. Det må tas i betraktning at dette var en test av ett område på trykkskroget, og at korrosjon andre plasser kan være høyere/lavere.	
Prosess	**Funn / observasjon**
4.2 / 4.6	• Tykkelsen på stålplatene i trykkskroget er stedvis redusert pga. korrosjon. Utover dette oppfører stålet seg som forventet for denne ståltypen, men har noe lavere bruddstyrke i sveisen enn basematerialet. Dette må tas hensyn til ved kapasitetsberegninger.
Største risikoer	
4.2 / 4.6	• Stålplatene i trykkskroget har noe redusert styrke og kan svikte under et løft med festepunkter i trykkskroget.
Utfordringer som må løses	
• Ved beregning av antall løftepunkter i skrog må resultatene fra materialtesten legges til grunn, samt en tilstrekkelig stor sikkerhetsmargin for å ta høyde for usikkerheten i reststyrken i trykkskroget.	

3.1.5 #5: Studietur til U-534

4.1. Forberedelser → 4.2. Etabl. tilgang til kjøl → 4.3. Åpne kjøl → 4.4. Ta ut Hg-flasker → 4.5. Ta Hg-flasker opp til mellomlager → 4.6. Stabilisere vraket før tildekking

Kort beskrivelse av grunnlagsdokumentet	
I 1993 ble den tyske ubåten U-534 hevet utenfor Danmark, og senere etablert som et museum i Liverpool. U-534 er en ubåt av typen IX C, som i stor grad er tilsvarende U-864 (type IX D2), men noe kortere. Som et ledd i å innhente mer informasjon om U-864 i forprosjektet, ble det gjennomført en studietur til U-534 for å se på denne. En av hovedmålene for inspeksjonen var å se på konstruksjonen av kjølkassene og ta nødvendige geometriske mål. Med på studieturen var også Wolfgang Lauenstein, som er tysk og den som fant lastepapirene til U-864 og meldte fra til norske myndigheter om at det i lastepapirene står beskrevet at ubåten var lastet med ca. 67 tonn med kvikksølv. Lauenstein besitter også kunnskap om U-859, som også var en type IX D2, som hadde kvikksølvlast da den ble torpedert nær Penang i Malaysia. U-859 ble også delt i to deler pga. torpederingen og vrakdelene ligger på sjøbunnen på ca. 30 m dyp. Kvikksølvlasten senere tatt ut. Lauenstein presenterte kort det han besitter av informasjon om operasjonen for å heve lasten (på 70-tallet).	
Prosess	**Funn / observasjon**
4.1	• U-534: Profilskroget hadde en tykkelse på 5-6 mm. Stagene mellom profil- og trykkskroget var svært korrodert, og flere av disse var løsnet helt.
4.2	• U-534: Kjølens sveiser var i god stand • U-534: Trykkskroget med avstivere var noe korrodert
4.3	• U-859: Sideplatene på kjølen ble tatt vekk for å få tilgang til kvikksølvflaskene i kjølen. • U-534: Bunn- og sider på kjølkassen (ikke dekkplatene) var ca. 15-16mm tykke. Vertikale Innerplater var 11,5 mm tykke • Størrelsen på kjølkassene ble målt, ca: 680x600x580mm (bxdxh) • Undersiden av trykkskroget var 18.3mm tykk
4.4	• U-859: Minst tre ulike typer kvikksølvflasker ble funnet. • U-859: Kjølkassene var i stor grad fylt med sedimenter, som var kommet inn gjennom åpninger. • U-859: Kvikksølvflaskene var «grodd sammen» pga. korrosjon. • U-859: Vekten av hver flaske med innhold var 37,5 kg. • U-859: Innholdet i kjølkamrene var: 1) Kvikksølvflasker, 2) Bly (ballast), 3) eller de var tomme. Det er også en mulighet for at det var en kombinasjon av kvikksølvflasker og ballast i ett kjølkammer.
Største risikoer	
4.1	• Profilskroget m/ stag er svært korrodert og har derfor lite styrke og vil lett kunne løsne når det utsettes for krefter
4.2	• Trykkskrogets avstivere var noe korrodert
4.3	• Godset på kjølkassen er tykke og kan være krevende å skjære gjennom

4.4	• Kjølkassene kan være fylt med sedimenter som gjør tilgangen til kvikksølvflaskene krevende • Kvikksølvflaskene kan være korrodert sammen og derfor vanskelige å ta ut av kjølkassen pga. at kjølkassens åpning kan være mindre i høyde og/eller bredde enn inne i kjølkassen.
Utfordringer som må løses	
• Det kan bli behov for å sikre profilskroget dersom arbeid skal skje under ubåten. Skal dykkere benyttes, må profilskroget sikres godt eller fjernes. • Dersom skroget rulles over på siden vil profilskroget med stor sannsynlighet bli knust, men det er usikkert om dette også vil skje med kjølkassen. Dette må det tas hensyn til ved utvikling av løsning for å få tilgang til kjølkassene. • Kjølkassens konstruksjon kan medføre at tilgang til innholdet må skje ved at sideplatene på begge sider fjernes. Å få tilgang til innholdet via bunnplate eller gjennom langsgående senterplate kan være svært utfordrende. • Kvikksølvflaskene kan være korrodert sammen, noe som gjør det krevende å få disse ut. Enten pga. høy vekt og lite plass tilgjengelig for å få de ut av kjølen, eller ved at flasker punkteres dersom det forsøkes å ta flaskene fra hverandre. Spesialtilpasset utstyr med god kontroll med kraftoverføring til flaskene vil være nødvendig.	

3.1.6 #6: Mulighetsstudie «heving av last»

4.1. Forberedelser → 4.2. Etabl. tilgang til kjøl → 4.3. Åpne kjøl → 4.4. Ta ut Hg-flasker → 4.5. Ta Hg-flasker opp til mellomlager → 4.6. Stabilisere vraket før tildekking

Kort beskrivelse av grunnlagsdokumentet	
For å kunne vurdere gjennomførbarhet, risiko og kostnader for en operasjon for heving av last fra kjølkassene til U-864 har prosjektet søkt bistand fra offshore industrien. Fem selskaper ble tilbudt kontrakt om å bistå i en betalt RFI (Request for information): 1) DOF Subsea, 2) Oceaneering, 3) Technip, 4) Swire Seabed og 5) Subsea7 (nummereringen benyttes videre nedenfor). Basert på en to-dagers workshop med hvert selskap har disse selskapene foreslått hver sine løsninger for hvordan kvikksølvflaskene kan hentes ut av kjølkassene, og der det ble identifisert eventuelle risikoer i de seks nevnte prossesstegene i operasjonen.	
Prosess	**Funn / observasjon**
4.1	• 1: Grave en grøft for å fremprovosere at vrakdelene ruller over på ønsket side. • 2: Stabilisere forseksjon og fylle dette med vann (drenere luftlommer) for å stabilisere vraket • 2: Plassere en løfteramme m/vinsjer over hver vrakseksjon • 2: Feste løfteankre til trykkskroget og koble wire fra disse til vinsjene • 3: Feste løfteballonger til skroget og fylle disse med luft for å stabilisere vraket • 3: Fjerne sedimenter langs sidene av vrakdelene. Mudring med vanjet må brukes der sedimentene er harde. • 3: Rotere vraket ved å fylle mer luft i løfteballongene. • 4: Plassere plattformer (jig) på hver side av vraket som ROVen kan jobbe ut fra. • 4/5: Feste ankre til skroget, og forbinde disse til en hydraulisk vinsj. Vinsjen er festet til fjell eller sugeankre. Dette gjøres på begge sider av vraket for å kontrollere bevegelsene. • 5: Fjerne vrakdeler rundt vraket deretter sikre vraket med wire.
4.2	• 1/3/4/5: Om ikke vrakene ruller tilstrekkelig over på siden, grave/mudre mer for å gjøre kjølen tilgjengelig. • 2: Løfte vrakdelene med vinsjene. Fylle løfteballonger på forseksjon for å redusere vekten på skråningen. • 2: Rulle ut plast el. under vrakdelene som kan samle evt. fritt kvikksølv som renner ut av kjølkassene. • 4: Fjerning av forurensede sedimenter kan gjøres ved bruk av fyseteknikk. • 4/5: Trekke vraket over på siden ved bruk av vinsjene.
4.3	• 1/5: Åpne kjølkassene ved å fjerne skruene til sideplatene eller kutte hull. • 1/5: Tilgang til motsatt side av kjølkassen gjøres ved å skjære gjennom senterplaten. • 2/5: Kutte et hull i platene for å kunne suge ut evt. flytende kvikksølv, forurensede sedimenter og inspisere kammeret • 2: Kutte skruene til sideplatene og deretter fjerne platene. Dette gjøres på begge sider av kjølkassen. • 3: En arbeidsrigg m/ kutteutstyr plasseres langs vraket. • 3/4: Kutt hull i sideplater og senterplater eller bunnplate for å få tilgang til kvikksølvflaskene i begge kjølkamre (forutsetter at vrakseksjonene kan rulles over på en av sidene) • 5: Dersom kjølens styrke er vesentlig redusert etter kutting og fjerning av kvikksølvflasker så kan denne fylles med epoxy eller sementbasert mørtel (growting).
4.4	• 1/2/4/5: Bruke «suction pad» for å ta tak i kvikksølvflaskene, evt. et annet spesialtilpasset utstyr for å kunne ta tak i flere flasker om disse er korrodert sammen. • 1: Bruke en «suction pump» for å suge opp evt. flytende kvikksølv. • 3: Bruke dykkere for å hente ut kvikksølvflasker. • 4: Plassere et brett under kjølkassene for å samle opp evt. rent kvikksølv som renner ut.

4.5	• 1/2/3/4/5: Samle kvikksølvflaskene i en container («offshore basket») som så blir hevet til overflaten. • 3/5: Beholderen med kvikksølv blir ikke åpnet på dekk, men transportert direkte til depot.
4.6	• 2: Senke vraket ned på sedimentene og fjerne løfterammen. Sugeankrene blir værende på sjøbunn. • 3: Fjerne løfteballonger • 4/5: Fjerne vinsjer, men wire og ankre blir værende på sjøbunn.
Største risikoer	
4.1	• 1/3/5: Oppvirvling av forurensede sedimenter ved graving/mudring • 1/3/5: Ukontrollert bevegelse av skrogene • 2: Løfterammen står ikke stabilt på sjøbunnen • 2/4/5: Vrakdeler og store steiner skaper problemer for plassering av løfterammene og sugeankre. • 4: Oppvirvling av forurensede sedimenter ved trekking og stramming av wire. • 4: Wire kuttes under stramming pga. skarpe kanter på vrakdelene (profilskroget).
4.2	• 1/3/4: Oppvirvling av forurensede sedimenter ved graving/mudring. • 1/3/4: Ukontrollert bevegelse av skrogene. • 1: Vanskelig å bruke en graver (excavator) i skråningen der forskipet ligger. • 2: Havstrømmen tar tak i løfteballongene som skaper ustabile krefter i skroget. • 2: Løftepunktene ryker og vraket faller ned på sjøbunn. • 2: Kjølen løsner og kvikksølvflasker ødelegges. • 4: Sedimenter raser tilbake i grøften som er laget for å få tilgang til kjølen.
4.3	• 1: Skade kvikksølvflaskene når det kuttes i senterplaten og evt. sideplatene. • 1/2/3/4/5: Oppvirvling av forurensede sedimenter ved bruk av svømmende ROV • 3/4/5: Får ikke tilgang til den andre siden av kjølen
4.4	• 1/2/3/4/5:Knuse eller miste kvikksølvflasker • 3: Dykkerutstyr blir forurenset med kvikksølv
4.5	• 1/2/4: Kvikksølvforurensning spres på dekk på overflatefartøyet
Utfordringer som må løses	
• Redusere oppvirvling av forurensede sedimenter under arbeidet, spesielt under steg 1 og 2. • Sikre vraket slik at ukontrollerte bevegelser ikke skjer • Ved bruk av løfteramme må det påses at denne står stabilt • Vrakdeler og store steiner nær vraket bør fjernes • Sikre at wire som strammes langs vraket ikke kan kuttes på skarpe kanter på profilskroget, og sikre at ukontrollerte bevegelser ikke skjer ved at wire plutselig skjærer gjennom eller bøyer profilskroget. • Det må sikres tilstrekkelig løftekapasitet i hvert festepunkt for ankre. • Det må gjøres tiltak for å redusere muligheten for at kjølen løsner fra skroget under en rulle- eller løfteoperasjon. • Vraket må kunne rulles tilbake og over på motsatt sidefor å gi tilgang til den andre siden av kjølen dersom tilgang gjennom bunn- eller senterplater ikke er mulig.	

3.1.7 #7: Tokt 3b til U-864

Kort beskrivelse av grunnlagsdokumentet	
I januar 2014 ble det utført en 11 dager lang operasjon på U-864 for å innhente mer kunnskap om gjennomførbarheten av en eventuell operasjon for heving av last. Denne operasjonen ble gjennomført av DOF Subsea på oppdrag fra Kystverket. Mål for denne operasjonen var blant annet: 1) Flytte noen av vrakdelene som ligger tett inntil akterseksjonen noe lenger vekk, 2) grave eller mudre for å gi tilgang til de kjølkassene som er plassert lengst akterut på akterseksjonen på styrbord side. Dette er de kjølkassene som er lettest å grave frem, og 3) åpne en/flere kjølkasser. Dersom disse inneholder kvikksølvflasker, hente disse opp til overflaten.	
Prosess	**Funn / observasjon**
4.1 / 4.2	• Graving / mudring er svært tidkrevende pga. mye stein og vrakdeler i massene og harde sedimenter. Arbeidet virvler opp store mengder forurensede sedimenter. • Seks kvikksølvflasker ble funnet begravet i sedimentene, og alle gjennomkorrodert og tomme. • Under arbeid på sjøbunnen, spesielt graving, så reduseres sikten betraktelig pga. oppvirvling av sedimenter. Operasjonen måtte ofte vente for at sikten skulle bedres. • Rent kvikksølv ble observert i sedimentene, og ble sugd inn i mudringsutstyret. Dette var vanskelig å unngå. • Kvikksølv vil spres utenfor tiltaksområdet i konsentrasjoner som ikke er akseptable (rapport fra NIVA).
4.2	• Graving / mudring er svært tidkrevende pga. mye stein og vrakdeler i massene og harde sedimenter. Arbeidet virvler opp store mengder forurensede sedimenter.

4.3	• Kutting av sideplatene var tidkrevende, men to kjølkasser (to akterste kjølkamre på akterseksjon, styrbord side) ble åpnet. Disse var tomme. • Under kutting så reduseres sikten inne i kjølkassene betydelig pga. oppvirvling av partikler inne kassene.
4.5	• Selv om gravemaskinen var forsøkt rengjort om bord i «skitten sone», rant det flytende kvikksølv fra denne etter at den var flyttet til «ren sone» på dekk.
4.6	• Rengjøring av utstyr (som har vært på sjøbunnen) for kvikksølv var svært tidkrevende og komplisert.
Største risikoer	
4.1 / 4.2	• Svært tidkrevende å grave/mudre. • Oppvirvling av store mengder forurensede sedimenter under arbeid som kan spres utenfor tiltaksområdet. • Mye venting pga. at arbeidet på sjøbunnen (spesielt graving) virvler opp sedimenter som reduseres sikten.
4.3	• Sikten inne i kjølkassene reduseres betydelig ved kutting i sideplatene og forsinket fremdrift.
4.5	• Utstyr som har vært på sjøbunnen kan være sterkt forurenset med kvikksølv og vil kunne føre til at flytende kvikksølv kan komme over på ren sone på dekk/land.
4.6	• Svært tidkrevende og kostbart å rengjøre kvikksølvkontaminert utstyr etter operasjonen. Kan medføre at utstyret må kasseres.
Utfordringer som må løses	
• Metodikk for fjerning av sedimenter langs vrakene må sikres at blir effektiv og at den minimerer oppvirvling og spredning av forurensede sedimenter. • Det bør forsøkes å bore løs skruene på sideplatene slik at disse kan tas av hele, som vil være tidsbesparende ift. å kutte hull i sideplatene. Åpningen til kjølkassene vil også bli maksimalt store. • Ved bruk av inspeksjonshull i kjølkassene kan det være behov for annet utstyr enn optisk kamera for å inspisere innholdet pga. at det vil kunne ta lang tid før oppvirvlingen av partikler legger seg (ingen vanngjennomstrømning som bedrer sikten). Infrarødt kamera er en mulighet. • Det må sikres at utstyr benyttet på sjøbunnen blir rengjort helt for kvikksølv før disse flyttes over til ren sone på fartøyet, eller tas i bruk i operasjoner etter U-864 tiltaket. Evt. må utstyret kasseres iht. gjeldene regler.	

3.1.8 #8: Materialtesting av stålplater fra kjølkasser

Kort beskrivelse av grunnlagsdokumentet	
Under tokt 3b (jf. kapittel 3.1.7) ble det skåret løs et stykke av sideplaten. Denne sideplaten ble deretter testet i DNV GLs materiallaboratorie. Resultatet av testen kan si noe styrken til sideplatene og hvor harde disse vil være å kutte gjennom. Det må tas i betraktning at dette var en test av kun en del av kjølplatene, slik at styrken andre plasser kan være noe høyere/lavere.	
Pros.	**Funn / observasjon**
4.3	• Sideplaten er lite korrodert, slik at reduksjon i tykkelsen er minimal. • Normalt utstyr for å kutte bløtt karbonstål.
Største risikoer	
	• Ingen spesielle
Utfordringer som må løses	
Ingen spesielle	

3.1.9 #9: Miljømål og akseptkriterier for tiltak på U-864

Kort beskrivelse av grunnlagsdokumentet	
Dokumentet beskriver de miljømål og akseptkriterier som er utarbeidet for håndteringen av U-864.	
Pros.	**Funn / observasjon**
4.1-4.6	• Under hele operasjonen skal det pågå en miljøovervåkning. • Dersom spredning av forurensede sedimenter overstiger fastsatte akseptkriterier skal alle operasjoner stanses. Årsak til spredning skal kartlegges og forbedringer finnes før operasjonen starter opp igjen.
Største risikoer	
4.1-4.6	• Overvåkningsprogrammet fungerer ikke som planlagt
Utfordringer som må løses	
• Overvåkningsprogrammet må være robust og være godt testet før operasjonen iverksettes.	

3.1.10 #10 Use of divers to raise the mercury

Kort beskrivelse av grunnlagsdokumentet	
Studien vurderer risikoen for at dykkere blir utsatt for kvikksølvforurensning dersom disse benyttes under en operasjon for heving av last fra U-864.	
Pros.	**Funn / observasjon**
4.1-4.6	• Det frarådes å bruke dykkere under en operasjon for heving av last
Største risikoer	
4.1-4.6	• Dykkere blir utsatt for kvikksølvforurensning
Utfordringer som må løses	
• Ingen. ROVer kan benyttes i stedet for dykkere.	

3.2 Relevans per prossessteg

3.2.1 Forberedelser

Studie	Funn / observasjon	Tiltak
#1	• Alt. 2/3: Arbeid på bunnen gir fare for utglidning av skråning • Alt.2: Fare for at forberedelser til heving av last vil resultere i betydelig spredning av kvikksølv, pga. nødvendig arbeid på og i havbunnen	• Redusere faren for utglidning av sedimenter. • Det kan bli behov for å sikre eller fjerne profilskroget dersom arbeid skal skje under ubåten. Skal dykkere benyttes, må profilskroget sikres godt eller fjernes. • Redusere oppvirvling av forurensede sedimenter under arbeidet, spesielt under steg 1 og 2. • Sikre vraket slik at ukontrollerte bevegelser ikke skjer • Ved bruk av løfteramme må det påses at denne står stabilt
#2	• Alt.4A/4B: Behov for stabiliserende tiltak i skråningen før tiltaket startes.	
#3	• Vraket er tømt for olje. Det ingen indikasjoner på at det er mer ballast igjen i tankene. • Sveiser i formskroget for tankene er i svært dårlig forfatning/tilstand. • For- og akterseksjon, samt vrakdelene som ligger spredt rundt vrakene, utgjør hele vraket av U-864. Det er ingen andre vrakdeler på andre lokasjoner. • Sterk korrosjon har medført utlekking av dieselolje fra bunkerstankene over mange år og at dette ble først detektert under oljetømmingsoperasjonen.	
#5	• U-534: Profilskroget hadde en tykkelse på 5-6 mm. Stagene mellom profil- og trykkskroget var svært korrodert, og flere av disse var løsnet helt.	
#6	• 1: Grave en grøft for å fremprovosere at vrakdelene ruller over på ønsket side. • 2: Stabilisere forseksjon og fylle dette med vann (drenere luftlommer) for å stabilisere vraket • 2: Plassere en løfteramme m/vinsjer over hver vrakseksjon • 2: Feste løfteankre til trykkskroget og koble wire fra disse til vinsjene • 3: Feste løfteballonger til skroget og fylle disse med luft for å stabilisere	

	vraket • 3: Fjerne sedimenter langs sidene av vrakdelene. Mudring med vannjet må brukes der sedimentene er harde. • 3: Rotere vraket ved å fylle mer luft i løfteballongene. • 4: Plassere plattformer (jig) på hver side av vraket som ROVen kan jobbe ut fra. • 4/5: Feste ankre til skroget, og forbinde disse til en hydraulisk vinsj. Vinsjen er festet til fjell eller sugeankre. Dette gjøres på begge sider av vraket for å kontrollere bevegelsene. • 5: Fjerne vrakdeler rundt vraket deretter sikre vraket med wire.	• Vrakdeler og store steiner nær vraket bør fjernes • Sikre at wire som strammes langs vraket ikke kan kuttes på skarpe kanter på profilskroget, og sikre at ukontrollerte bevegelser ikke skjer ved at wire plutselig skjærer gjennom eller bøyer profilskroget. • Det må sikres tilstrekkelig løftekapasitet i hvert festepunkt for ankre. • Miljøovervåkningsprogrammet må være robust og være godt testet før operasjonen iverksettes. • Ikke å benytte dykkere
#7	• Graving / mudring er svært tidkrevende pga. mye stein og vrakdeler i massene og harde sedimenter. Arbeidet virvler opp store mengder forurensede sedimenter. • Seks kvikksølvflasker ble funnet begravet i sedimentene, og alle gjennomkorrodert og tomme. • Under arbeid på sjøbunnen, spesielt graving, så reduseres sikten betraktelig pga. oppvirvling av sedimenter. Operasjonen måtte ofte vente for at sikten skulle bedres. • Rent kvikksølv ble observert i sedimentene, og ble sugd inn i mudringsutstyret. Dette var vanskelig å unngå.	
#9	• Under hele operasjonen skal det pågå en miljøovervåkning. • Dersom spredning av forurensede sedimenter overstiger fastsatte akseptkriterier skal alle operasjoner stanses. Årsak til spredning skal kartlegges og forbedringer finnes før operasjonen starter opp igjen.	
#10	• Det frarådes å bruke dykkere under en operasjon for heving av last	

Oppsummering

- Tiltak for å redusere sedimentutglidning må utføres ved forseksjonen, samt stabil grunn for evt. tunge konstruksjoner på sjøbunn. Dette gjøres best ved å legge en støttefylling nederst i dalen. Konstruksjoner bør tilstrebes å plasseres på denne.
- Store vrakdeler og steiner må flyttes fra området rundt vraket for å sikre tilkomst og god tilgjengelig for utstyret.
- Løsningen må så langt det lar seg gjøre medføre minimal oppvirvling av forurensede sedimenter.
- Det er viktig å kunne kontrollere bevegelsene om vraket rulles. Pga. lavt tyngdepunkt vil kjølen ikke la seg heve med mindre større krefter benyttes, og at nødvendig mengde sedimenter er fjernet. Kreftene på wire fra skroget bør derfor ha en kraftkomponent opp i vertikalretningen, for å motvirke dette.
- På grunn av profilskrogets dårlige forfatning må wire festes til trykkskroget samt at wire må ligge langs trykkskroget når disse skal strammes. Dette for å unngå brå bevegelser om profilskroget gir etter når wire strammes.
- Løftekapasiteten i hvert anker må beregnes, og testes for hvert løftepunkt.
- Et sanntids miljøovervåkningsprogram må være operativt under hele operasjonen.

3.2.2 Skaffe tilgang til kjøl

Studie	Funn / observasjon	Tiltak
#1	• Alt.2: Arbeid på bunnen gir fare for utglidning av skråning. • Alt.2: Fare for at fritt kvikksølv renner ut, sedimenter eller kvikksølvbeholdere faller ut av skroget under løfting. • Alt.2: Fare for at forberedelser til heving vil resultere i betydelig spredning av kvikksølv, pga. nødvendig arbeid på og i havbunnen. • Alt.2: Risiko for detonasjon av sprenglegemer. • Alt.3: Skaffe tilgang til kjøl vil medføre mudring og rotasjon av vraket, som er forventet å gi medføre betydelig spredning av forurensede sedimenter i vannmassene, og utover tiltaksområdet.	• Redusere faren for utglidning av sedimenter. • Redusere oppvirvling av sedimenter under arbeidet på vraket. • Sikre en effektiv metodikk for fjerning av sedimenter.

#2	• Alt.2:Hevingsoperasjon gir tilkomst til kjøl med mindre mudret masse enn Alt. 3. • Alt.3/4B: Krever mudring i de mest forurensede massene for å gi tilkomst til kjølen, minimum på den ene siden av kjølen. Dette forventes å gi betydelig oppvirvling av sedimenter og som kan medføre spredning utover tiltaksområdet. • Alt.3: Dersom tilkomst til kjøl oppnås ved å løfte opp seksjonene, vil anslått mengde som må mudres bli redusert.	• Dersom skroget rulles over på siden vil profilskroget bli knust, men det er usikkert om dette også vil skje med kjølkassen. Dette må det tas hensyn til ved utvikling av løsning for å få tilgang til kjølkassene. • Det må gjøres tiltak for å redusere muligheten for at kjølen løsner fra skroget under en rulle- eller løfteoperasjon. • Vraket må kunne rulles tilbake over på motsatt side for å gi tilgang til den andre siden av kjølen dersom tilgang gjennom bunn- eller senterplater ikke er mulig. • Ved beregning av antall løftepunkter i skrog må resultatene fra materialtesten legges til grunn, samt en tilstrekkelig stor sikkerhetsmargin for å ta høyde for usikkerheten i reststyrken i trykkskroget. • Miljøovervåknings-programmet må være robust og være godt testet før operasjonen iverksettes. • Ikke å benytte dykkere
#3	• Sveiser i formskroget for tankene er i svært dårlig forfatning/tilstand. • Plater falt av når skroget ble børstet rent for marin groe forut innsetting av ventiler.	
#4	• Tykkelsen på stålplatene i trykkskroget er stedvis redusert pga. korrosjon. Utover dette oppfører stålet seg som forventet for denne ståltypen, men har noe lavere bruddstyrke i sveisen enn basematerialet. Dette må tas hensyn til ved kapasitetsberegninger.	
#5	• U-534: Kjølens sveiser var i god stand • U-534: Trykkskroget med avstivere var noe korrodert	
#6	• 1/3/4/5: Om ikke vrakene ruller tilstrekkelig over på siden, grave/mudre mer for å gjøre kjølen tilgjengelig. • 2: Løfte vrakdelene med vinsjene. Fylle løfteballonger på forseksjon for å redusere vekten på skråningen. • 2: Rulle ut plast el. under vrakdelene som kan samle evt. fritt kvikksølv som renner ut av kjølkassene. • 4: Fjerning av forurensede sedimenter kan gjøres ved bruk av fryseteknikk. • 4/5: Trekke vraket over på siden ved bruk av vinsjene.	
#7	• Graving / mudring er svært tidkrevende pga. mye stein og vrakdeler i massene og harde sedimenter. Arbeidet virvler opp store mengder forurensede sedimenter. • Seks kvikksølvflasker ble funnet begravet i sedimentene, og alle gjennomkorrodert og tomme. • Under arbeid på sjøbunnen, spesielt graving, så reduseres sikten betraktelig pga. oppvirvling av sedimenter. Operasjonen måtte ofte vente for at sikten skulle bedres. • Rent kvikksølv ble observert i sedimentene, og ble sugd inn i mudringsutstyret. Dette var vanskelig å unngå.	
#9	• Under hele operasjonen skal det pågå en miljøovervåkning. • Dersom spredning av forurensede sedimenter overstiger fastsatte akseptkriterier skal alle operasjoner stanses. Årsak til spredning skal kartlegges og forbedringer finnes før operasjonen starter opp igjen.	
#10	• Det frarådes å bruke dykkere under en operasjon for heving av last	

Oppsummering

- Ved graving/mudring må tilstrekkelig mengde av masser fjernes slik at gravehelningen er så lav at sedimenter ikke glir ned i gropen.
- Løsningen må, så langt det lar seg gjøre, medføre minimal oppvirvling av forurensede sedimenter. Samle opp kvikksølvforurensning under vraket ved bruk av en duk el.
- Det bør gjøres tiltak for å redusere sugekreftene mellom kjølkassen og sedimentene, slik at løft/rulle skjer enklest mulig og reduserer sannsynligheten for at kjølkassen løsner.
- Resultater fra materialtest av trykkskroget må legges til grunn for beregning av antall løftepunkter, og med tilstrekkelig sikkerhetsmargin for å ivareta usikkerhet.
- Løsningen må være slik at vraket skal kunne rulles til begge sider slik at kjølkassene kan gjøres tilgjengelige på begge sider.
- Ved å løfte vraket reduseres mengden sedimenter som å fjernes, og samtidig faren for spredning utover tiltaksområdet. Det gir også tilgang til begge sider av kjølen i samme operasjon, og reduserer faren for at kjølen knuses ved rulling.
- Løfteballonger kan benyttes for å redusere kraften mot sjøbunnen og/eller i konstruksjoner, men sideveis kraftkomponent som skyldes havstrøm må tas hensyn til i beregningene.
- Et sanntids overvåkningsprogram må være operativt under hele operasjonen.

3.2.3 Åpne kjøl

4.1. Forberedelser → 4.2. Etabl. tilgang til kjøl → **4.3. Åpne kjøl** → 4.4. Ta ut Hg-flasker → 4.5. Ta Hg-flasker opp til mellomlager → 4.6. Stabilisere vraket før tildekking

Studie	Funn / observasjon	Tiltak
#3	• Sveiser i formskroget for tankene er i svært dårlig forfatning/tilstand. • Plater falt av når skroget ble børstet rent for marin groe forut innsetting av ventiler.	• Sveiser i formskroget for tankene er i dårlig forfatning. • Forsøke å fjerne skruer på sideplatene og ta platene av hele. • Benytte en arbeidsrigg • Ved bruk av inspeksjonshull i kjølkassene kan det være behov for annet utstyr enn optisk kamera for å inspisere innholdet pga. at det vil kunne ta lang tid før oppvirvlingen av partikler legger seg (ingen vanngjennomstrømning som bedrer sikten). • Miljøovervåknings-programmet må være robust og være godt testet før operasjonen iverksettes. • Ikke å benytte dykkere
#5	• U-859: Sideplatene på kjølen ble tatt vekk for å få tilgang til kvikksølvflaskene i kjølen. • U-534: Bunn- og sider på kjølkassen (ikke dekkplatene) var ca. 15-16mm tykke. Vertikale Innerplater var 11,5 mm tykke • Størrelsen på kjølkassene ble målt, ca: 680x600x580mm (bxdxh) • Undersiden av trykkskroget var 18.3mm tykk	
#6	• 1/5: Åpne kjølkassene ved å fjerne skruene til sideplatene eller kutte hull. • 1/5: Tilgang til motsatt side av kjølkassen gjøres ved å skjære gjennom senterplaten. • 2/5: Kutte et hull i platene for å kunne suge ut evt. flytende kvikksølv, forurensede sedimenter og inspisere kammeret • 2: Kutte skruene til sideplatene og deretter fjerne platene. Dette gjøres på begge sider av kjølkassen. • 3: En arbeidsrigg m/ kutteutstyr plasseres langs vraket. • 3/4: Kutt hull i sideplater og senterplater eller bunnplate for å få tilgang til kvikksølvflaskene i begge kjølkamre (forutsetter at vrakseksjonene kan rulles over på en av sidene) • 5: Dersom kjølens styrke er vesentlig redusert etter kutting og fjerning av kvikksølvflasker så kan denne fylles med epoxy eller sementbasert mørtel (growting).	
#7	• Kutting av sideplatene var tidkrevende, men to kjølkasser (to akterste kjølkamre på akterseksjon, styrbord side) ble åpnet. Disse var tomme. • Under kutting så reduseres sikten inne i kjølkassene betydelig pga. oppvirvling av partikler inne kassene.	
#8	• Sideplaten er lite korrodert, slik at reduksjon i tykkelsen er minimal. • Normalt utstyr for å kutte bløtt karbonstål.	
#9	• Under hele operasjonen skal det pågå en miljøovervåkning. • Dersom spredning av forurensede sedimenter overstiger fastsatte akseptkriterier skal alle operasjoner stanses. Årsak til spredning skal kartlegges og forbedringer finnes før operasjonen starter opp igjen.	
#10	• Det frarådes å bruke dykkere under en operasjon for heving av last	

Oppsummering

- Løsningen må så langt det lar seg gjøre redusere oppvirvling av forurensede sedimenter. Dette kan gjøres ved å ha en arbeidsrigg langs vraket som en ROV el. kan monteres til og arbeide ut fra. Dette reduserer bruk av en «svømmende» ROV med trustere eller utstyr som står på bunnen og som må flyttes på underveis i operasjonen.
- Løsningen bør søkes å fjerne skruer på sideplatene og ta platene av hele. Det vil være tidsbesparende.
- Dersom inspeksjonshull benyttes for å kontrollere innholdet, bør det vurderes om utstyr som kan se i dårlig sikt kan benyttes (IR-kamera el.). Dersom flere kjølkasser, bak samme dekkplate, er tomme eller inneholder ballast, trengs ikke denne dekkplaten å fjernes.
- Et sanntids overvåkningsprogram må være operativt under hele operasjonen.

3.2.4 Ta ut Hg-flasker

4.1. Forberedelser → 4.2. Etabl. tilgang til kjøl → 4.3. Åpne kjøl → **4.4. Ta ut Hg-flasker** → 4.5. Ta Hg-flasker opp til mellomlager → 4.6. Stabilisere vraket før tildekking

Studie	Funn / observasjon	Tiltak
#3	• Sveiser i formskroget for tankene er i svært dårlig forfatning/tilstand. • Plater falt av når skroget ble børstet rent for marin groe forut innsetting av ventiler.	• Det kan bli behov for å sikre profilskroget dersom utstyr skal brukes under dette. Skal dykkere benyttes, må profilskroget sikres godt. • Kvikksølvflaskene kan være korrodert sammen, noe som gjør det krevende å få disse ut. Enten pga. høy vekt og lite plass tilgjengelig for å få de ut av kjølen, eller ved at flasker punkteres dersom det forsøkes å ta flaskene fra hverandre. Spesialtilpasset utstyr med god kontroll med kraftoverføring til flaskene vil være nødvendig. • Miljøovervåknings-programmet må være robust og være godt testet før operasjonen iverksettes. • Ikke å benytte dykkere
#5	• U-859: Minst tre ulike typer kvikksølvflasker ble funnet. • U-859: Kjølkassene var i stor grad fylt med sedimenter, som var kommet inn gjennom åpninger. • U-859: Kvikksølvflaskene var «grodd sammen» pga. korrosjon. • U-859: Vekten av hver flaske m/ innhold var 37,5 kg. • U-859: Innholdet i kjølkamrene var: 1) Kvikksølvflasker, 2) Bly (ballast), 3) eller de var tomme. Det er også en mulighet for at det var en kombinasjon av kvikksølvflasker og ballast i ett kjølkammer.	
#6	• 1/2/4/5: Bruke «suction pad» for å ta tak i kvikksølvflaskene, evt. et annet spesialtilpasset utstyr for å kunne ta tak i flere flasker om disse er korrodert sammen. • 1: Bruke en «suction pump» for å suge opp evt. flytende kvikksølv. • 3: Bruke dykkere for å hente ut kvikksølvflasker • 4: Plassere et brett under kjølkassene for å samle opp evt. rent kvikksølv som renner ut.	
#9	• Under hele operasjonen skal det pågå en miljøovervåkning. • Dersom spredning av forurensede sedimenter overstiger fastsatte akseptkriterier skal alle operasjoner stanses. Årsak til spredning skal kartlegges og forbedringer finnes før operasjonen starter opp igjen.	
#10	• Det frarådes å bruke dykkere under en operasjon for heving av last	

Oppsummering

- Løsningen må være fleksibel mht. hvilket utstyr som skal benyttes for å fjerne kvikksølvflaskene og evt. flytende kvikksølv.
- Sveiser i formskroget er i svært dårlig forfatning, derfor kan det være behov for å sikre dette. Spesielt dersom dykkere benyttes.
- Et sanntids overvåkningsprogram må være operativt under hele operasjonen.

3.2.5 Ta Hg-flasker opp til mellomlager

4.1. Forberedelser → 4.2. Etabl. tilgang til kjøl → 4.3. Åpne kjøl → 4.4. Ta ut Hg-flasker → **4.5. Ta Hg-flasker opp til mellomlager** → 4.6. Stabilisere vraket før tildekking

Studie	Funn / observasjon	Tiltak
#1	• De som jobber med håndtering av kvikksølvflaskene (transport og deponering) vil kunne eksponeres for kvikksølvdamp.	• Redusere faren for personell under håndtering av kvikksølv etter at dette er hentet opp. • Miljøovervåknings-programmet må være robust og være godt testet før operasjonen iverksettes. • Utstyr eller dykkere som er i kontakt med sjøbunnen må forventes å bli forurenset av kvikksølv. Derfor må nødvendig rengjøring av utstyr gjennomføres. Metningsdykk i denne type forurensede miljøer frarådes.
#5	• U-859: Minst tre typer kvikksølvflasker ble funnet. • U-859: Kjølkassene var i stor grad fylt med sedimenter, som var kommet inn gjennom åpningene. • U-859: Kvikksølvflaskene var festet til hverandre pga. korrosjon. • U-859: Vekten av hver flaske med innhold var 37,5 kg. • U-859: Innholdet i kjølkamrene var: 1) Kvikksølvflasker, 2) Bly (ballast), 3) eller de var tomme. Det er også en mulighet for at det var en kombinasjon av kvikksølvflasker og ballast i ett kjølkammer.	
#6	• 1/2/3/4/5: Samle kvikksølvflaskene i en container («offshore basket») som så blir hevet til overflaten. • 3/5: Beholderen med kvikksølv blir ikke åpnet på dekk, men transportert direkte til depot.	
#7	• Selv om gravemaskinen var forsøkt rengjort om bord i «skitten sone», rant det flytende kvikksølv fra denne etter at den var flyttet til «ren sone» på dekk.	
#9	• Under hele operasjonen skal det pågå en miljøovervåkning. • Dersom spredning av forurensede sedimenter overstiger fastsatte akseptkriterier skal alle operasjoner stanses. Årsak til spredning skal kartlegges og forbedringer finnes før operasjonen starter opp igjen.	
#10	• Det frarådes å bruke dykkere under en operasjon for heving av last	

Oppsummering

- Kvikksølvet bør mellomlagres på sjøbunnen i egnet container/beholder og tas opp når det skal transporteres direkte til deponi.
- Unngå å bruke metningsdykkere, da det vanskelig kan sikres at dykkerdrakt og -utstyr ikke er forurenset av kvikksølv når de går inn i dykkerklokken.
- Et sanntids overvåkningsprogram må være operativt under hele operasjonen.

3.2.6 Stabilisere vraket før tildekking

4.1. Forberedelser → 4.2. Etabl. tilgang til kjøl → 4.3. Åpne kjøl → 4.4. Ta ut Hg-flasker → 4.5. Ta Hg-flasker opp til mellomlager → 4.6. Stabilisere vraket før tildekking

Studie	Funn / observasjon	Tiltak
#3	• Sveiser i formskroget for tankene er i svært dårlig forfatning/tilstand. • Plater falt av når skroget ble børstet rent for marin groe forut for innsetting av ventiler for ventilering/tømming av olje.	• Ved beregning av antall løftepunkter i skrog må resultatene fra materialtesten legges til grunn, samt en tilstrekkelig stor sikkerhetsmargin for å ta høyde for usikkerheten i materialstyrken. • Det må sikres at utstyr benyttet på sjøbunnen blir rengjort helt før disse flyttes over til ren sone på fartøyet, eller tas i bruk i operasjoner etter U-864 tiltaket. Evt. må utstyret kasseres iht. gjeldene regler. • Ved arbeid under vraket er det behov for å sikre at deler av formskroget, evt. andre deler av vraket, ikke faller ned og ødelegger utstyr. Dette er spesielt viktig dersom dykkere skal brukes i arbeid på kjølkassene. • Miljøovervåknings-programmet må være robust og være godt testet før operasjonen iverksettes. • Ikke å benytte dykkere
#4	• Tykkelsen på stålplatene i trykkskroget er stedvis redusert pga. korrosjon. Utover dette oppfører stålet seg som forventet for denne ståltypen, men har noe lavere bruddstyrke i sveisen enn basematerialet. Dette må tas hensyn til ved kapasitetsberegninger.	
#5	• 2: Senke vraket ned på sedimentene og fjerne løfterammen. Sugeankrene blir værende på sjøbunn. • 3: Fjerne løfteballonger • 4/5: Fjerne vinsjer, men wire og ankre blir værende på sjøbunn.	
#7	• Rengjøring av utstyr (som har vært på sjøbunnen) for kvikksølv var svært tidkrevende og komplisert.	
#9	• Under hele operasjonen skal det pågå en miljøovervåkning. • Dersom spredning av forurensede sedimenter overstiger fastsatte akseptkriterier skal alle operasjoner stanses. Årsak til spredning skal kartlegges og forbedringer finnes før operasjonen starter opp igjen.	
#10	• Det frarådes å bruke dykkere under en operasjon for heving av last	

Oppsummering

- Det må rettes stor oppmerksomhet på rengjøring av utstyr som har vært i kontakt med de forurensede sedimentene. Vurdere å la utstyr som ikke må gjenbrukes stå igjen på sjøbunn.
- Vraket må etterlates i en stabil posisjon, og helst på en måte som reduserer høyden på overdekningen med steinmasser (redusere det totale volumet).
- Et sanntids overvåkningsprogram må være operativt under hele operasjonen.

3.3 Løsninger for heving av last

3.3.1 Løsningsalternativer

Basert på informasjonen som er innhentet og systematisert i kapittel 3.1 og 3.2, og oppsummeringene som er gjort i hvert prossessteg er følgende overordnede føringer for løsningene funnet:

- Skråningen ved forseksjonen må stabiliseres for å motvirke sedimentutglidning under arbeid på vraket. Ved graving/mudring ellers må dette gjøres slik at helningen er så slak at utglidning ikke inntreffer.
- Arbeider i sedimentene (graving, mudring og bruk av utstyr på sedimentene) må reduseres mest mulig for å redusere oppvirvling. Alternativt må tiltak iverksettes for å sikre at forurensede masser spres utover tiltaksområdet.
- Et sanntids miljøovervåkningssystem må etableres og være operasjonelt under hele operasjonen. Når grenseverdier overskrides, skal alt arbeid stoppes og årsaken til de forhøyde verdiene skal kartlegges og endringer gjennomføres for å sikre nye overskridelser før arbeidet kan starte opp igjen.
- Feste av wire på vrakdelene må være på trykkskroget, og wire må føres langs trykkskroget, ikke på profilskroget.
- For å få tilgang til kjølen må vraket enten løftes ut av sedimentene eller påføres tilstrekkelige krefter påføres ved rulle slik at kjølen tvinges opp. Tilstrebe å redusere sugekreftene mellom kjøl og sedimenter for å redusere nødvendige krefter som må tilføres og mulighet for skade på kjøl.
- Alle tiltak på vraket må være nøye planlagte og gjennomføres på en slik måte at ukontrollerte bevegelser ikke oppstår da dette kan skade kjøl og/eller virvle opp forurensede sedimenter..
- Løsningen må ta høyde for at tilgang til kjølkassene må kunne etableres fra begge sider. Sideplatene bør primært fjernes ved å bore ut skruene som platene er festet med.
- Metningsdykkere frarådes å inngå i operasjoner på sjøbunnen pga. de sterkt kvikksølvforurensede sedimentene (jf. Vedlegg 3.04).
- Kvikksølvflaskene og beholdere brukt for oppsamling av flytende kvikksølv bør samles og mellomlagres på sjøbunnen frem til de tas opp og transporteres direkte til deponi.
- Etter endt operasjon må vrakdelene etterlates i en stabil posisjon. Utstyr som ikke må gjenbrukes og som kan etterlates på sjøbunnen, bør ikke tas opp. Alt annet utstyr som har vært i kontakt med de forurensede sedimentene må gjennomgå en grunding rengjøring i etterkant.

For å kunne gjøre en analyse har DNV GL og Kystverket søkt å finne noen prinsipielt forskjellige løsninger for heving av last ut i fra informasjonen som er samlet og gjengitt i foregående kapitler. Disse skal danne grunnlaget for analyse av kostander, fremdrift og risiko for deloperasjonen «heving av last» i Alternativ 3. Hensikten med å søke å finne flere mulige løsninger er for å bedre fange opp mulighetsrommet og tilhørende usikkerhet for valg av løsning i nåværende fase av prosjektet.

Følgende to hovedprinsipper er foreslått for hovedprosess 4 (jf. Figur 2):

4A: Etablere tilgang til kjølkassene ved å rulle vraket over på siden

4B: Etablere tilgang til kjølkassene ved å løfte vraket opp fra sedimentene

For løsning 4B er det videre to ulike metoder som er vurdert som aktuelle for å løfte vraket opp fra sedimentene:

4B1: Løfte de to vrakdelene ved hjelp av en løfterigg som er plassert på sjøbunnen.

$4B_2$: Løfte vrakdelene fra overflaten ved hjelp av et kranfartøy og over i hver sine tilpassede krybber på sjøbunnen.

Disse tre løsningene er videre omtalt som: 4A = «Rulle», 4B1: «Rigg», og 4B2 = «Krybbe». Dette er tre forskjellige løsninger for å gi tilgang til kjølkassene, og har sine styrker og svakheter. De fleste av anbefalingene for hvilke hensyn som bør tas i de ulike operasjonsstegene (delprosess 1-6) gjelder uavhengig av hvilken løsning som velges.

I Tabell 1under er de overordnede prinsippene for disse tre løsningene beskrevet per delprosessteg (jf. Figur 2).

Figur 4 Hovedprosesser og delprosesser for Alt. 3 «Heving av last»

Tabell 1 Overordnede prinsipper for løsningen per delprosess (steg)

Pros.	Rulle	Rigg	Krybbe
3	**Etablere støttefylling**		
4.1	• Feste ankere, wire, vinsjer	• Installere rigg (m/ kranfartøy) • Feste ankere, wire, vinsjer	• Installere krybber Feste ankere, wire, vinsjer
4.2	• Fjerne sedimenter langs vrak • Rulle vrak • Installere arbeidsrigg	• Løfte vrak opp fra sedimentene med rigg • Installere arbeidsrigg	• Løfte vrak opp fra sedimentene fra fartøy og over i krybbe • Installere arbeidsrigg
4.3	• Fjerne sideplater		
4.4	• Fjerne kvikksølvflasker og evt. flytende kvikksølv og samle disse i en container el. (våtdeponi) ved vraket		
4.5	• Løfte container opp til overflaten på et fartøy som frakter dette videre til deponi		
4.6	• Fjerne ankere, wire, vinsjer	• Løfte opp rigg (m/ kranfartøy) • Fjerne ankere	• Løfte vrak fra krybbe og legge det stabilt på sjøbunnen • Fjerne krybber

Felles for alle løsningene er et robust miljøovervåkningsprogram som skal pågå under hele operasjonen.

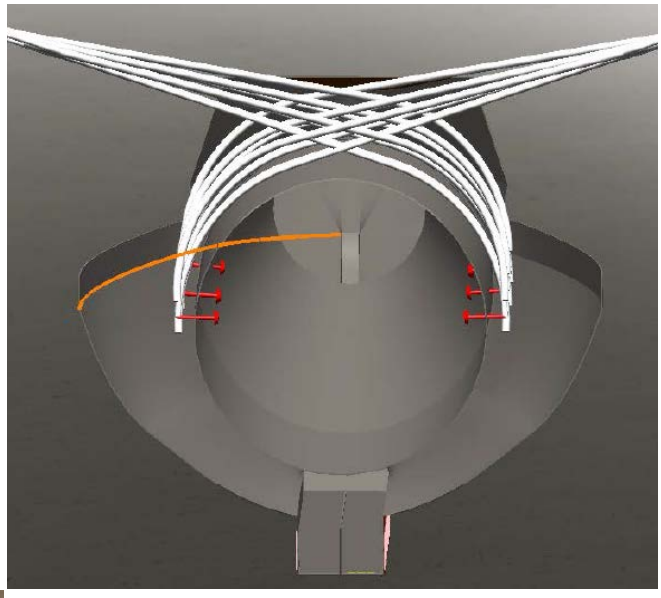
I de etterfølgende kapitlene er hver enkelt løsning beskrevet noe mer i detalj, og der skisser av hvert operasjonssteg er inkludert. Et komplett sett med tegninger er vedlagt i kapittel 6. For beskrivelse av støttefyllingen, se Vedlegg V0.03.

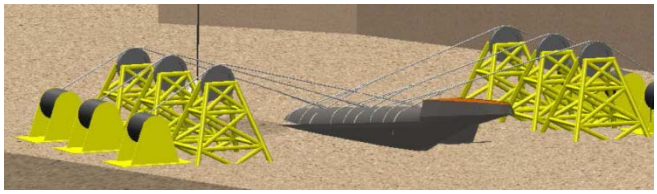
3.3.2 Rulle vrakdelene

Nedenfor gis det en kort beskrivelse av hver delprosess for løsningen «Rulle», og gjelder for både for- og akterseksjon av U-864.

4.1 Forberedelser

- Deler av profilskroget må fjernes slik at ankere kan festes til trykkskroget og at wire kan legges langs dette.
- For å motvirke motvirker at vraket presses ned i sedimentene når wire strammes benyttes bukker for å sikre en oppadrettet kraftkomponent.
- Wire og vinsjer installeres. Vinsjer festes til fjell eller ved bruk av sugeankere. Wire festes på begge sider av trykkskroget for å ha kontroll på rotasjonen.
- Det er gjort en styrkeberegning av ankerfestene for å beregne hvor mange festepunkter som er nødvendig. Denne analysen er gjengitt i kapittel 6.
- Hvert anker trekkes til med den trekkraften som må benyttes under rotasjonen, for å være sikker på at festet holder og at evt. rør etc. på innsiden av trykkskroget som er klemt på innsiden av ankeret klemmes flatt før rulleoperasjonen utføres.





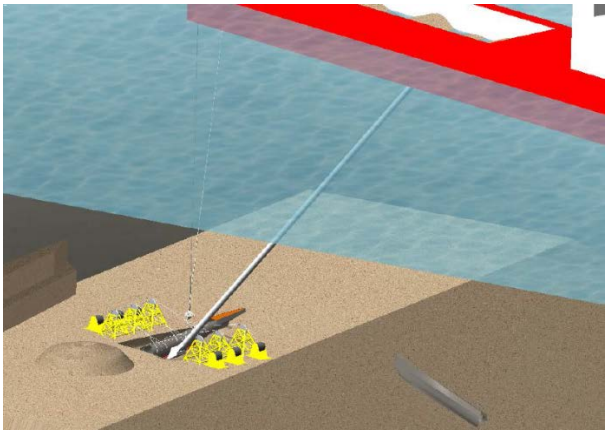
4.2 Skaffe tilgang til kjøl

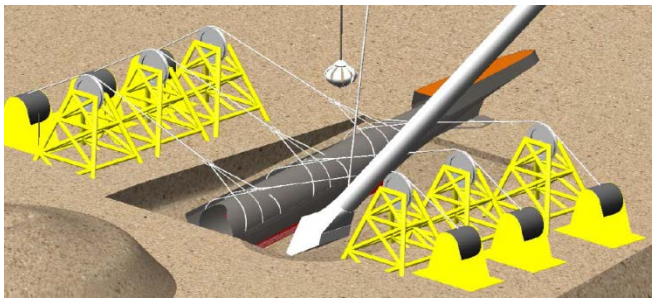
- Steiner og vrakrester fra sjøbunnen rundt vraket fjernes med klo eller annet egnet verktøy som kan fjerne store volumer på en effektiv måte og som ikke medfører spredning av forurensede sedimenter ut over grenseverdiene.

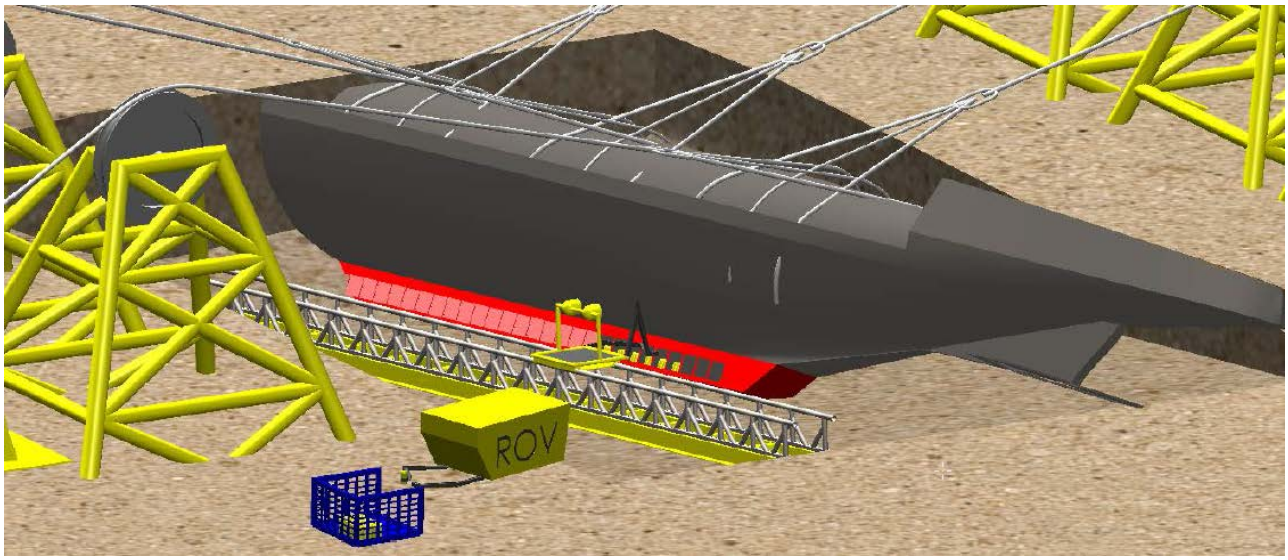
- Sedimenter fjernes fra begge sider av vraket slik at kjølen gjøres tilgjengelig og ikke påføres unødvendig store krefter ved rulle. Dette gjøres i hovedsak med klo, mens inntil vraket blir det nødvendig å mudre. Mudring gjøres med en «hopper dredger» for sugemudring i et lukket system der sedimentene suges opp til en flytende arbeidsplattform. Dette for å redusere spredning av forurensede sedimenter.

- Vraket rulles over på siden vha. vinsjene.

- En arbeidsrigg installeres langs kjølen. Denne gjør at utstyr ikke må jobbe direkte på forurensede sedimenter, og at det gir utstyr (ROV) som kobles til denne mulighet for mer kraftoverføring og stabil posisjon.

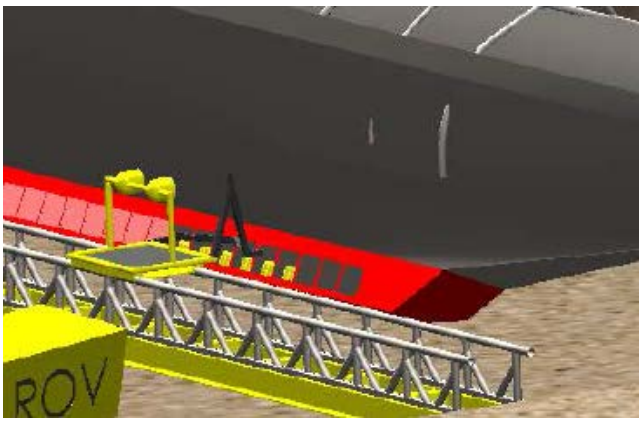






4.3 Åpne kjølkasser

- Skruene som sideplatene er festet med bores ut for å kunne fjerne hele sideplaten. Alternativt må det kuttes hull i sideplaten.

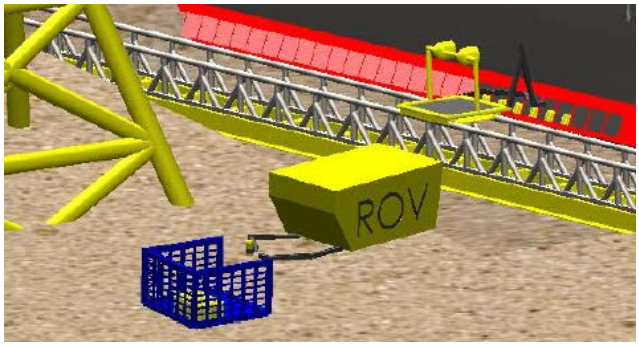


4.4 Ta ut kvikksølvflasker

- Kjølkamre som inneholder kvikksølvflasker tømmes for disse. Dersom flaskene er korrodert sammen, må det vurderes om hele enheten (flere flasker) kan løftes ut samlet, eller om flaskene må separeres.

- Flytende kvikksølv må suges/fjernes med egnet utstyr, og fylles over i egnede beholdere for å kunne transporteres til mellomlager på sjøbunn eller på land.

- Kvikksølvflaskene og beholdere med oppsamlet flytende kvikksølv flyttes til mellomlager på sjøbunn eller på land. Ved mellomlager på sjøbunn vil dette kunne oppbevares frem til det kan transporteres videre til sluttdeponi. Dette må skje før sjøbunnen tildekkes. Dersom tildekking skjer før det er bestemt deponiløsning for kvikksølvflaskene, så må disse plasseres i et mellomlager på land.



4.5 Ta kvikksølvflaskene opp til mellomlager

- Det er senere vurdert at det er best om mellomlager står på sjøbunnen frem til det kan transporteres videre til deponi. Det skjer derfor ingen aktiviteter i dette delprossessteget.

- Dersom tildekking skjer før det er bestemt deponiløsning for kvikksølvet, så må disse legges på et mellomlager på land.

4.6 Stabilisere vraket før tildekking

- Vrakdelene legges stabilt.

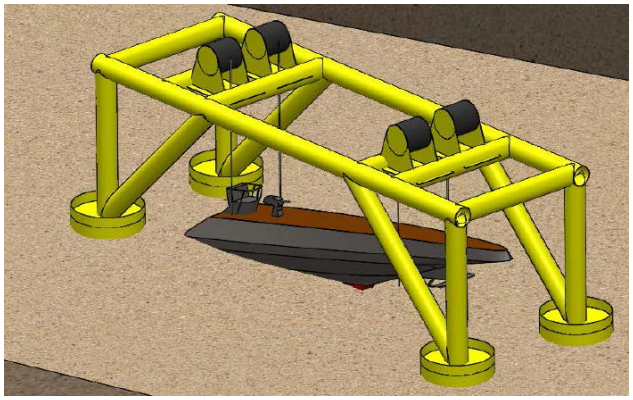
- Wire, vinsjer, bukker og sugeankre fjernes.

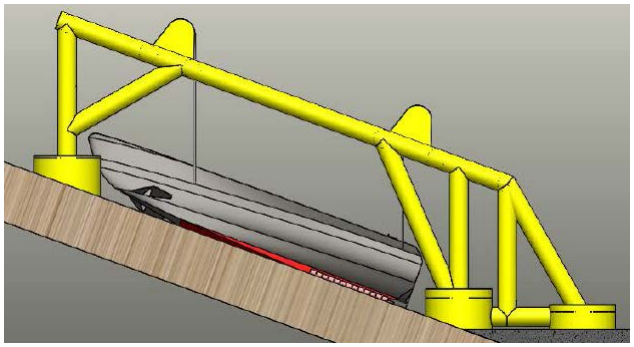
I prosessen beskrevet over er det flere operasjonssteg som kan gjøres i parallell. Dersom man ikke får tilgang til begge kjølkasser ved å rulle over til den ene siden, må samme seksjon rulles over på motsatt side for å gi tilgang til motstående side av kjølen.

3.3.3 Løfte vrakdelene i en rigg

Nedenfor gis det en kort beskrivelse av hvert delprosessteg for løsningen «Rigg», og gjelder både for for- og akterseksjon av U-864.

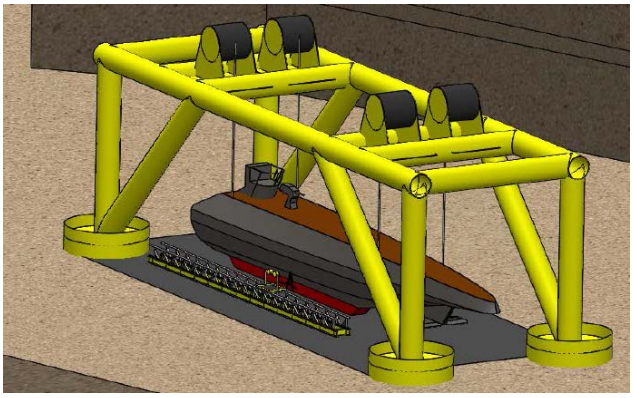
4.1 Forberedelser





- Deler av profilskroget må fjernes slik at ankere kan festes til trykkskroget
- Det er gjort styrkeberegninger av ankerfestene for å beregne hvor mange festepunkter som er nødvendig. Beregninger viser at det vil være behov for i størrelsesorden 30 ankere for hver av seksjonene som har en estimert vekt på 800 tonn. Analysen er gjengitt i kapittel 6.
- Hvert anker trekkes til med den trekkraften som må benyttes under løft, for å være sikker på at festet holder og at evt. rør etc. på innsiden av trykkskroget som er klemt på innsiden av ankeret klemmes flatt før løftet utføres.
- Løfterigg m/subseavinsjer settes på bunnen (over vraket). Styrken i sedimentene må beregnes, og evt. utbedres om nødvendig (bruk av sandsekker som riggen kan stelles på, fundamentering el.). Det må lages to rigger, en for hver seksjon. For forseksjonen plasseres de nederste bena i rammen direkte på støttefyllingen. Fundamenter må utplasseres først og geometri av ramme må tilpasses faktisk posisjon av fundamenter
- Wire festes til subseavinsjer og ankere.
- For å redusere sugekreftene mellom kjøl og sjøbunnen kan vann injiseres i sedimentene under kjølen.
- Oppdriftselementer kan evt. festes til vraket for å redusere belastning på sjøbunnen og nødvendig styrke i riggens konstruksjon.

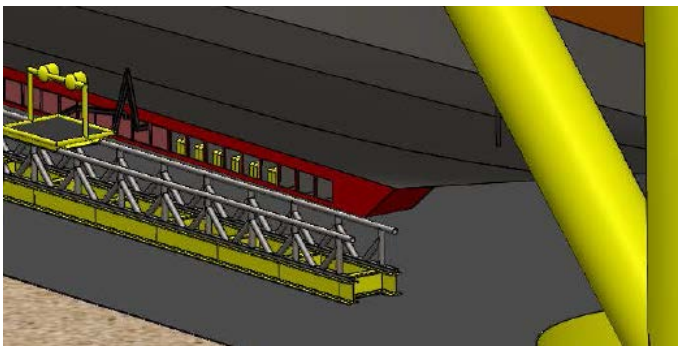
4.2 Skaffe tilgang til kjøl



- Steiner og vrakrester i sjøbunnen rundt vraket fjernes med klo
- Vraket løftes opp i riggen
- Kjølen renses for sedimenter
- En duk kan legges under kjølen for å samle opp evt. flytende kvikksølv som renner ut når kjølkassen åpnes.
- En arbeidsrigg installeres langs kjølen. Denne gjør at utstyr ikke må jobbe direkte på forurensede sedimenter, og at det gir utstyr (ROV) som kobles til denne mulighet for mer kraftoverføring og stabil posisjon.

4.3 Åpne kjølkasser

- Skruene som sideplatene er festet med bores ut for å kunne fjerne hele sideplaten. Alternativt må det kuttes hull i sideplaten.

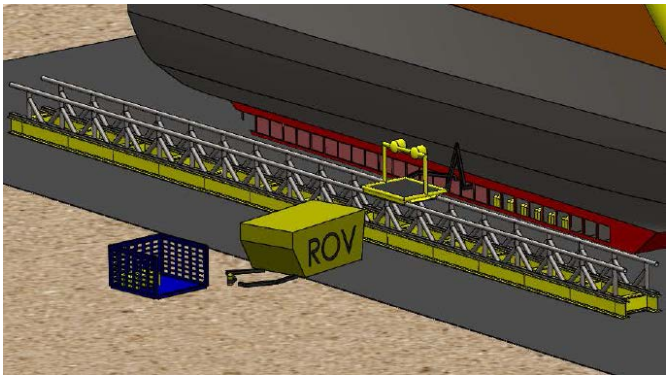


4.4 Ta ut kvikksølvflasker

- Kjølkamre som inneholder kvikksølvflasker tømmes for disse. Dersom flaskene er korrodert sammen, må det vurderes om hele enheten (flere flasker) kan løftes ut samlet, eller om flaskene må separeres.

- Flytende kvikksølv må suges/fjernes med egnet utstyr, og fylles over i egnede beholdere for å kunne transporteres til mellomlager på sjøbunn eller på land.

- Kvikksølvflaskene og beholdere med oppsamlet flytende kvikksølv flyttes til mellomlager på sjøbunn eller på land. Ved mellomlager på sjøbunn vil dette kunne oppbevares frem til det kan transporteres videre til sluttdeponi. Dette må skje før sjøbunnen tildekkes. Dersom tildekking skjer før det er bestemt deponiløsning for kvikksølvflaskene, så må disse plasseres i et mellomlager på land.



4.5 Ta kvikksølvflaskene opp til mellomlager

- Det er senere vurdert at det er best om våtdeponiet står på sjøbunnen frem til det kan transporteres videre til deponi. Det skjer derfor ingen aktiviteter i dette delprossessteget.

- Dersom tildekking skjer før det er bestemt hvilket deponi kvikksølvflaskene skal til, så må disse legges på et mellomlager på land.

4.6 Stabilisere vraket før tildekking

- Vraket senkes ned på sjøbunnen og wire frakobles.

- Rigg m/ subseavinsjer løftes opp av kranfartøy.

- Sugeankre fjernes om mulig.

I prosessen beskrevet over er det flere operasjonssteg som kan gjøres i parallell.

3.3.4 Løfte vrakdelene over i en krybbe

Nedenfor gis det en kort beskrivelse av hvert delprosessteg for løsningen «Krybbe», og gjelder både for- og akterseksjon av U-864.

4.1 Forberedelser

- Deler av profilskroget må fjernes slik at ankere kan festes til trykkskroget

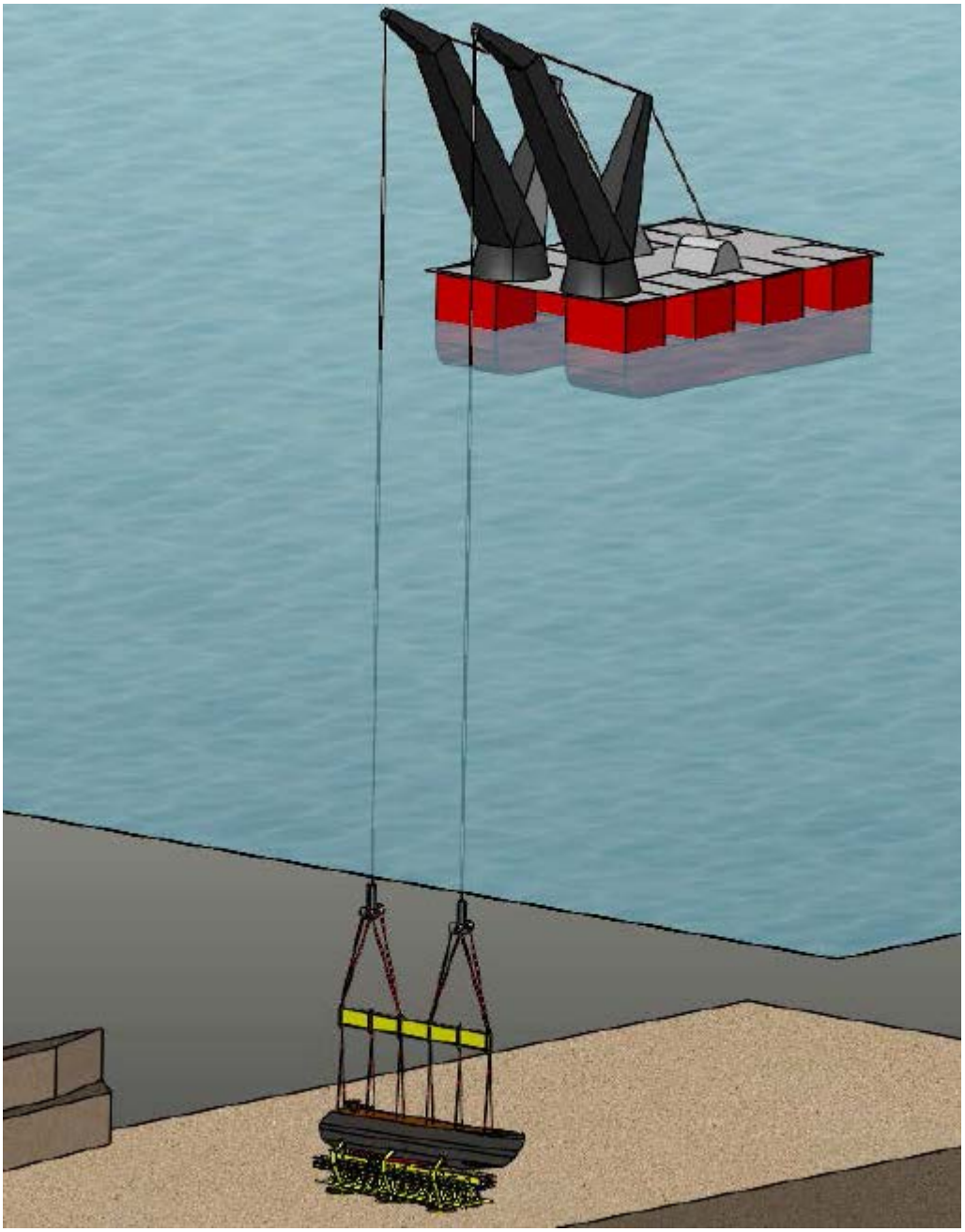
  Det er gjort en styrkeberegning av ankerfestene for å beregne hvor mange feste-punkter som er nødvendig. Denne analysen er gjengitt i kapittel 6.

- Hvert anker trekkes til med den trekkraften som må benyttes under løft, for å være sikker på at festet holder og at evt. rør etc. på innsiden av trykk-skroget som er klemt på innsiden av ankeret klemmes flatt før løftet utføres.

- En krybbe for hver seksjon settes på støttefyllingen, som har god styrke og planhet. Krybben må designes slik at den gir god tilgang til kjølkassene.

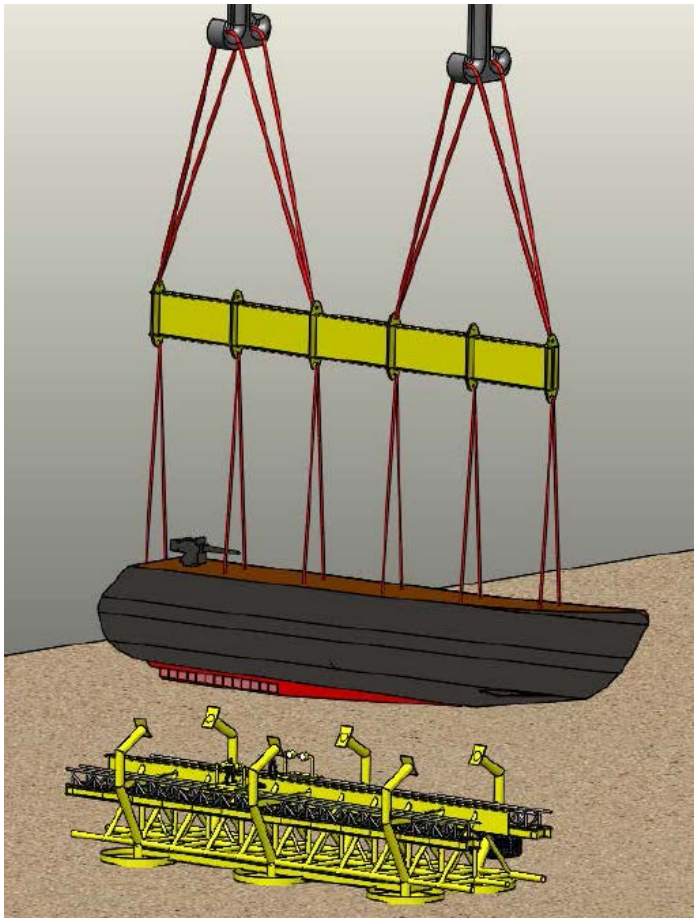
- For å redusere sugekreftene mellom kjøl og sjøbunnen kan vann injiseres i sedimentene under kjølen.

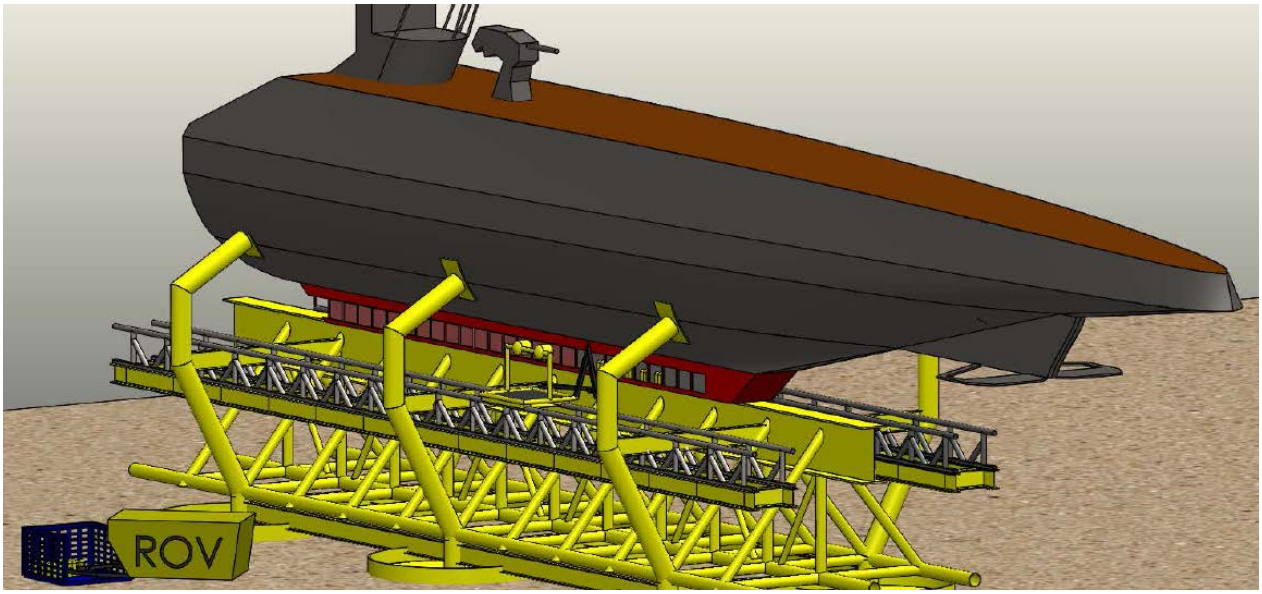
- Wire fra kranfartøy festes til vraket.



4.2 Skaffe tilgang til kjøl

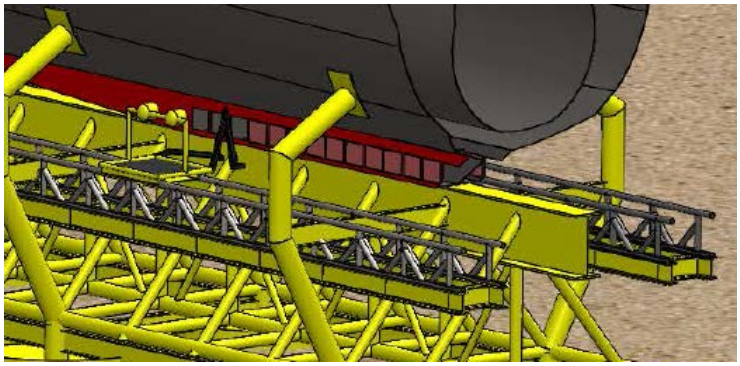
- Steiner og vrakrester fra sjøbunnen rundt vraket fjernes med klo
- Kranfartøyet løfter dette over i krybben. Høyde over sjøbunnen bør være så lav som mulig for å begrense området forurensede sedimenter spres over og redusere konsekvensene dersom festene ryker. Dette gjøres for begge vrakdeler.
- Kjølen renses for sedimenter
- Krybben har en arbeidsrigg langs begge sider. Dette gjør at utstyr ikke må jobbe direkte på forurensede sedimenter, og at det gir utstyr (ROV) som kobles til denne mulighet for mer kraftoverføring og stabil posisjon.





4.3 Åpne kjølkasser

- Skruene som sideplatene er festet med bores ut for å kunne fjerne hele sideplaten. Alternativt må det kuttes hull i sideplaten.

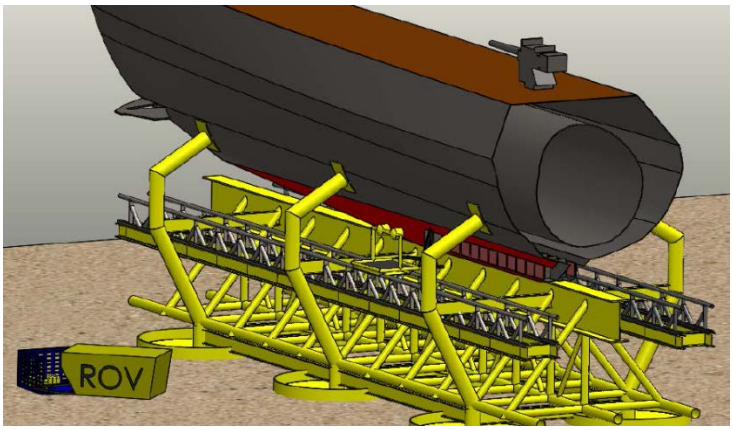


4.4 Ta ut kvikksølvflasker

- Kjølkamre som inneholder kvikksølvflasker tømmes for disse. Dersom flaskene er korrodert sammen, må det vurderes om hele enheten (flere flasker) kan løftes ut samlet, eller om flaskene må separeres.

- Flytende kvikksølv må suges/fjernes med egnet utstyr, og fylles over i egnede beholdere for å kunne transporteres til mellomlager på sjøbunn eller på land.

- Kvikksølvflaskene og beholdere med oppsamlet flytende kvikksølv flyttes til mellomlager på sjøbunn eller på land. Ved mellomlager på sjøbunn vil dette kunne oppbevares frem til det kan transporteres videre til sluttdeponi. Dette må skje før sjøbunnen tildekkes. Dersom tildekking skjer før det er bestemt deponiløsning for kvikksølvflaskene, så må disse plasseres i et mellomlager på land.



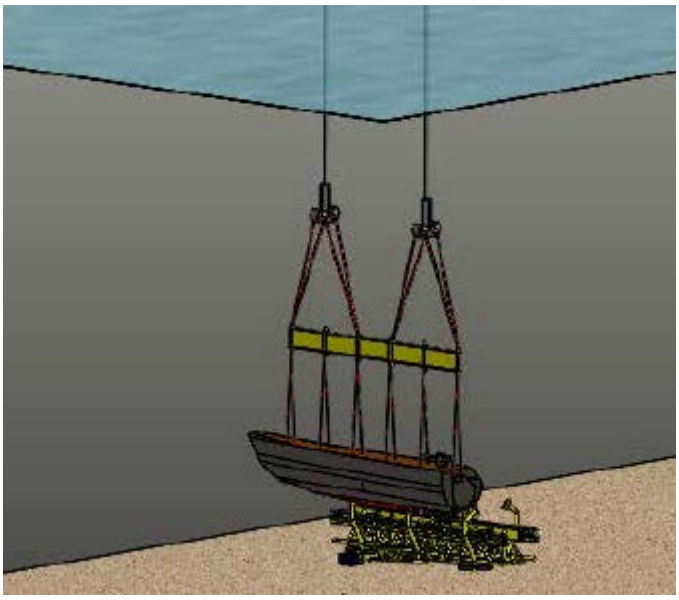
4.5 Ta kvikksølvflaskene opp til mellomlager

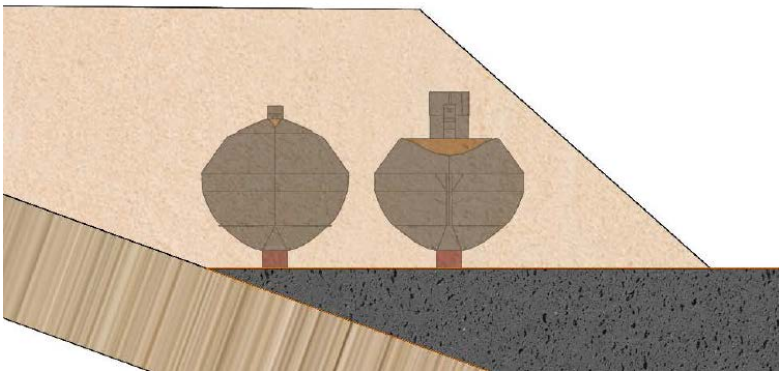
- Det er senere vurdert at det er best om våtdeponiet står på sjøbunnen frem til det kan transporteres videre til deponi. Det skjer derfor ingen aktiviteter i dette delprossessteget.

- Dersom tildekking skjer før det er bestemt hvilket deponi kvikksølvflaskene skal til, så må disse legges på et mellomlager på land.

4.6 Stabilisere vraket før tildekking

- Vraket løftes ut av krybben med et kranfartøy og senkes ned på sjøbunnen på en egnet plass. Vraket bør legges ett sted der de reduserer det mengden materiale som er nødvendig for tildekkingen. Dette kan være inntil en fjellside eller på støttefyllingen mot skråningen.
- Wire frakobles.
- Krybber løftes opp av kranfartøy.
- Alternativt kan vrakene stå igjen i krybbene på støttefyllingen. Da er det ikke behov for ny mobilisering av kranfartøy, men mengden materiale til tildekkingen kan øke noe pga. økt høyde (vrak + krybbe).





I prosessen beskrevet over er det flere operasjonssteg som kan gjøres i parallell.

4 KONKLUSJON

I kapittel 3.3 er det beskrevet tre prinsipielt forskjellige løsninger for heving av last. Disse løsningene er lagt til grunn for kostnads-, fremdrifts- og risikoanalysen av Alternativ 3 (delprosess 4). Disse løsningene er utarbeidet basert på den informasjonen som er gjennomgått i 3.1.

Metodene for å heve lasten som ble foreslått av de ulike selskapene har flere likhetstrekk, men også forskjeller. Dette er ikke en standard operasjon som krever standard utstyr, og derfor er det i forprosjektet valgt å sette ideene sammen til tre prinsipielt ulike løsningsmetoder som grunnlag til å beregne kostnader og gjennomføringstid, og se på variasjoner i kost og økonomi.

I dette dokumentet er det vist mulige løsninger for gjennomføring en operasjon med heving av lasten fra U-864. Et konkurransegrunnlag som skal omfatte operasjonen «heving av last» må være funksjonsbasert og ikke låses til en bestemt løsning da dette vil kunne være konkurransedreiende og favorisere enkelte leverandører. Derfor er en funksjonsbasert spesifikasjon med tilhørende krav til bl.a. sikkerhet og ytre miljø en løsning som forprosjektet konkluderer med.

Men de løsninger som er beskrevet i flere steg i dette dokumentet kan være en kilde til ideer for leverandører som ønsker å delta i konkurransen om en kontrakt med å heve lasten fra U-864.

5 KILDER

Dok ID	Dokument	Utarbeidet av	Dato
D01	Konseptvalgutredning for håndtering av U-864	Kystverket	04.11.2011
D02	Kvalitetssikring fase 1 (KS1 – Konseptvalg) av Håndtering av U-864. Rapport til KKD og FIN	Metier	25.01.2012
D03	Tafel VII: Uboottyp IX D2 - Generalplan		

6 STRENGTH CALCULATIONS

Denne analysen er utarbeidet av DNV GL AS.

6.1 Objective

- Evaluating different lifting alternatives based on a structural strength assessment of the hull sections.
- Rough estimate of cost of support structures for supporting wreck sections subsequent to lifting operations.

6.2 Assumptions

Assumed weight of wreck sections:

- Stern section: 800 metric tonnes
- Aft section: 800 metric tonnes
- Both sections assumed to have uniform weight distribution.

Pressure hull characteristic

- Diameter: 4.4m
- Length: 34m for each wreck section
- Scantlings: see Figure 1 (based on structural drawings /D03/
- Web-frame spacing : 500mm (based on structural drawings /D03/)
- Steel yield strength: 355MPa (based on laboratory tests of pressure hull jf. vedlegg V3.07)

Safety factors used in the calculations

- Uncertainty factor (combined load and material factor): 2.0 [-]*

*Includes uncertainties towards sediments, sea-bed constraint, weight distribution and other factors that may affect the resulting load at the different anchor points in the hull. The magnitude of the factor 2.0 is not based on any thorough evaluation of the actual uncertainties.

Result evaluation:

- The acceptance criteria used in this report are not related to any official standards or regulations. They are solely based on the understanding of structural mechanics by the engineer assessing the results.

6.3 Lifting alternative examples

There are two methods that are identified as possible for lifting of the fore- and aft section of the wreck from U-864 out of the seafloor. One using a template (truss work), and the other is lifting of the sections from the sea surface using a crane operated on a vessel.

6.3.1 Lifting of hull in a template

Lifting of hull using a template on the seafloor, where winches are placed on top of the template. The hull is lifted up from the seabed inside the template structure. The Hull will, after removal of mercury canisters, be lowered down to the seabed and released from the frame (template). See Figure 1.

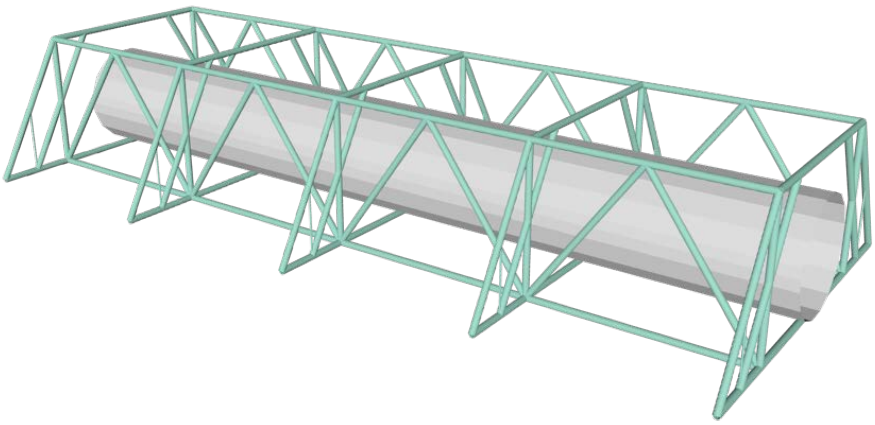


Figure 1: Frame/template general arrangement

6.3.2 Lifting of hull in a template

Hull is lifted out of the seafloor from a surface vessel and transported to a cradle for removal of mercury canisters. The hull is later lifted to a favorable position on the seafloor ready for capping. See Figure 2.

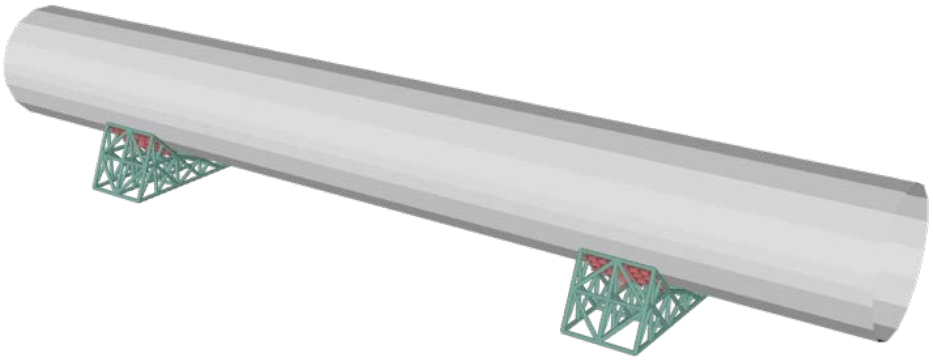


Figure 2: Cradle support general arrangement

6.4 Lifting operation structural analysis

A finite element model of the pressure hull has been modelled and analysed according to assumptions made relating to lifting options available. The acceptance criteria in the different analyses are stresses beyond yield in the first alternative (frame lift) and change in structural stiffness for the second alternative (plate lift). The second alternative is allowed stresses beyond yield as there will be some redistribution of loads.

The following scantlings are used based on assumptions obtained from measuring directly in the original drawings. The distance between the centerlines of the frames is specified on drawings, while the rest of the dimensions are measured directly in the structural drawings, scaling from the given frame spacing, leaving some room for error. The structural drawings was supplied by the Norwegian Coastal Administration (Kystverket).

Thickness reductions have been applied due to corrosion. These numbers are arbitrary and do not necessarily reflect the actual conditions. An indication for the condition of the hull is obtained from the pressure hull plating laboratory material testing report (V3.07).

Figure 1 shows the drawing based scantlings on the left, and the scantlings with corrosion reduction on the right. The figure shows the cross-section of the internal transverse frame with the pressure hull plating on the bottom.

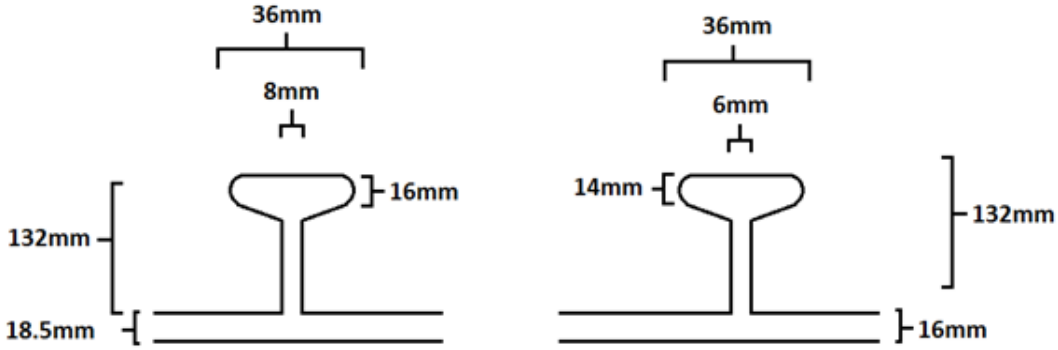


Figure 3: Assumed dimensions of the pressure hull (bottom) and frame cross-section.

6.4.1 Plug – Lifting by frames

An option that has previously been used in similar operations is a plug that, once inserted through the pressure hull plating, is expanded and anchored in two frames (see Figure 4).

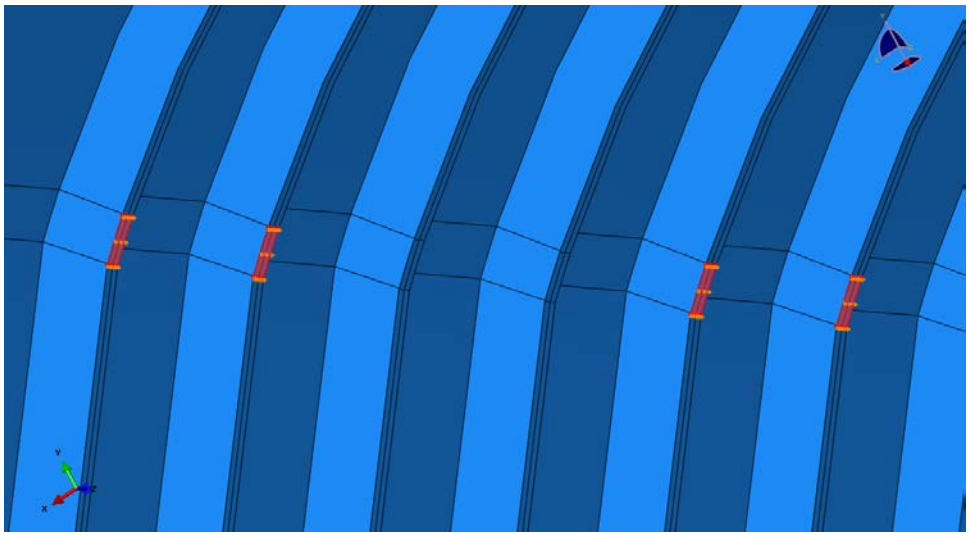


Figure 4: Lifting foot-prints on internal frames.

The results from using 28 lifting plugs show that the stresses are above yield across the entire web of the frames. This is not considered local stress, and should therefore be avoided if possible. The ductility of the steel will allow for some redistribution of stresses, but since this is at a conceptual stage, a better acceptance criterion would be to only allow local stresses above yield.

Consequently a reasonable estimation of required plugs is approximately 30. Note that the assumption of even weight distribution is a non-conservative assumption.

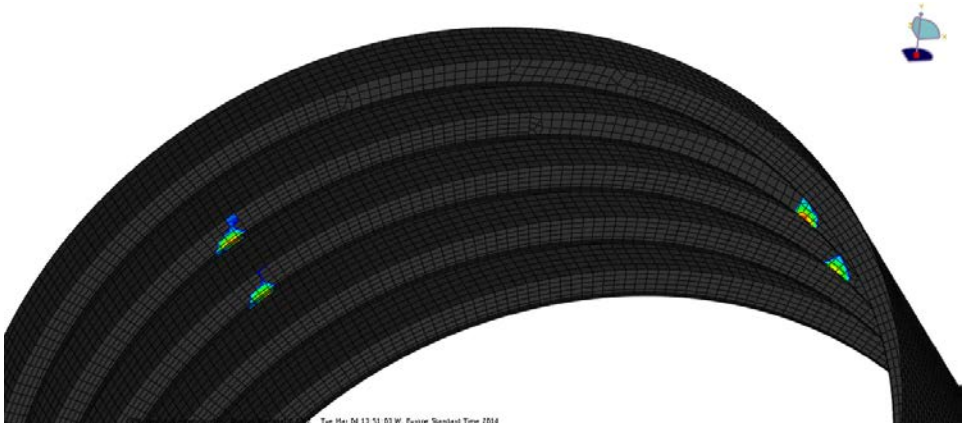


Figure 5: Stress plot showing equivalent stresses above material yield level

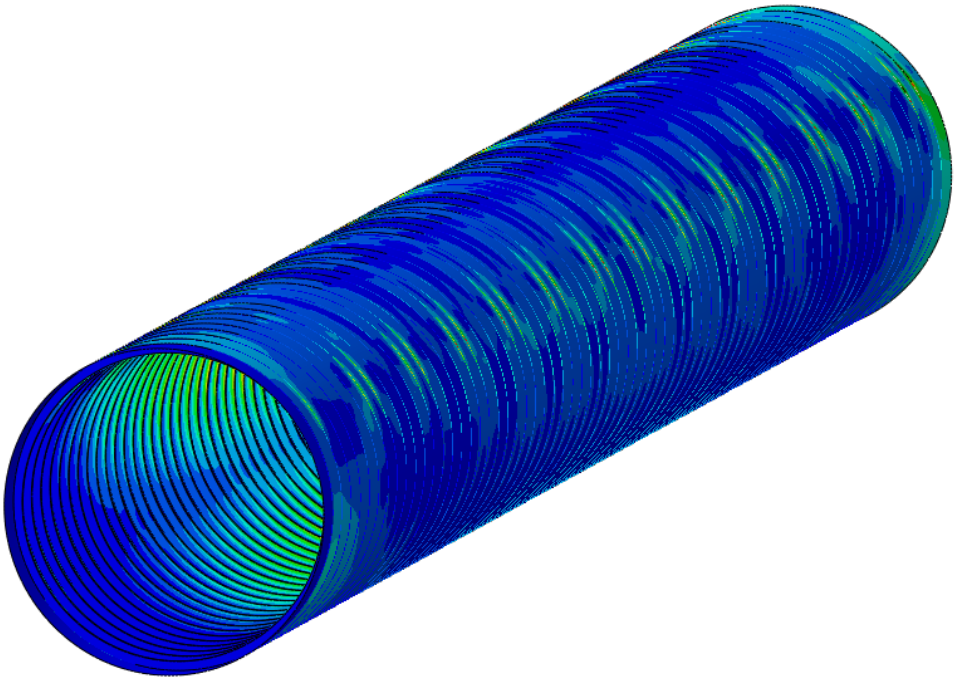


Figure 6: Equivalent stress plot showing support locations along the hull.

6.4.2 Plug – Lifting by plate

Considering the possibility of problems caused by obstacles (pipes or other installations) inside the pressure hull compartment, it might be difficult to expand a plug/anchor so that it covers two frames. The option of lifting directly on the hull plating, in a similar fashion to the frame lifting, has been assessed (see **Figure 7**). An assumption with this option is that the pressure from the plug contact is evenly distributed across the entire contact area.

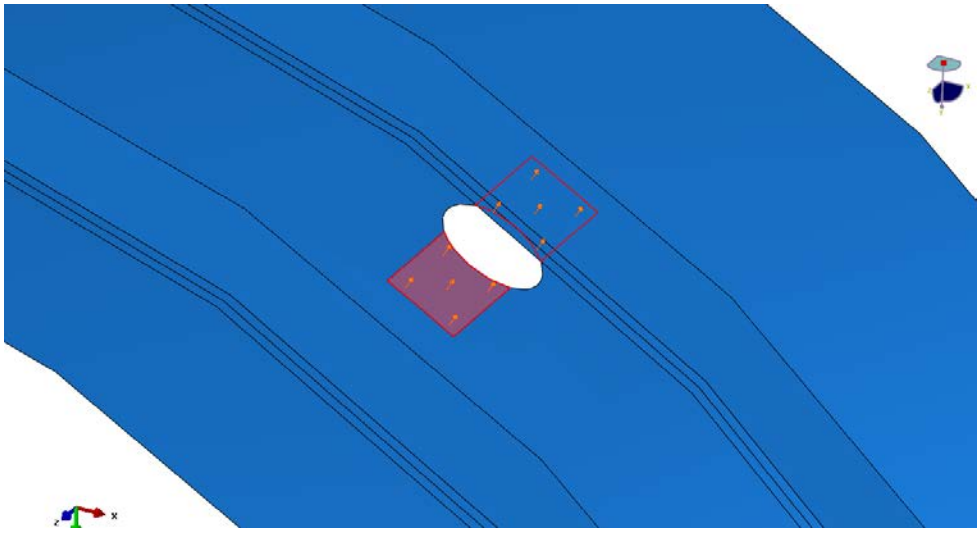


Figure 7: Lifting foot-print on plating.

According to conservative estimations, including safety/uncertainty margins, the number of lifting plugs would have to be approximately 35 for this case.

The acceptance criteria used for this kind of lifting are:

- Equivalent plastic strain above 5%
- Marked reduction in stiffness due to onset of redundancy loss.

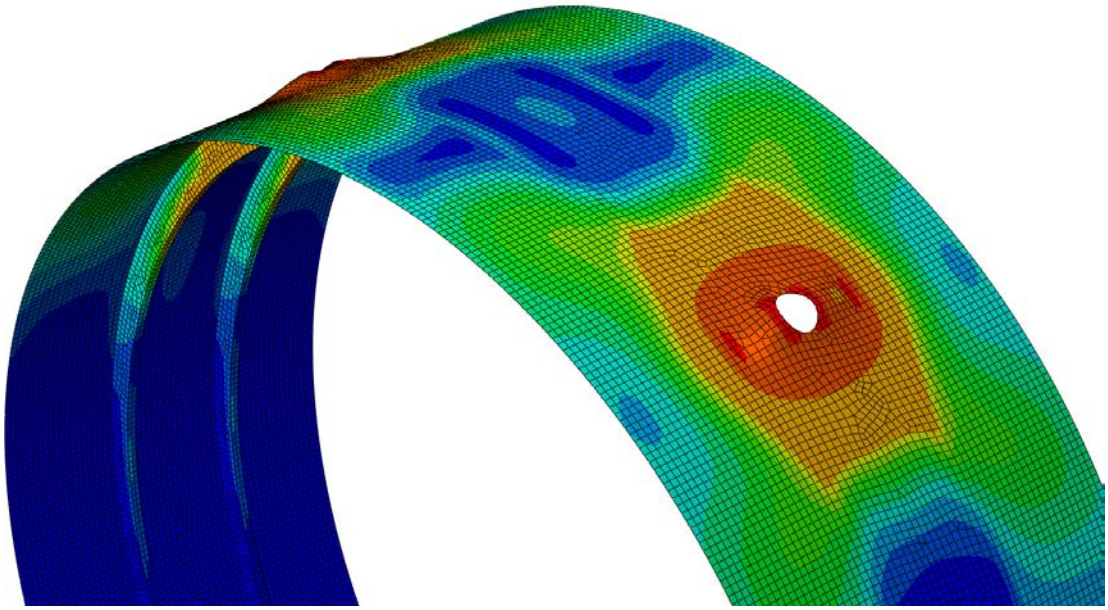


Figure 8: Equivalent stress plot of structure surrounding plug hole. Stresses beyond material yield are present.

As there might be a limitation on how many wires the control module may handle, a suitable option could be to use yokes or equivalent means in order to accommodate for the relatively large amount of lifting points.

6.5 Support and suspension system

For suspending the U-boat after lifting it from the sea-bed, it is to be supported by some means. Two suggestions have been short-listed. These are the cradle support and the suspension template.

Based on requirements to main function and suggestions involving engineering judgment, a rough sketch of how the supports would look is presented. These have been modelled using finite element models and analysed.

Note that the objective of this chapter is only to make a general prediction or estimation of the costs of the different systems for supporting the wreck. It does not attempt to provide a design solution, and it should not be treated as such.

6.5.1 Cradle Support

One suggestion for a cradle support is presented in Figure 9 and Figure 10. This shows one of two cradle supports for each half sections of the hull.

For such a structure to be able to support the weight of the hull, the total weight of the steel structure is calculated to be approximately 25 tons per support. In total 50 tons of steel is needed to support one half section of the u-boat.

Based on cost estimates (that are in essence unofficial quotes from suppliers in the offshore industry), the cost will be around 5 MNOK (for two supports). It will be necessary to make the side-pads adjustable in some way possible by hydraulic jacks. This is not included in this suggestion, and will cause additional cost to this estimate.

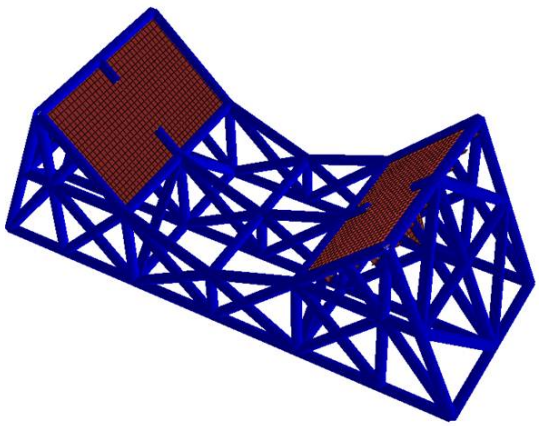


Figure 9: Birds eye view of cradle support

Note that the suggestion illustrated here is only an estimate of what is needed strength-wise, and consequently gives a rough estimation of the needed steel volume (and weight) of such a structure. A different structure would need to accommodate for different functions such as access to keel and adjustable contact pads.

6.5.2 Suspension Template

One suggestion for the suspension template (frame structure for lifting the U-boat wreck sections) can be seen in Figure 11. This shows an example of a template that would support one half of the U-boat within its boundaries. The structure can accommodate supports at several sections along the hull.

For such a structure to be able to support the weight of the sub, the total mass should be in the vicinity of 220 tons per template.

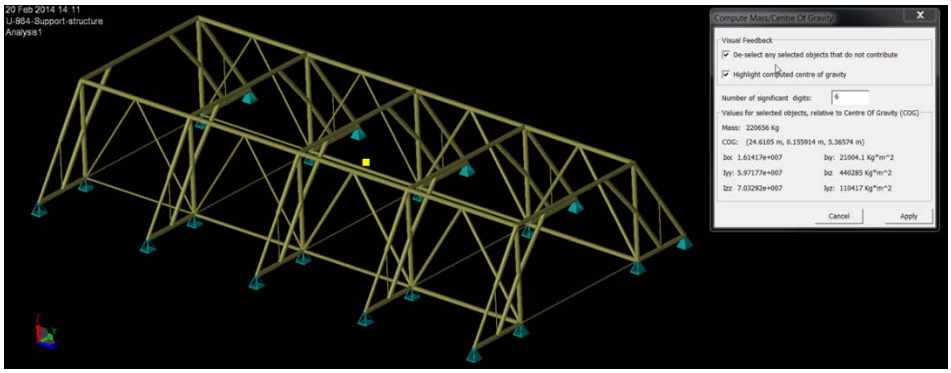


Figure 10: Suspension template illustration

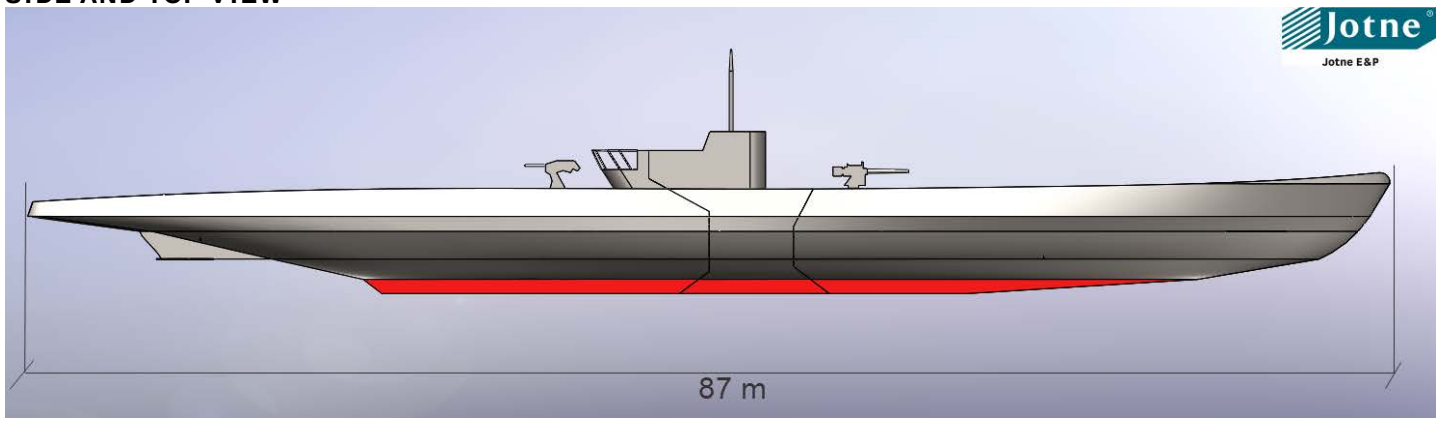
It should be noted that Figure 11 only shows an example of a template structure that would sustain the mass of each half of the submarine in order to be able to roughly predict the amount of steel weight needed, and thus an estimation of the cost of producing such a template. The cost of equipment and installation would be additional.

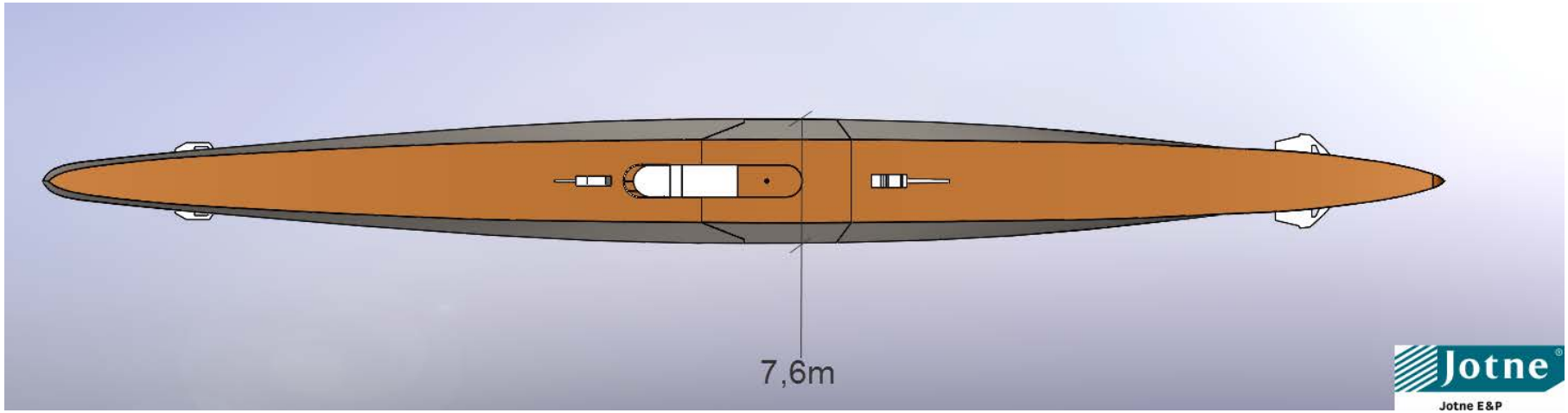
An actual template should take into account the actual amount of lifting points, and be optimized for reducing the need for cost and time consumption for installation of foundations at the seafloor that can carry the total weight of the frame and wreck section.

7 SKISSER

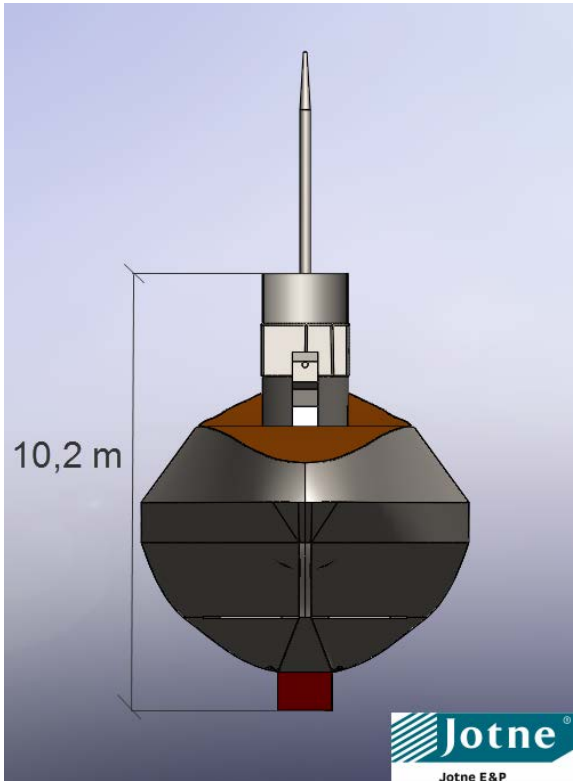
På de nesten siden er flere og større skisser av de tre løsningene presentert.

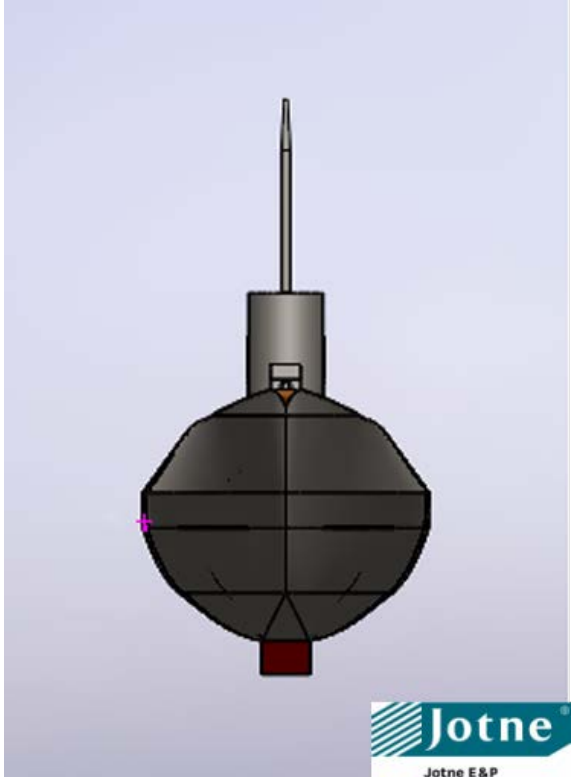
SIDE AND TOP VIEW





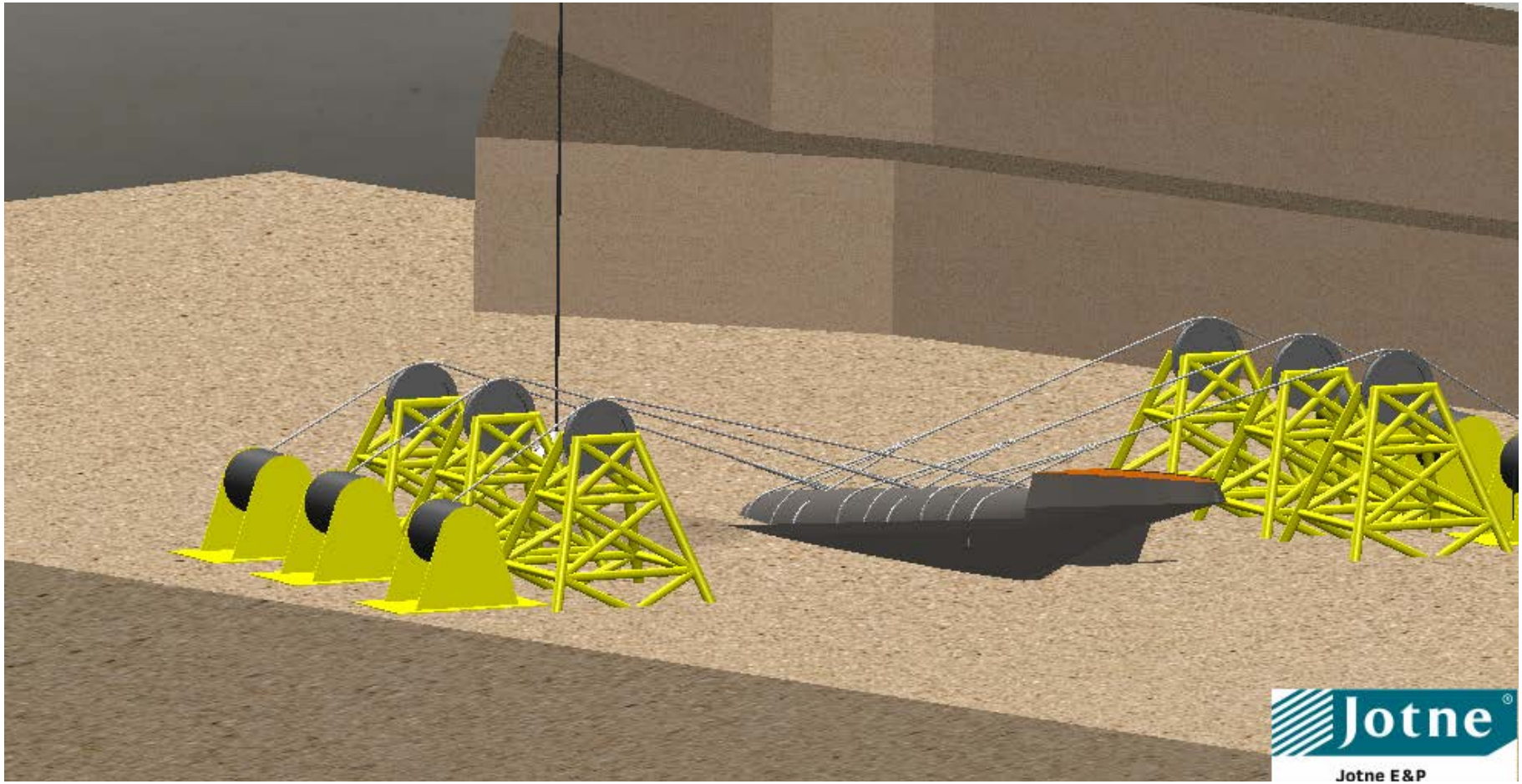
FWD AND AFT VIEW



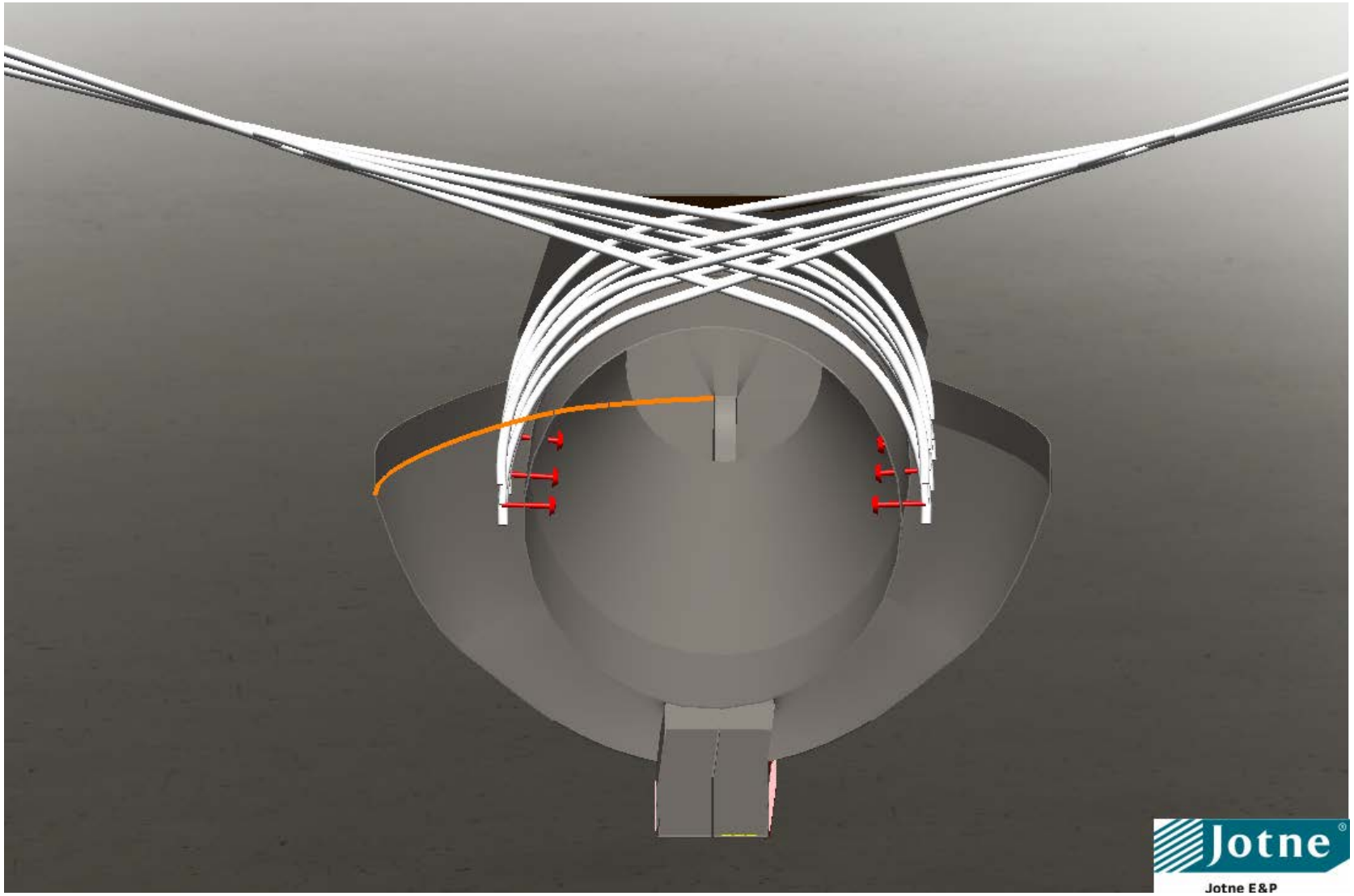


7.1 "Rulle"

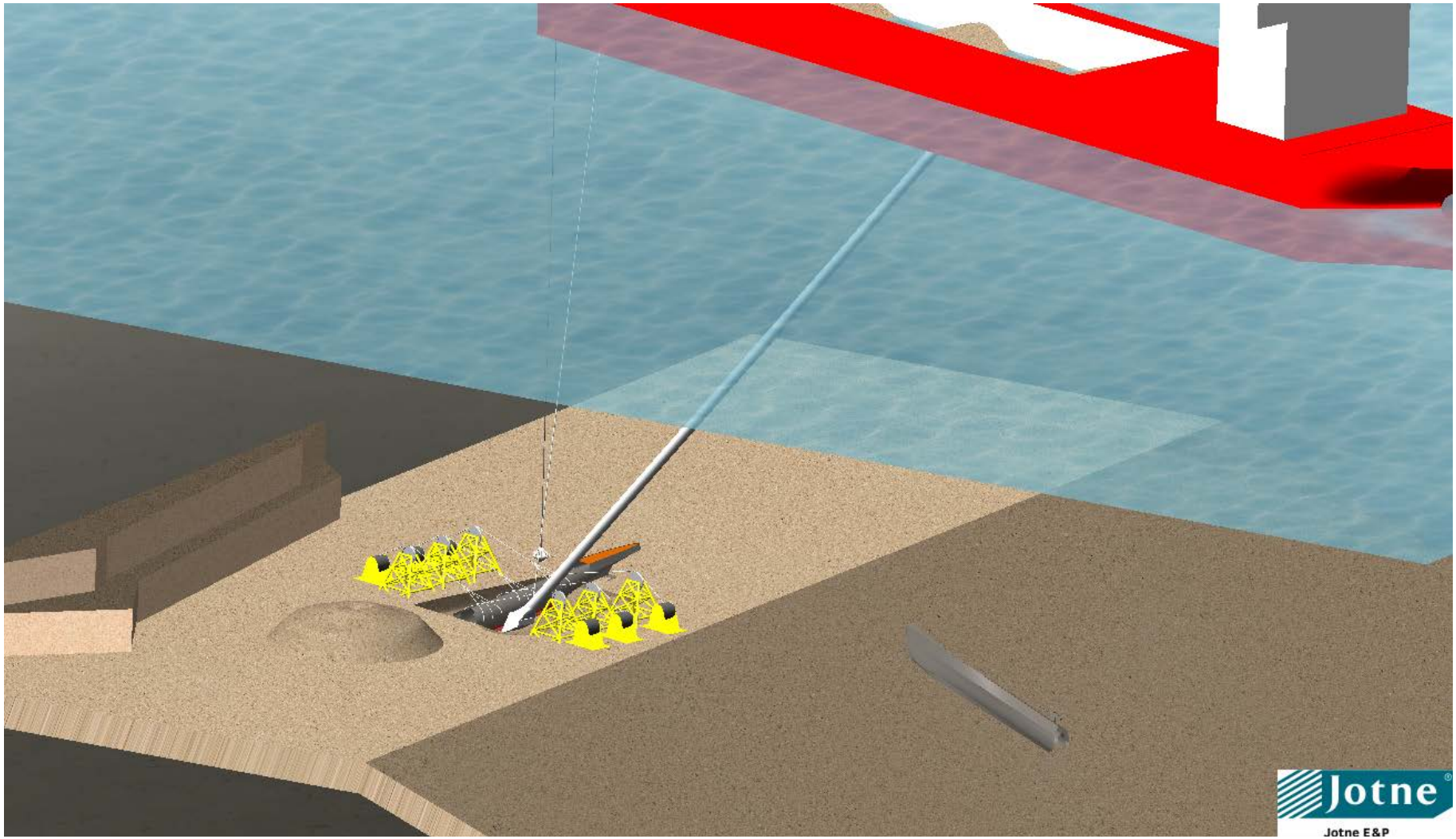
Picture Roll.1



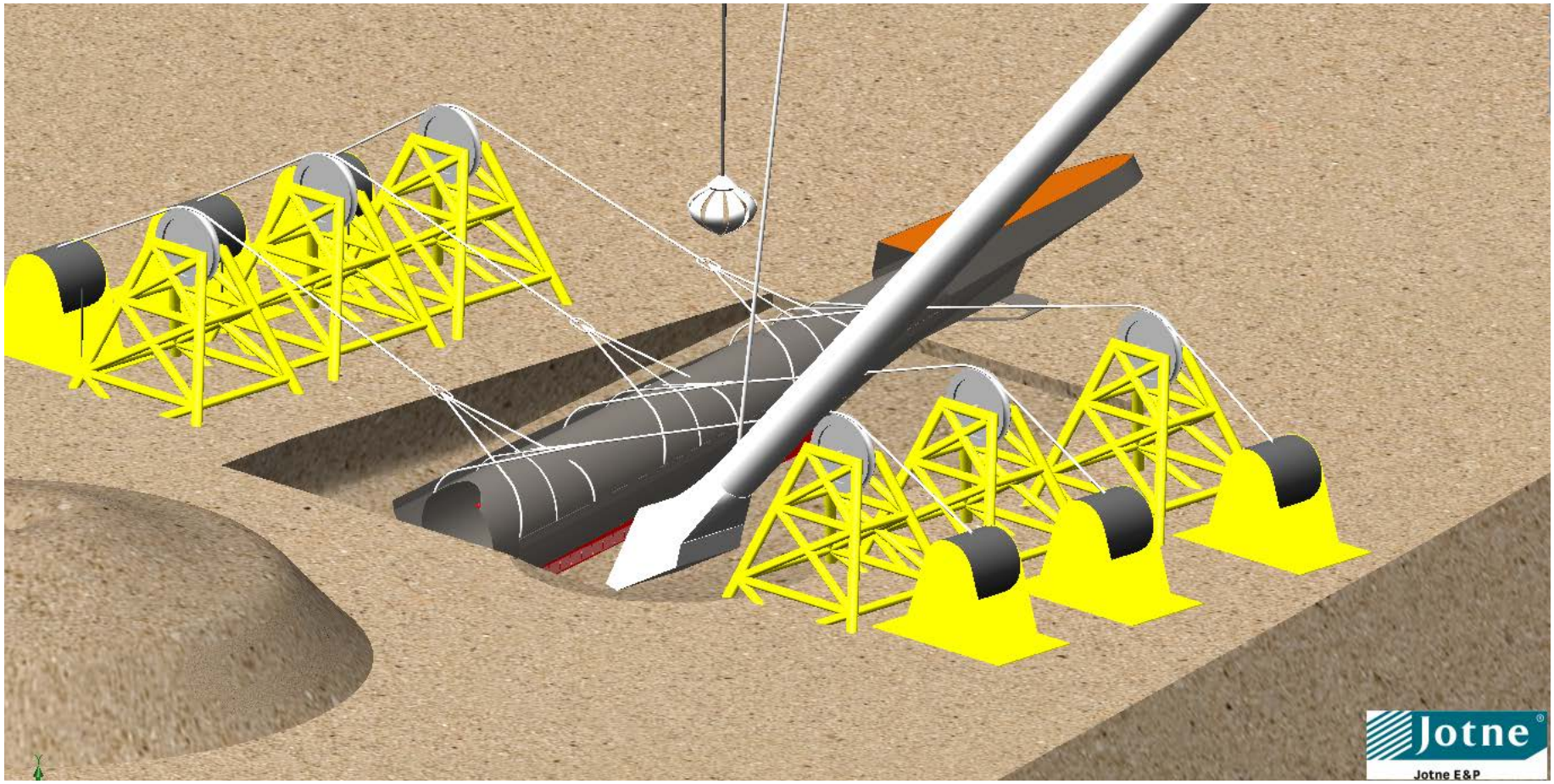
Picture Roll.2



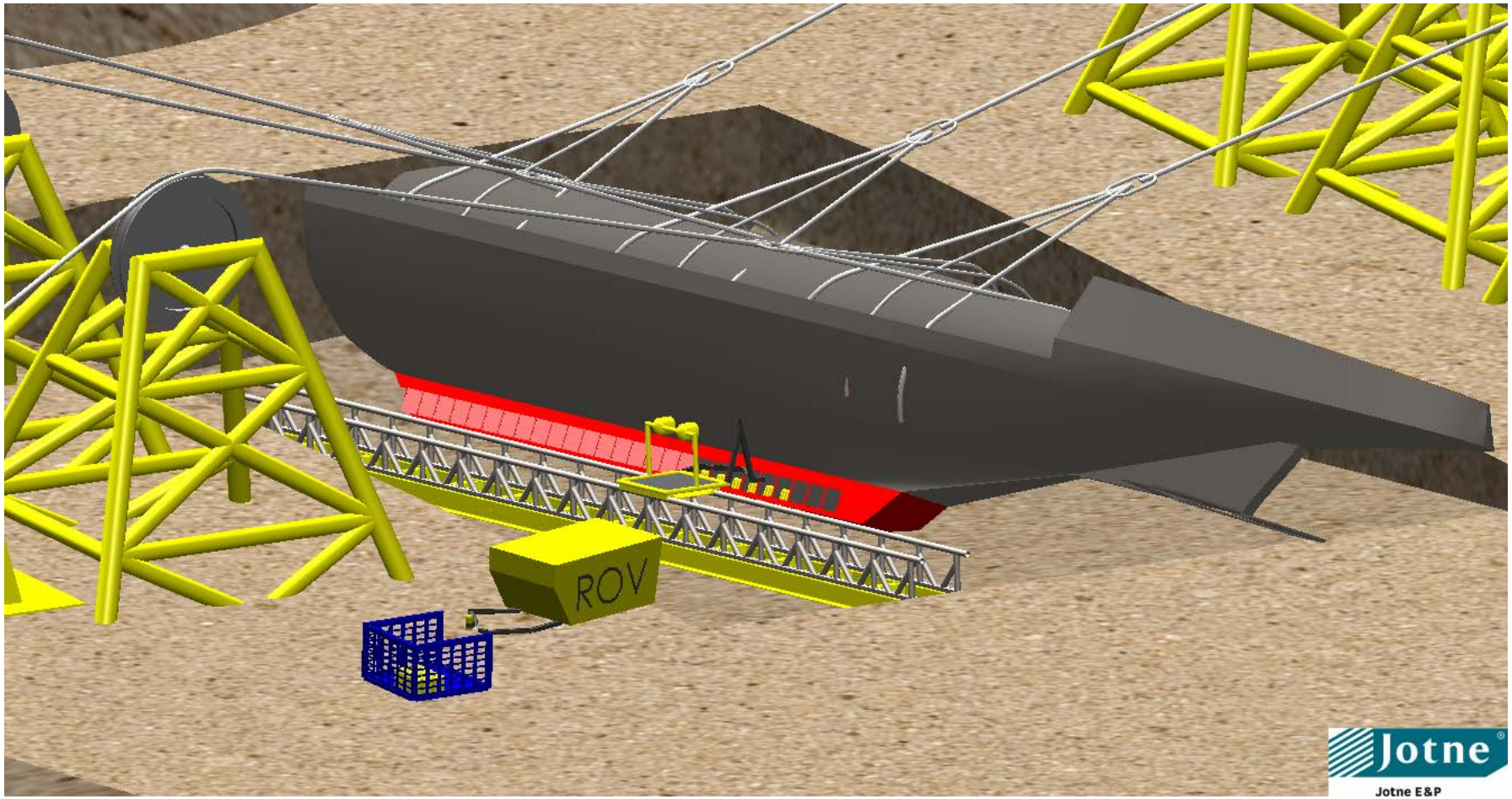
Picture Roll.3



Picture Roll.4



Picture Roll.5



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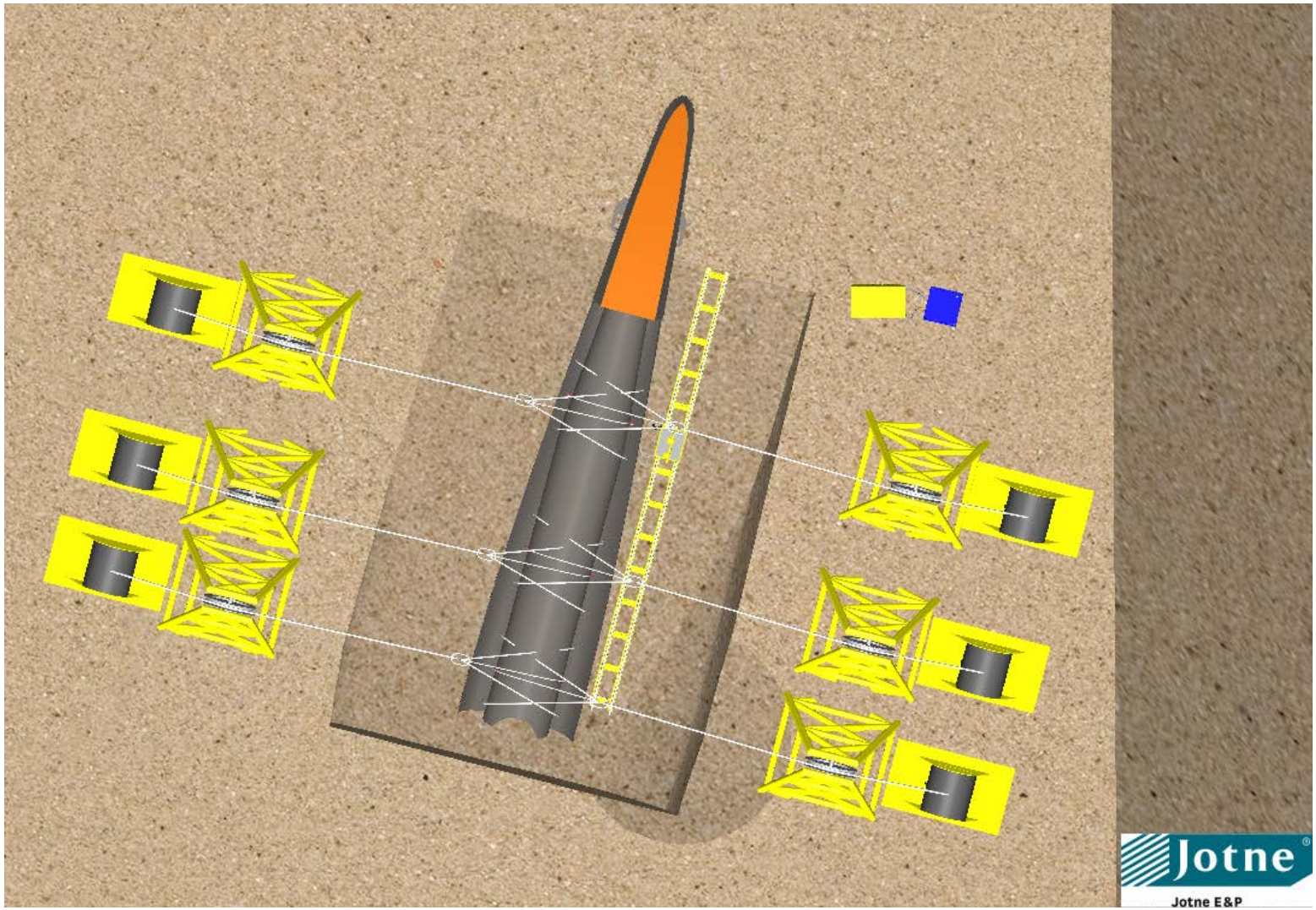
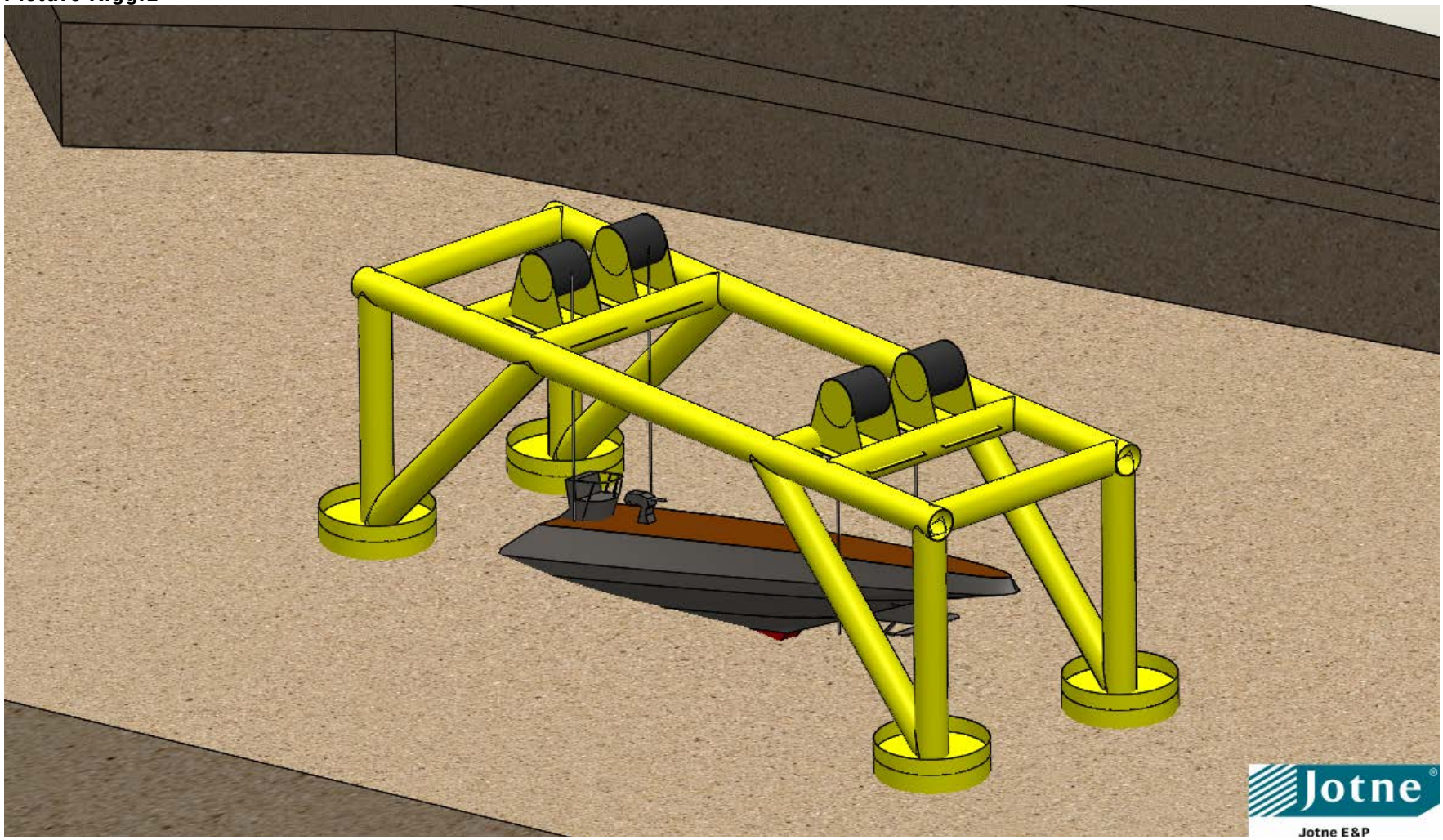
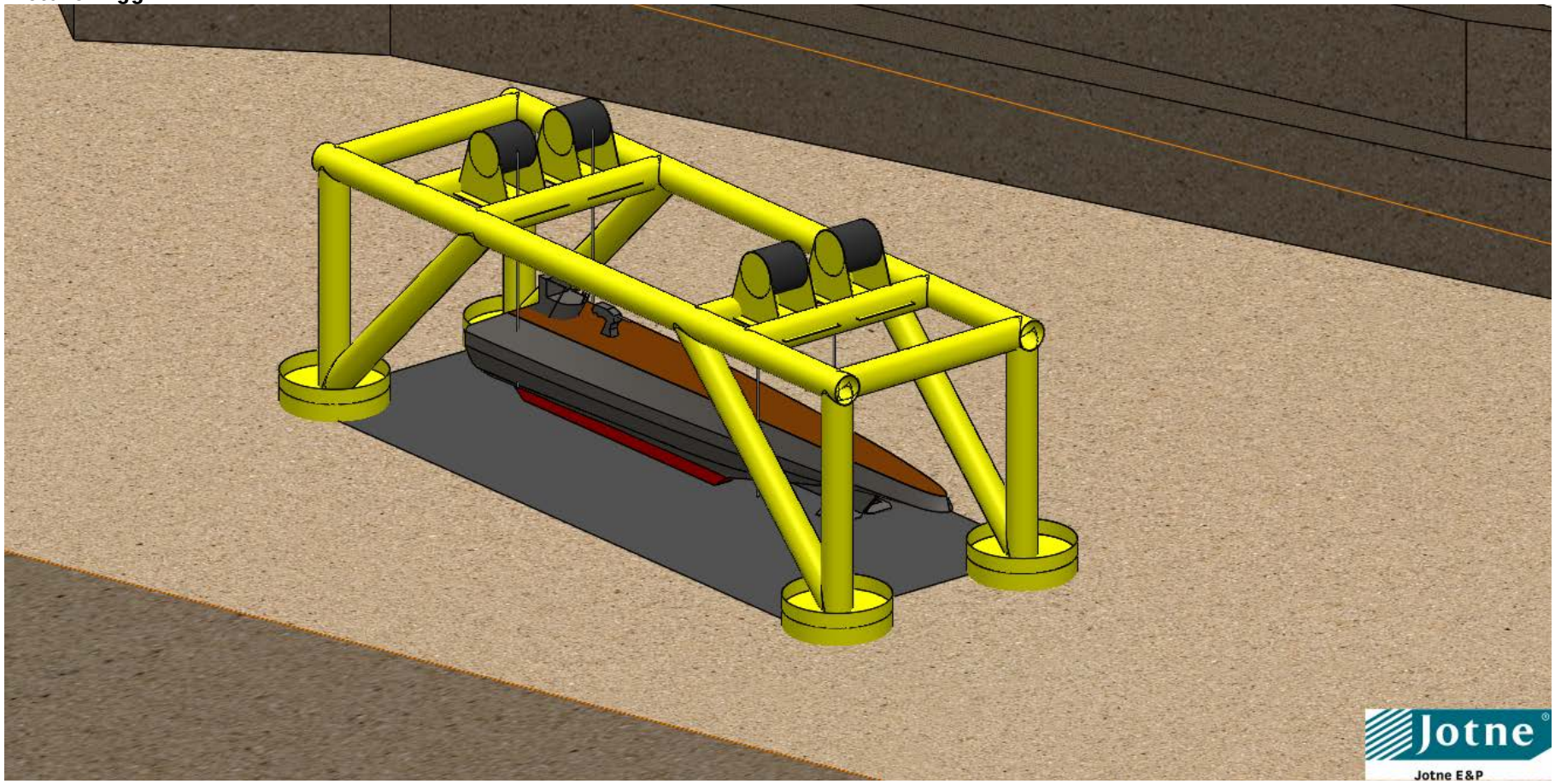


7.2 CONSEPT "RIGG"

Picture Rigg.1



Picture Rigg.4



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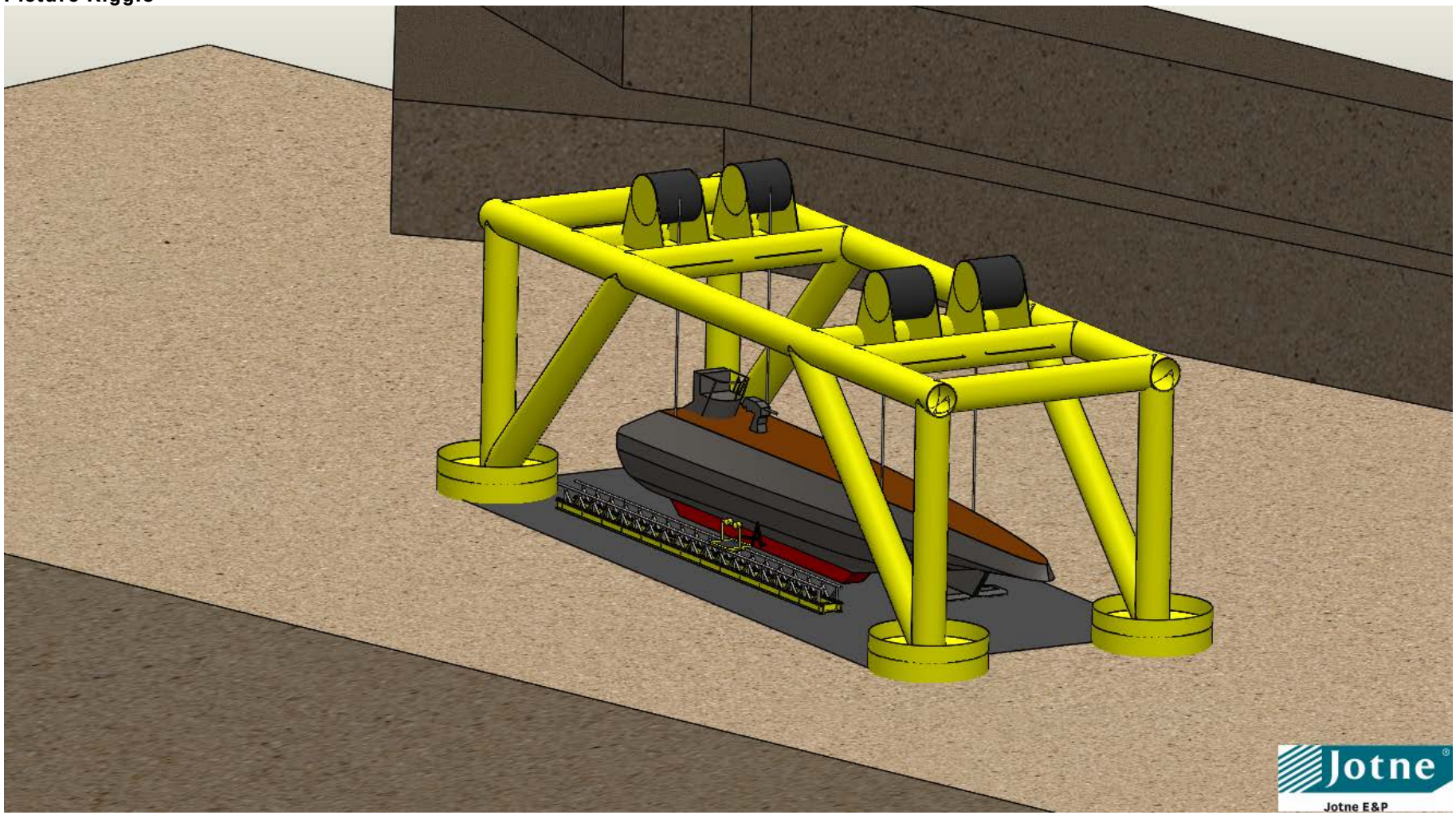
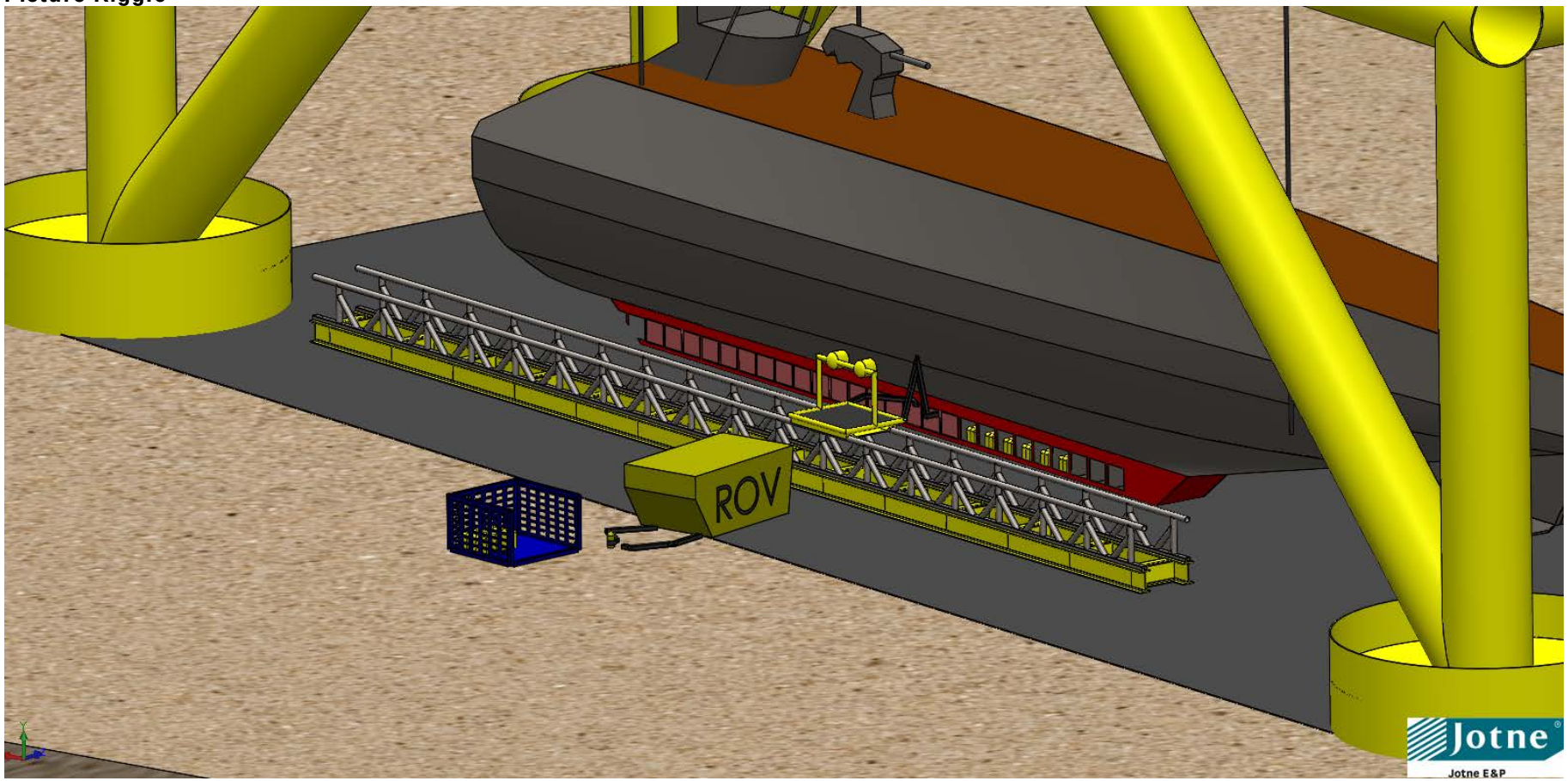
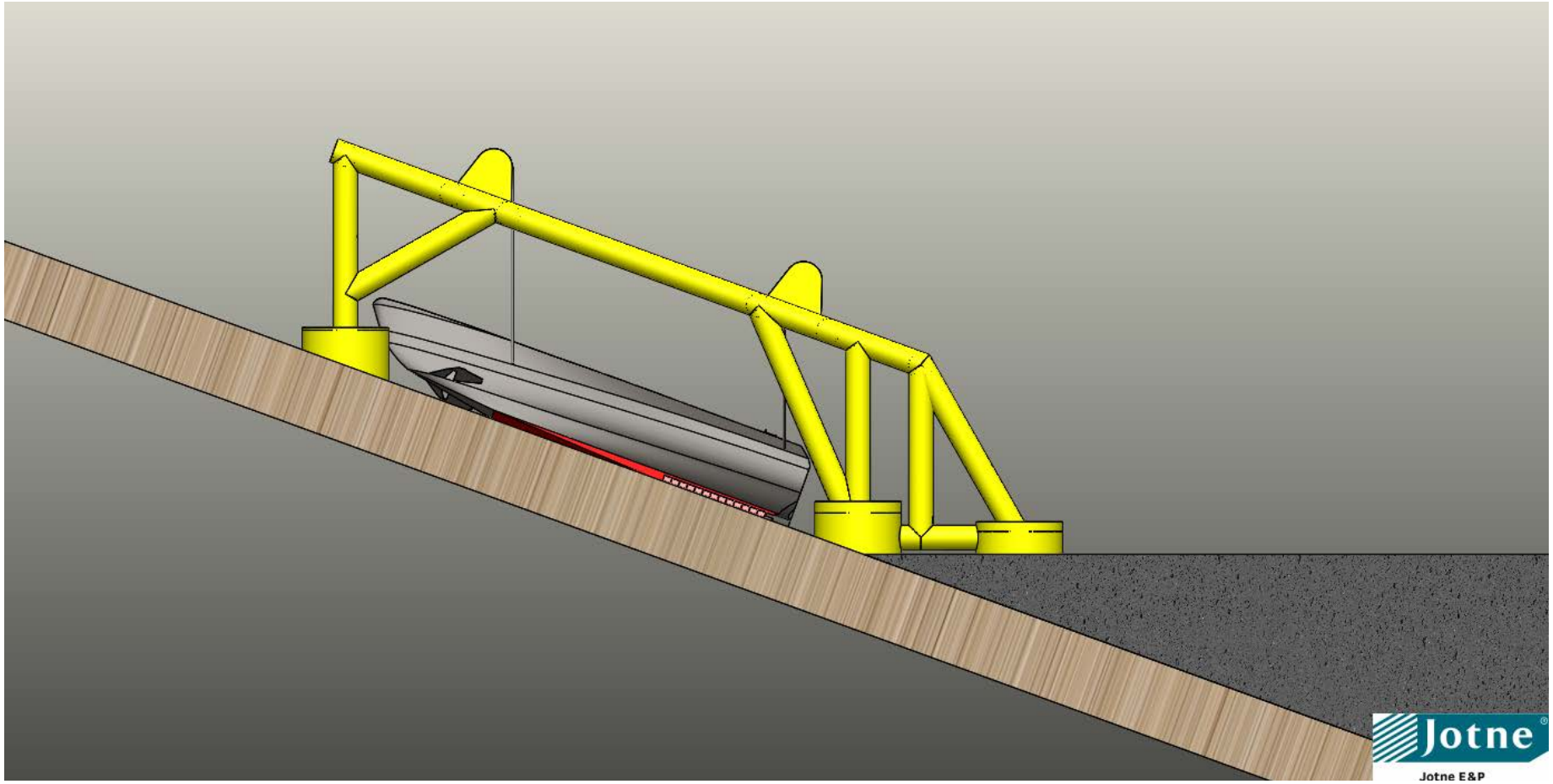


Picture Rigg.6

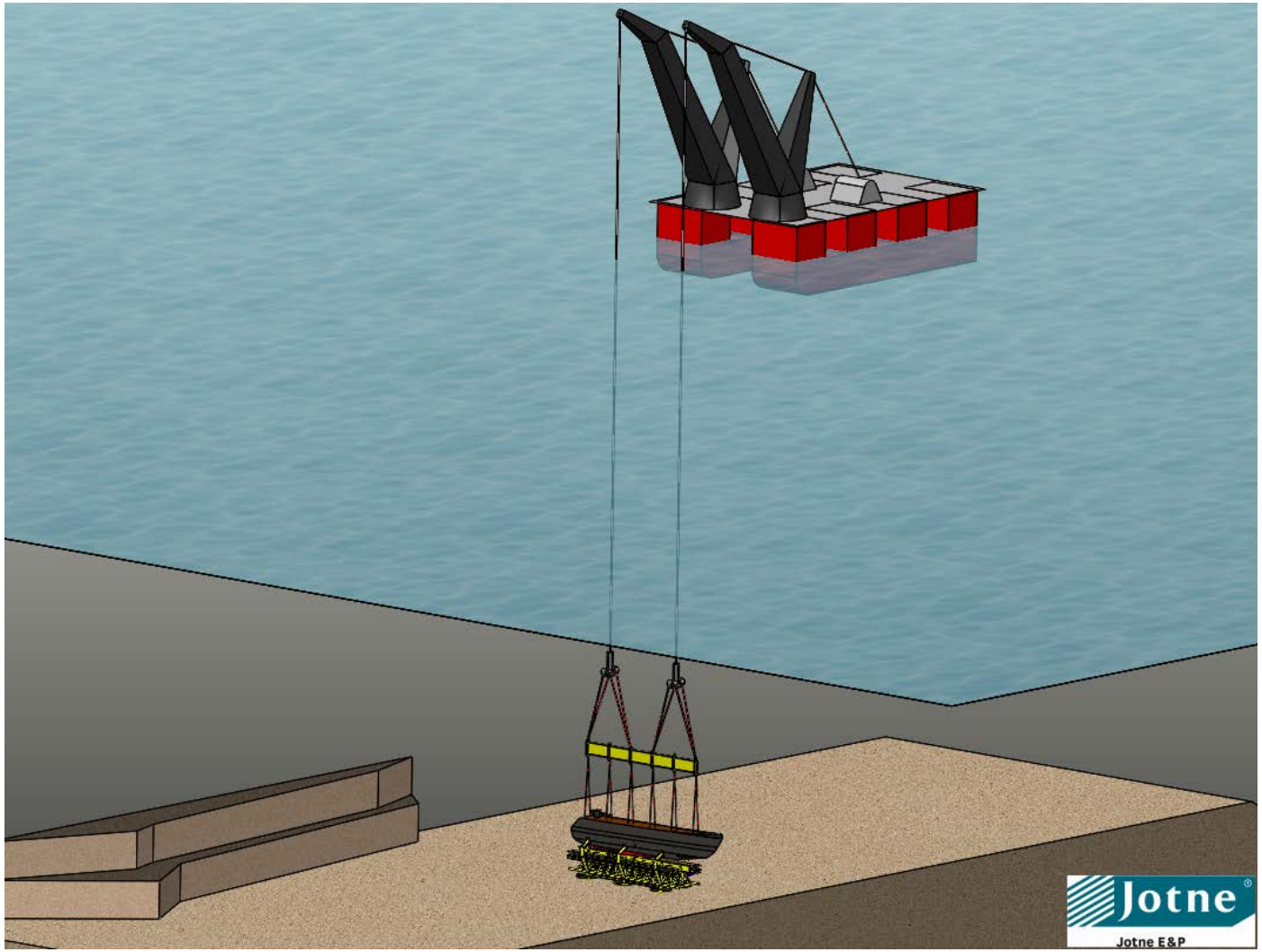


Picture RIGG.7



7.3 CONSEPT "CRIB"

Picture CRIB.12



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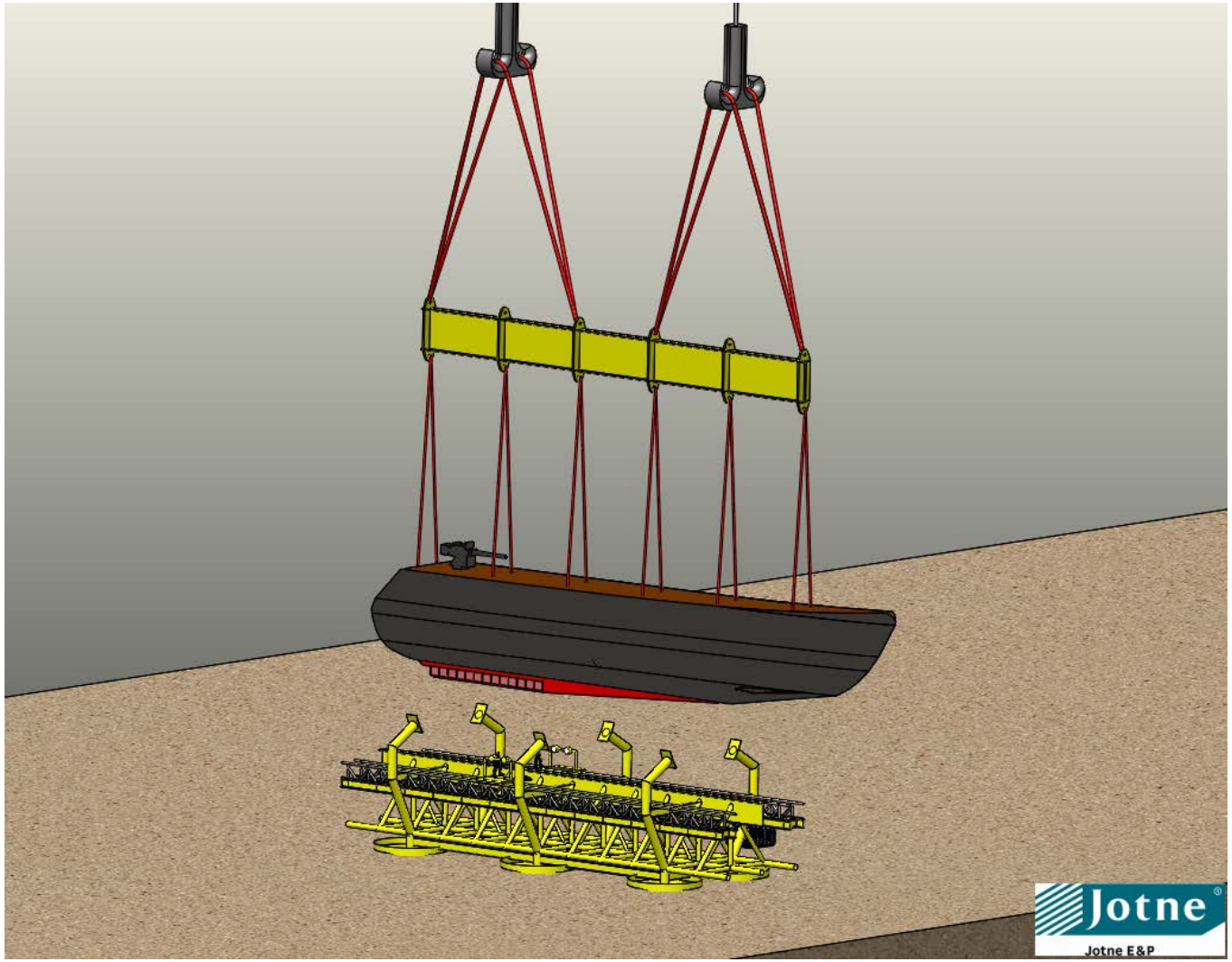

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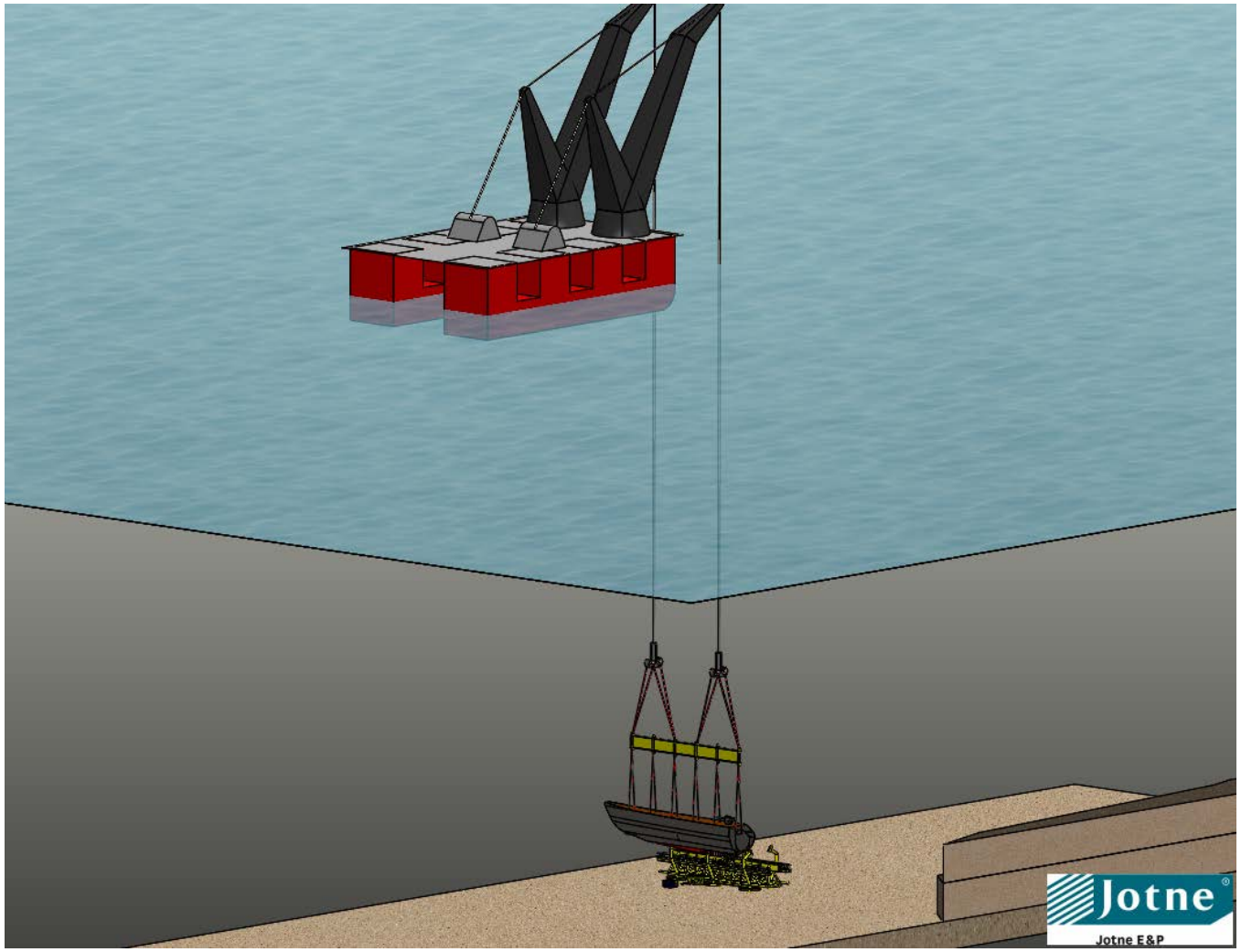
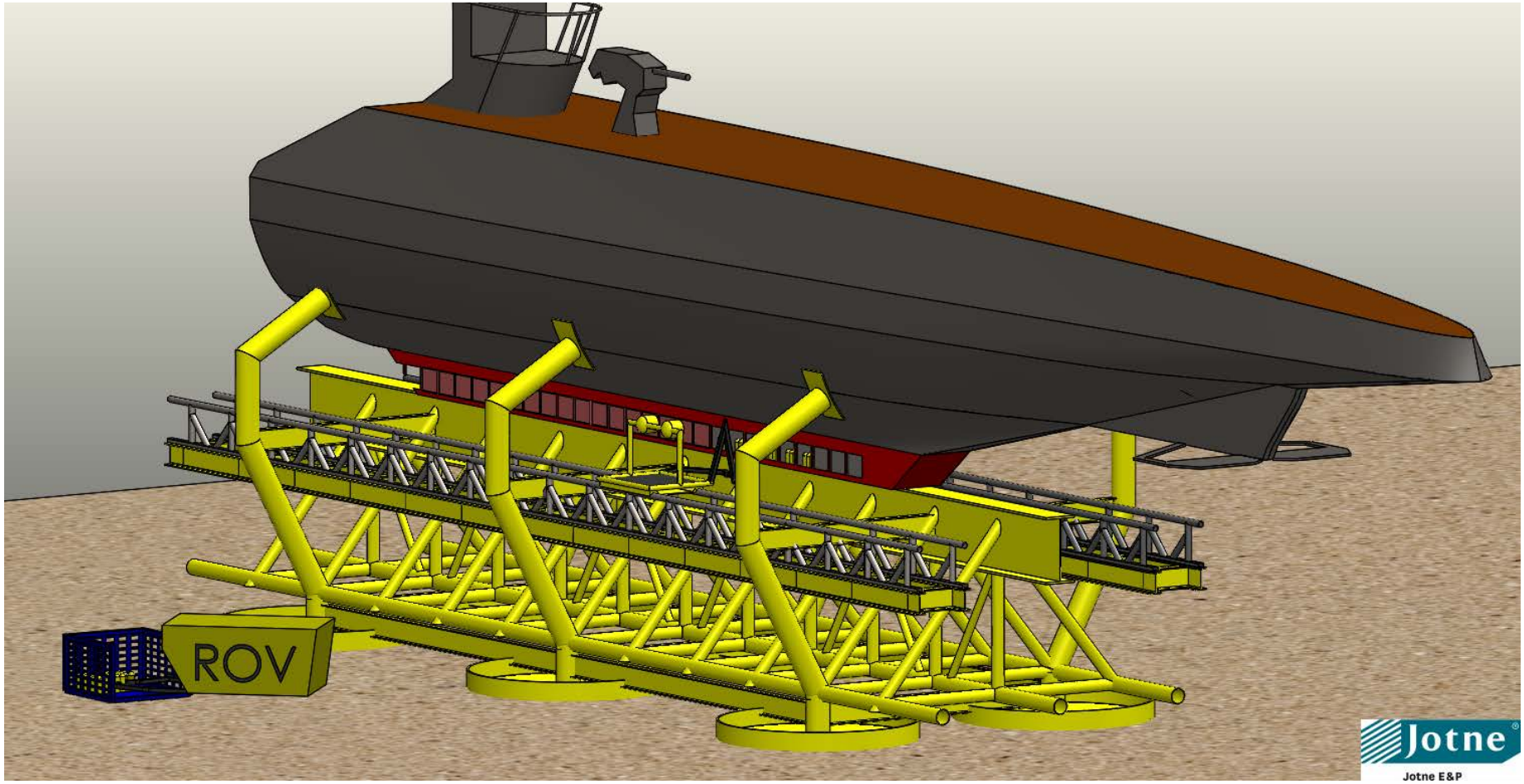


Picture CRIB.1



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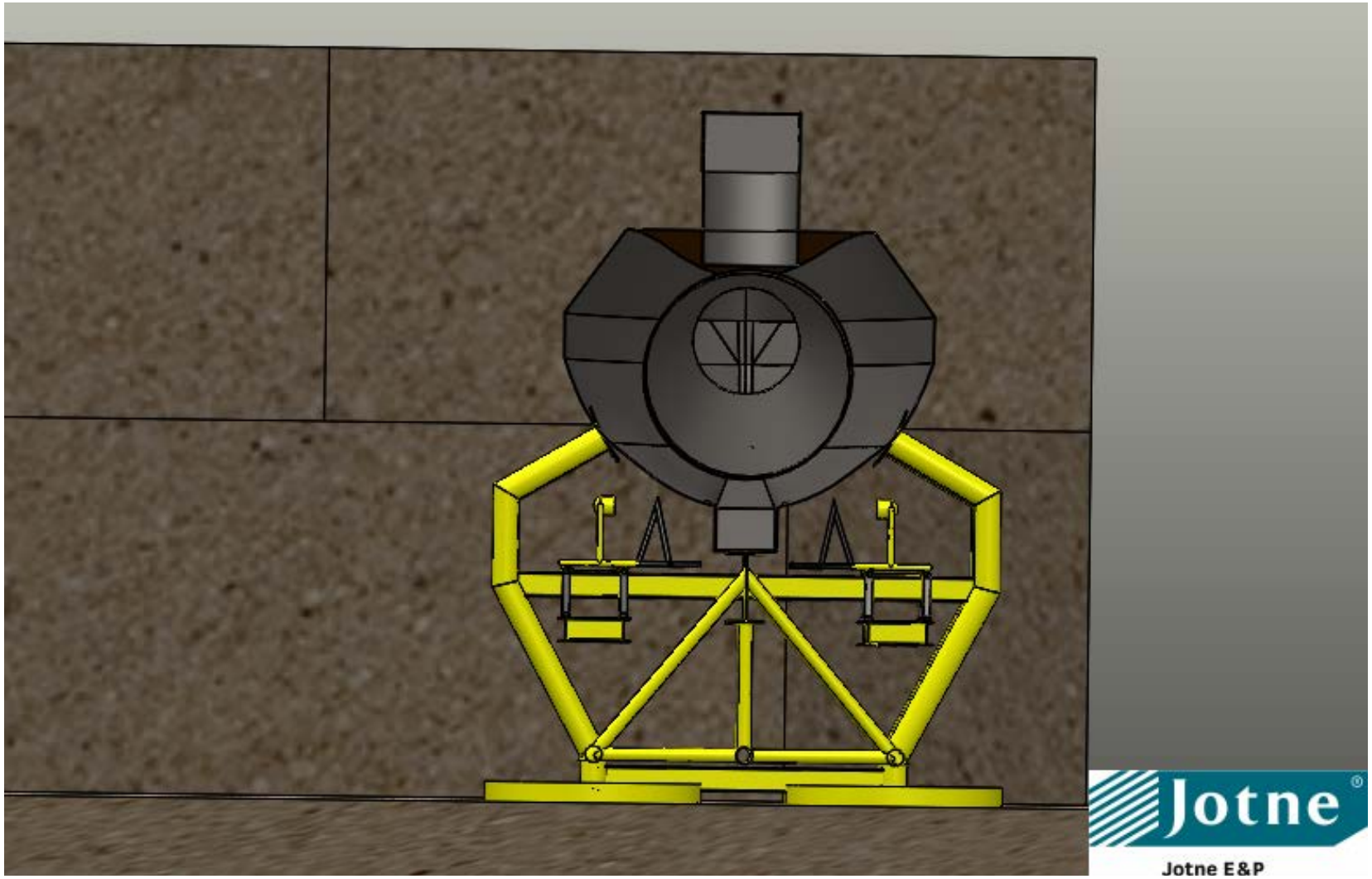

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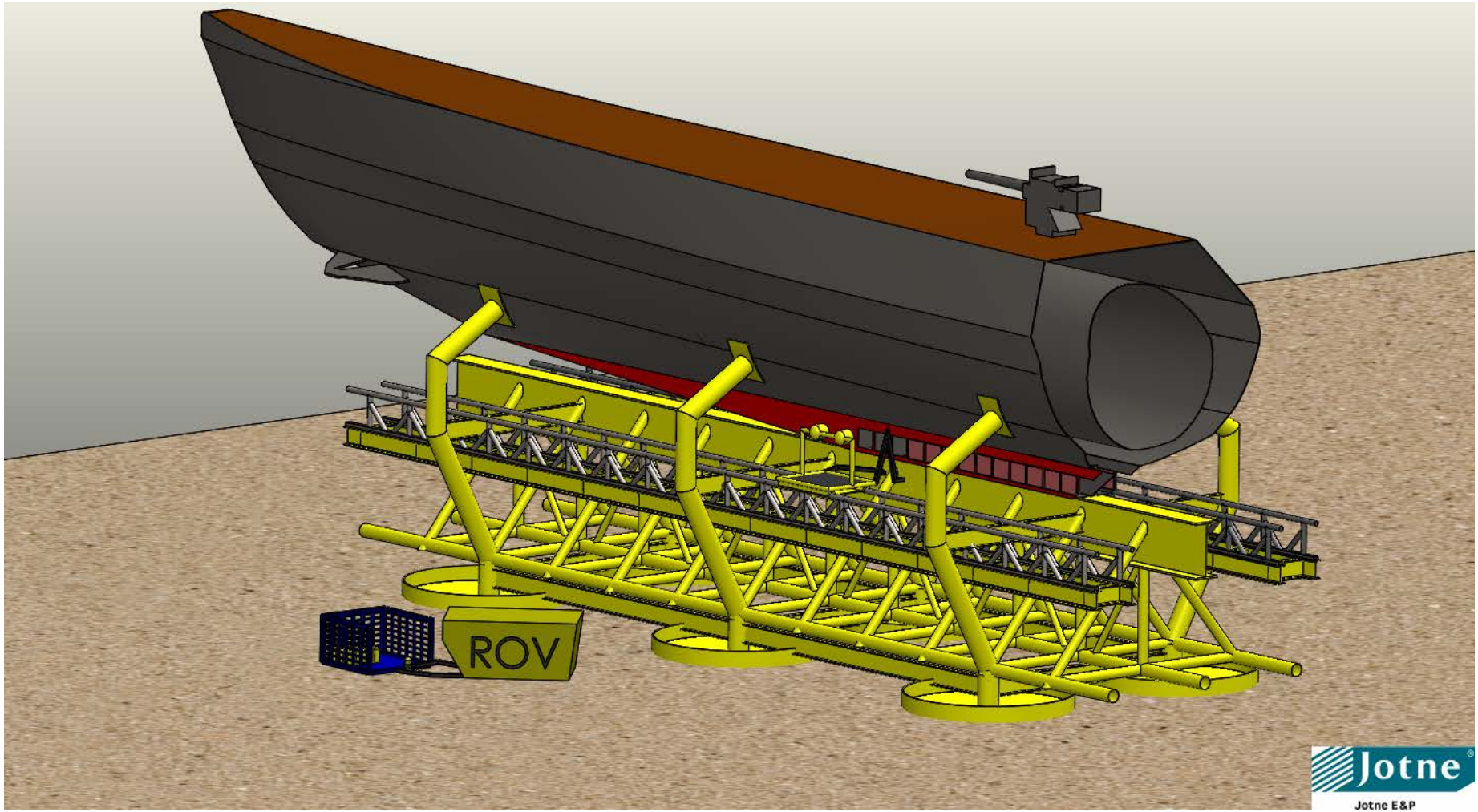

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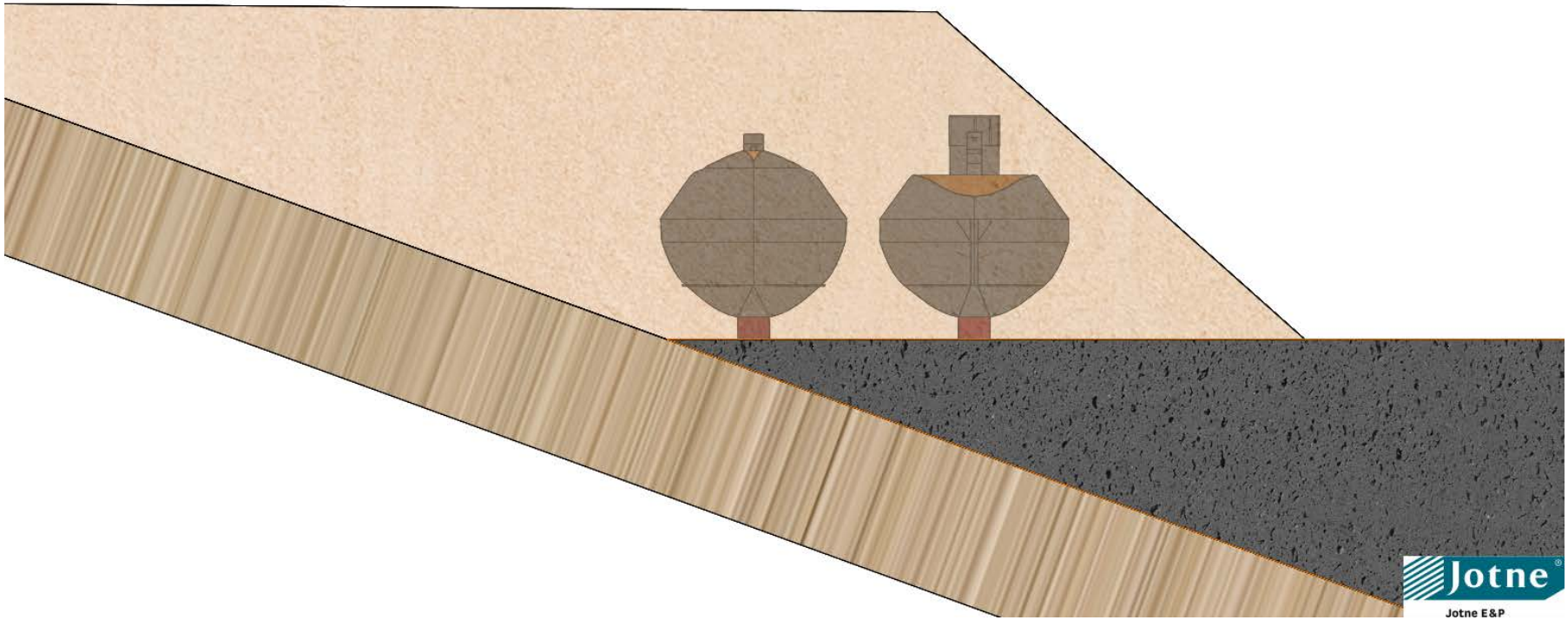

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Appendix V3.07

ENVIRONMENTAL MEASURES FOR THE WRECK OF U-864

Material Testing of Pressure Hull Specimen on U-864

DNV GL AS

Project name: Environmental measures for the wreck of U-864
Report title: Material Testing of Pressure Hull Specimen

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Project Management & Technical Services Program
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Dato: 12.5.2014

Reference to part of this report which may lead to misinterpretation is not permissible

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1 EXECUTIVE SUMMARY

The German submarine U-864 was torpedoed by the British submarine Venturer 9th of February 1945, approximately 2 nautical miles west of the Island Fedje in Hordaland. The submarine was loaded with war material, and according to historical documents approximately 67 ton of floating metallic mercury in steel canisters stored in the keel.

In 2013 DNV-GL was assigned by the Norwegian Coastal Administration to carry out a pre-project that will assess the possibility of recovering the mercury canisters from the wreck parts before capping the wreck parts and the polluted seabed-area.

As part of the scope of work, a steel sample from the pressure hull of U-864 has been examined to determine the material properties.

The steel sample taken from the pressure hull has been tested in the DNV laboratories at Høvik, Norway. To assess the properties of the material, the following tests have been performed:

- Visual inspection
- Chemical composition analysis
- Metallographic examination
- Thickness measurement
- Hardness measurement
- Mechanical testing: Tensile testing and Charpy V-notch testing at temperature

The main conclusions with respect to residual structural strength of the steel sample are:

1. The wall thickness is reduced in some places due to corrosion, so uncertainties in wall thickness should be taken into account when evaluating strength.
2. The Stress-strain curves show that the material behaves according to expectations of this type of structural steel. Somewhat lower ultimate tensile strength in the weld was revealed compared to base material. This should be taken into account in strength evaluations.

This is only a spot check of the pressure hull. It does not necessarily give a full picture of the condition of the entire hull.

2 INTRODUCTION

The German submarine U-864 was torpedoed by the British submarine Venturer 9th of February 1945, approximately 2 nautical miles west of the Island Fedje in Hordaland. U-864 was on its way from Germany via Norway to Japan. The submarine was loaded with war material, and according to historical documents approximately 67 ton of floating metallic mercury in steel canisters stored in the keel. The torpedo split the submarine into two parts. The wreck parts were discovered by the Royal Norwegian Navy at a depth of approximately 150-175 m. Several studies have revealed feasible measures for pollution abatement. The risks related to these measures have been assessed and indicate the following:

- High mercury concentrations in the soil, especially around the wreck parts.
- The bow section is inclining and has a high risk of sliding downhill. (Geotechnical unstable)
- Torpedoes and ammunition in general.
- Oil in the wreck.
- The condition of the two wreck parts.
- The condition of the mercury canisters.

In 2013 DNV-GL was assigned by the Norwegian Coastal Administration to carry out a pre-project that will assess the possibility of recovering the mercury canisters from the wreck parts before capping the wreck parts and the polluted seabed-area. As part of the assignment, competent subsea companies have been invited to discuss feasible solutions and cost pertaining to the proposed solutions.

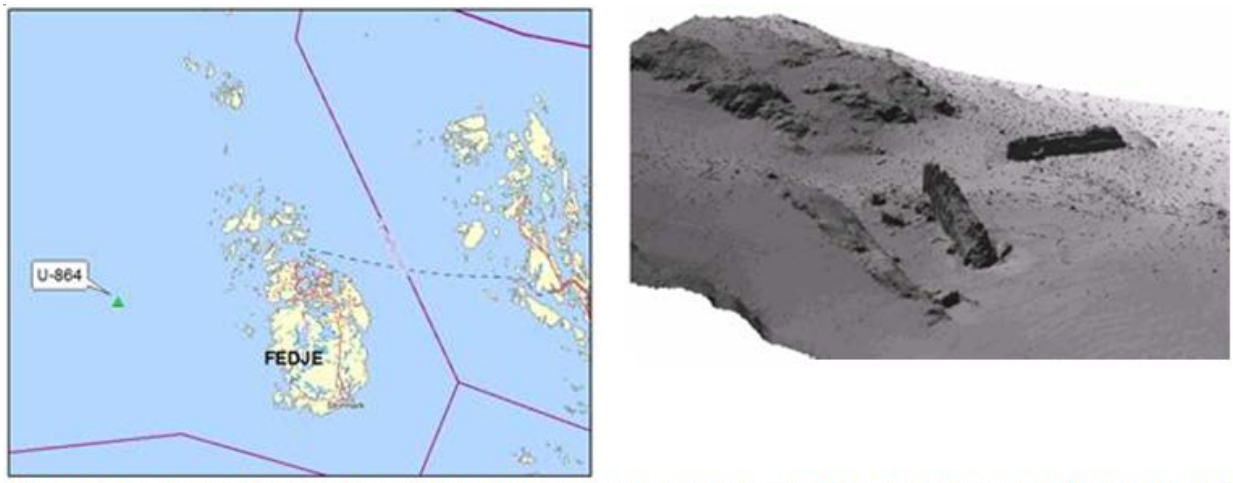

Figure 1.Loction of the wreck outside Fedje (left) and sonar image of bow and aft part of the wreck (right)

3 TESTING

3.1 Visual Examination

The sample sent for examination was rust colored with a scaling at one of the sides to the received sample. Pits and wall thickness reduction could be observed on the sample, in addition to some preferential corrosion in the weld/HAZ area. Images of the sample as received are shown in Figure 1 and Figure 2. Some deeper pits with a diameter up to ø2 mm at the surface were observed in some areas. Pits were observed on both sides of the sample, the preferential corrosion attack (along weld) was only observed on one side (Side A).

In order to better reveal if pits were present on the surface to the sample (Side B), the sample was ground with an angle grinder, image is shown in Figure 3.

Figure 1: Overview image of received sample in as-received condition (DNV reference: Side A). White dashed line is section for metallographic examination, chemical composition and thickness measurements. White dashed box is macro section.

Figure 2: Opposite side as shown in Fig.1 of sample as-received (DNV reference: Side B)

Figure 3: Sample Side B after grinding of the scaling

3.2 Chemical Composition Analysis

A spectrographic analysis was carried out for the base material in addition the chemical composition of the weld material was analysed. The chemical composition of the material in question is given in Table 1.

Table 1: Chemical composition analysis results of examined sample and weld material

Element	Base material	Weld material
C	0.17	0.11
Si	0.52	0.25
Mn	1.19	0.61
P	0.021	0.024
S	0.026	0.021
Cr	0.096	0.033
Ni	0.037	0.063
Mo	0.007	0.004
Al	0.013	0.003
Cu	0.058	0.16
Co	0.010	0.016
Ti	0.003	0.013
Nb	<0.001	<0.001
V	0.002	0.002
B	<0.0001	0.0002
W	<0.001	<0.001
Pb	0.001	<0.001
Sn	0.005	0.009
As	0.006	0.007
N	0.003	0.006
Fe	97.7	98.5

The weld material has a lower Carbon, Silicon and Manganese content compared to base material which could give a lower strength.

3.3 Metallographic Examination

The samples were ground, polished and etched according to standard metallographic procedure. The microstructure consisted of a fine grained ferritic pearlitic microstructure. The material is most likely in as-normalised condition. Some intermetallic inclusions were observed e.g. MnS and oxides, as expected. Representative microstructures for the base material from both sides of the weld are shown in Figure 4 and Figure 5. The rolling direction appears to be parallel to the weld.

A macro section was taken out as shown in Figure 6, the macro section showed that the weld is of a double sided full penetration butt weld. The preferential corrosion attack observed close to the weld is located in the fusion line/HAZ.

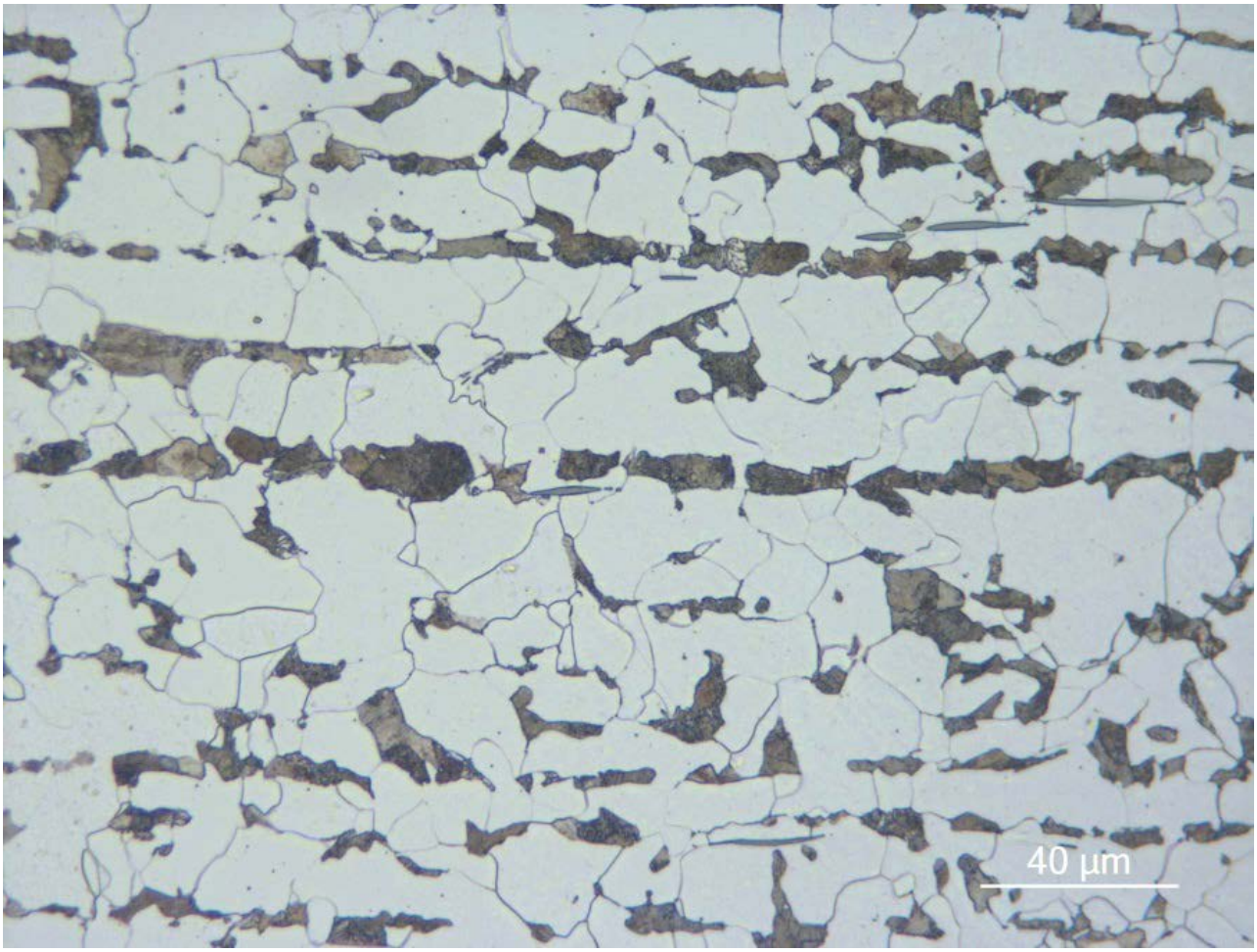

Figure 4: Microstructure longitudinal direction, etched in 2% Nital

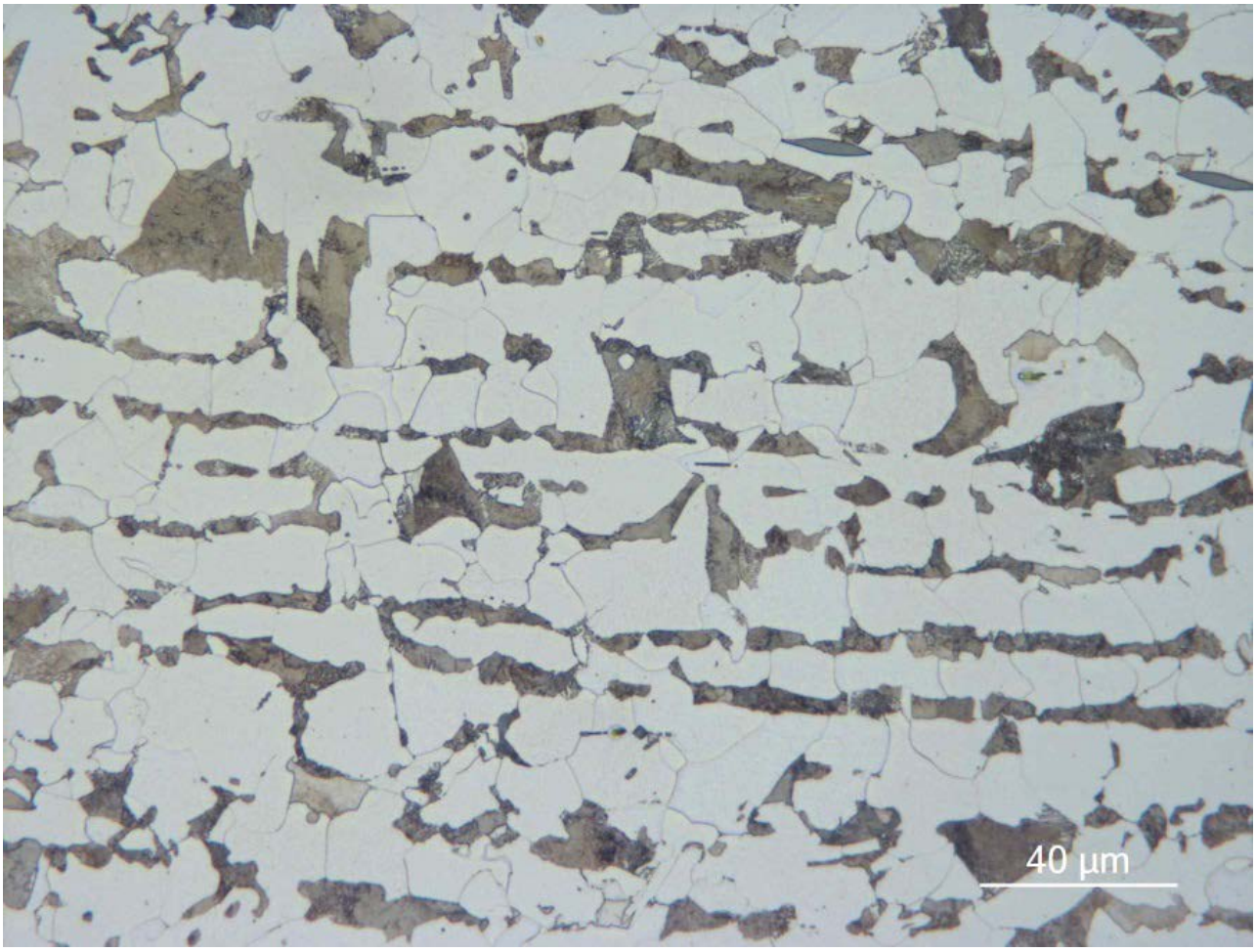

Figure 5: Microstructure transverse direction, etched in 2 % Nital

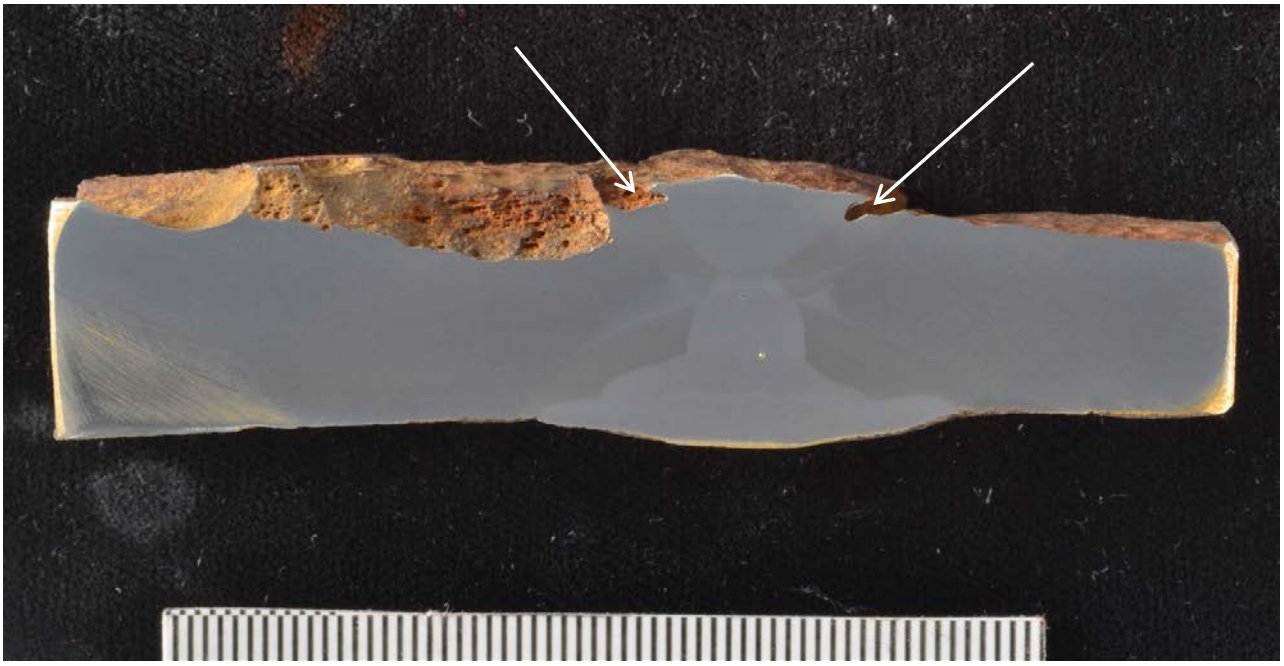

Figure 6: Macro section through the weld, taken as shown in Figure 1 (arrows indicate preferential corrosion attack close to weld)

3.4 Thickness Measurements

Thickness measurements were carried out in two different sections where thickness appeared visually to have been reduced the most. The sections were taken out as shown in Figure 1. The thickness was measured with a calliper and the thinnest part on the base material section had a thickness of 11.4 mm and the thickest part was measured to 16.3 mm, see figure Figure 7. On the macro section taken out in the weld area the thinnest part (pit) was measured to 10.6 mm and the thickest part 17.6 mm (Weld). Image of measurements on macro section is shown in Figure 8.

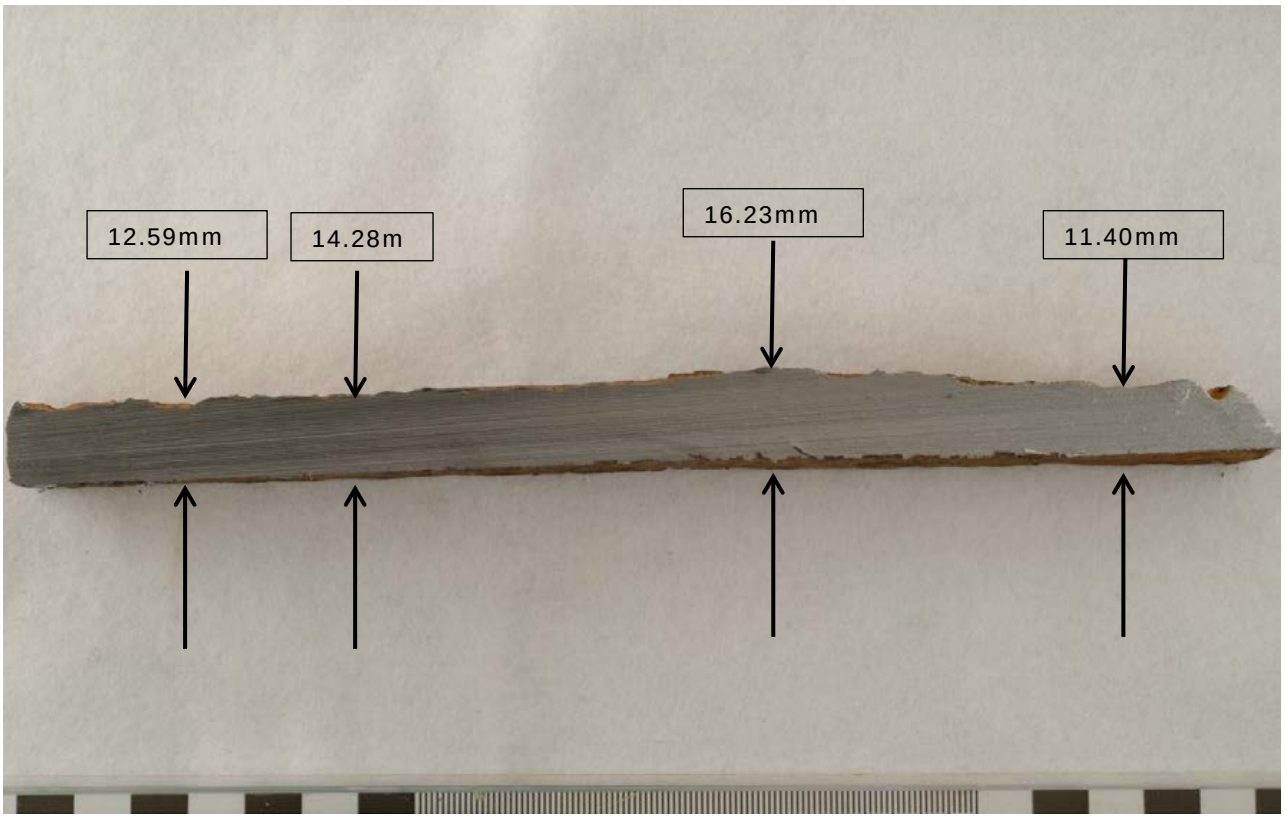

Figure 7: Thickness measurements on section cut as shown in Figure 1.

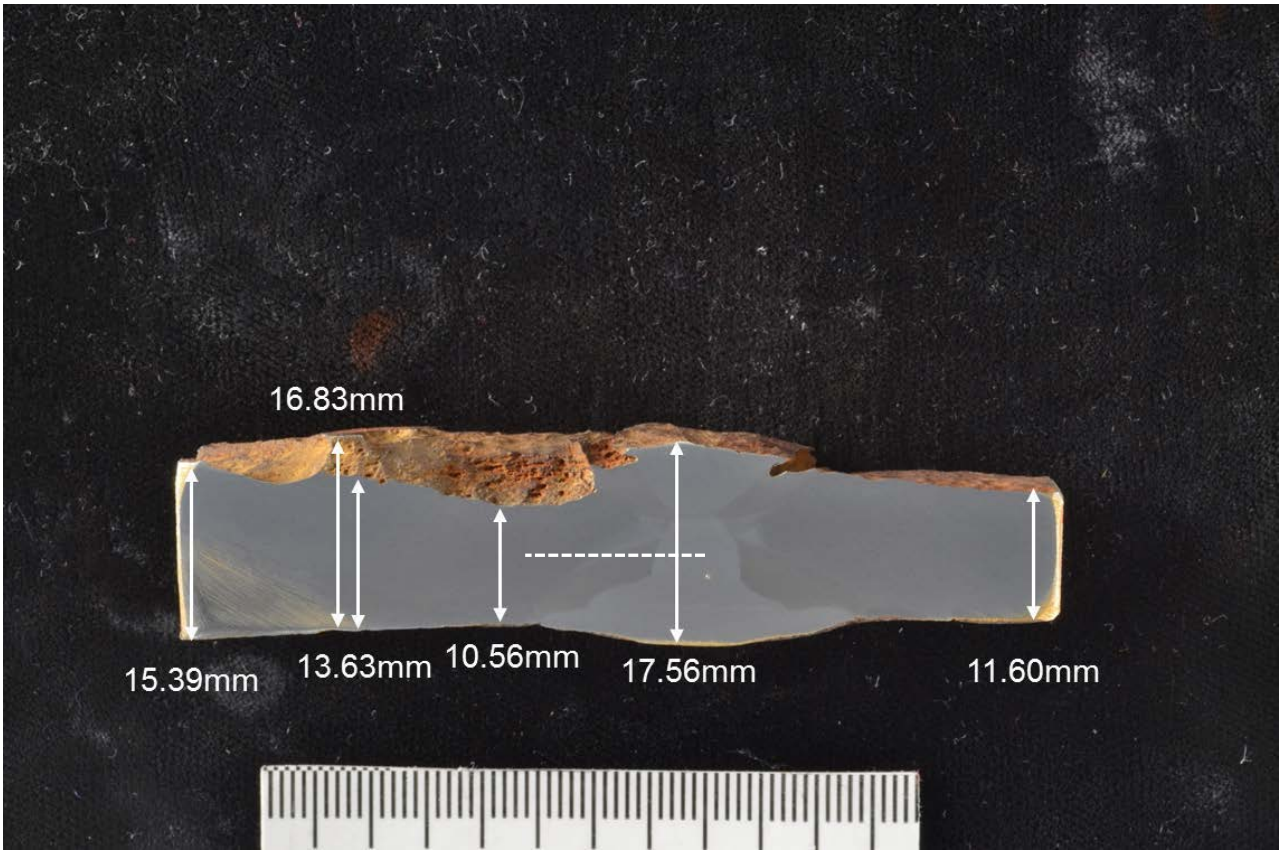

Figure 8: Thickness measurements on macro section Figure 1 (white line indicates position to hardness measurements)

3.5 Hardness Measurements

Hardness measurements were carried out according to ISO 6507 on the macro section with a stationary Vickers hardness indenter with a load of 10kg, HV10. The measurements are shown in Table 2. The location of the hardness measurements is shown in Figure 8.

Table 2: Hardness measurment on macro section

Location	Vickers Hardness (HV10) measured value	Hardness (avg. HV10)
Weld metal	163-165-165	164
Base Material	186-186-186	186
Fusion Line	174	
FL+1 mm	207	
FL+2 mm	205	
FL+3 mm	194	
FL+4 mm	187	
FL+5 mm	185	

The weld material has somewhat lower hardness compared to the base material.

3.6 Mechanical testing

The samples for mechanical testing were taken out as shown in Figure 9.

Figure 9: Samples taken for mechanical testing.

3.6.1 Tensile Testing

Three tensile tests were conducted on the plate; one all-weld sample along the weld, one in the base material in the longitudinal direction (parallel to the weld) and one in the base material in the transverse direction (perpendicular to the weld). The testing was performed in accordance with the test standard: ISO 6892. See Figure 9 for a schematic of where the tensile samples were extracted. The results are presented in Table 3.

Table 3: Sample sizes

Sample location/orientation	Diameter[mm]	Length [mm]
Longitudinal	8.53	45
Transversal	8.51	45
Weld	6.45	20

Table 4: Mechanical properties.

Material	Yield strength [MPa]	Ultimate Tensile Strength [MPa]	Elongation [%]
Base material – longitudinal direction	378/367*	549	35
Base material – Transverse direction	371/354*	552	34.5
Weld	419	504	24

*** Due to the yield discontinuity in these curves, both the peak and plateau values are reported**

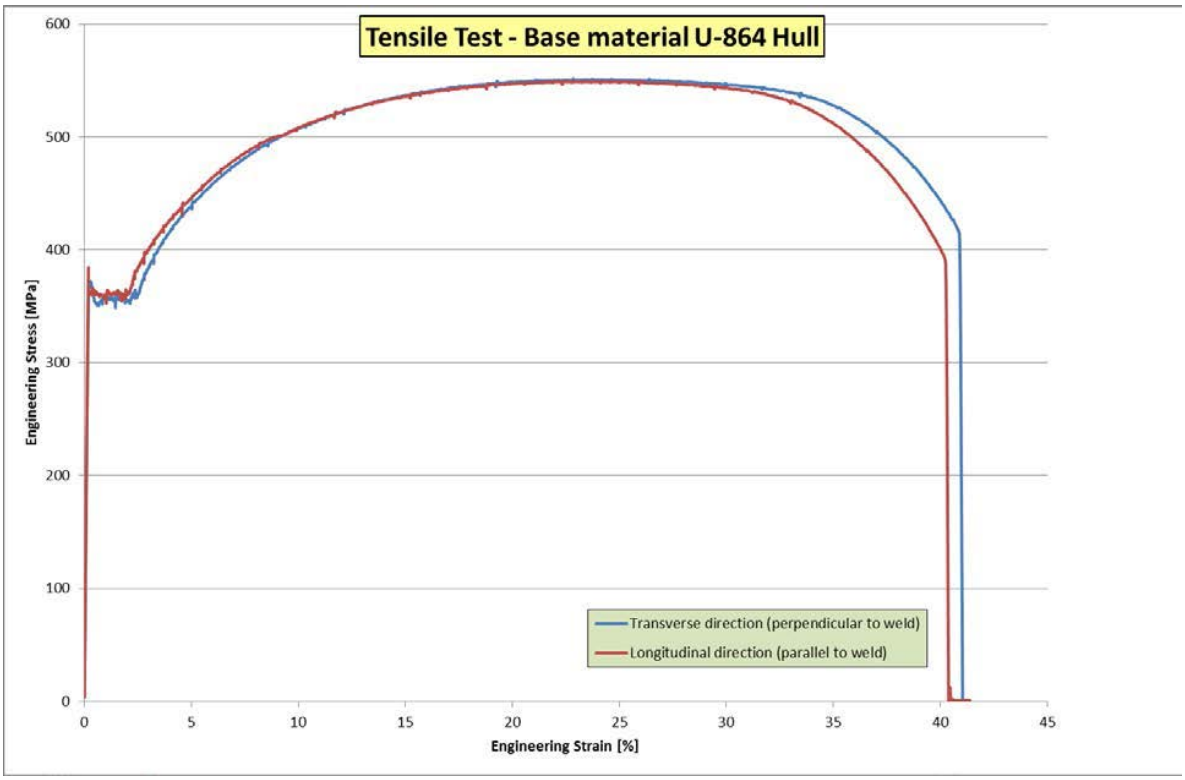

Figure 10: Load-displacement curves for base material.

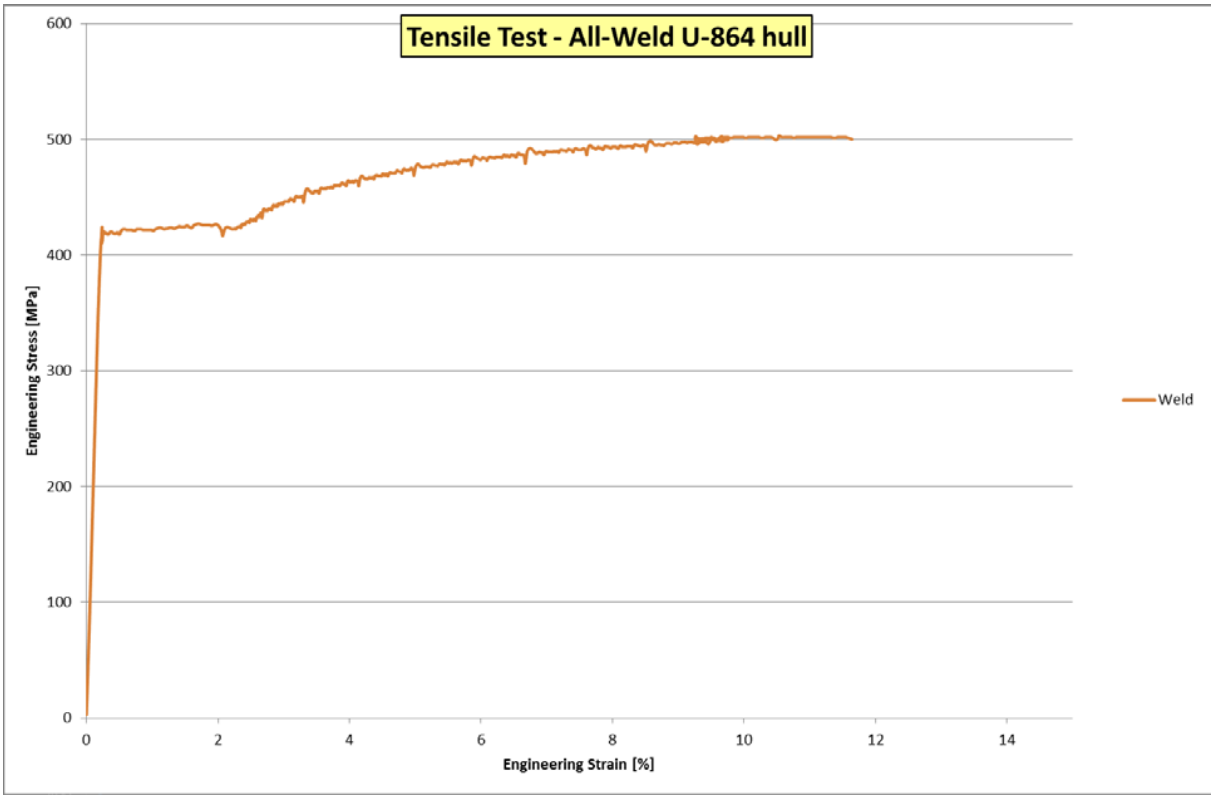

Figure 11: Load-displacement curve for weld material

3.6.2 Charpy V-notch Testing

Charpy V-notch testing was conducted on 3 samples from the location indicated in Figure 9. The testing was performed in accordance with the test standard: ISO 148.

Dimension of test specimens: 10 x10 mm
Sampling : Test specimens were sampled approx. 1 mm below surface, and with the notch perpendicular to the surface.

The results can be seen below in Table 4.

Sample	Test temp. [°C]	Impact energy, KV 300, [J]			
		Single values [J]			Average[J]
Base material	4	39	38	42	40

4 CONCLUSIONS

The findings reveal two important factors:

1. The wall thickness is reduced in some places due to corrosion, so uncertainties in wall thickness should be taken into account when evaluating strength.
2. The Stress-strain curves show that the material behaves according to expectations of this type of structural steel. Somewhat lower ultimate tensile strength in the weld was revealed compared to base material. This should be taken into account in strength evaluations.

This is only a spot check of the pressure hull. It does not necessarily give a full picture of the condition of the entire hull.

5 REFERENCES

/1/ Preliminary specimen test report: EVALUATION OF FINDINGS FROM U-864 SURVEY (2013)

About DNV GL

Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter and greener.

Appendix V3.08

U-864 SUPPLEMENTARY REPORT

Material Testing of Steel Plate from Side of Keel Box on U-864

DNV GL AS

Project name: Environmental measures for the wreck of U-864
Report title: Material Testing of Pressure Hull Specimen

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Dato: 12.5.2014

Reference to part of this report which may lead to misinterpretation is not permissible

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1 EXECUTIVE SUMMARY

The German submarine U-864 was torpedoed by the British submarine Venturer 9th of February 1945, approximately 2 nautical miles west of the Island Fedje in Hordaland. The submarine was loaded with war material, and according to historical documents approximately 67 ton of floating metallic mercury in steel canisters stored in the keel.

In 2013 DNV-GL was assigned by the Norwegian Coastal Administration to carry out a pre-project that will assess the possibility of recovering the mercury canisters from the wreck parts before capping the wreck parts and the polluted seabed-area.

As part of this task, a steel sample from the keel side plate of U-864 has been taken, in order to determine the material properties.

The steel sample taken has been tested in the DNV laboratories at Høvik, Norway. To assess the properties of the material, the following tests have been performed:

- Visual inspection
- Chemical composition analysis
- Metallographic examination
- Thickness measurement
- Hardness measurement
- Mechanical testing

The main conclusions are:

- The chemical composition is as expected for low-carbon steel plate. The sulphur level is somewhat high, which is shown in the microstructure as a relatively high amount of MnS inclusions. The microstructure is otherwise normal for hot rolled plate.
- The impact testing gave an average of 38.5 J at 0 °C, which is above what is considered brittle.
- The tensile strength is also as expected for this type of material, with a relatively low tensile strength of 440 MPa and good ductility. This strength level/hardness corresponds to a S235 (EN10025) type of steel, or grade NV B.
- Due to little corrosion in the plate, the reduction in plate thickness is minimal.
- When cutting this steel plate, no special considerations should be necessary. Equipment for cutting soft carbon steel should suffice.

2 INTRODUCTION

The German submarine U-864 was torpedoed by the British submarine Venturer 9th of February 1945, approximately 2 nautical miles west of the Island Fedje in Hordaland. U-864 was on its way from Germany via Norway to Japan. The submarine was loaded with war material, and according to historical documents approximately 67 ton of floating metallic mercury in steel canisters stored in the keel. The torpedo split the submarine into two parts. The wreck parts were discovered by the Royal Norwegian Navy at a depth of approximately 150-175 m. Several studies have revealed feasible measures for pollution abatement. The risks related to these measures have been assessed and indicate the following:

- High mercury concentrations in the soil, especially around the wreck parts.
- The bow section is inclining and has a high risk of sliding downhill. (Geotechnical unstable)
- Torpedoes and ammunition in general.
- Oil in the wreck.
- The condition of the two wreck parts.
- The condition of the mercury canisters.

In 2013 DNV-GL was assigned by the Norwegian Coastal Administration to carry out a pre-project that will assess the possibility of recovering the mercury canisters from the wreck parts before capping the wreck parts and the polluted seabed-area. As part of the assignment, competent subsea companies have been invited to discuss feasible solutions and cost pertaining to the proposed solutions.

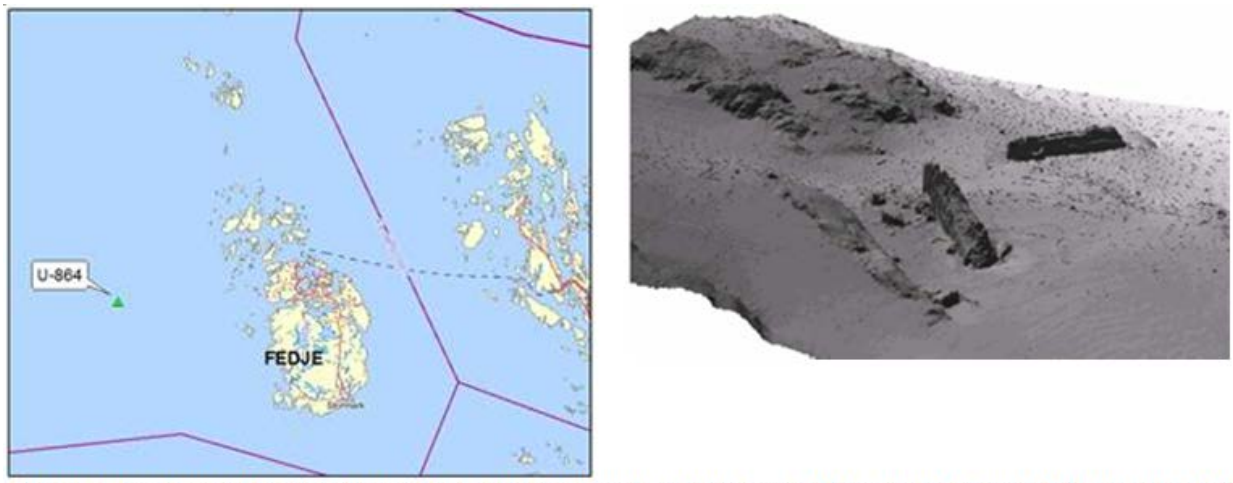

Figure 1.Loction of the wreck outside Fedje (left) and sonar image of bow and aft part of the wreck (right)

3 TESTING

3.1 Visual Examination

The sample sent for examination was rust coloured. Very little local corrosion on the surface of the sample could be observed. Images of the sample as received are shown in Figure 1 and Figure 2.

Figure 1: Overview picture of received sample.

Figure 2: Overview picture of received sample opposite side, ref. Figure 1.

3.2 Chemical Composition Analysis

A spectrographic analysis was carried out for the plate. The chemical composition of the material in question is given in Table 1.

Table 1: Spectrometric analysis of the plate

Element	%
C	0.220
Si	0.014
Mn	0.467
P	0.022
S	0.032
Cr	0.049
Ni	0.056
Mo	<0.0010
Al	0.0013
Cu	0.063
Co	0.015
Ti	<0.001
Nb	<0.001
V	0.001
B	<0.0002
W	0.007
Pb	<0.001
Sn	0.005
As	0.011
N	0.011
Fe	98.8

3.3 Metallographic Examination

The samples were ground, polished and etched according to standard metallographic procedure. A metallographically prepared sample can be seen in Figure 3 and a close-up in Figure 4. The microstructure is consisting of ferrite and pearlite. The material is most likely in as-normalised condition. Non-metallic inclusions in the plate material were observed. Representative microstructure for the plate is shown in Figure 5. Figure 6 is showing a close-up.

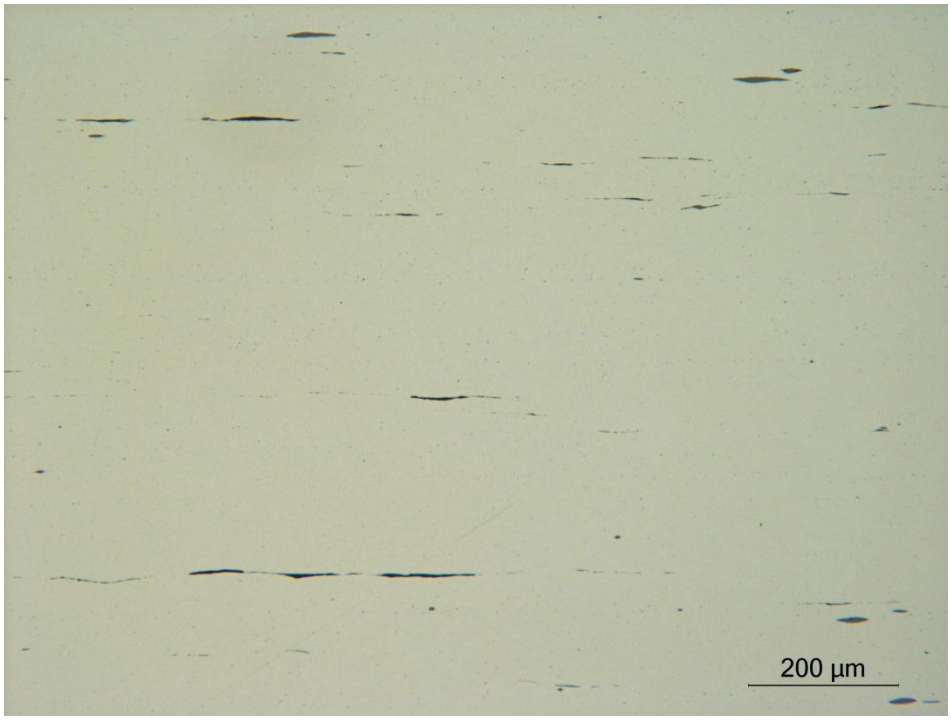

Figure 3: Metallographically prepared sample in as polished condition shows non-metallic inclusion in the plate material. Magnification 100X.

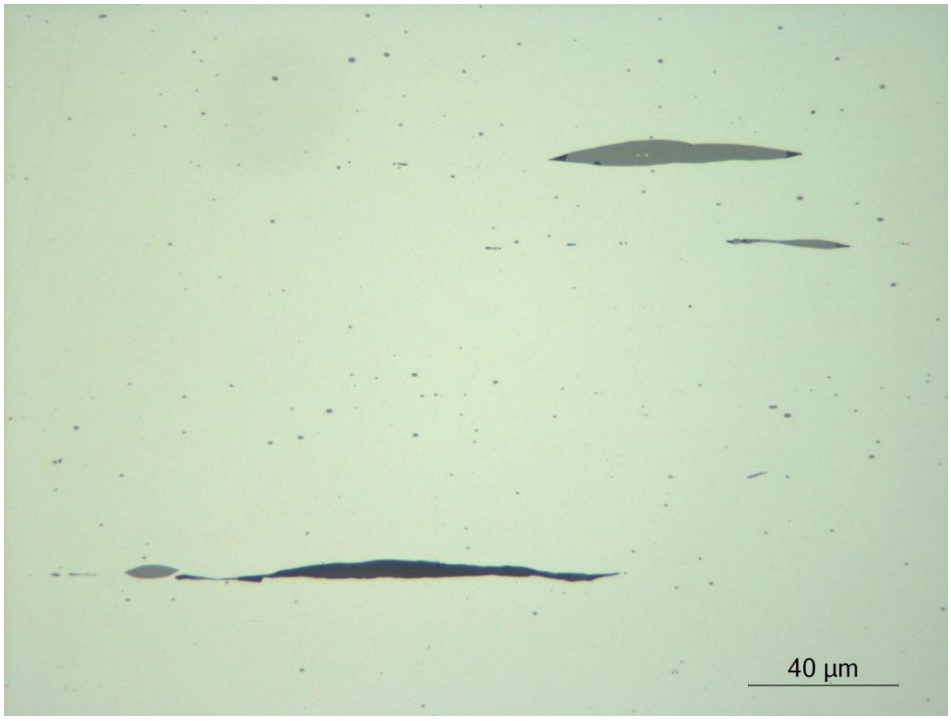

Figure 4: Close-up of Figure 3. Magnification 500X.

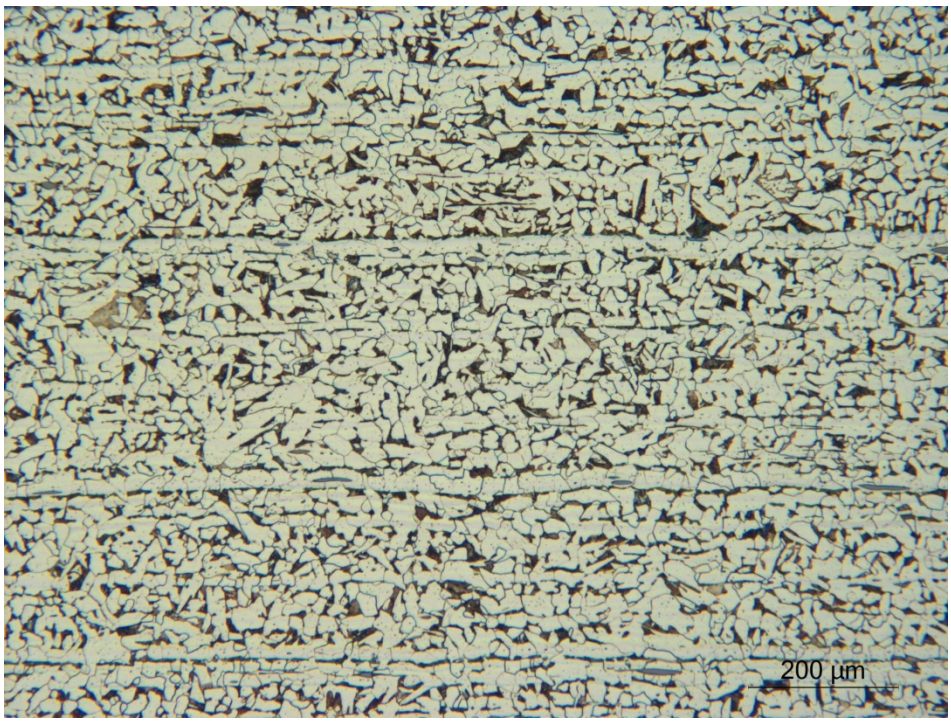

Figure 5: Microstructure representing the plate material consisting of ferrite and pearlite in as normalized condition. Magnification 100X.

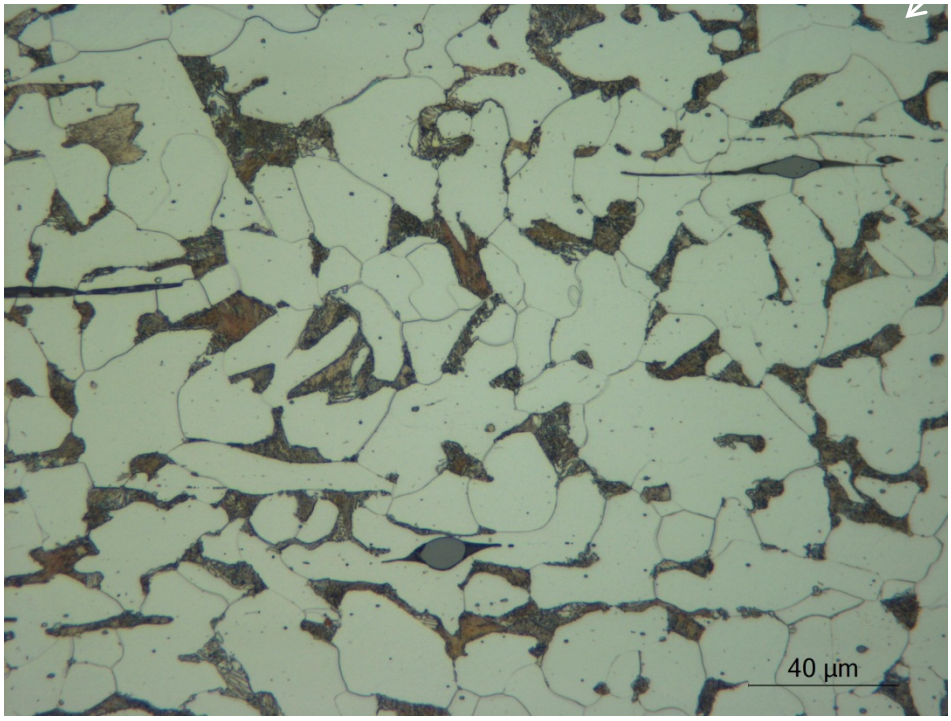

Figure 6: Close-up of Figure 5 Magnification 500X.

3.4 Thickness Measurements

The plate thickness was measured with a calliper and the thinnest part on the plate had a thickness of 6.5 mm and the thickest part was measured to 7.5 mm. The measurements were carried out along the plate edge.

3.5 Hardness Measurements

Hardness measurements were carried out in the plate by means of a stationary Vickers hardness test equipment and 10 kpf load [HV 10]. The results are given in Table 2. The values correspond well to the measured tensile strength.

Table 2: Hardness measurements carried out in the plate material

Sample location	Single measurements]HV]	Average values [HV]
Rolling direction	121-122-120	121
Transverse to rolling direction	136-136-136	136

3.6 Mechanical testing

3.6.1 Tensile Test

The testing was performed in accordance with the test standard: ISO 6892. Due to the thickness of the plate, a flat specimen was prepared. The results are presented in Table 3.

Table 3: Results from tensile tests

Specimen No.:	Dim. [mm]	Area [mm^2]	Proof strength R_{eH} / $R_{p0.2}$		Tensile strength R_m		Elong. $L_0=60$ [%]
			[kN]	[MPa]	[kN]	[MPa]	
Base material	19.88 x5.69	113.12	30.9	273	50.24	440	35.1

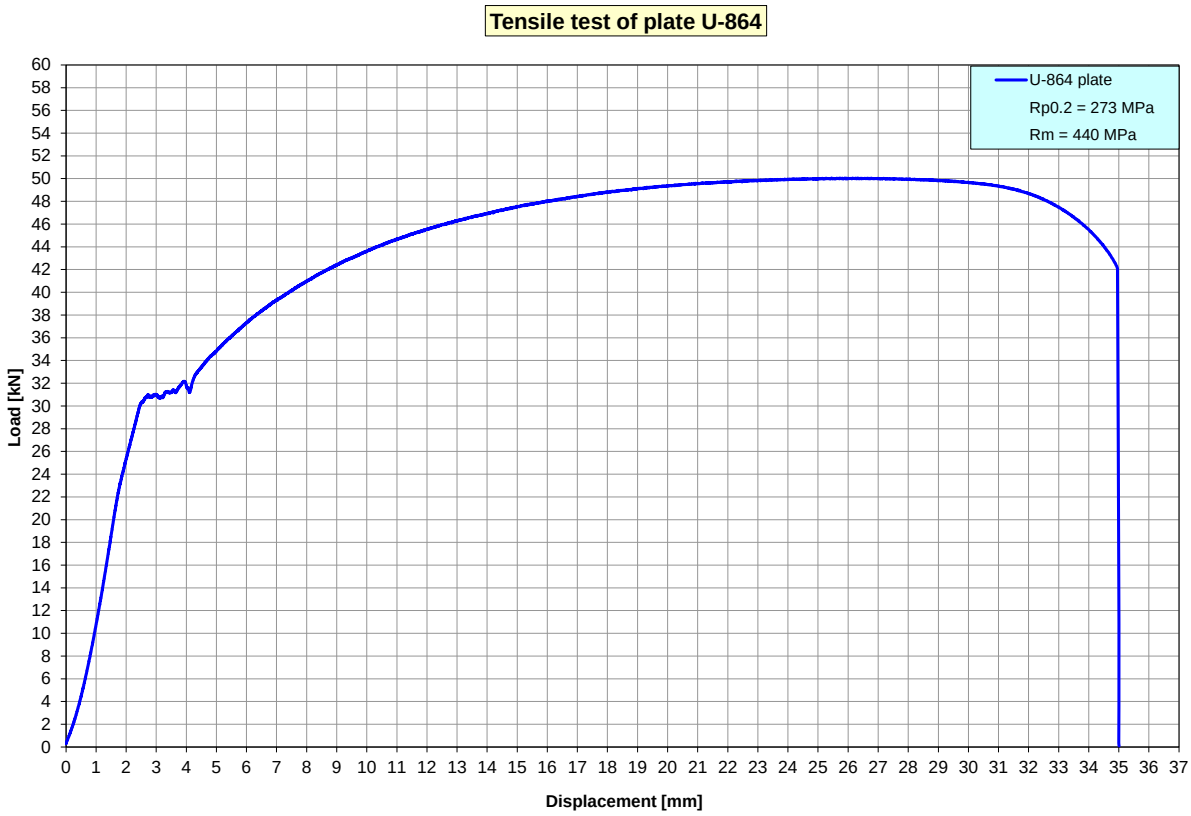

Figure 7: Stress-strain curve for the plate.

3.6.2 Charpy V-Notch Impact Tests

The testing was performed in accordance with the test standard: ISO 148.

Dimension of test specimens: 5 x10 mm
Sampling : Test specimens were sampled approx. 1 mm below surface, and with the notch perpendicular to the surface.

The results are presented in Table 4. Note: due to non-standard size specimens, the average value is multiplied by 1.5 for the corresponding full size specimen average.

Table 4: Results from Charpy V-notch impact test

Sample	Test temp. [°C]	Impact energy, KV 300, [J]				
		Single values [J]			Average [J]	Calculated for full size [J]
Base material	0	24	26	27	26	38.5

4 CONCLUSIONS

Based on the tests performed, the following is concluded:

- The chemical composition is as expected for low-carbon steel plate. The sulphur level is somewhat high, which is shown in the microstructure as a relatively high amount of MnS inclusions. The microstructure is otherwise normal for hot rolled plate.
- The impact testing gave an average of 38.5 J at 0 °C, which is above what is considered brittle.
- The tensile strength is also as expected for this type of material, with a relatively low tensile strength of 440 MPa and good ductility. This strength level/hardness corresponds to a S235 (EN10025) type of steel, or grade NV B.
- Due to little corrosion in the plate, the reduction in plate thickness is minimal.
- When cutting this steel plate, no special considerations should be necessary. Equipment for cutting soft carbon steel should suffice.

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Appendix V3.09

ENVIRONMENTAL MEASURES FOR THE WRECK OF U-864

Report from the visit to U-534

DNV GL AS

Project name: Environmental measures for the wreck of U-864

Report title: Report from the visit to U-534

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Dato: 12.5.2014

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1 INTRODUCTION

The German submarine U-864 was torpedoed by the British submarine Venturer 9th of February 1945, approximately 2 nautical miles west of the Island Fedje in Hordaland. U-864 was on its way from Germany via Norway to Japan. The submarine had a cargo of war material, and according to historical documents approximately 67 ton of liquid metallic mercury in steel canisters stored in the keel. The torpedo split the submarine into two parts. The wreck parts were discovered by the Royal Norwegian Navy at a depth of approximately 150-175 m.

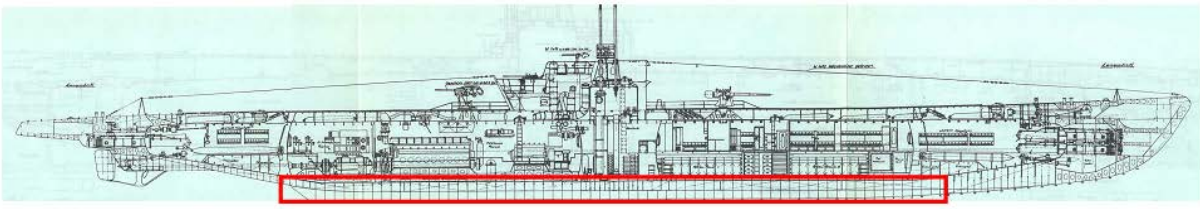

Figure 5-1 Type IX D. The red rectangle shows the keel, in which the mercury canisters were stored.

In 2013 DNV GL was assigned by the Norwegian Coastal Administration (NCA) to carry out a pre-project that will consider the following two options to reduce the mercury pollution that affects the marine environment in the area:

1. collect as many mercury canisters as possible from the keel, then cap the wreck parts and the polluted sediments with clean sediments, or
2. to cap the wreck parts (including the mercury canisters) and the polluted sediments with clean sediments.

1.1 Visit to U-534

On the 17th of September 2013 a delegation from NCA and DNV GL visited the museum in Liverpool housing the German WWII submarine U-534. This is a type IX C submarine salvaged outside Denmark in 1993. The IX C type is similar to IX D2, but approximately 11 m shorter. Norwegian delegation was accompanied by Mr Wolfgang Lauenstein from Germany who has been studying the story of U-864 and other similar cases for many years.

The main goals for the trip, was to:

- get a more detailed view of the dimensions of the submarine
- take measures of the keel, thickness of the plates and study how it was designed.
- get information from Mr Lauenstein about U-864 as well as from other similar submarines and submarine operations (U-534 and U-859).

Participants:

When selecting the team from DNV GL, participation from three important categories was considered vital:

- Project and group leaders
- Expert on submarines
- Technical experts on structure and subsea operations

The team from DNV consisted of the following members:

Henning Vahr	Project manager
Jan Holme	Group Leader Geo technology and seabed stability
Jens Laugesen	Group Leader Environmental aspects
Andrew Junge	Group Leader, technical and marine subsea operations
Nicolaj Tidemand	Submarine expert
Torstein Alexander Pettersen	Structural expert
Arve Lepsøe	Expert on subsea operations

From NCA the project manager for the U-864 project, Hans Petter Mortensholm, participated.

Wolfgang Lauenstein participated as an expert on German WWII submarines and the salvage of these submarines after the war.

The program:

0830 - 0900:	Introduction of the U-534 Case (Hans Petter Mortensholm, NCA)
0900 - 0930:	Risks for salvage Hg canisters U-864 (Andrew Junge, DNV GL)
0930 - 0945:	Coffee break
0945 - 1030:	Technical discussions on keel construction U-534/U-864
1030 - 1200:	The U-859 case (Mr Lauenstein)
1200 - 1300:	Lunch
1300 - 1400:	Ferry from Liverpool to Birkenhead
1400 - 1800:	Visit to the U-534 display

2 INFORMATION ON U-859 WITH A LOAD OF MERCURY THAT WAS SUNK DURING WWII

2.1 Introduction

This section is based on information provided by Wolfgang Lauenstein in the meeting in Liverpool, September 17th, 2013 and from open internet sources (mainly Wikipedia).

2.2 The History of U-859

The German submarine U-859 was sunk 23 September, 1944 near Penang in the Malacca strait, at position 05.46N, 100.04E, by torpedoes from the British submarine HMS Trenchant. 47 of the crew died and 20 survived.

U-859 had sailed from Kiel in April 1944, carrying a secret cargo of mercury and was bound for Japanese occupied Penang. U-859 was torpedoed less than an hour from her destination, after six months at sea and after sailing 20 000 miles.

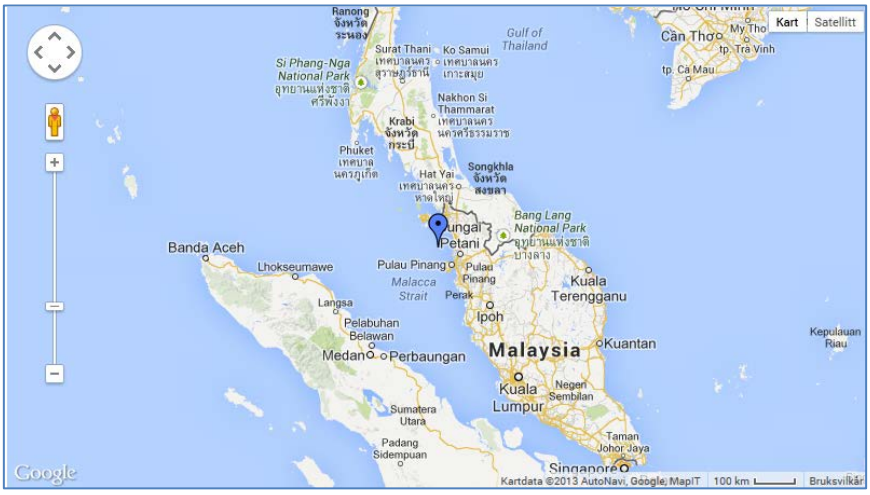

Figure 1: Position 05.46N, 100.04E where it was reported that U-859 was sunk (Google maps)

U-859 was a long range U-boat of the type IX D2, the same submarine type as U-864. Like U-864 it was carrying a load of mercury when it was torpedoed and sunk. U-859 was lying at 33 m depth and the mercury load was salvaged by the company Barracuda in 1973. The aim of the salvage was to sell the mercury that they salvaged. The salvage was done by divers from the company (European, American and Malaysian divers).

The seabed was flat but the keel had sunk into the seabed so they had to excavate pits along both sides of the wreck (estimated 3 to 5 pits) and from those pits the divers dug a tunnel along the keel so that they could take out the mercury that was stored in the keel. They had to remove the vertical steel plates that were screwed to the keel to get access to the mercury. The bottles were standing vertically in the keel and there were at least 3 different types of bottles. The bottles were stuck together due to corrosion. The divers had to separate them before they were placed in a metal transport box and hauled on board the vessel they used.

In the compartments in the keel where the mercury bottles were stored there was also a substantial amount of mud. The mud had probably entered through small openings in the compartment. It is assumed that the small openings were designed to ensure that the compartments with the mercury were filled with seawater during transport. This was due to the fact that the Germans did not want any air to be trapped that later could escape, and reveal their position when the submarine was submerged, and for pressure equalization of the keel compartments.

Barracuda salvaged about 530 mercury bottles from the aft of the submarine and 323 bottles from the bow, a total of 853 bottles. However, the submarine had been visited earlier by «pirates» and an unknown amount of bottles had probably been taken at that time. The total amount of mercury that was in the keel is therefore not known. The content of each bottle always had a mass of 34.5 kg mercury irrespective of which type of bottle was used. The total weight of each bottle (steel + mercury) was approximately 37 kg.

The pictures of the compartments in the keel in U-859 presented by Lauenstein showed that there were holes in the side plates between each compartment. That means that free mercury could potentially flow from compartment to compartment.

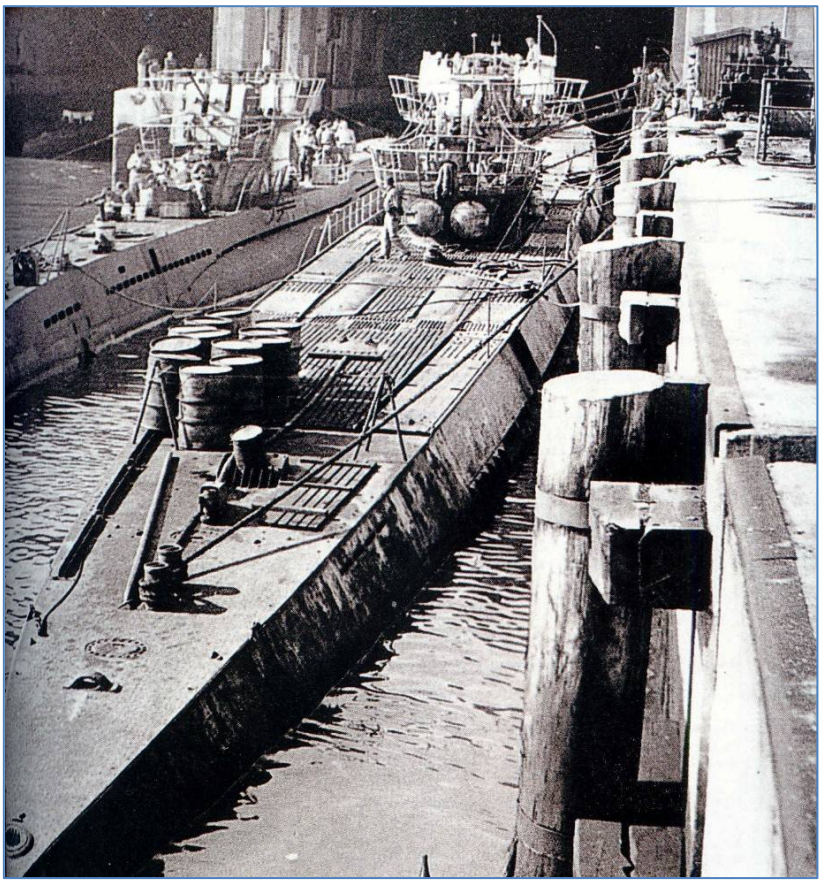

Figure 2: IX D 2 class submarine (from www.wrecksite.eu)

2.3 Comparing U-859 with U-864

The submarines of the type IX D2 had a keel ballast capacity of approximately 90 tonnes.

U-864 is assumed to have stored approximately 70 tonnes of bottles with mercury (1857 bottles x 37 kg). The remaining ballast would most probably have been steel blocks or lead blocks.

How the ballast was distributed had to do with the trimming of the submarine. Lauenstein has been looking for people that know anything about the trimming of this type of submarine but so far without any luck. It could for instance be that in some compartments of U-864 there is a mixture of mercury bottles and steel or lead blocks. That this is a possibility is, according to Lauenstein, documented through loading documents showing a weight difference in each compartment in the keel that otherwise has the same volume.

This gives the following options of what could be found in a keel compartment in U-864:

- The compartment is empty (no need for ballast in that compartment)
- Mercury bottles
- Steel blocks
- Lead blocks
- A mixture of mercury bottles and steel and/or lead blocks

It was also mentioned that sometimes the submarines were transporting raw glass to Japan, which may have been stored in the keel. As mentioned earlier, we can also assume that mud will be found in the compartments. It is most probable that the way the mercury was stored in U-864 was the same as in U-859 as it was the same type of submarine and it was loaded in the same harbour (Kiel).

3 SUMMARY OF THE MEASUREMENTS PERFORMED DURING THE VISIT TO U-534

3.1 Introduction

To get an impression of the size and the detailed measurement of a German WWII submarine the delegation visited the museum hosting the U-534. In addition to seeing the public display the museum gave full access to the lower part of the submarine where the structure and subsea operational experts could perform additional measurements. In this chapter the most important measurements are documented.

3.2 Documentation of Measurements

The thickness of the steel in the saddle tank/casing shell, spanning from the area immediately forward of the conning tower to the area immediately aft of it, was measured to be 25-26 mm (See figure 3). The relatively thick steel in this area is quite likely due to repairs performed after damages during the war. In other areas of the casing the thickness is 5-6 mm. Otherwise the casing is in poor condition due to a high degree of general corrosion and detached strut connections due to corroded joints.

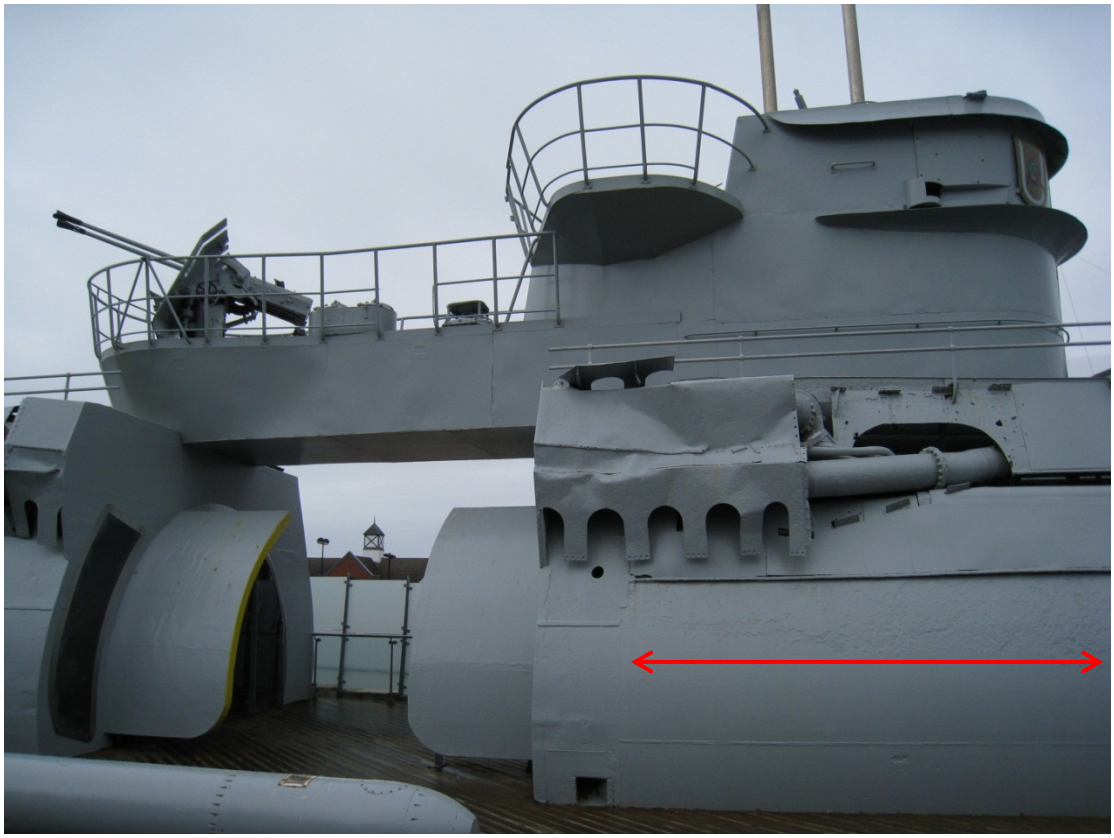

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Figure 4: Internal structure in the casing/saddle tank

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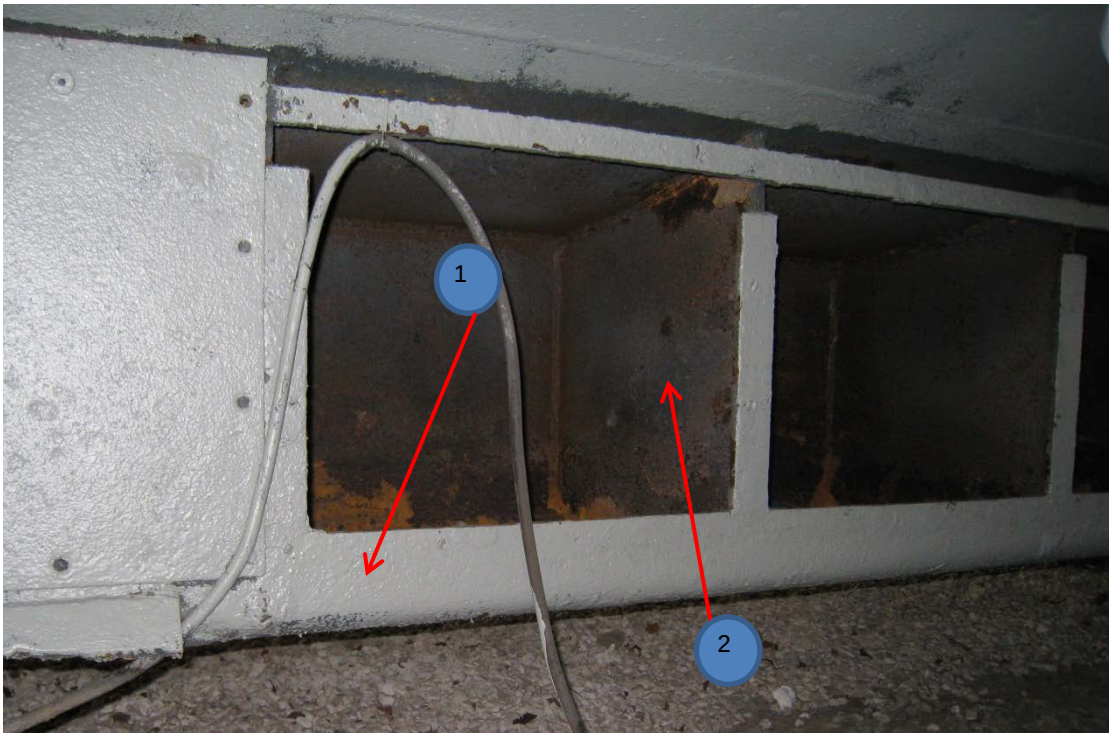

Figure 6: Picture of the keel ballast/storage compartment. Looking from port to starboard.

The steel thickness of the side and bottom of the keel is approximately 15 – 16 mm. In most areas there is some corrosion (See arrow one in figure 6).

The keel's vertical inner plates are all measured to be 11.5 mm. Moderate/minor amounts of corrosion can be found on them (See arrow two in figure 6).

The other dimensions of the keel are according to the drawing (See figure 7):

#1: 1200 mm – 1250 mm, including the keel cover.

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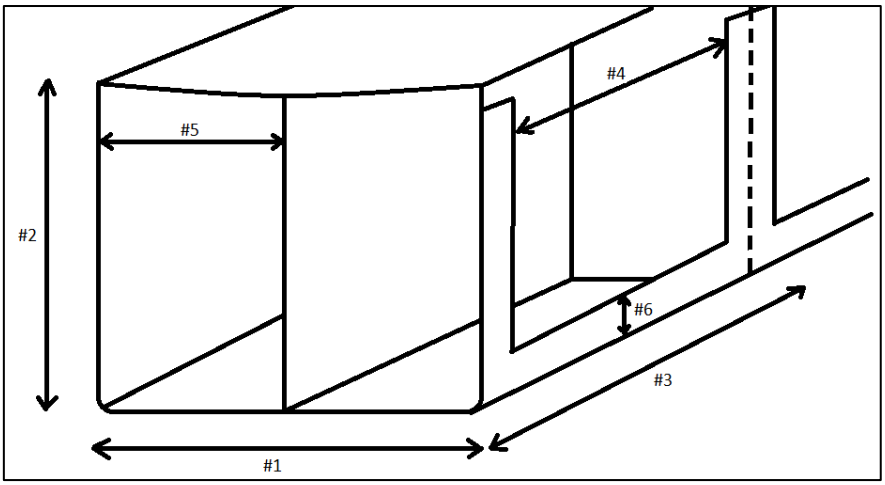

Figure 7: Keel dimensions

On the lower part of the pressure hull the thickness is 18.3mm (Figure 8). This is an average of several measurements.

Figure 8: Thickness of lower part of pressure hull

3.3 The Welding Inside the Keel

- In good condition
- Transversal/cross plate welded on to continuous centerplate.
    - Fillet weld on each side.
    - Ca. 9mm leg length (measured with tape measure).
    - Good condition. No visible welding defects. Minor/moderate corrosion.
- Continuous centerplate welded to pressure hull.
    - Multi-pass weld (2 visible «passes». May indicate 3 in total)
    - Ca. 10.5mm leg length (measured with tape measure)
    - Good condition. No visible welding defects. Minor/moderate corrosion.

Figure 9: Transversal plate to the right, continuous centerplate straight ahead and pressure hull above.

Figure 10: Welding between continuous centreplate and pressure hull.

Figure 11: Welding between cross plate and the continuous centerplate

3.4 Pressure Hull

- The shell and transverse frames comprise the main structure
- The transverse plates in the keel are assumed to be welded directly beneath the transverse frames and will therefor transfer the loads directly to these frames.
- There is some corrosion on the inside of the pressure hull
- Rough measurements are performed on the internal structure (See figure 12)

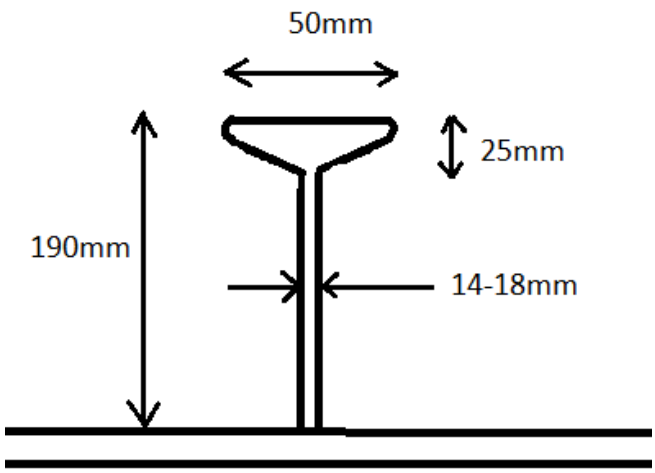

Figure 12: Approximate dimensions of the ring-stiffeners (frames) inside the pressure hull

Figure 13: The inside of the pressure hull

Figure 14: The condition of the ring-stiffener (frames), moderate corrosion.

About DNV GL

Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter and greener.

Appendix V3.09

ENVIRONMENTAL MEASURES FOR THE WRECK OF U-864

Report from the visit to U-534

DNV GL AS

Project name: Environmental measures for the wreck of U-864

Report title: Report from the visit to U-534

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Prepared by:
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Dato: 12.5.2014

Reference to part of this report which may lead to misinterpretation is not permissible

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1 INTRODUCTION

The German submarine U-864 was torpedoed by the British submarine Venturer 9th of February 1945, approximately 2 nautical miles west of the Island Fedje in Hordaland. U-864 was on its way from Germany via Norway to Japan. The submarine had a cargo of war material, and according to historical documents approximately 67 ton of liquid metallic mercury in steel canisters stored in the keel. The torpedo split the submarine into two parts. The wreck parts were discovered by the Royal Norwegian Navy at a depth of approximately 150-175 m.

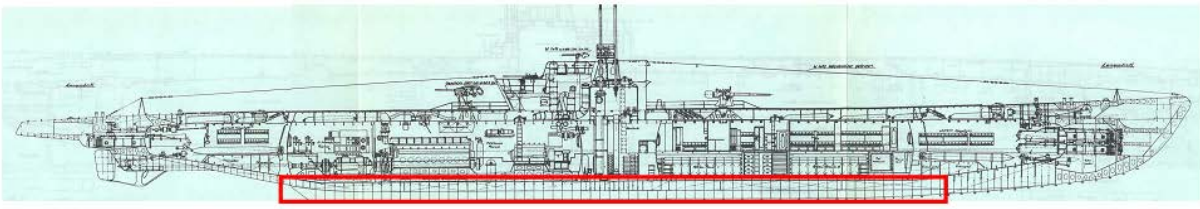

Figure 5-1 Type IX D. The red rectangle shows the keel, in which the mercury canisters were stored.

In 2013 DNV GL was assigned by the Norwegian Coastal Administration (NCA) to carry out a pre-project that will consider the following two options to reduce the mercury pollution that affects the marine environment in the area:

1. collect as many mercury canisters as possible from the keel, then cap the wreck parts and the polluted sediments with clean sediments, or
2. to cap the wreck parts (including the mercury canisters) and the polluted sediments with clean sediments.

1.1 Visit to U-534

On the 17th of September 2013 a delegation from NCA and DNV GL visited the museum in Liverpool housing the German WWII submarine U-534. This is a type IX C submarine salvaged outside Denmark in 1993. The IX C type is similar to IX D2, but approximately 11 m shorter. Norwegian delegation was accompanied by Mr Wolfgang Lauenstein from Germany who has been studying the story of U-864 and other similar cases for many years.

The main goals for the trip, was to:

- get a more detailed view of the dimensions of the submarine
- take measures of the keel, thickness of the plates and study how it was designed.
- get information from Mr Lauenstein about U-864 as well as from other similar submarines and submarine operations (U-534 and U-859).

Participants:

When selecting the team from DNV GL, participation from three important categories was considered vital:

- Project and group leaders
- Expert on submarines
- Technical experts on structure and subsea operations

The team from DNV consisted of the following members:

Henning Vahr	Project manager
Jan Holme	Group Leader Geo technology and seabed stability
Jens Laugesen	Group Leader Environmental aspects
Andrew Junge	Group Leader, technical and marine subsea operations
Nicolaj Tidemand	Submarine expert
Torstein Alexander Pettersen	Structural expert
Arve Lepsøe	Expert on subsea operations

From NCA the project manager for the U-864 project, Hans Petter Mortensholm, participated.

Wolfgang Lauenstein participated as an expert on German WWII submarines and the salvage of these submarines after the war.

The program:

0830 - 0900:	Introduction of the U-534 Case (Hans Petter Mortensholm, NCA)
0900 - 0930:	Risks for salvage Hg canisters U-864 (Andrew Junge, DNV GL)
0930 - 0945:	Coffee break
0945 - 1030:	Technical discussions on keel construction U-534/U-864
1030 - 1200:	The U-859 case (Mr Lauenstein)
1200 - 1300:	Lunch
1300 - 1400:	Ferry from Liverpool to Birkenhead
1400 - 1800:	Visit to the U-534 display

2 INFORMATION ON U-859 WITH A LOAD OF MERCURY THAT WAS SUNK DURING WWII

2.1 Introduction

This section is based on information provided by Wolfgang Lauenstein in the meeting in Liverpool, September 17th, 2013 and from open internet sources (mainly Wikipedia).

2.2 The History of U-859

The German submarine U-859 was sunk 23 September, 1944 near Penang in the Malacca strait, at position 05.46N, 100.04E, by torpedoes from the British submarine HMS Trenchant. 47 of the crew died and 20 survived.

U-859 had sailed from Kiel in April 1944, carrying a secret cargo of mercury and was bound for Japanese occupied Penang. U-859 was torpedoed less than an hour from her destination, after six months at sea and after sailing 20 000 miles.

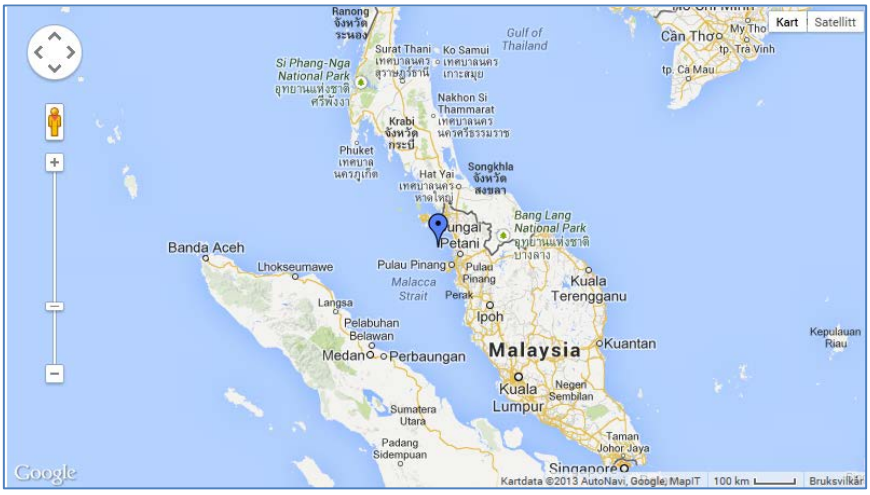

Figure 1: Position 05.46N, 100.04E where it was reported that U-859 was sunk (Google maps)

U-859 was a long range U-boat of the type IX D2, the same submarine type as U-864. Like U-864 it was carrying a load of mercury when it was torpedoed and sunk. U-859 was lying at 33 m depth and the mercury load was salvaged by the company Barracuda in 1973. The aim of the salvage was to sell the mercury that they salvaged. The salvage was done by divers from the company (European, American and Malaysian divers).

The seabed was flat but the keel had sunk into the seabed so they had to excavate pits along both sides of the wreck (estimated 3 to 5 pits) and from those pits the divers dug a tunnel along the keel so that they could take out the mercury that was stored in the keel. They had to remove the vertical steel plates that were screwed to the keel to get access to the mercury. The bottles were standing vertically in the keel and there were at least 3 different types of bottles. The bottles were stuck together due to corrosion. The divers had to separate them before they were placed in a metal transport box and hauled on board the vessel they used.

In the compartments in the keel where the mercury bottles were stored there was also a substantial amount of mud. The mud had probably entered through small openings in the compartment. It is assumed that the small openings were designed to ensure that the compartments with the mercury were filled with seawater during transport. This was due to the fact that the Germans did not want any air to be trapped that later could escape, and reveal their position when the submarine was submerged, and for pressure equalization of the keel compartments.

Barracuda salvaged about 530 mercury bottles from the aft of the submarine and 323 bottles from the bow, a total of 853 bottles. However, the submarine had been visited earlier by «pirates» and an unknown amount of bottles had probably been taken at that time. The total amount of mercury that was in the keel is therefore not known. The content of each bottle always had a mass of 34.5 kg mercury irrespective of which type of bottle was used. The total weight of each bottle (steel + mercury) was approximately 37 kg.

The pictures of the compartments in the keel in U-859 presented by Lauenstein showed that there were holes in the side plates between each compartment. That means that free mercury could potentially flow from compartment to compartment.

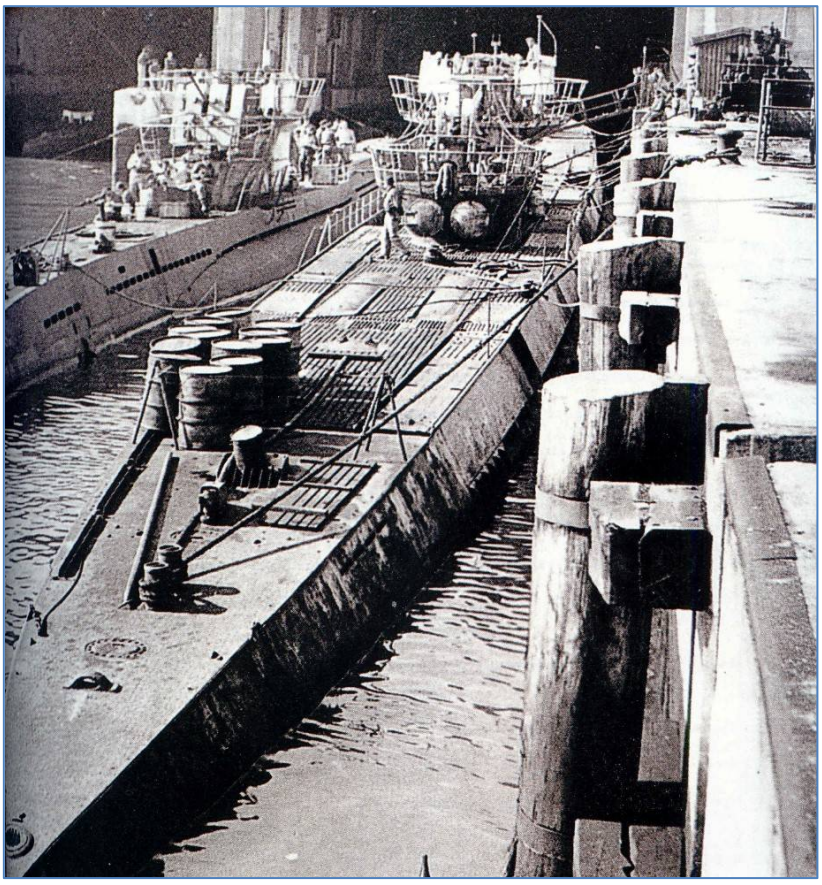

Figure 2: IX D 2 class submarine (from www.wrecksite.eu)

2.3 Comparing U-859 with U-864

The submarines of the type IX D2 had a keel ballast capacity of approximately 90 tonnes.

U-864 is assumed to have stored approximately 70 tonnes of bottles with mercury (1857 bottles x 37 kg). The remaining ballast would most probably have been steel blocks or lead blocks.

How the ballast was distributed had to do with the trimming of the submarine. Lauenstein has been looking for people that know anything about the trimming of this type of submarine but so far without any luck. It could for instance be that in some compartments of U-864 there is a mixture of mercury bottles and steel or lead blocks. That this is a possibility is, according to Lauenstein, documented through loading documents showing a weight difference in each compartment in the keel that otherwise has the same volume.

This gives the following options of what could be found in a keel compartment in U-864:

- The compartment is empty (no need for ballast in that compartment)
- Mercury bottles
- Steel blocks
- Lead blocks
- A mixture of mercury bottles and steel and/or lead blocks

It was also mentioned that sometimes the submarines were transporting raw glass to Japan, which may have been stored in the keel. As mentioned earlier, we can also assume that mud will be found in the compartments. It is most probable that the way the mercury was stored in U-864 was the same as in U-859 as it was the same type of submarine and it was loaded in the same harbour (Kiel).

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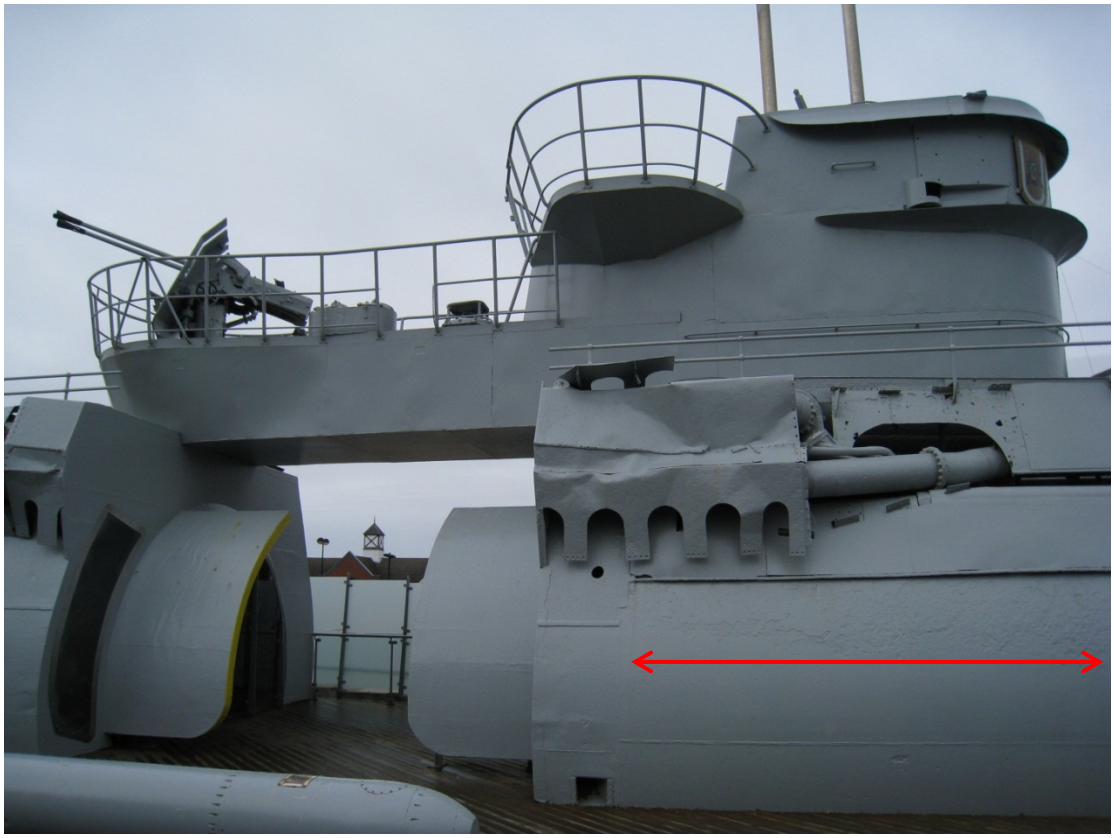

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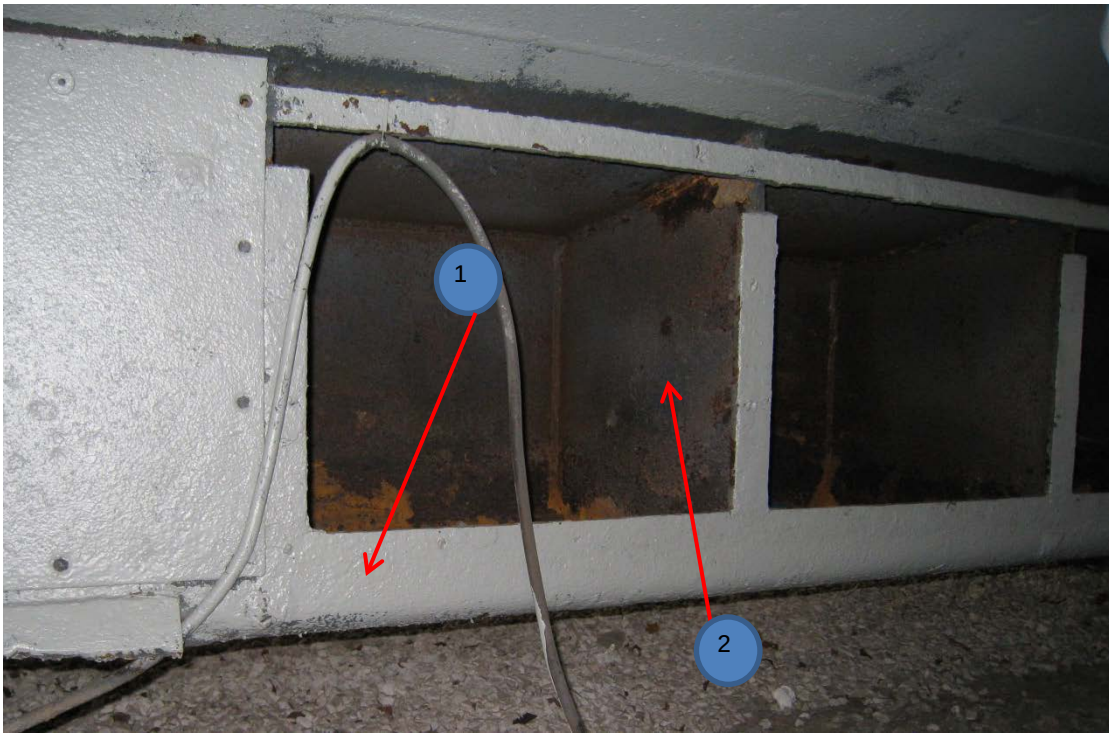

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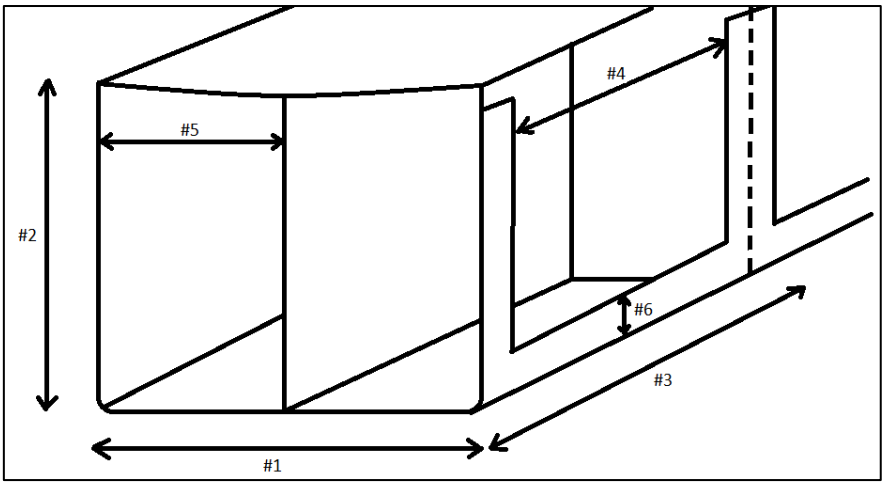

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On the lower part of the pressure hull the thickness is 18.3mm (Figure 8). This is an average of several measurements.

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- In good condition
- Transversal/cross plate welded on to continuous centerplate.
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    - Ca. 9mm leg length (measured with tape measure).
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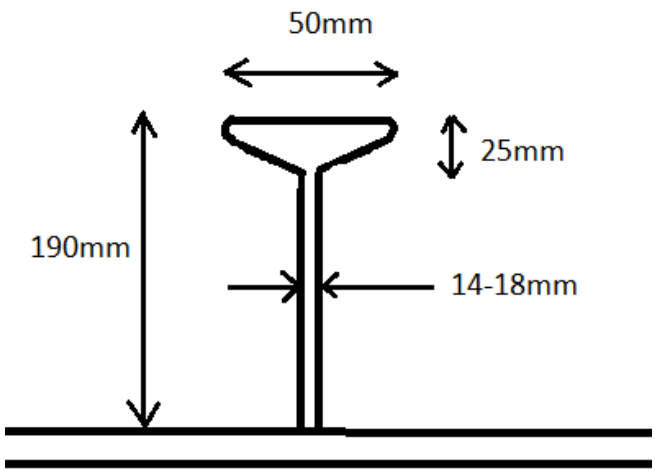

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