# VEDLEGG

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| 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 |
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| 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 |
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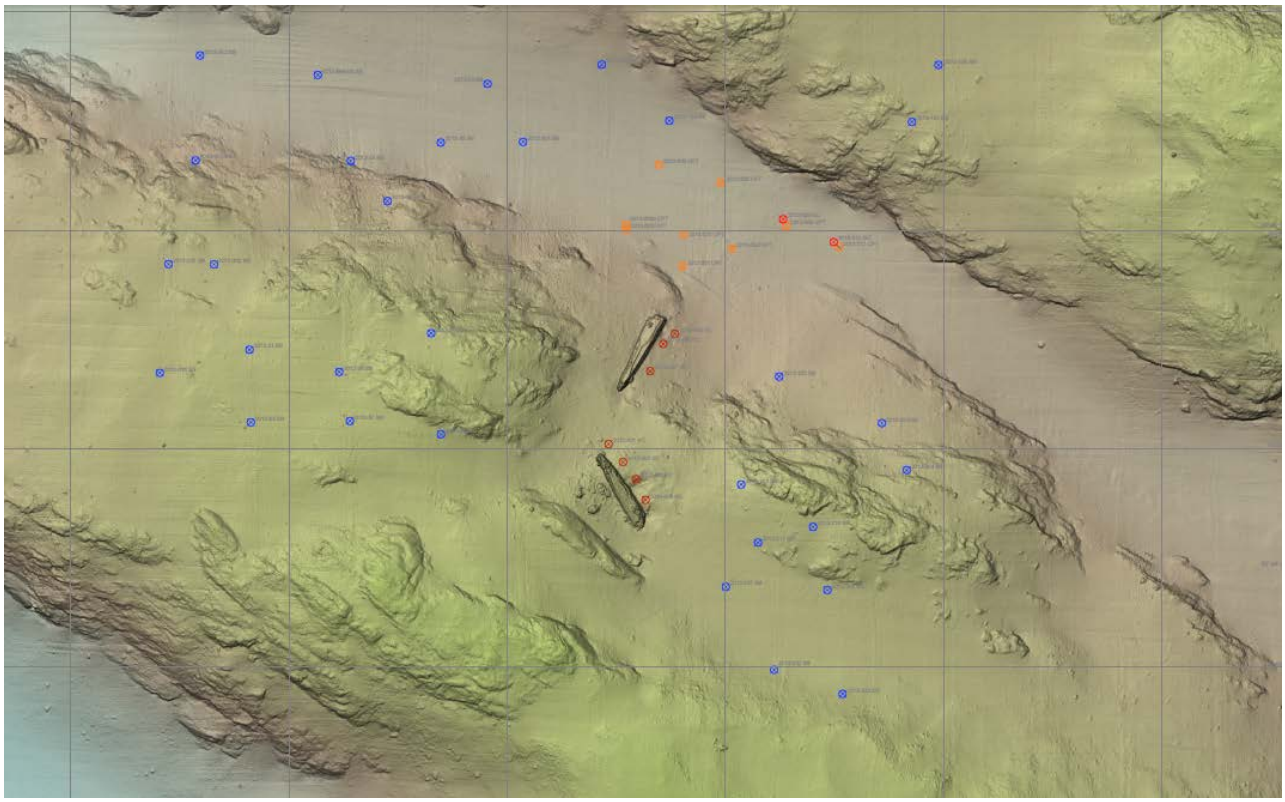
| V1.01 | Fremdriftsplan for alternativ 1 | DNV GL AS | 2014 | 14 |
| V1.02 | Usikkerhetsanalyse av kostnad for alternativ 1 | DNV GL AS | 2014 | 23 |
| V1.03 | Kvalitativ risikoanalyse Alt. 1 “Tildekking” | DNV GL AS | 2014 | 17 |
| V1.04 | Kontraktsstrategier U-864 - Alternativ 1 | Kvale Advokat-firma DA | 2014 | 28 |

# 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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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 alle operasjoner stoppes. *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.*

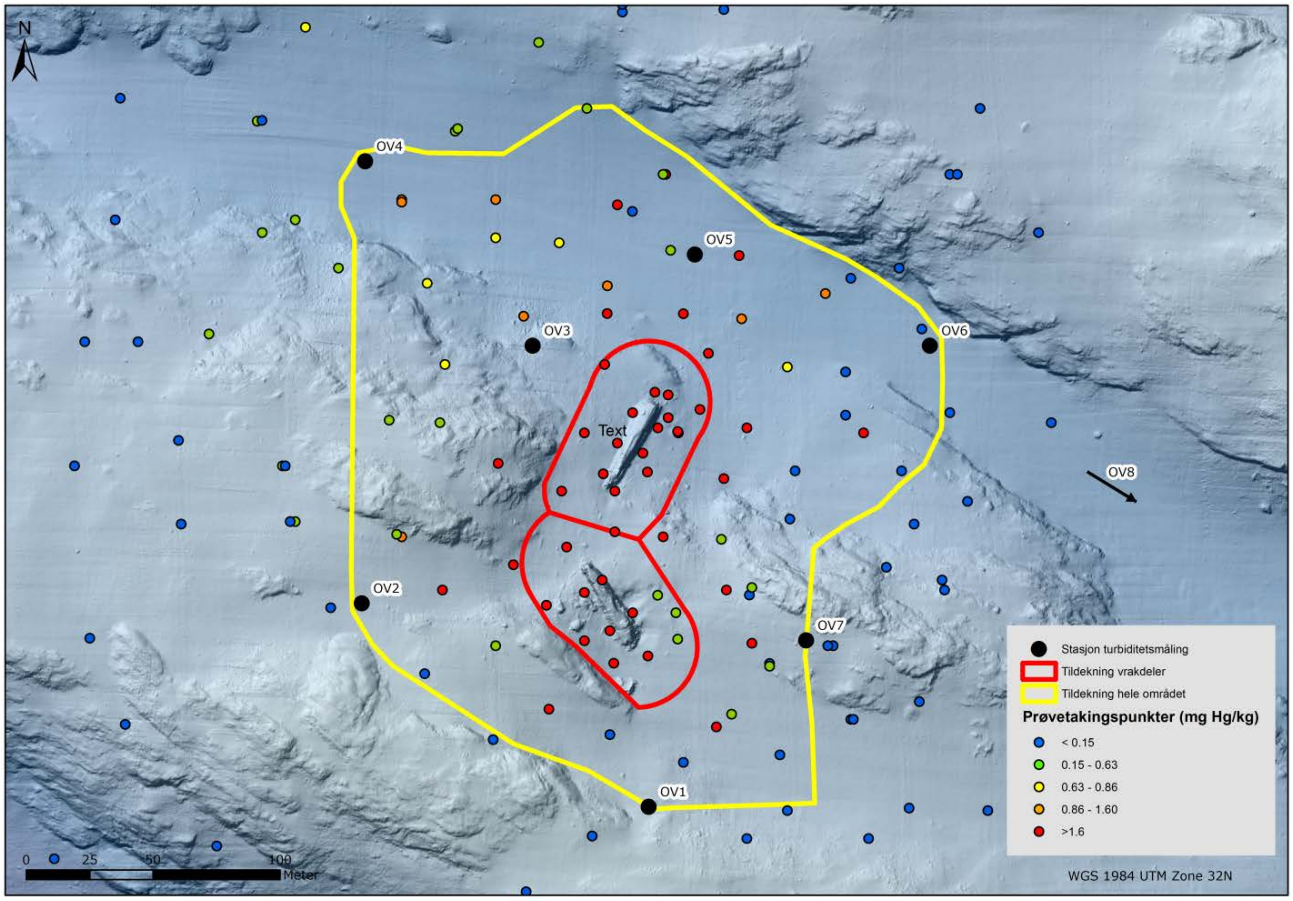
**Olje i vann:**
*Ved synlig olje på vannoverflaten av betydning[3] skal tiltak iverksettes (oljelenser, absorbenter, skimmere etc.[4]).*

**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 tiltaks-området. 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.

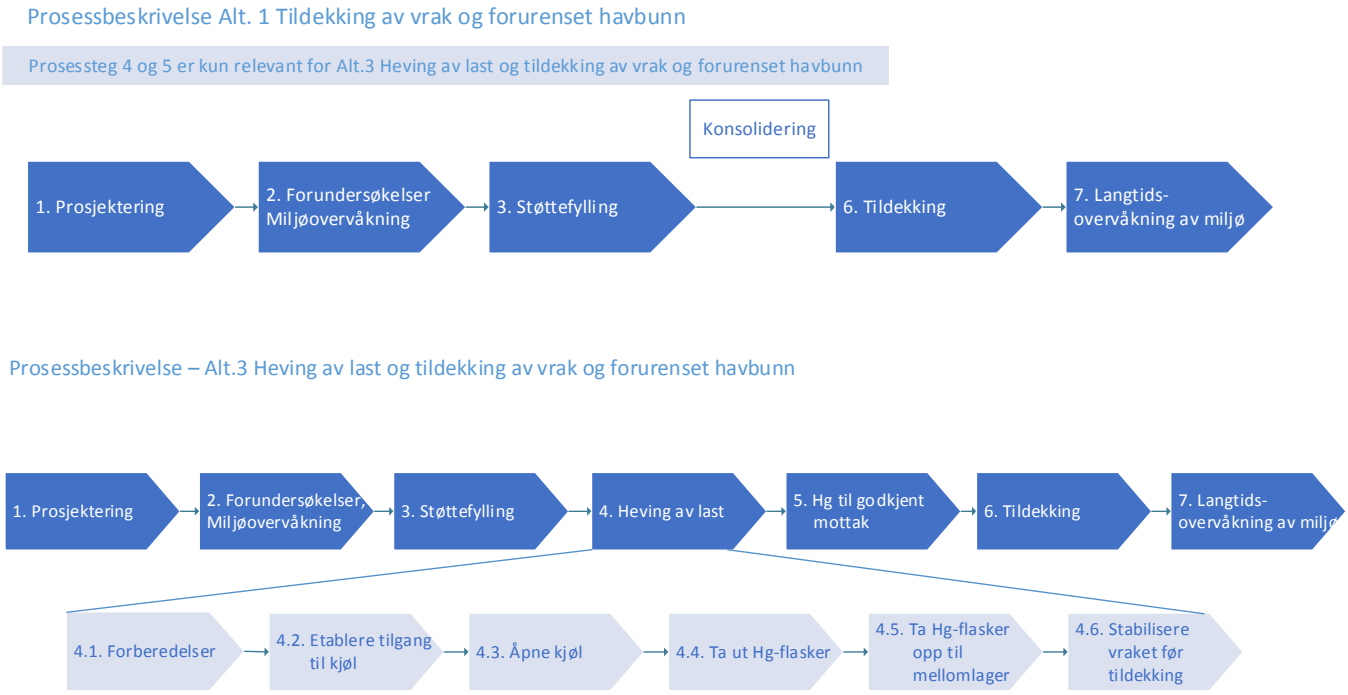
Dette gir til sammen 16 prøvepunkter. Målerne kan måle kontinuerlig eller ved gitte frekvenser under tiltaket. Det skal gjøres bakgrunnsmålinger på samtlige stasjoner før tiltaket starter.

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.

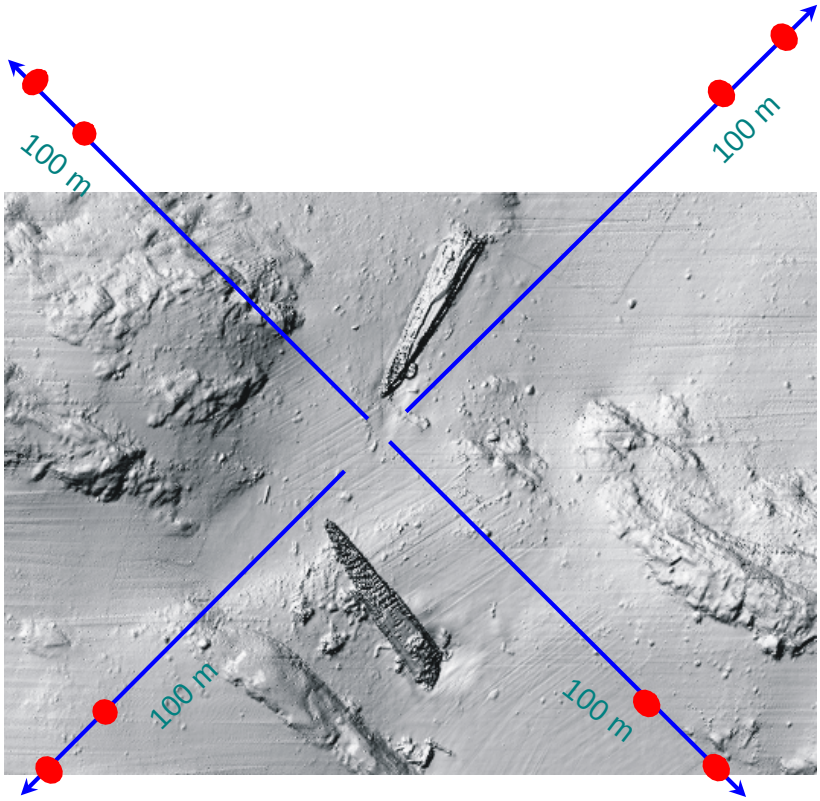
***Kvikksølvkonsentrasjon i vannsøylen***

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:

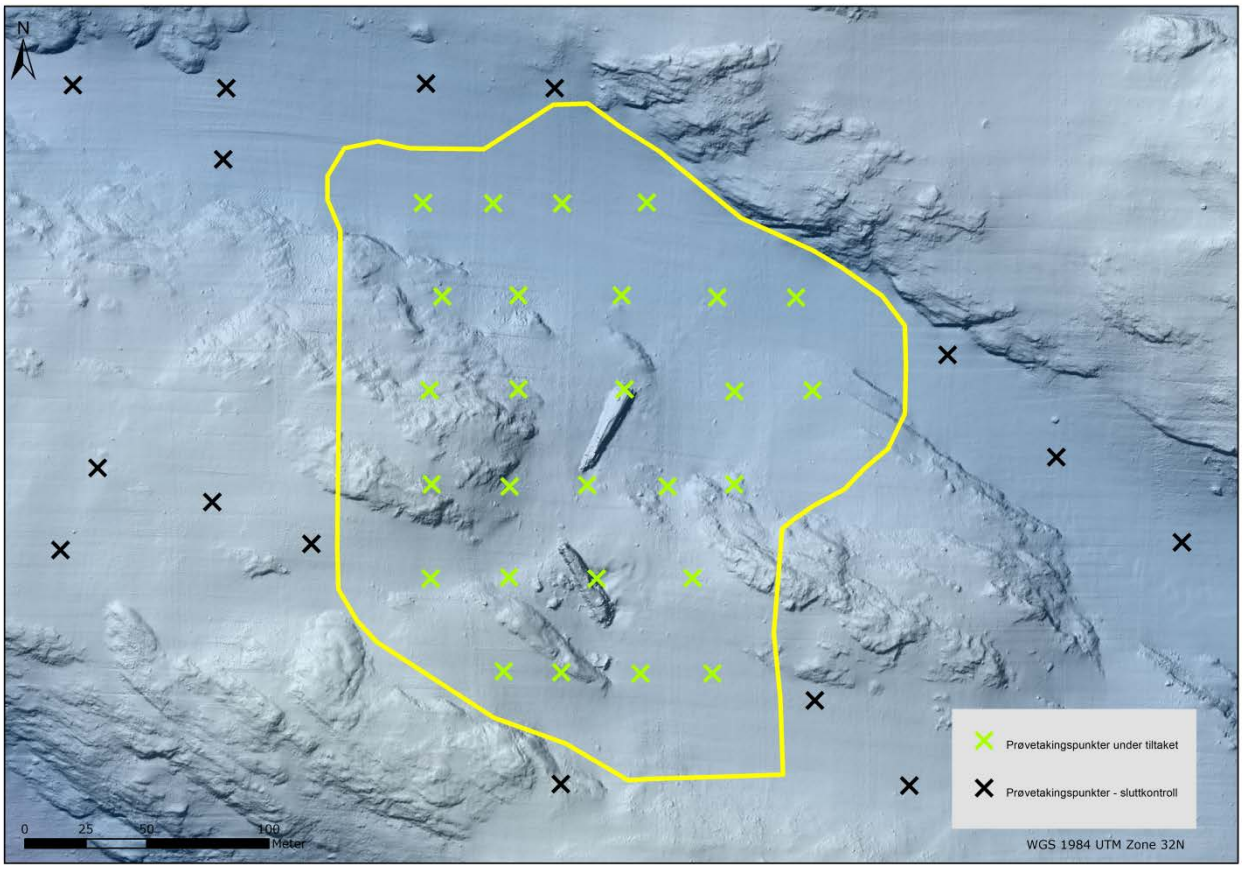
- ***Ved sluttkontrollen skal konsentrasjonen av kvikksølv i det øverste sedimentlaget (2 cm) ikke overstige 0,63 mg/kg (klasse II – god).***
- ***Tildekkingen kontrolleres slik at 100 % av tiltaksområdet skal være tildekket. Arealer rundt vrakdelene skal være tildekket med planlagt tykkelse og minst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

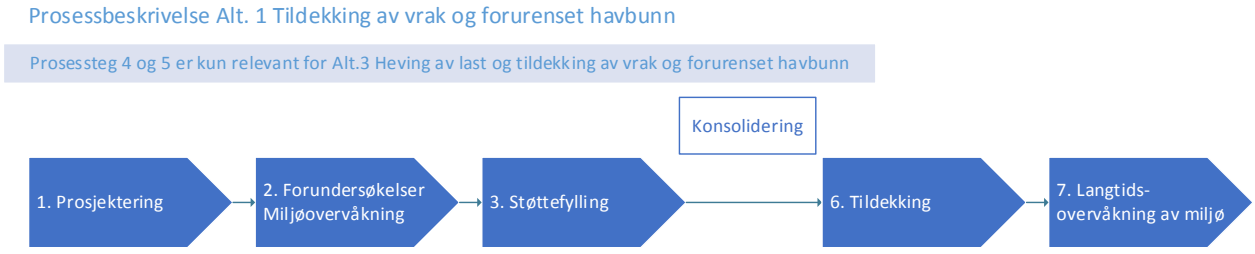
***Tildekking kontrolleres slik at 100 % av tiltaksområdet skal være tildekket og arealer rundt vrakdelene skal være tildekket med planlagt tykkelse og minst 90 % av øvrige areal skal være dekket til med fastsatt tykkelse på dekklaget.***

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:

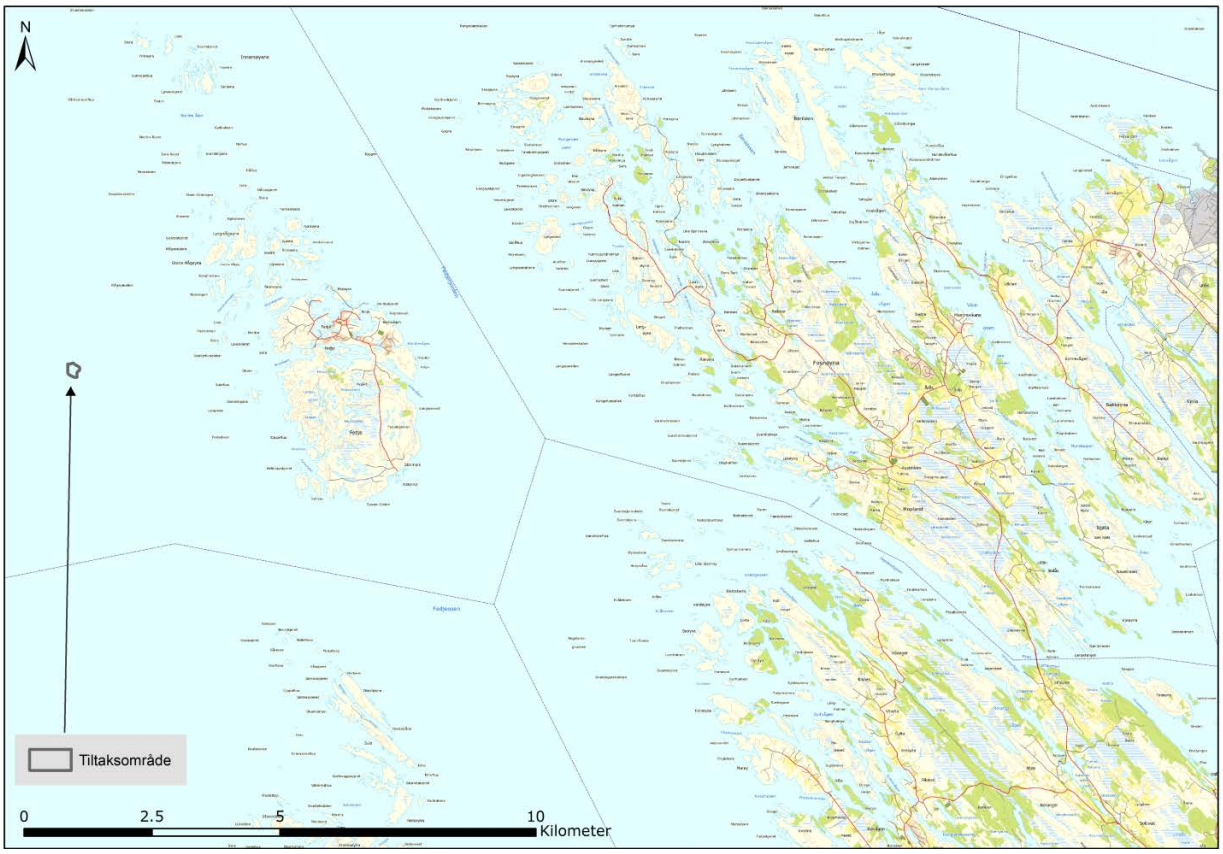
- Dr. Espen Eek, Norges Geotekniske Institutt
- Cand scient. Thomas Møskeland, DNV GL AS
- Dr. Jens Laugesen (Ansvarlig), DNV GL AS
- M.Sc. Aase Holsen, DNV GL AS

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)

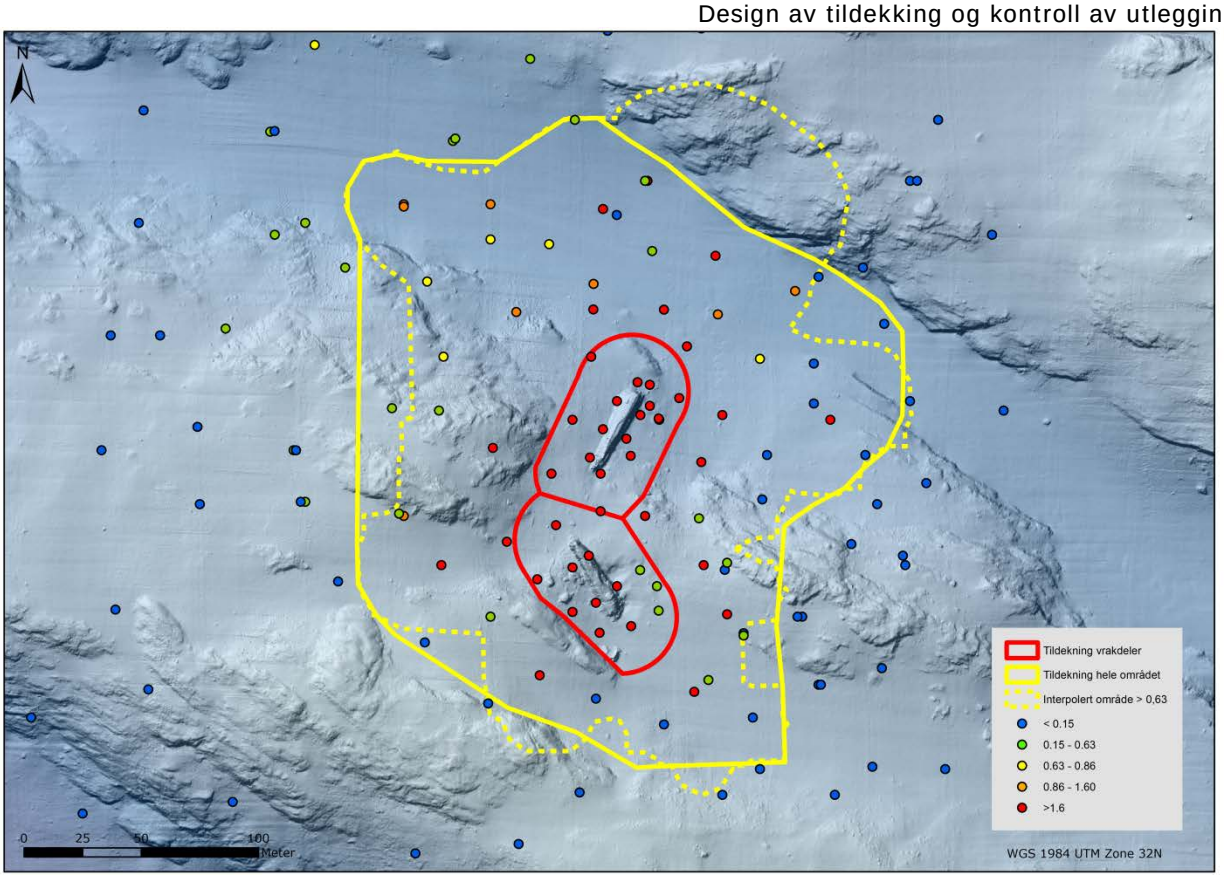
# 2 AREAL SOM SKAL TILDEKKES

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.

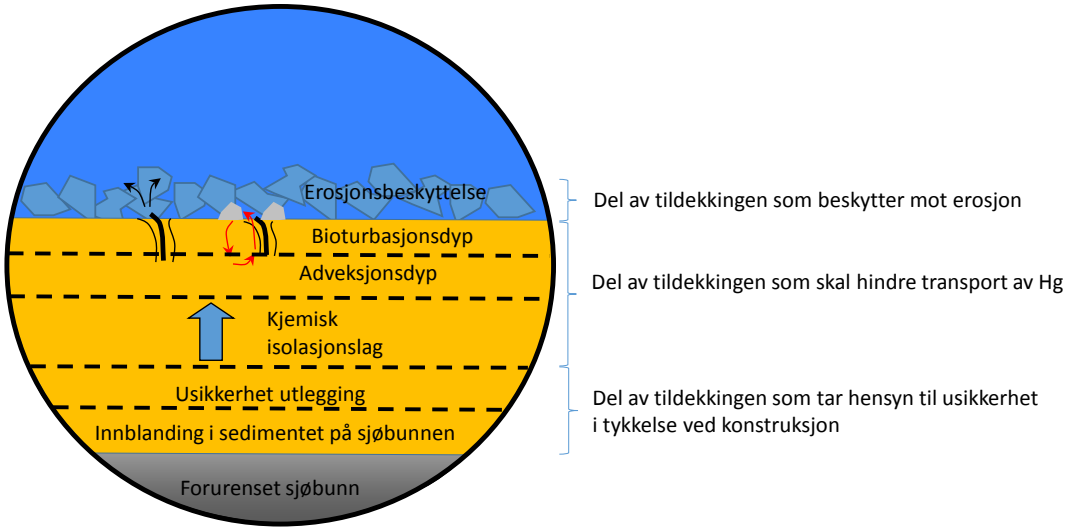
Det er to områder med tildekking som må designes:

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.

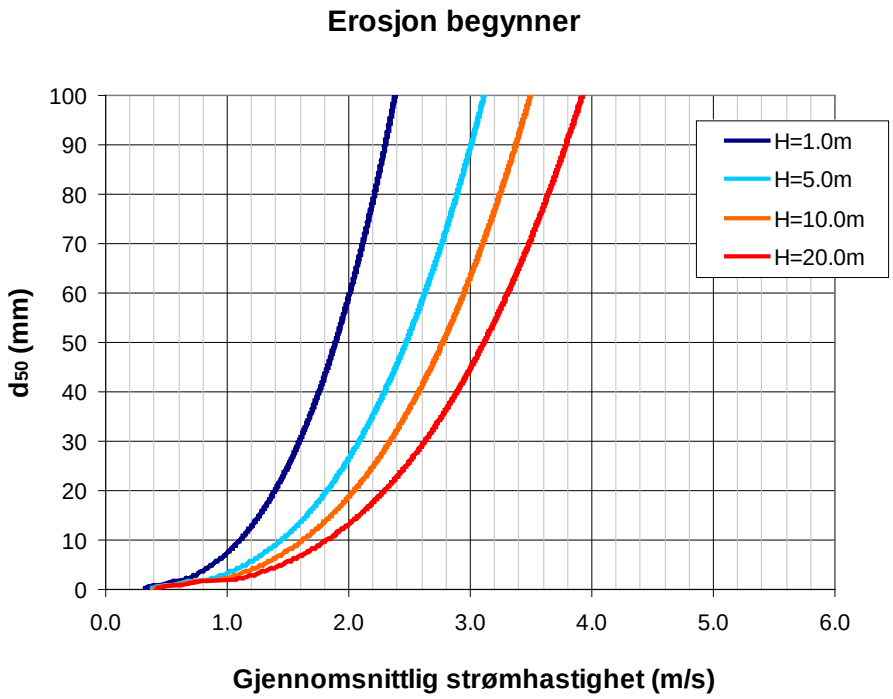
Dette er gjort fordi det i dette prosjektet ansees som vesentlig å etablere tilstrekkelig sikkerhetsmargin for at tiltaket beskytter miljøet mot forurensingen i området like ved vraket.

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).

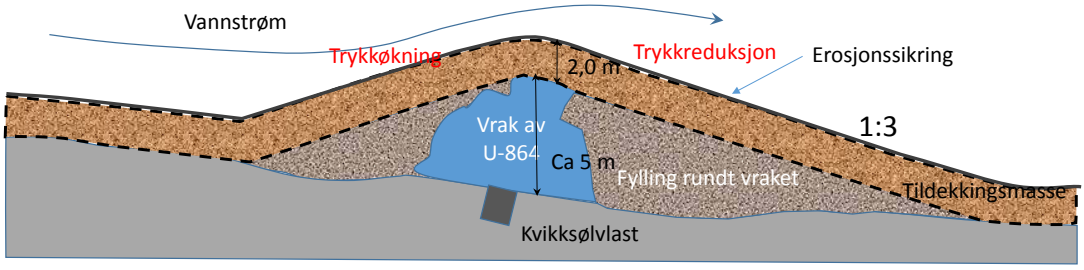
Konklusjon: Bioturbasjonslagets tykkelse settes til 15 cm i hele tiltaksområdet (konservativt).

## 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.

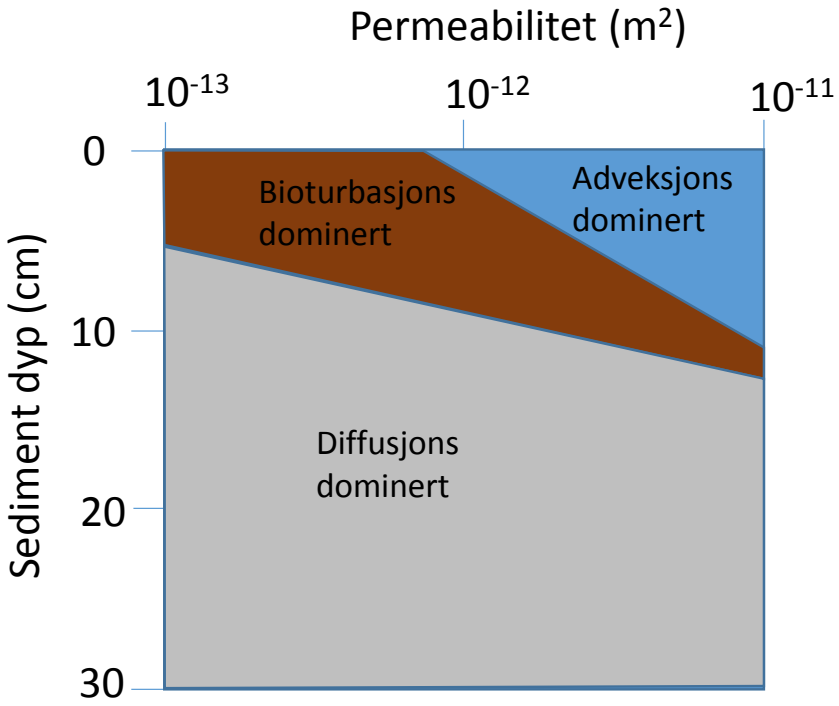
For at adveksjonlaget skal oppnå en hydraulisk ledningsevne på lavere enn $10^{-4}$ cm/s må det bestå av masser med $d_{10}$ < 0,01 mm (betyr at 10 % av materialet er mindre enn 0,01 mm). Det betyr at materialet i hele tildekkingen bør bestå av subbus med mye finstoff (0 – 2 eller 0 – 4 mm).

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.

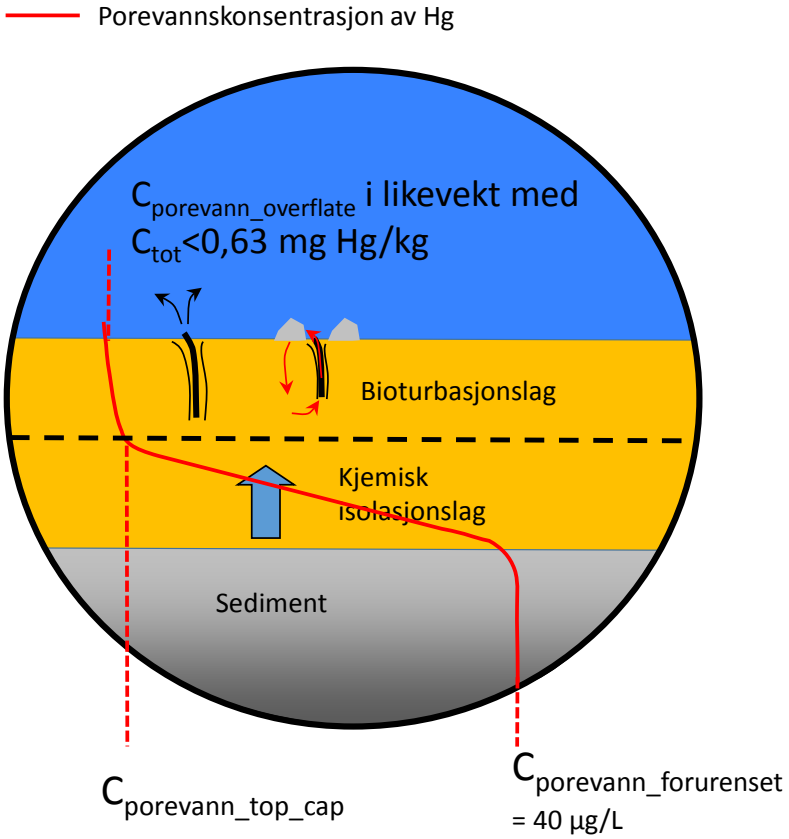
Massene bør ha en hydraulisk ledningsevne som er mindre enn $10^{-2}$ cm/s. Dette kan oppnås ved å bruke sandige masser eller subbus med en del finstoff med $d_{10}$ < 0,1 mm.

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:*<br>*Lav-permeabelt lag (leirbasert adveksjonslag)* | *Alt. B:*<br>*Aktiv tildekking med sorpsjon av Hg* | *Alt. C:*<br>*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.

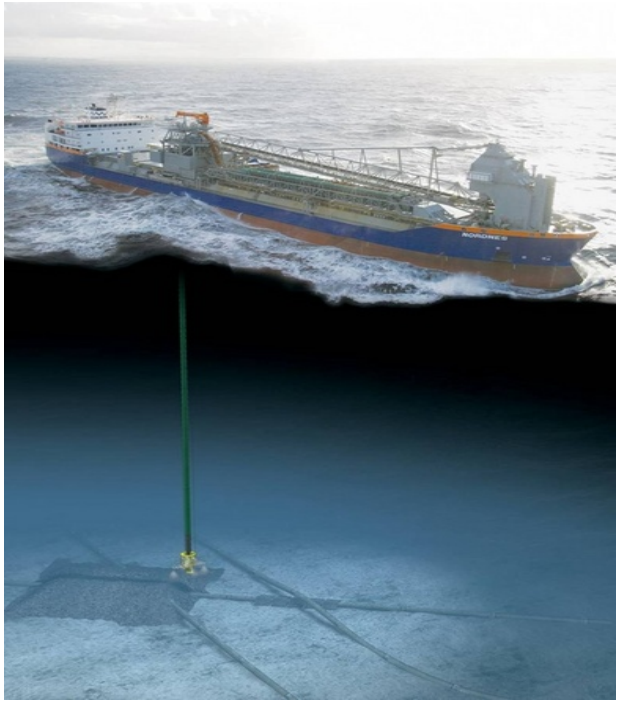
Merknad: For alternativet med heving av last vil det i forkant bli lagt et beskyttende lag på bunnen langs kjølen der hvor man vil gå inn for å hente ut kvikksølvet. Det vil være enten en geotekstilduk eller et sandlag. Hensikten er å beskytte dette området mot spredning av kvikksølvforurensede sedimenter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

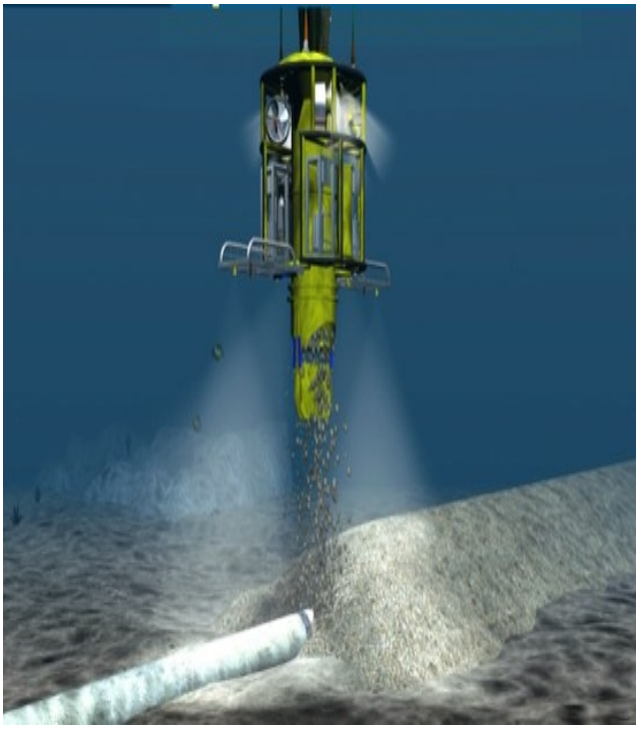
## 7.2 Utstyr til plasseringen av tildekkingsmasser

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

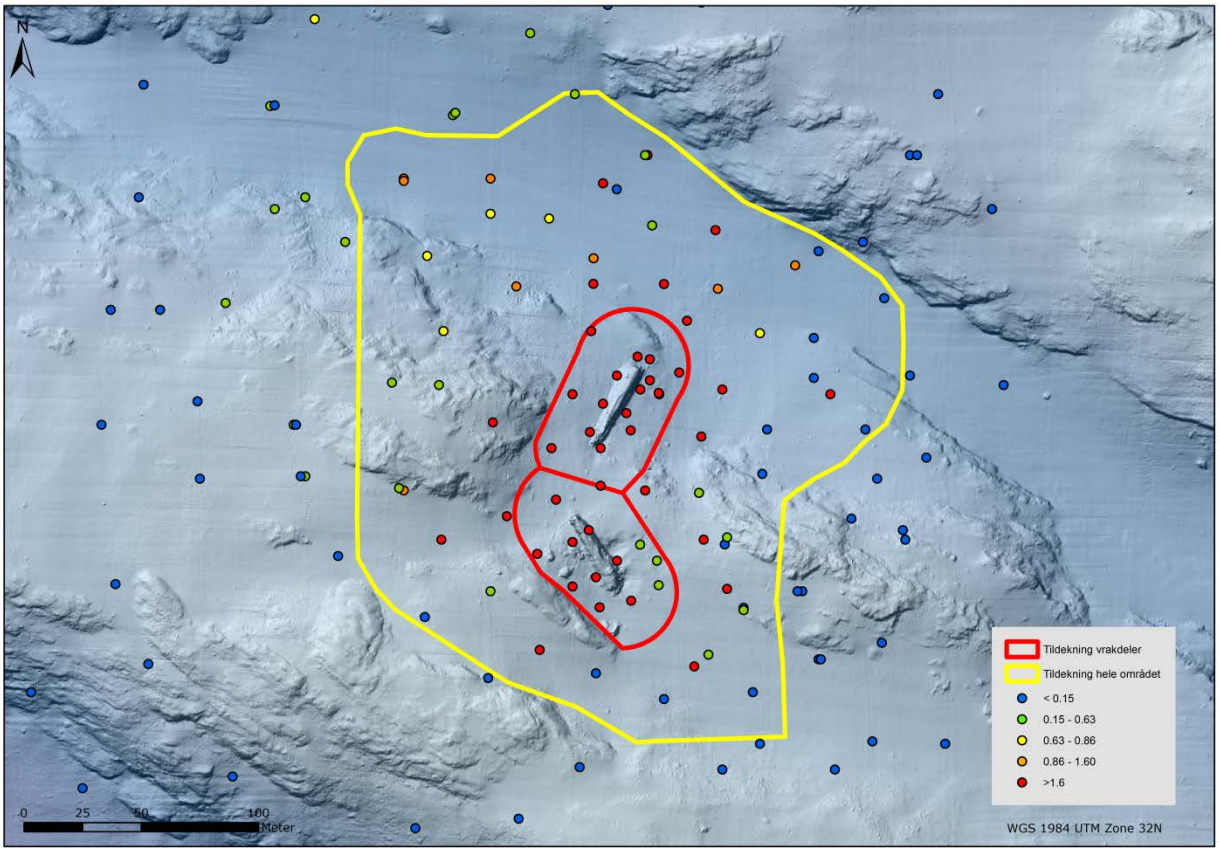
Rekkefølgen på tildekkingen i resten av det forurensede området er følgende:

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.

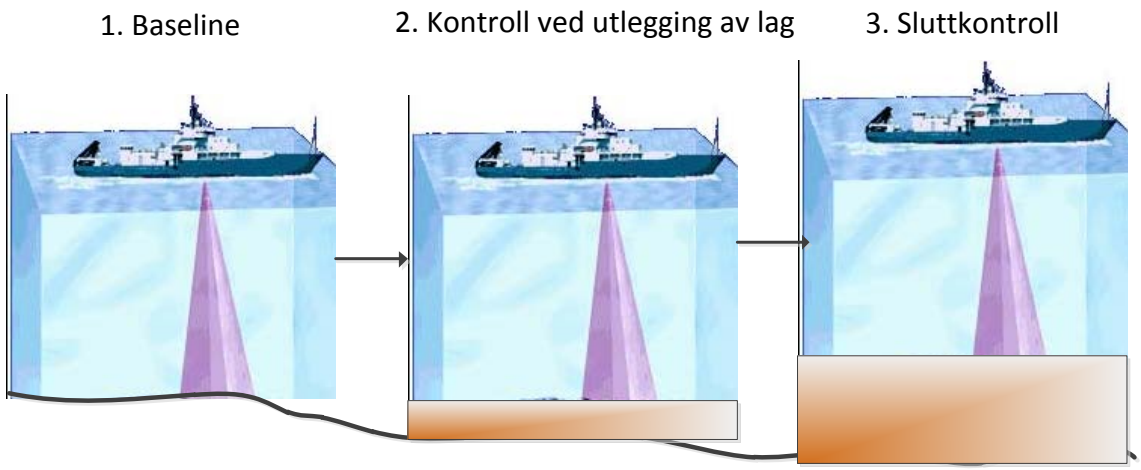
Andre feilkilder er relatert til setninger av sjøbunn og tildekkingsmasse som:

- 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:

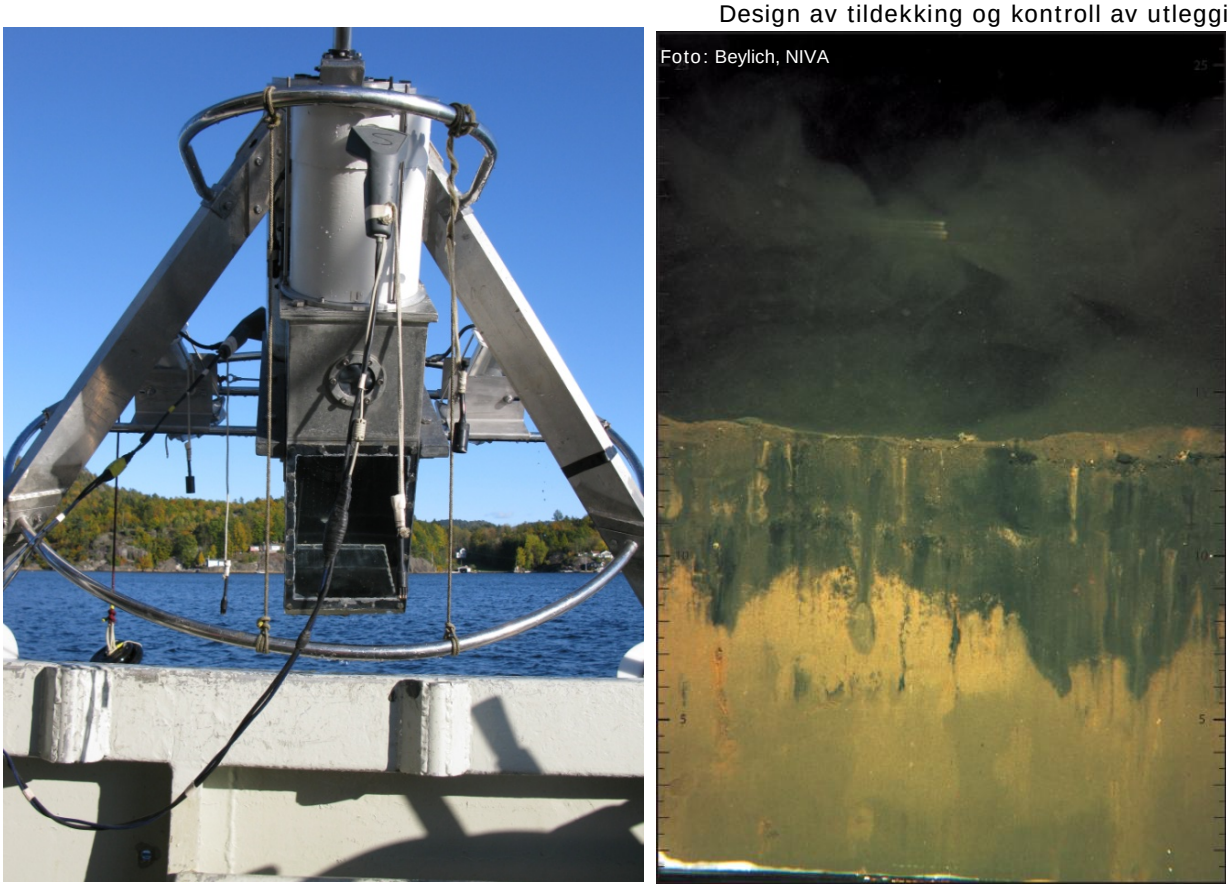
- Oppmåling av tiltaksområdet før tiltaket starter (baseline). Målingene før tiltaket starter skal være av høy og samme kvalitet som målingene som planlegges under og etter tiltaket
- Oppmålinger etter utlegging av ulike lag, altså underveis i tiltaket, som kontroll på at utlekkingen er i henhold til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

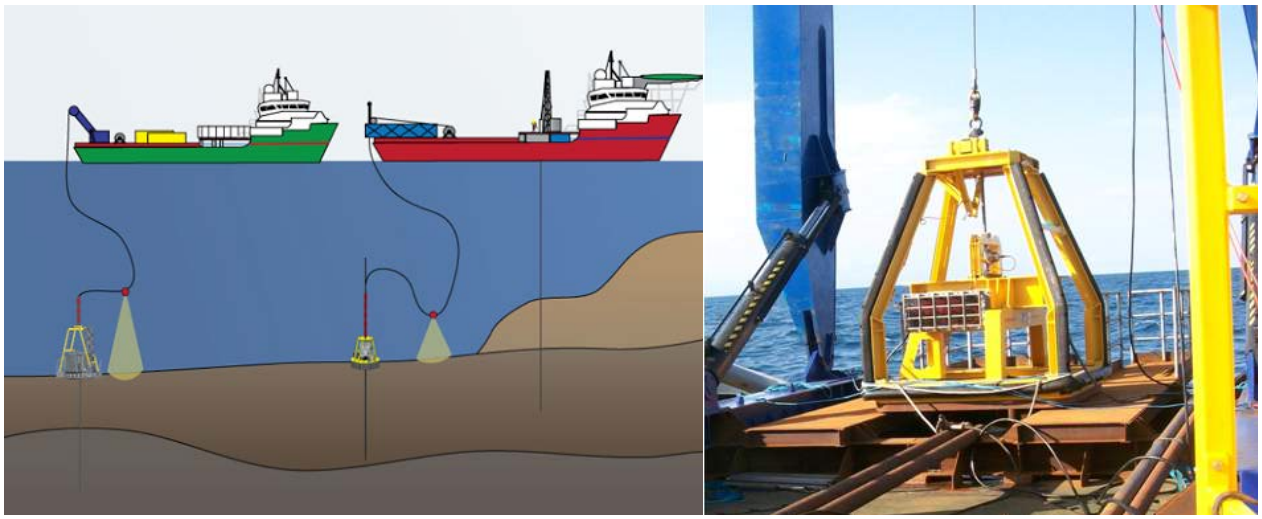
Metoden kan derfor brukes til å kontrollere tykkelsen av de første lagene med tildekking som legges ut ved U-864, dersom tildekkingen blir lagt ut i tilstrekkelig tynne lag. For tildekkingslag som er tynnere enn 15 cm, ansees denne metoden som mer nøyaktig en målestaver. Bruk av SPI kamera kan benyttes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

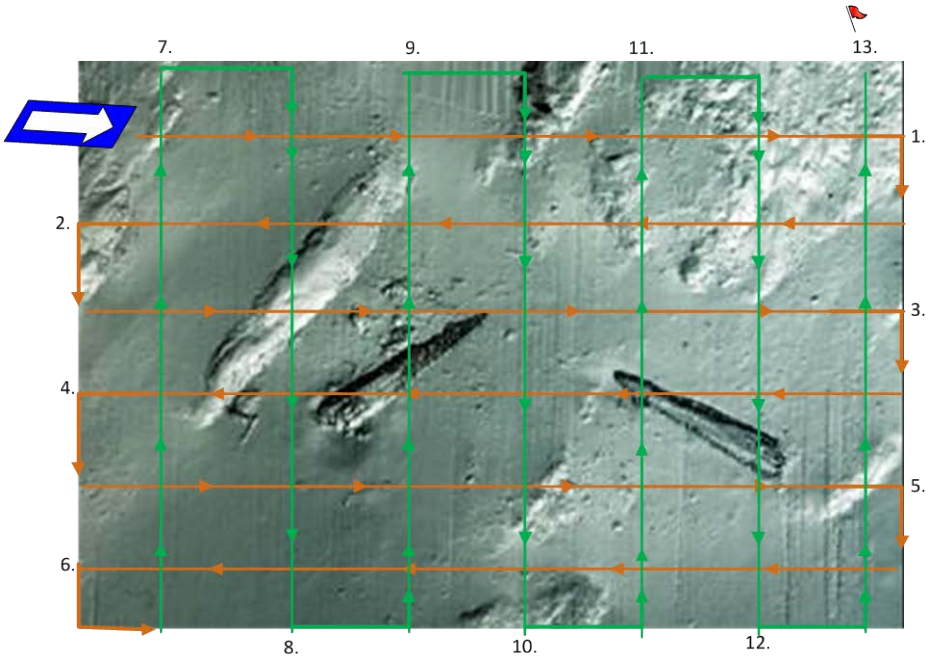
Poretrykksmålere kan derfor plasseres i grunnen under tildekkingen for å overvåke denne poretrykksoppbyggingen og for å kunne avbryte tildekkingen dersom stabiliteten svekkes slik at den ikke lenger er tilfredsstillende. Poretrykksmålerne utstyres med dataoverføring til land for online overvåkning av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



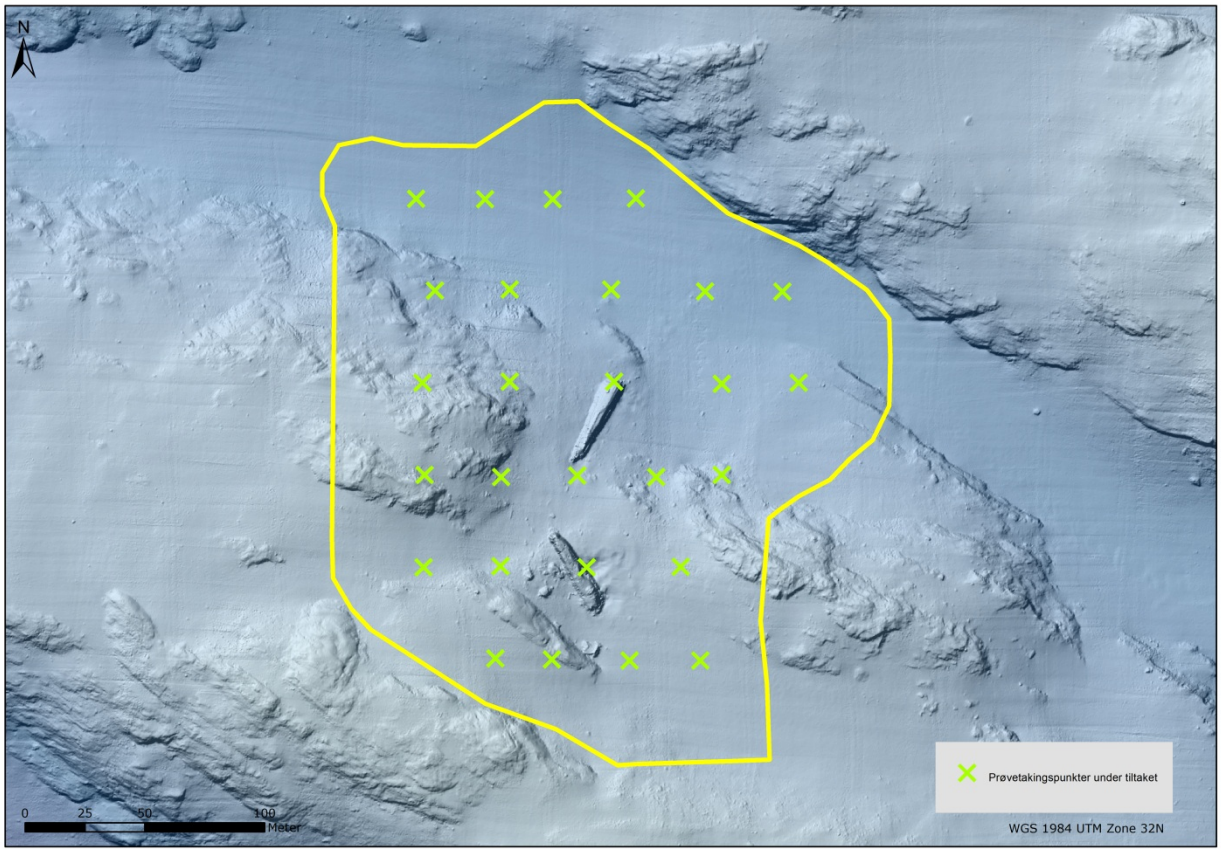

**Figur 12:** Konseptskisse for grid for ROV.

## 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

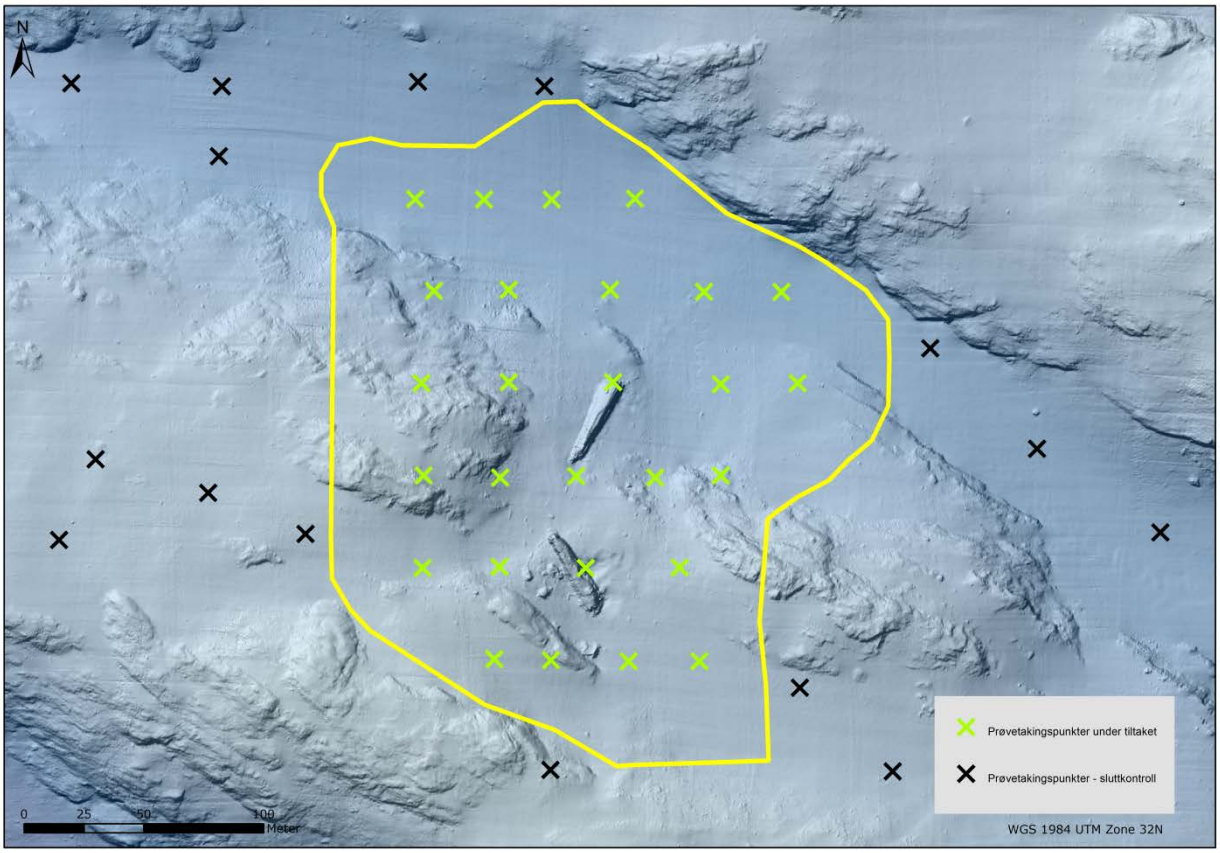
Prøvetaking av overflatesediment og porevann gjøres som en kontroll på konsentrasjoner av kvikksølv i endelig topplag av sedimentet. Denne type prøvetaking er tidligere beskrevet i DNV (2008). Denne prøvetakingen må gjøres før etableringen av erosjonslaget.

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.

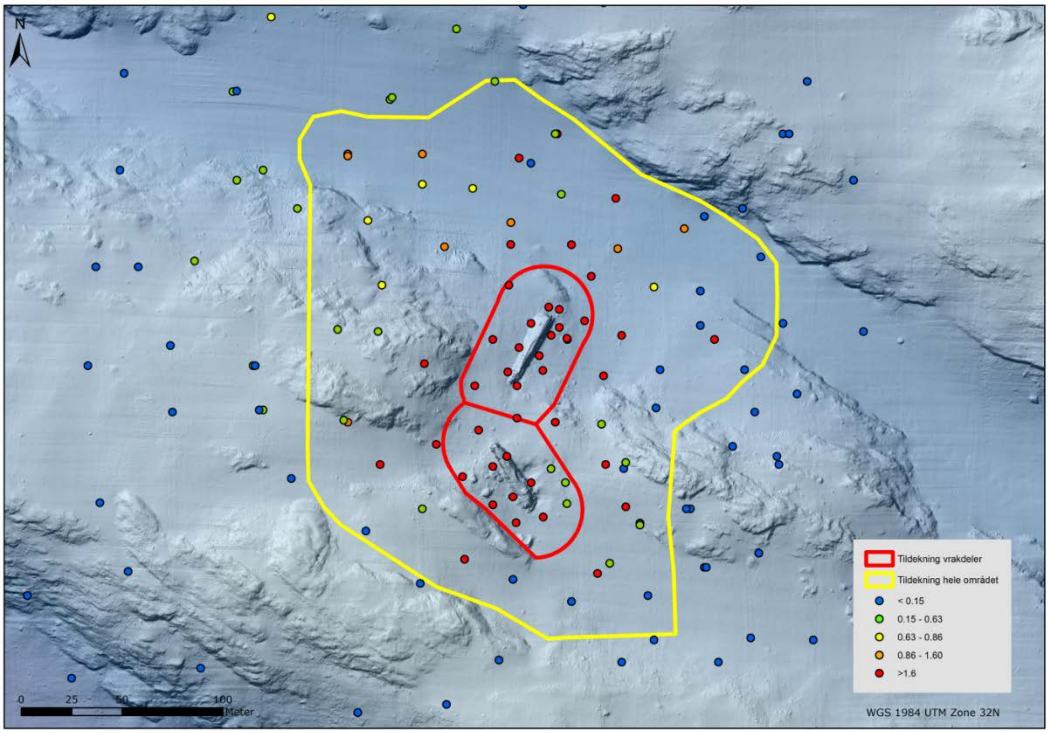
Dette notatet beskriver design av tykkelse på tildekkingen av U-864 og kvikksølv-forurenset sediment utenfor vraket.

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:

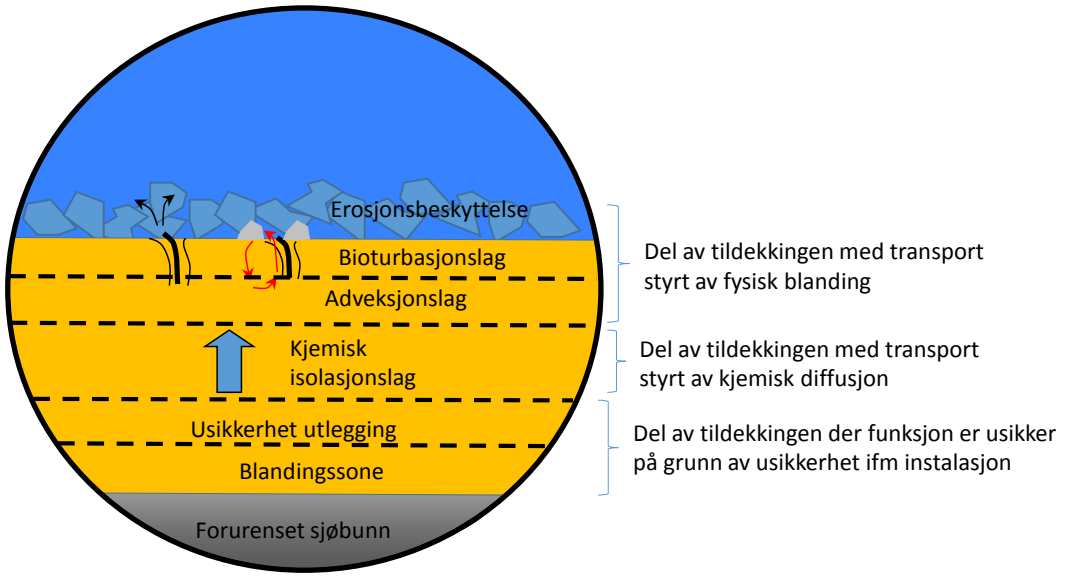
1. Sammensynkning hindres ved å fylle masser inn i vraket før dette tildekkes.
2. Tildekking repareres dersom nødvendig etter en sammensynkning av skroget. Dette forutsetter overvåkning av tildekkingen med tanke på å observere når skroget synker sammen.
3. Det dekkes til med nok masse over vraket slik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

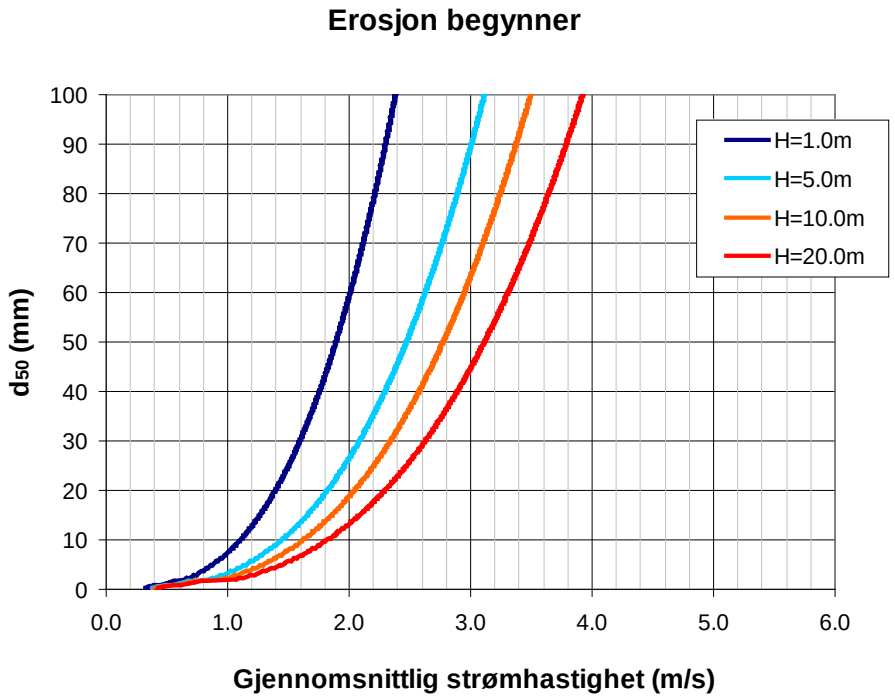



*Figur 2. Illustrasjon av designlag i tildekkingen av forurensingen i og ved vraket av U-864.*

### *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.**

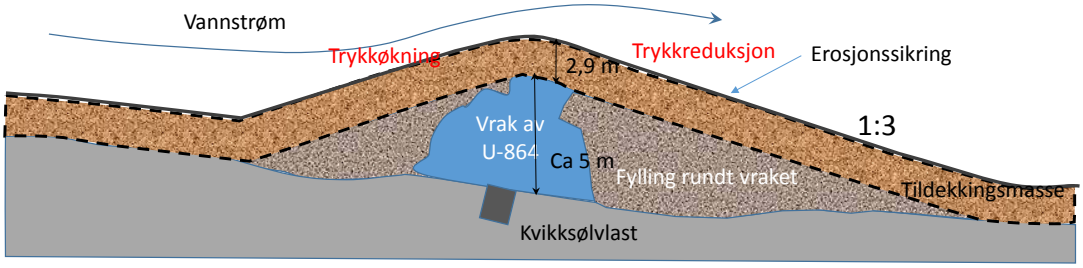
## *3.4 Adveksjonslag*

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).*

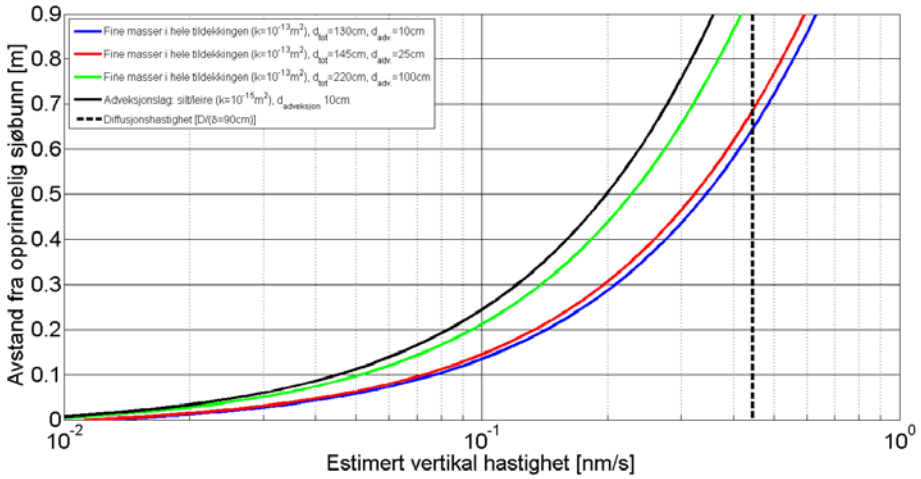
Trykkforskjellen ($\Delta p$) over fyllingene rundt vrakdelene er beregnet med ligningen:

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

Der formfaktoren, $C_D$. er lik 1, $\rho$ 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*

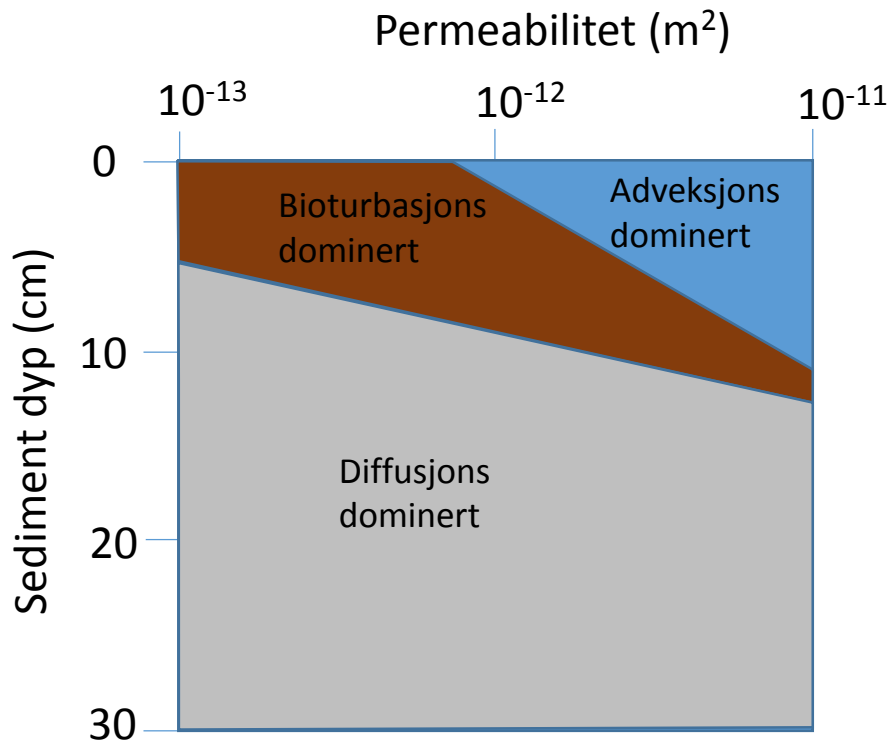
Tilstrekkelig reduksjon av adveksjonstransporten i isolasjonslaget kan også oppnås med et adveksjonslag bestående av et 10 cm tykt lag med materialer som har permeabilitet lavere enn $10^{-15}$ $m^2$ (hydraulisk ledningsevne $<10^{-6}$ cm/s). Dette er en permeabilitet som bare oppnås med masser med betydelig 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.

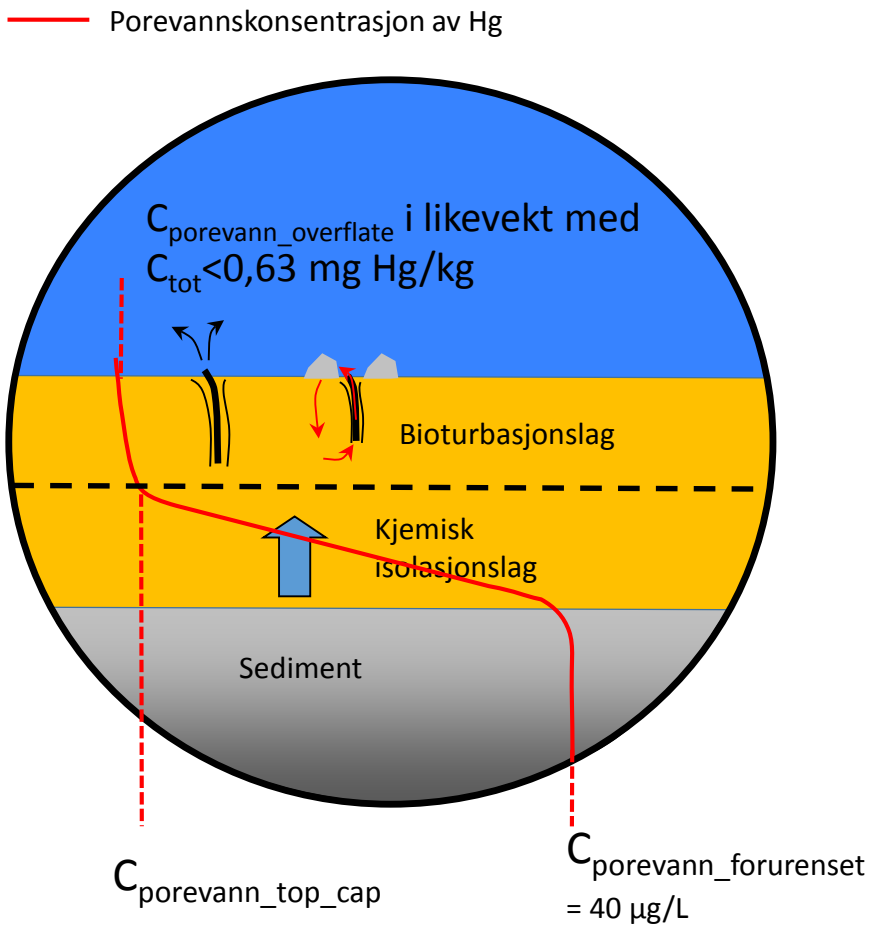
Erosjonsbeskyttelseslaget vil sannsynligvis være for grovt for å tilfredsstille kravene til permeabilitet i adveksjonslaget, mens massene i bioturbasjonslaget godt kan bygges opp med det samme type masser som adveksjonslag slik at tykkelse avsatt til adveksjonslaget kan settes til 40 cm minus tykkelse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

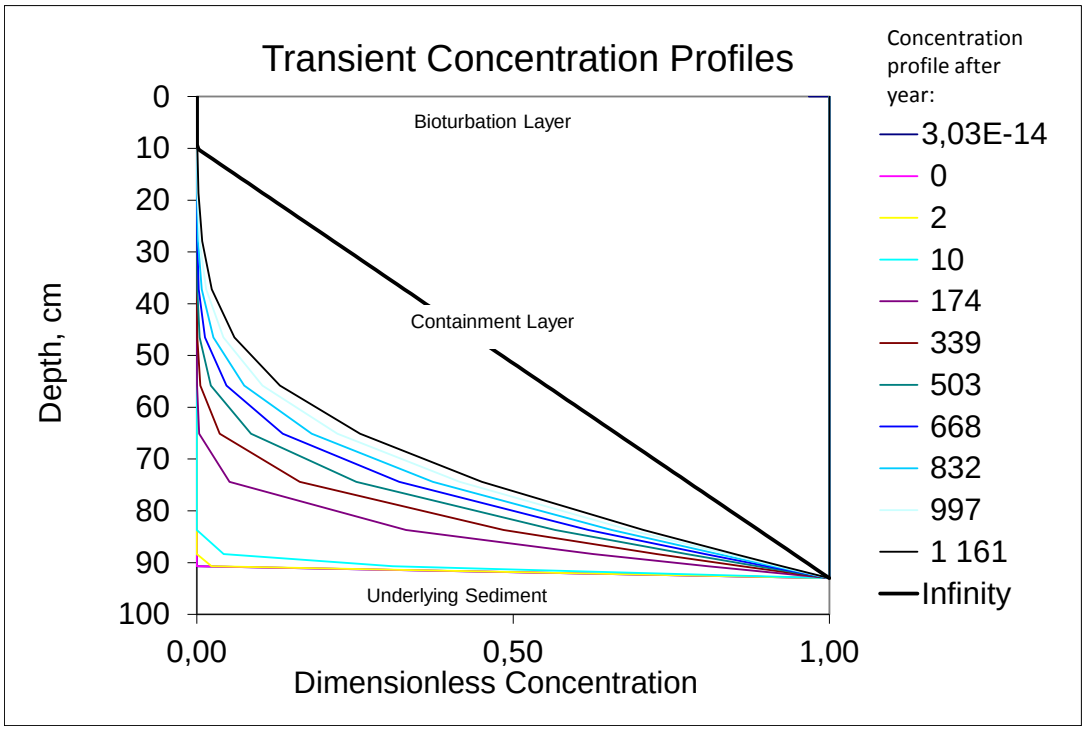
I den delen av tildekkingslaget som ikke påvirkes av bioturbasjon eller vannstrøm og trykkforskjeller vil diffusjon være den viktigste mekanismen for transport av Hg (det kjemiske isolasjonslaget). Hastigheten av Hg-diffusjon gjennom tildekkingen vil bestemme hvor mye Hg som tilføres overflatesedimentet 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 (Miljødirektoratet 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, log$K_{DOC}$ | 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), $\lambda_1$ | 0,00 | $yr^{-1}$ | |
| Bioturbation layer decay rate (porewater basis), $\lambda_2$ | 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,$\rho_{DOC}$ | 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, $\varepsilon$ | 0,4 | | |
| Particle Density, $\rho_P$ | 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 | |

**Output-Steady State Model**

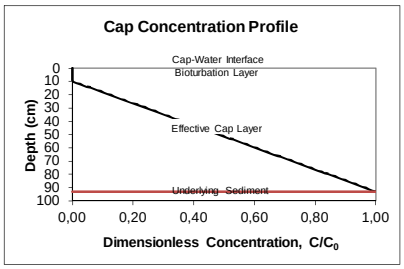
| | | | |
|---|---|---|---|
| Pore water concentration at depth, $C(z)$ | 0,006 | ug/L | |
| Solid concentration at depth of interest, $W(z)$ | 625,0 | ug/kg | |
| Average bioturbation layer loading, $(W_{bio})_{avg}$ | 625 | ug/kg | |
| Flux to overlying water column,$J$ | 394 | $ug/m^2/yr$ | |
| Cap-bioturbation 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 |
| $\beta$ = SQRT($Pe_1^2/4+Da$) | 0,00 |
| Bioturbation layer Peclet no., $Pe_2$ | 0,00 |
| Bioturbation layer Damkohler no.,$Da_2$ | 0,00 |
| $\gamma$ = 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, $\alpha$ | 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 |




**Steady State Model Equations**

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

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

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

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

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

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

*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, log$K_{DOC}$ | 6,63 | log L/kg | |
| Water diffusivity, $D_w$ | 8,8E-06 | $cm^2/s$ | Konservativt, ca 5. |
| Cap decay rate (porewater basis), $\lambda_1$ | 0,00 | $yr^{-1}$ | |
| Bioturbation layer decay rate (porewater basis), $\lambda_2$ | 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,$\rho_{DOC}$ | 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 |
| 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, $\varepsilon$ | 0,4 | |
| Particle Density, $\rho_P$ | 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 |

**Output-Steady State Model**

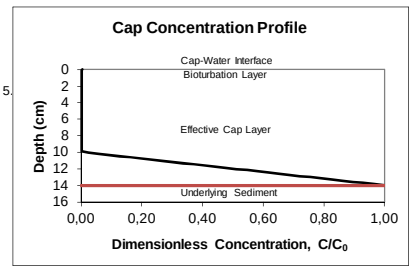
| | | | |
|---|---|---|---|
| Pore water concentration at depth, $C(z)$ | 0,006 | ug/L | |
| Solid concentration at depth of interest, $W(z)$ | 624,6 | ug/kg | |
| Average bioturbation layer loading, $(W_{bio})_{avg}$ | 625 | ug/kg | |
| Flux to overlying water column,$J$ | 394 | $ug/m^2/yr$ | |
| Cap-bioturbation 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 |
| $\beta$ = SQRT($Pe_1^2/4+Da$) | 0,00 |
| Bioturbation layer Peclet no., $Pe_2$ | 0,00 |
| Bioturbation layer Damkohler no.,$Da_2$ | 0,00 |
| $\gamma$ = 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, $\alpha$ | 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 |




**Steady State Model Equations**

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

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

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

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

10 cm bioturbasjonslag resten isolasjonslag (4 cm)

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

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

*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*

## Dokumentinformasjon/*Document information*

| | |
|---|---|
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| **Dokumenttype/*Type of document***<br>Teknisk notat / Technical Note<br>**Distribusjon/*Distribution***<br>Begrenset/Limited | **Dato/*Date***<br>2014-04-28<br>**Rev.nr.&dato/*Rev.No.&date***<br>0 |
| **Oppdragsgiver/*Client***<br>Det Norske Veritas | |
| **Emneord/*Keywords***<br>Forurensing på sjøbunnen, Tildekking | |

## Stedfesting/*Geographical information*

| | |
|---|---|
| **Land, fylke/*Country, County*** | **Havområde/*Offshore area*** |
| **Kommune/*Municipality***<br>Fedje | **Feltnavn/*Field name*** |
| **Sted/*Location*** | **Sted/*Location*** |
| **Kartblad/*Map*** | **Felt, blokknr./*Field, Block No.*** |
| **UTM-koordinater/*UTM-coordinates*** | |

## Dokumentkontroll/*Document control*

**Kvalitetssikring i henhold til/*Quality assurance according to* NS-EN ISO9001**

| **Rev./ *Rev.*** | **Revisjonsgrunnlag/*Reason for revision*** | **Egen-kontroll/ *Self review* av/*by:*** | | **Sidemanns-kontroll/ *Colleague review* av/*by:*** | | **Uavhengig kontroll/ *Independent review* av/*by*:** | | **Tverrfaglig kontroll/ *Inter-disciplinary review* av/*by:*** | |
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| **Dokument godkjent for utsendelse/ *Document approved for release*** | **Dato/*Date*** | **Sign. Prosjektleder/*Project Manager*** |
|---|---|---|
| | 28. april 2014 | Espen Eek |

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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 | DNV GL AS |
| Report title: | Geoteknisk vurdering av stabilitet ved tildekking | Project Management & Technical Services Program<br>P.O.Box 300<br>1322 Høvik<br>Norway<br>Tel: +47 67 57 99 00 |

Utført av:
Jan Holme (DNV GL AS)

Revidert av:
Carl Erik Høy-Petersen (DNV GL AS)
Rasmus Tofte Klinkvort (NGI)

Dato: 12.5.2014

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

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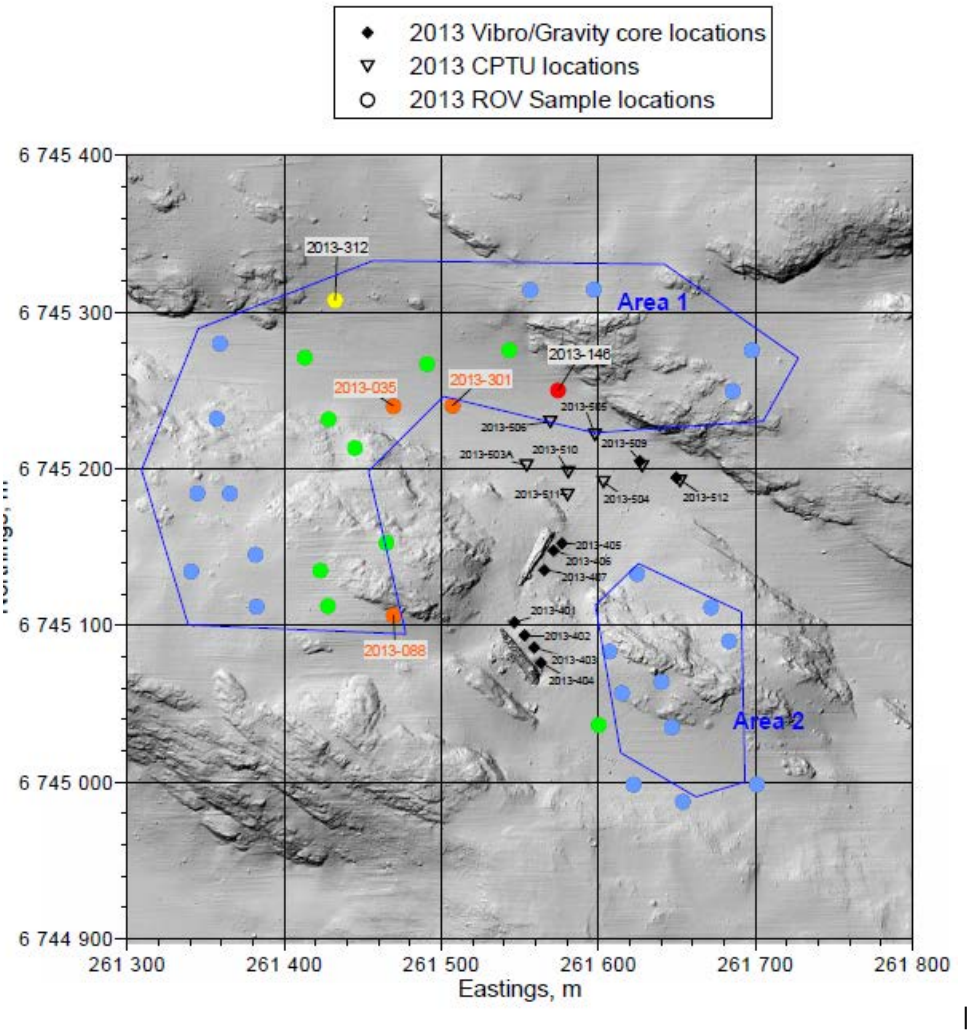
1.2 Geoteknisk stabilitet ved heving av last 4

# 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.

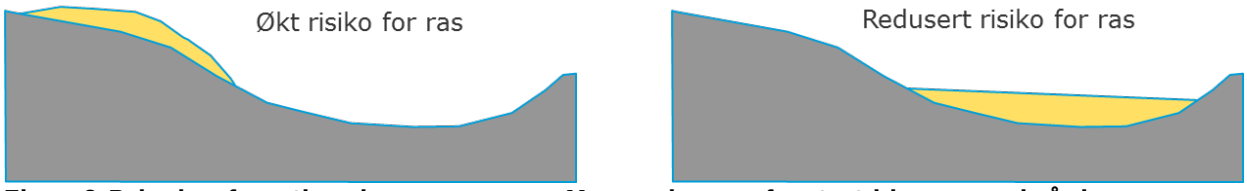
Miljøavdelingene ved NGI og DNVGL har vurdert nærmere design av tildekkingslaget og funnet at tildekkingslaget må justeres, spesielt rundt vrakdelene i forhold til det som ble lagt til grunn i analysesen utført av Geopartner i 2007. Ved vrakdelene er tildekkingslaget blitt økt og lenger vekk fra vrakdelene 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. 80.000$m^3$). 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.12.500$m^3$) med diameter på fallrør ca. 1m. Etter at støttefyllingen er lagt ut, vil det være nødvendig å legge ut ca. 160.000$m^3$ med tildekkings masser.

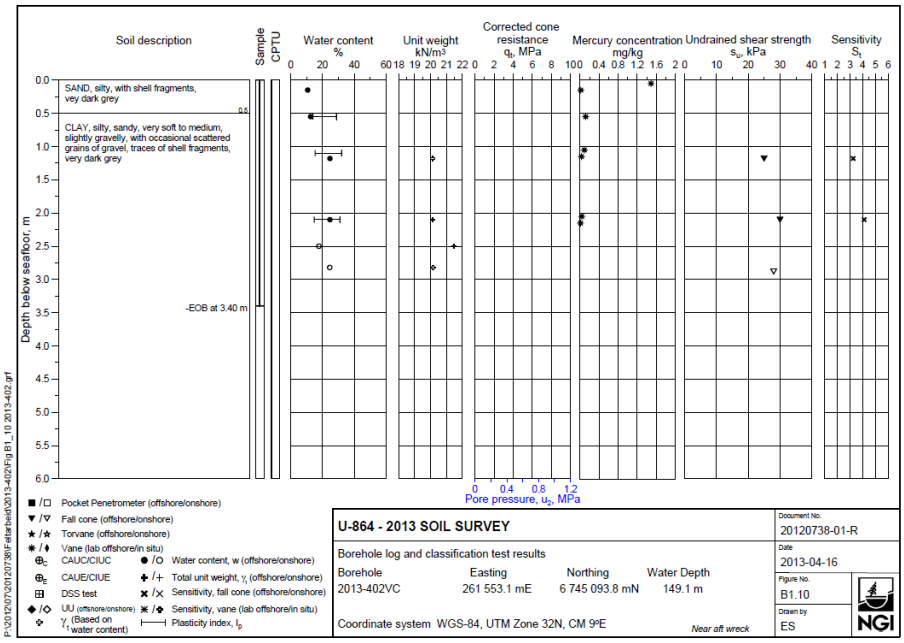



**Figur 3 Spesialskip for utlegging av sand og stein, Van Oord (ref www.vanoord.com).**

## 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.**

Vi vet fortsatt ikke om kjølen har truffet harde morenemasser eller fjell da vrakdelene traff sjøbunnen. Deler av kjølen kan enten være intakt eller ødelagt.

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NGI 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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| Document title: | Geotechnical Report |
| Document No.: | 20120738-01-R |
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# Client

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|---|---|
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| Client's contact person: | Agnete Strømme |
| Contract reference: | PO 3121221 |

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| Project manager: | Egil Solhjell |
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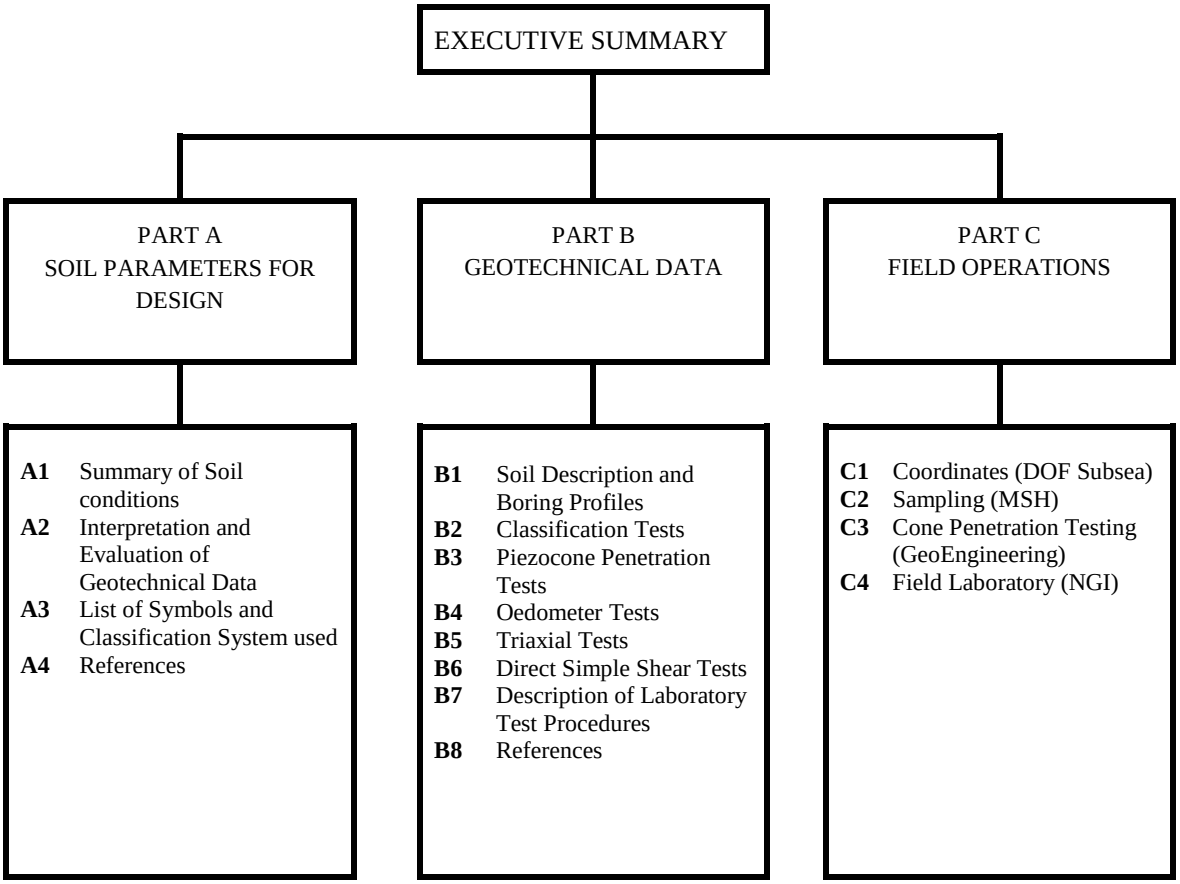
| Reviewed by: | Tom Lunne |

# 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 B
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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 Vicinity map

## 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

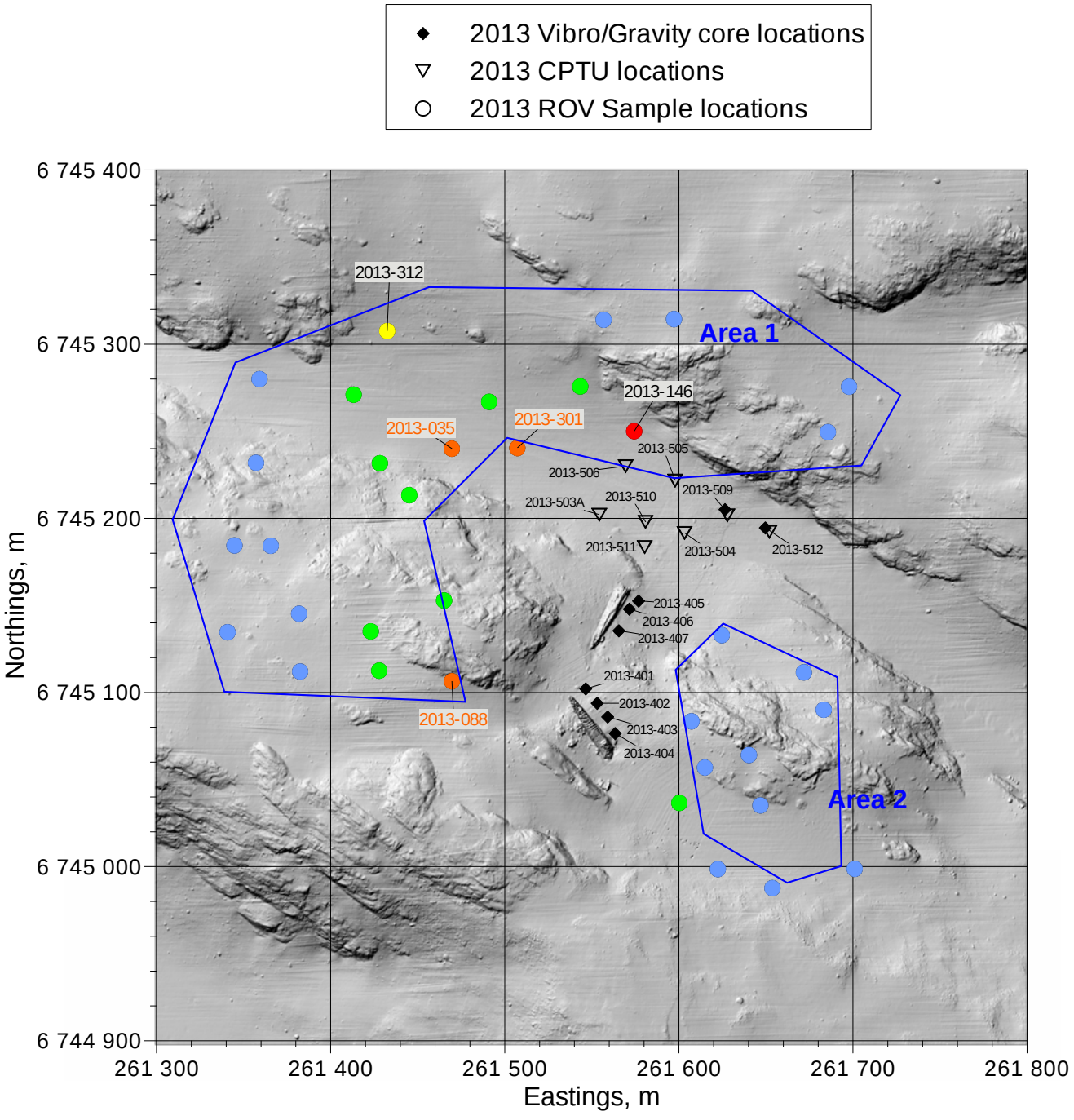
In the 2013 soil investigation following two units was encountered:

- 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

Document No.
20120738-01-R

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, $\gamma$, 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, $\gamma_s$, 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 $s_u^C/\sigma'_v$, 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
$\sigma_{v0}$ = 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 $\phi'$ 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 °, a = 5 kPa (in compression)

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

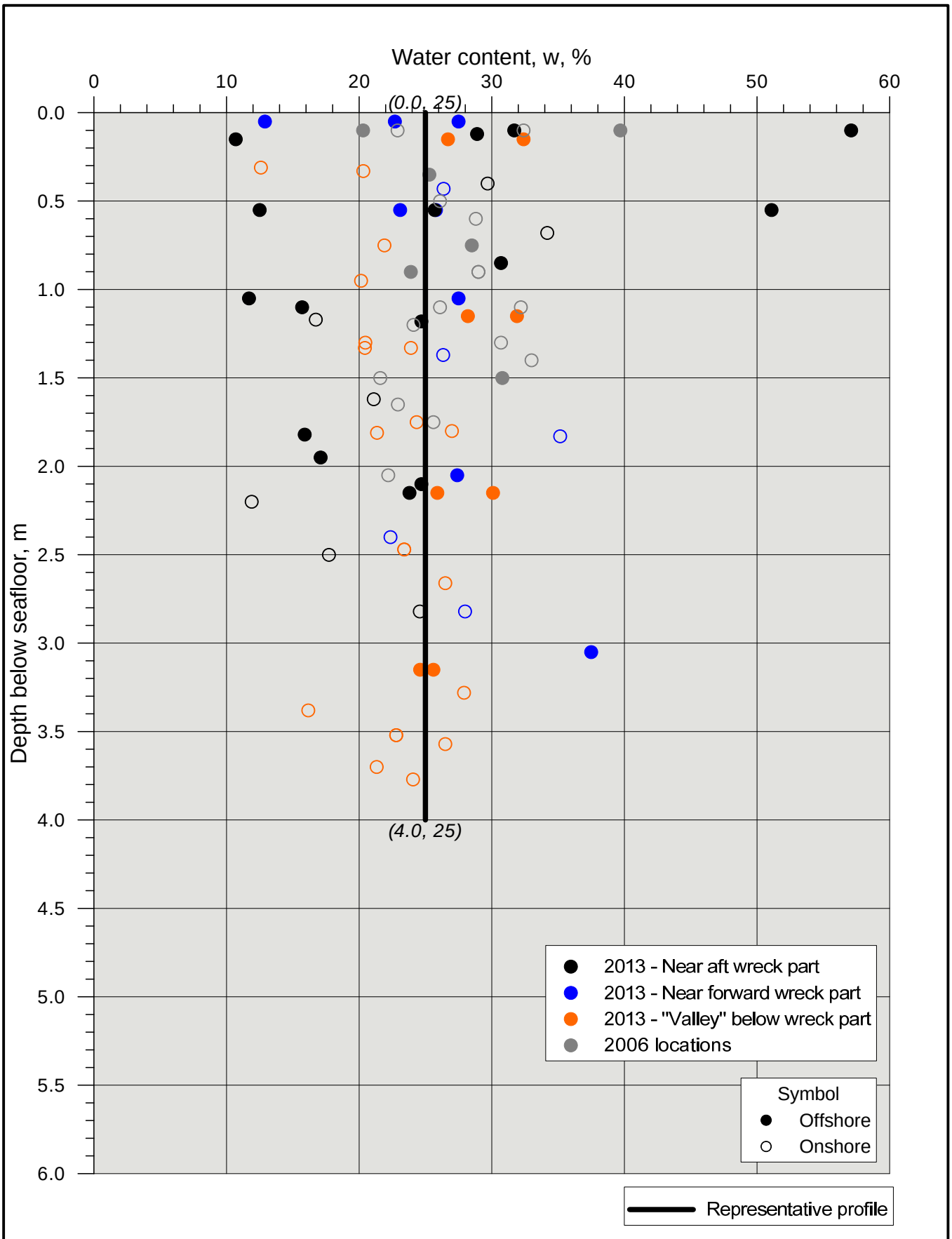
$\varphi_u$' = 31.0°, a = 3.3 kPa (in compression)

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.




Label: *(depth, value)*

P:\2012\07\20120738\Leveransedokumenter\Rapport\20120738-01-R U-864\Figures\A2_01, water content versus depth.grf

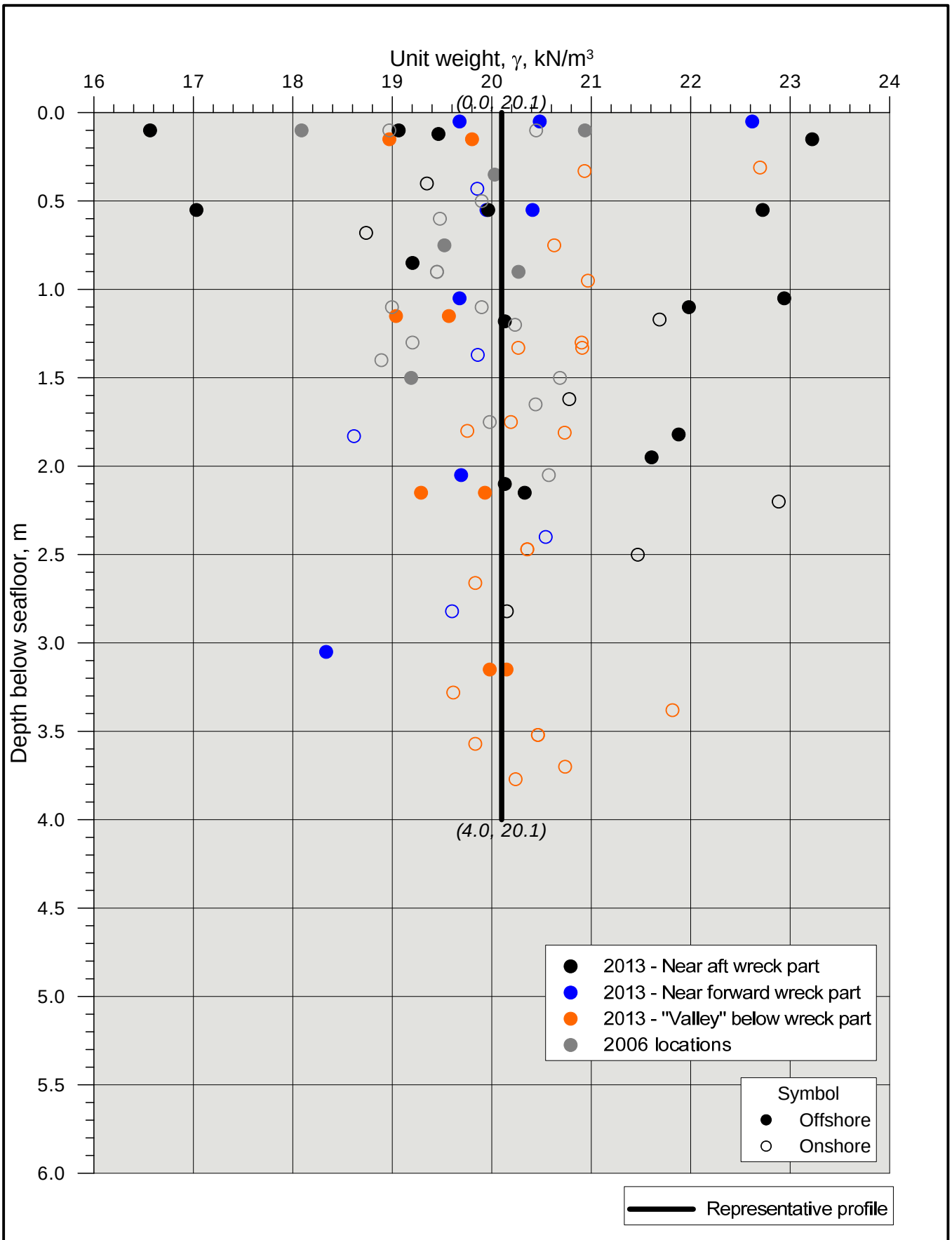
**U-864 - 2013 SOIL SURVEY**

Water content versus depth.

All locations (performed in 2006 and in 2013).

| | |
|---|---|
| Document No. | 20120738-01-R |
| Date | 2013-03-20 |
| Figure No. | A2.1 |
| Drawn by | ES |

NGI




Label: *(depth, value)*

**U-864 - 2013 SOIL SURVEY**

Unit weight versus depth (based on water content).

All locations (performed in 2006 and in 2013).

| | |
|---|---|
| Document No. | 20120738-01-R |
| Date | 2013-03-20 |
| Figure No. | A2.2 |
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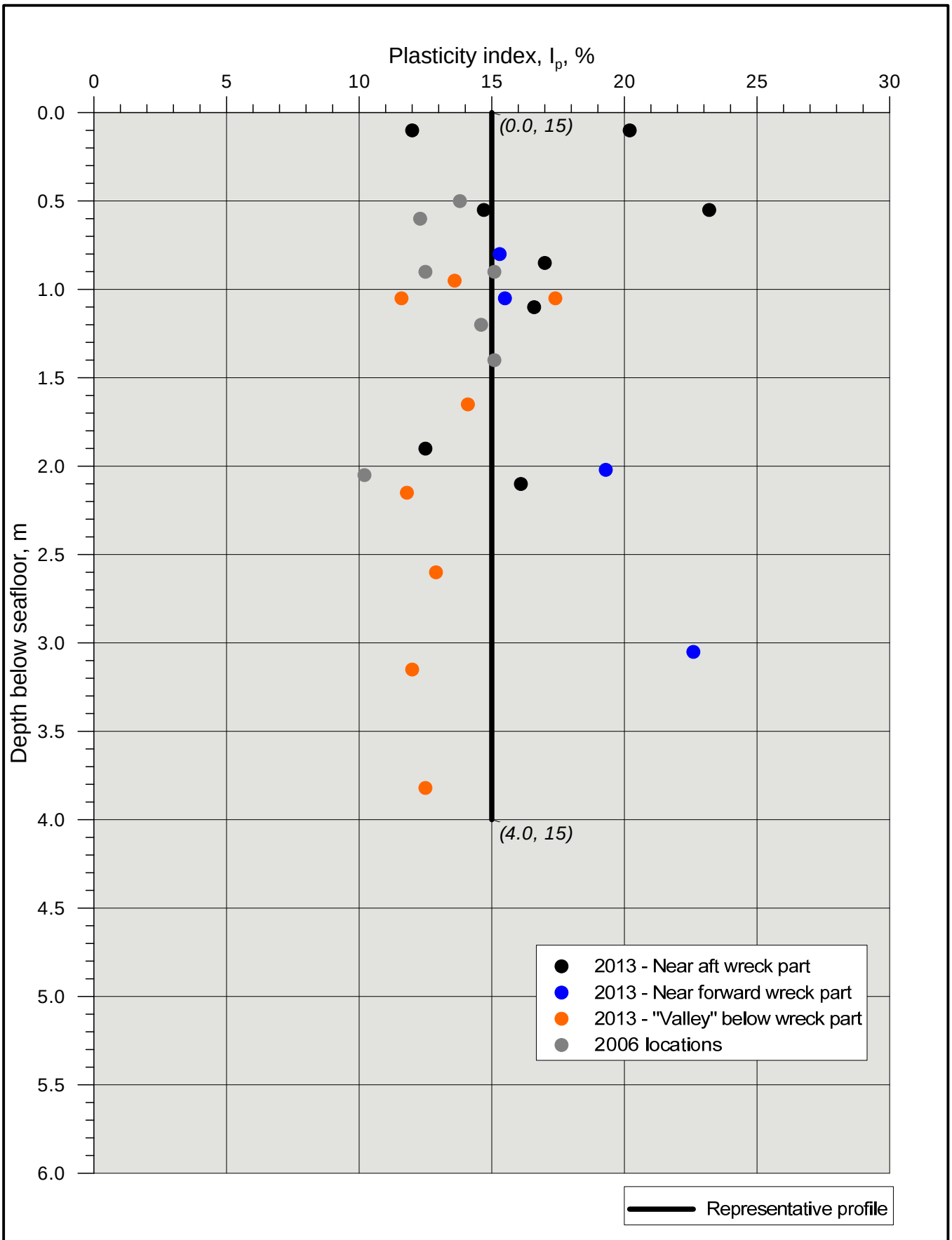


Label: *(depth, value)*

**U-864 - 2013 SOIL SURVEY**

Plasticity index versus depth.

All locations (performed in 2006 and in 2013).

| | |
|---|---|
| Document No. | 20120738-01-R |
| Date | 2013-03-20 |
| Figure No. | A2.3 |
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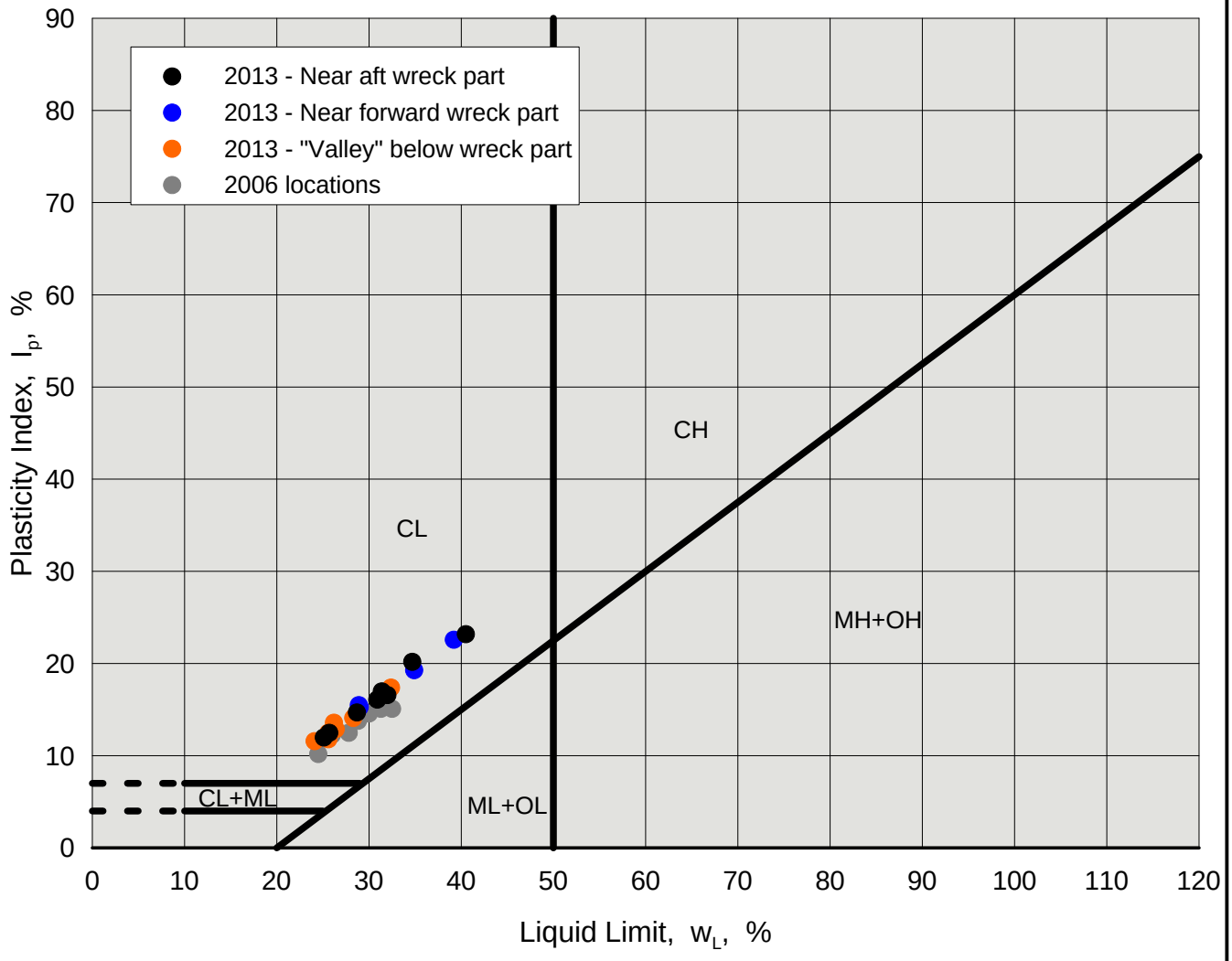


UNIFIED SOIL CLASSIFICATION

| | |
|---|---|
| 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).

Document No. 20120738-01-R

Date 2013-03-20

Figure No. A2.4

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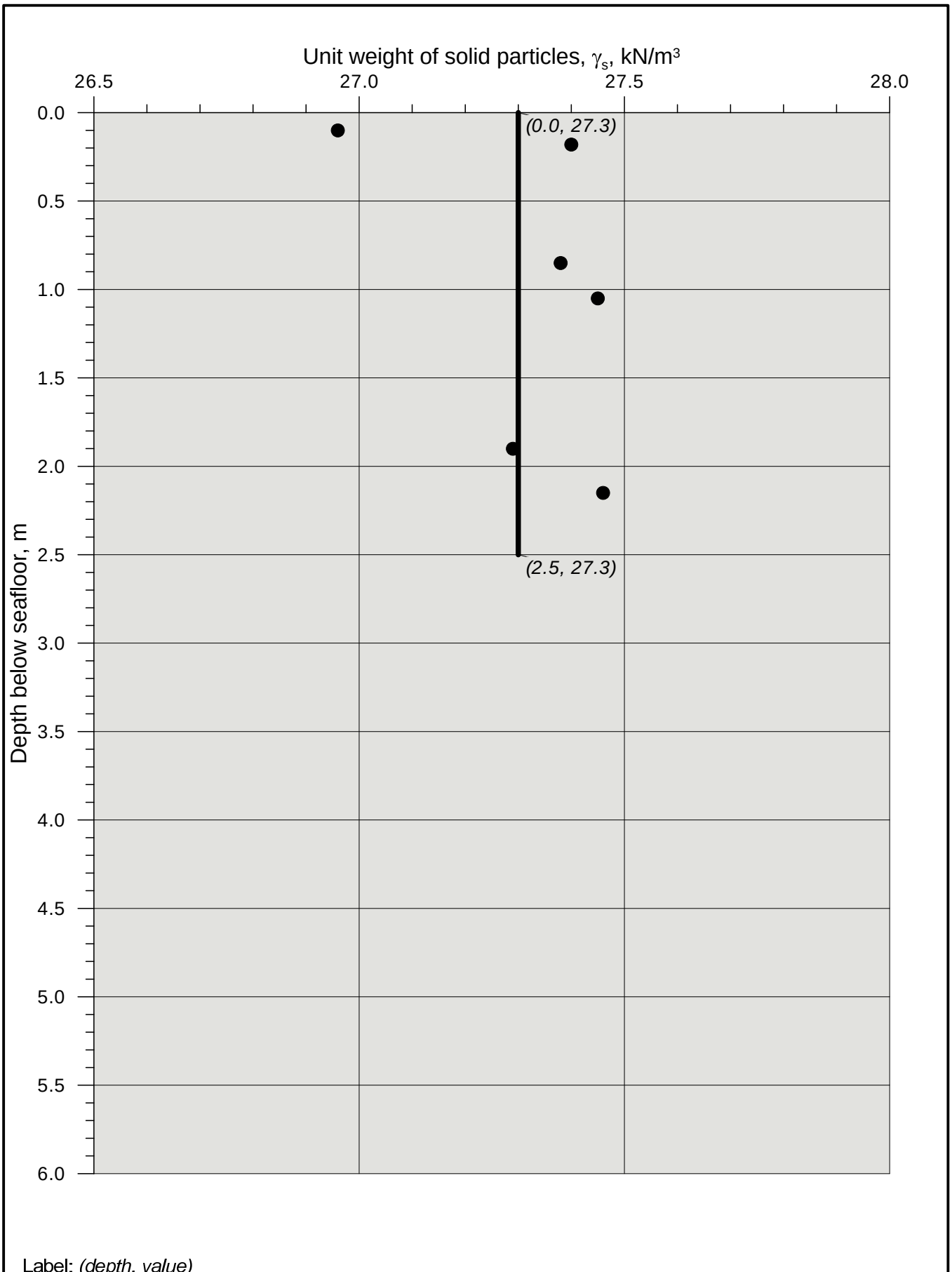


Label: *(depth, value)*

**U-864 - 2013 SOIL SURVEY**

Unit weight of solid particles versus depth.

All locations (performed in 2013).

| | |
|---|---|
| Document No. | 20120738-01-R |
| Date | 2013-03-20 |
| Figure No. | A2.5 |
| Drawn by | ES |

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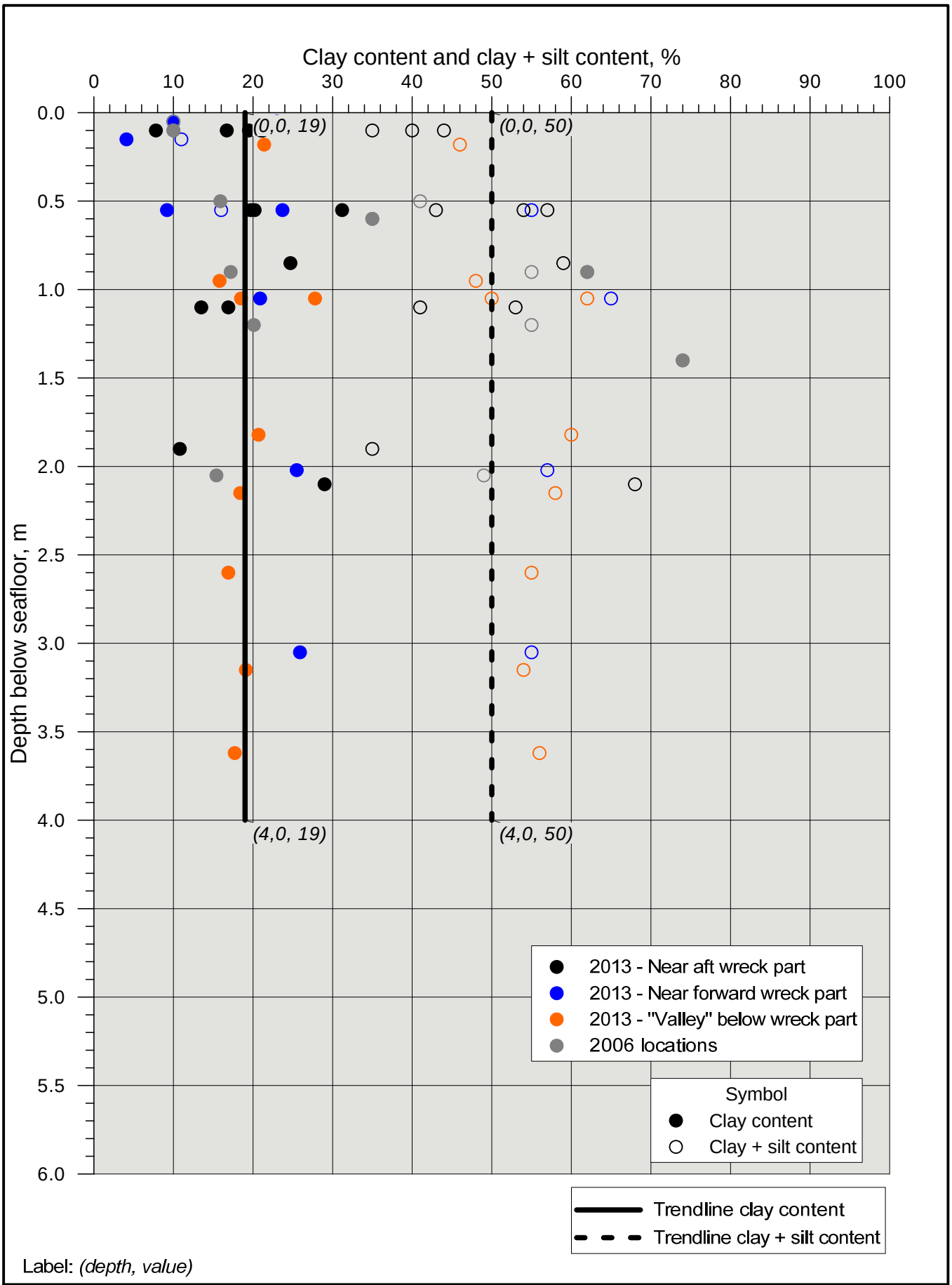


Label: *(depth, value)*

**U-864 - 2013 SOIL SURVEY**

Clay content and clay + silt content versus depth.

All locations (performed in 2006 and in 2013).

| | |
|---|---|
| Document No. | 20120738-01-R |
| Date | 2013-03-20 |
| Figure No. | A2.6 |
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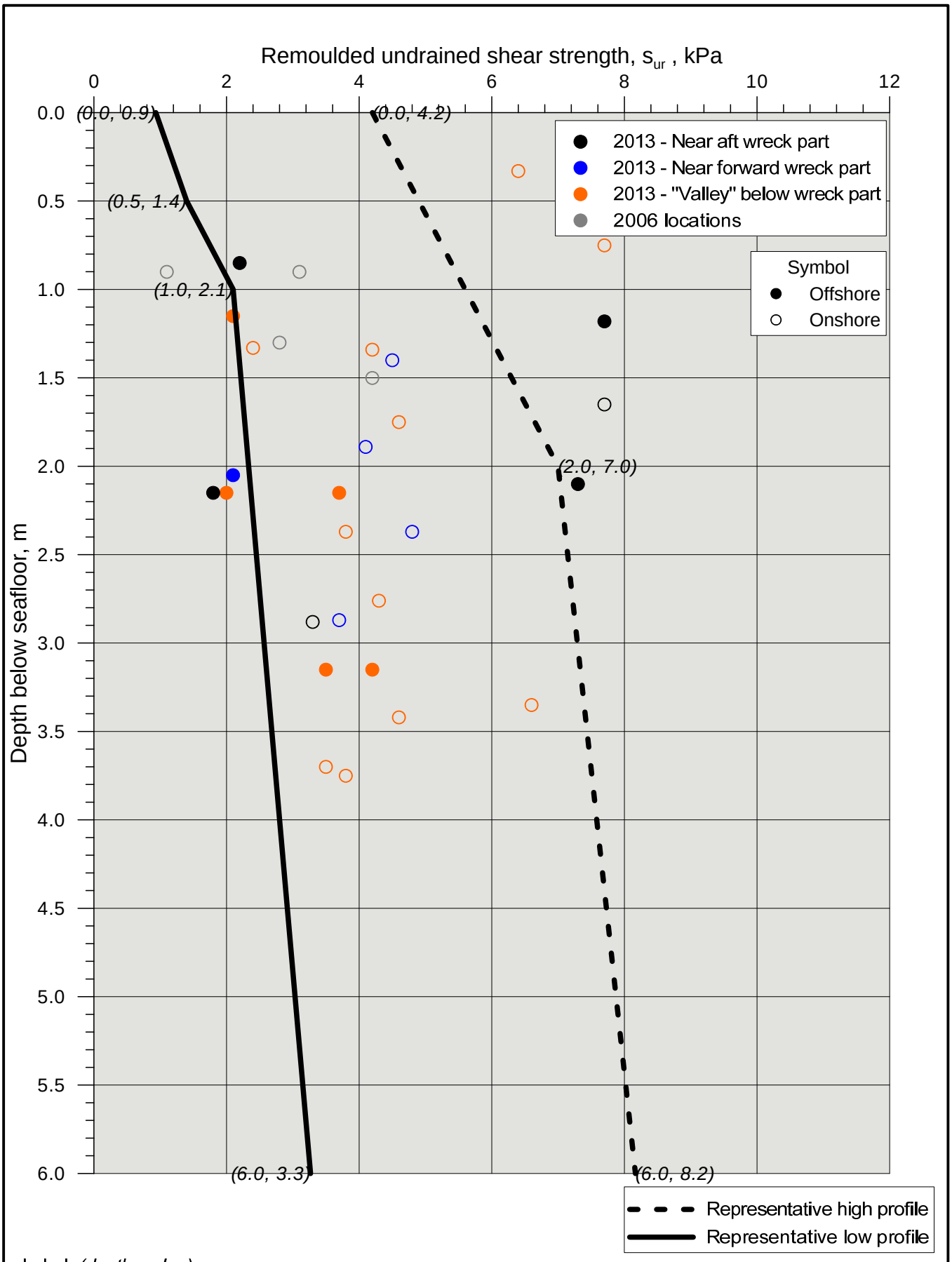


Label: *(depth, value)*

**U-864 - 2013 SOIL SURVEY**

Remoulded undrained shear strength versus depth.

All locations (performed in 2006 and in 2013).

| | |
|---|---|
| Document No. | 20120738-01-R |
| Date | 2013-03-20 |
| Figure No. | A2.7 |
| Drawn by | ES |

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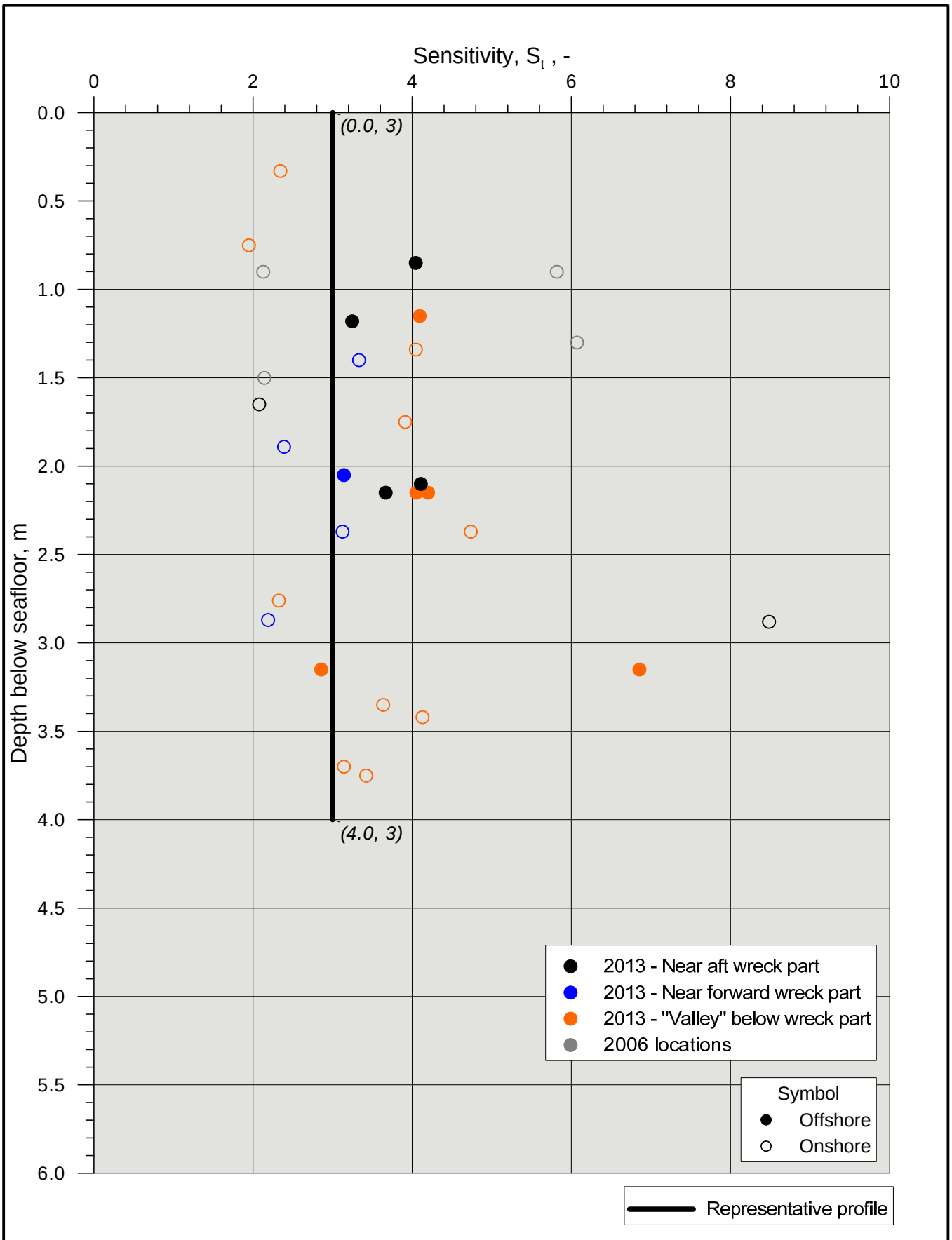


Label: *(depth, value)*

**U-864 - 2013 SOIL SURVEY**

Sensitivity versus depth.

All locations (performed in 2006 and in 2013).

| | |
|---|---|
| Document No. | 20120738-01-R |
| Date | 2013-03-20 |
| Figure No. | A2.8 |
| Drawn by | ES |

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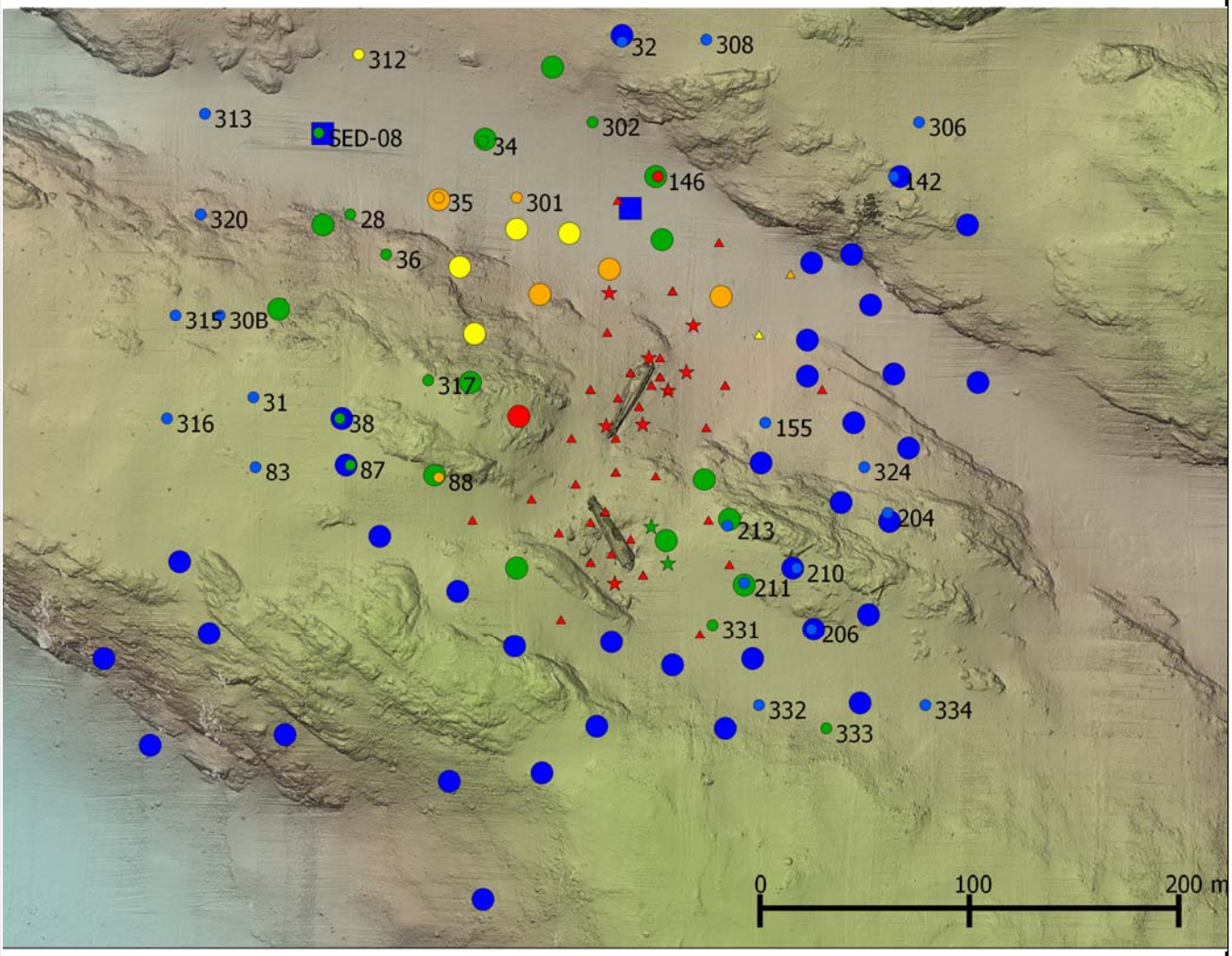
| | Class I Background | Class II Good | Class III Moderately polluted | Class IV Bad | Class V Very bad |
|---|---|---|---|---|---|
| Mercury (mg/kg) dry weight | <0.15 | 0.15 – 0.63 | 0.63 – 0.86 | 0.86 – 1.6 | >1.6 |

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

**U-864 - 2013 SOIL SURVEY**

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

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ES

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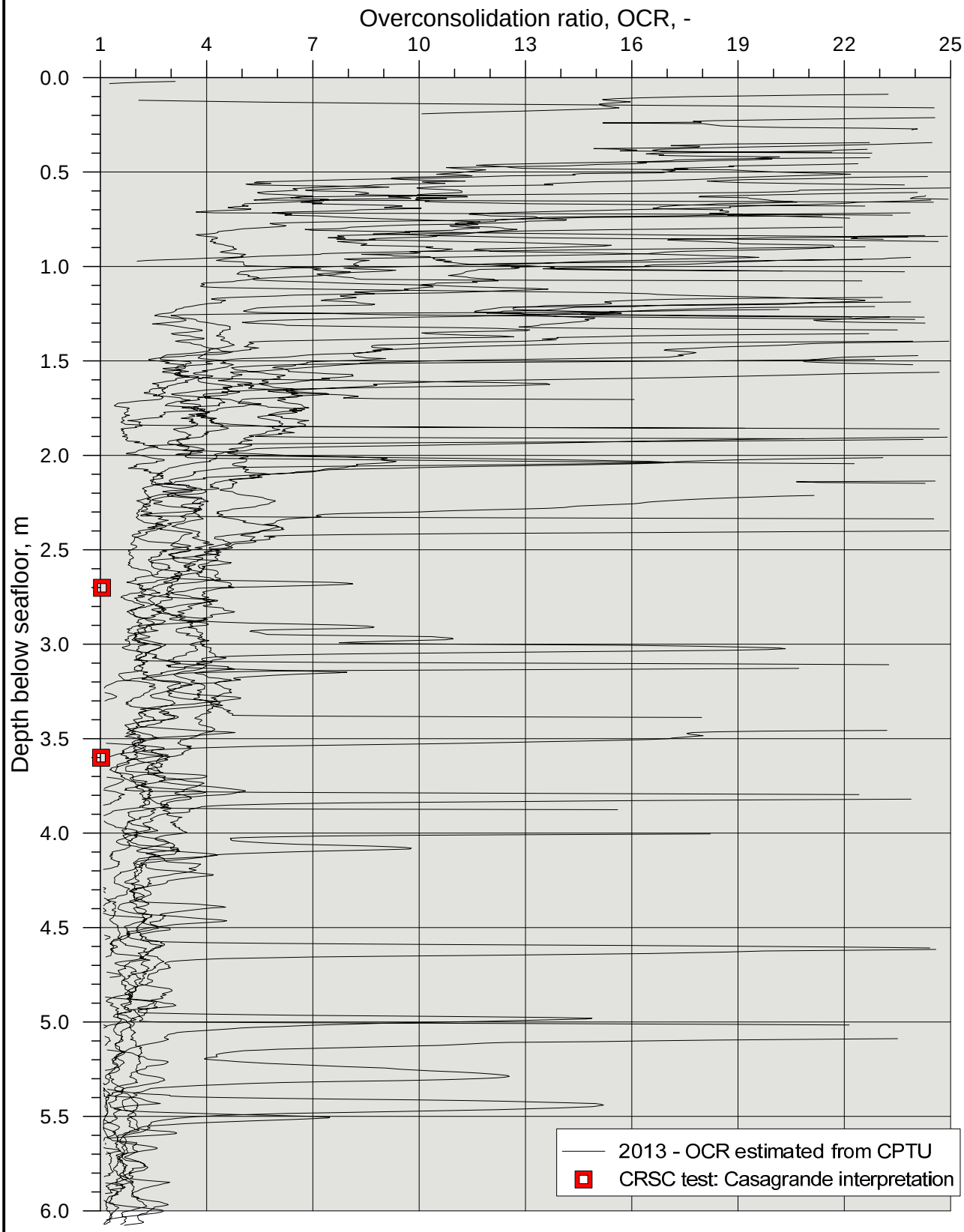


NOTE:
$q_t$ is used for interpretation of CPTU using
$\gamma$=20 kN/m3, $N_{kt}$ = 12 and $I_p$ = 15%.
OCR in clay from CPTU using Andresen et al. (1979).

Label: *(depth, value)*

**U-864 - 2013 SOIL SURVEY**

Remoulded undrained shear strength versus depth.

All locations (performed in 2013).

| | |
|---|---|
| Document No. | 20120738-01-R |
| Date | 2013-03-21 |
| Figure No. | A2.10 |
| Drawn by | ES |

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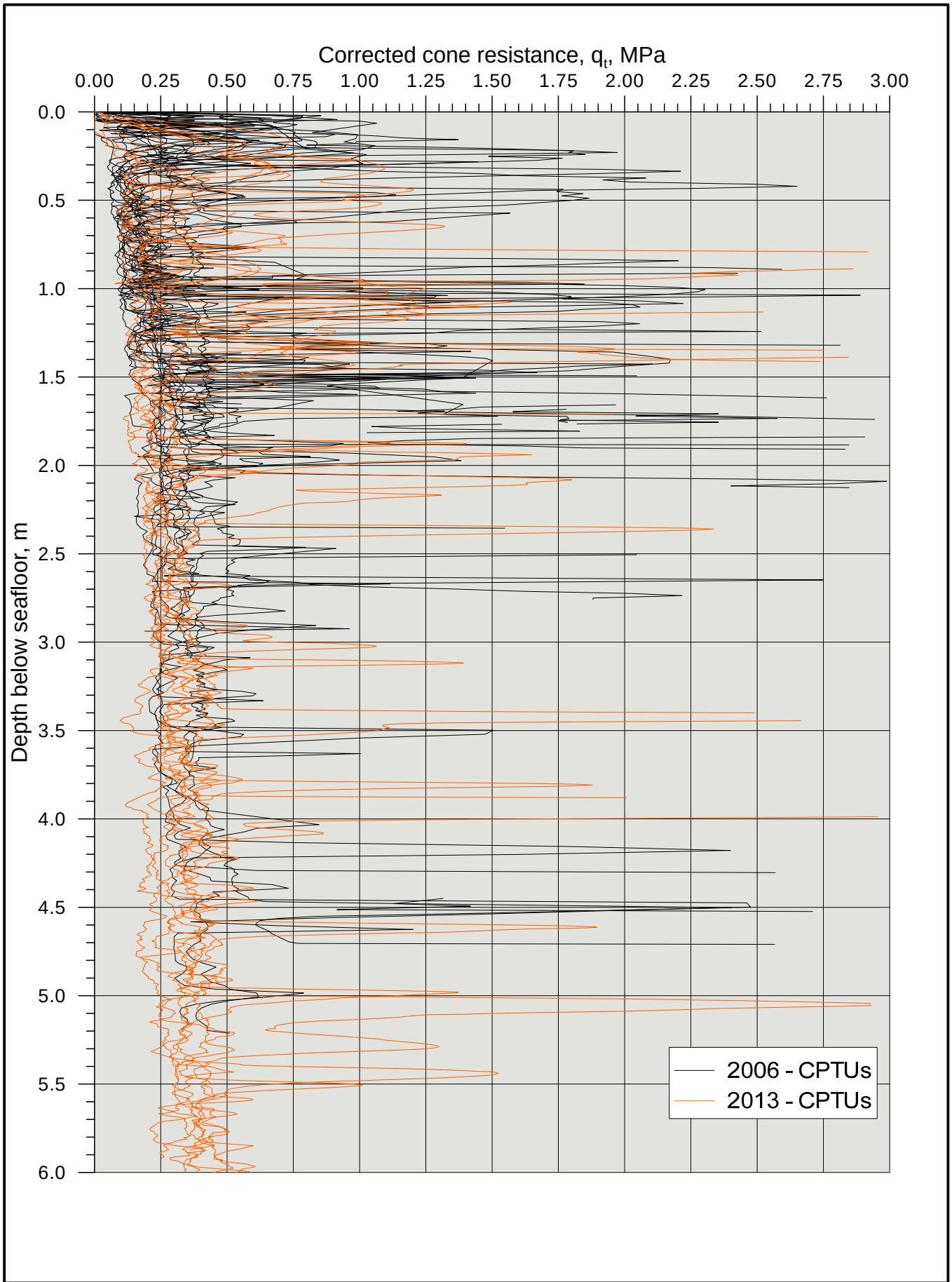


**U-864 - 2013 SOIL SURVEY**

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 |
| Drawn by | ES |

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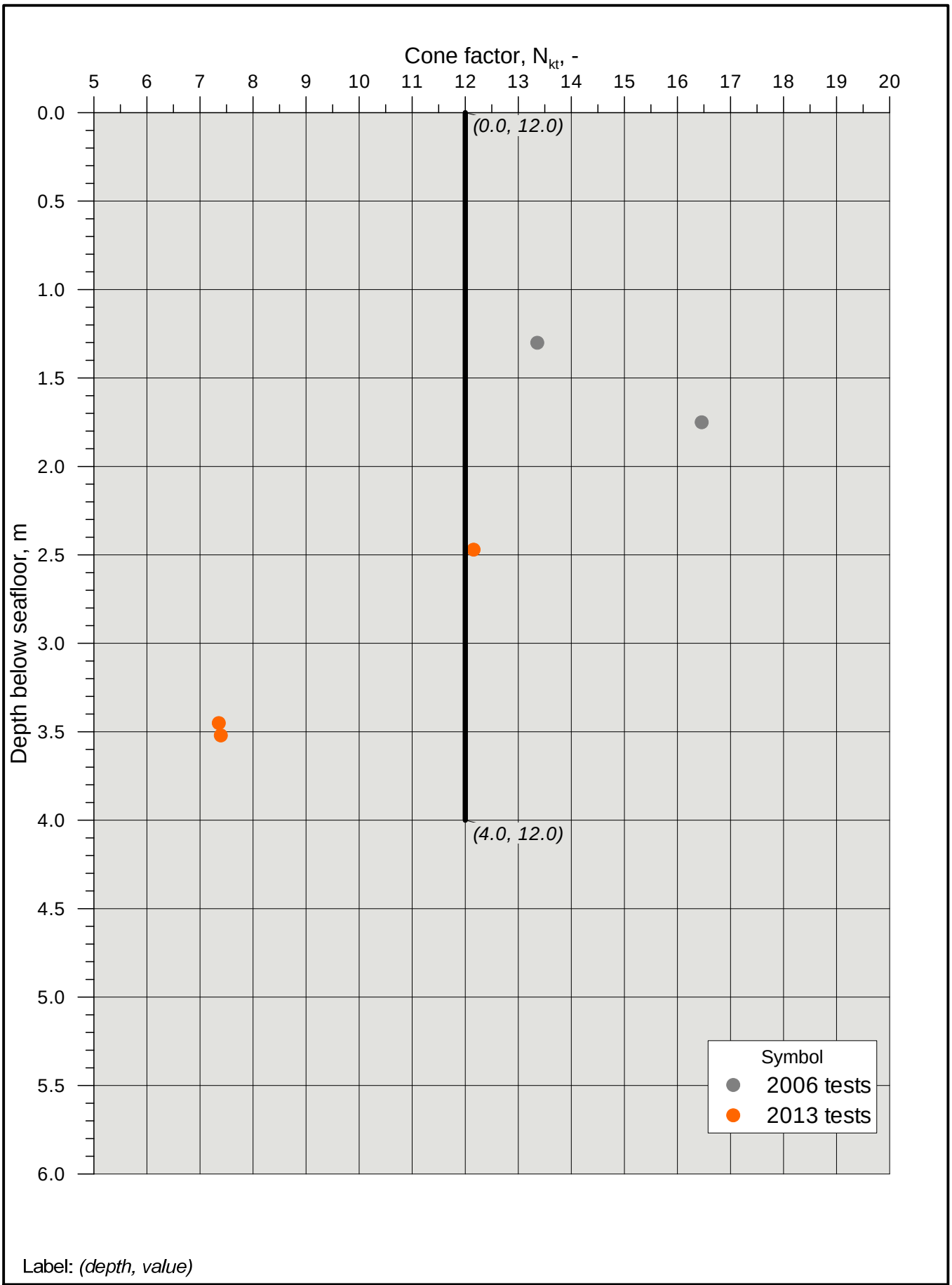


Label: *(depth, value)*

**U-864 - 2013 SOIL SURVEY**

Document No.
20120738-01-R

Date
2013-03-20

$N_{kt}$ versus depth.

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

Figure No.
A2.12

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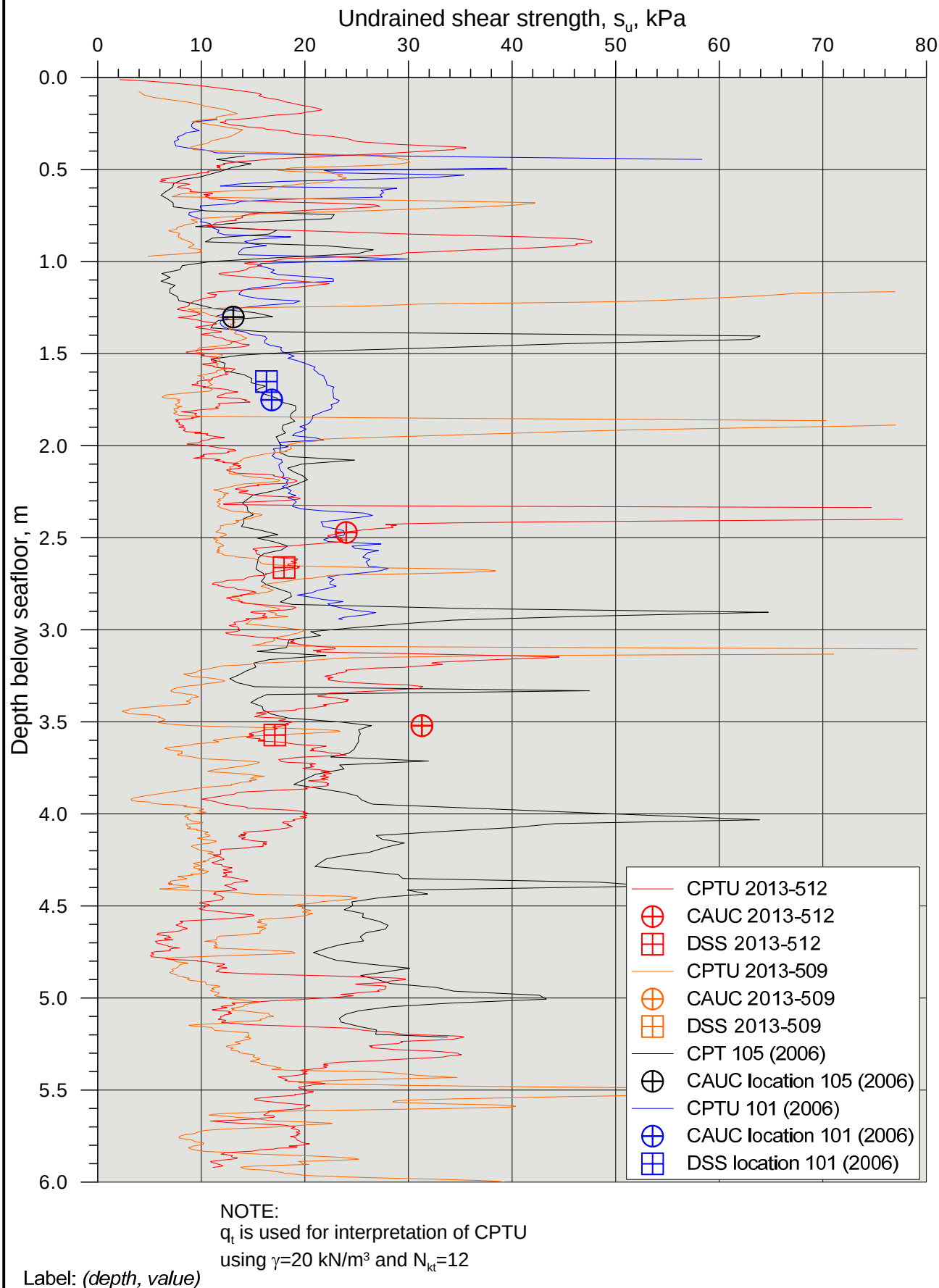


NOTE:
$q_t$ is used for interpretation of CPTU
using $\gamma$=20 kN/m$^3$ and $N_{kt}$=12

Label: *(depth, value)*

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**U-864 - 2013 SOIL SURVEY**

Undrained shear strength versus depth.

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

| | |
|---|---|
| Document No. | 20120738-01-R |
| Date | 2013-04-16 |
| Figure No. | A2.13 |
| Drawn by | ES |

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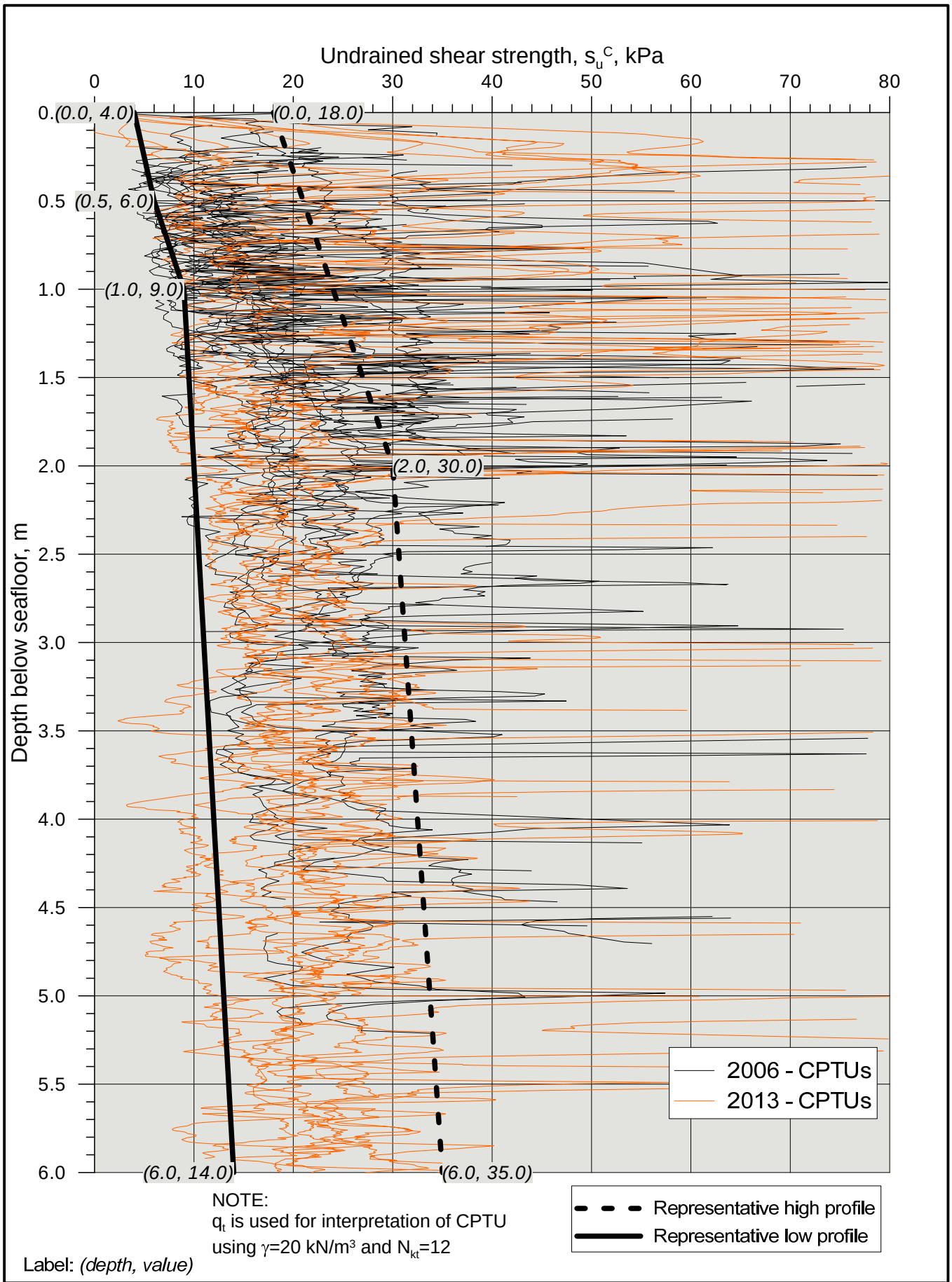


NOTE:
$q_t$ is used for interpretation of CPTU
using $\gamma$=20 kN/m$^3$ and $N_{kt}$=12

Label: *(depth, value)*

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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 | 2013-03-21 |
| Figure No. | A2.14 |
| Drawn by | ES |

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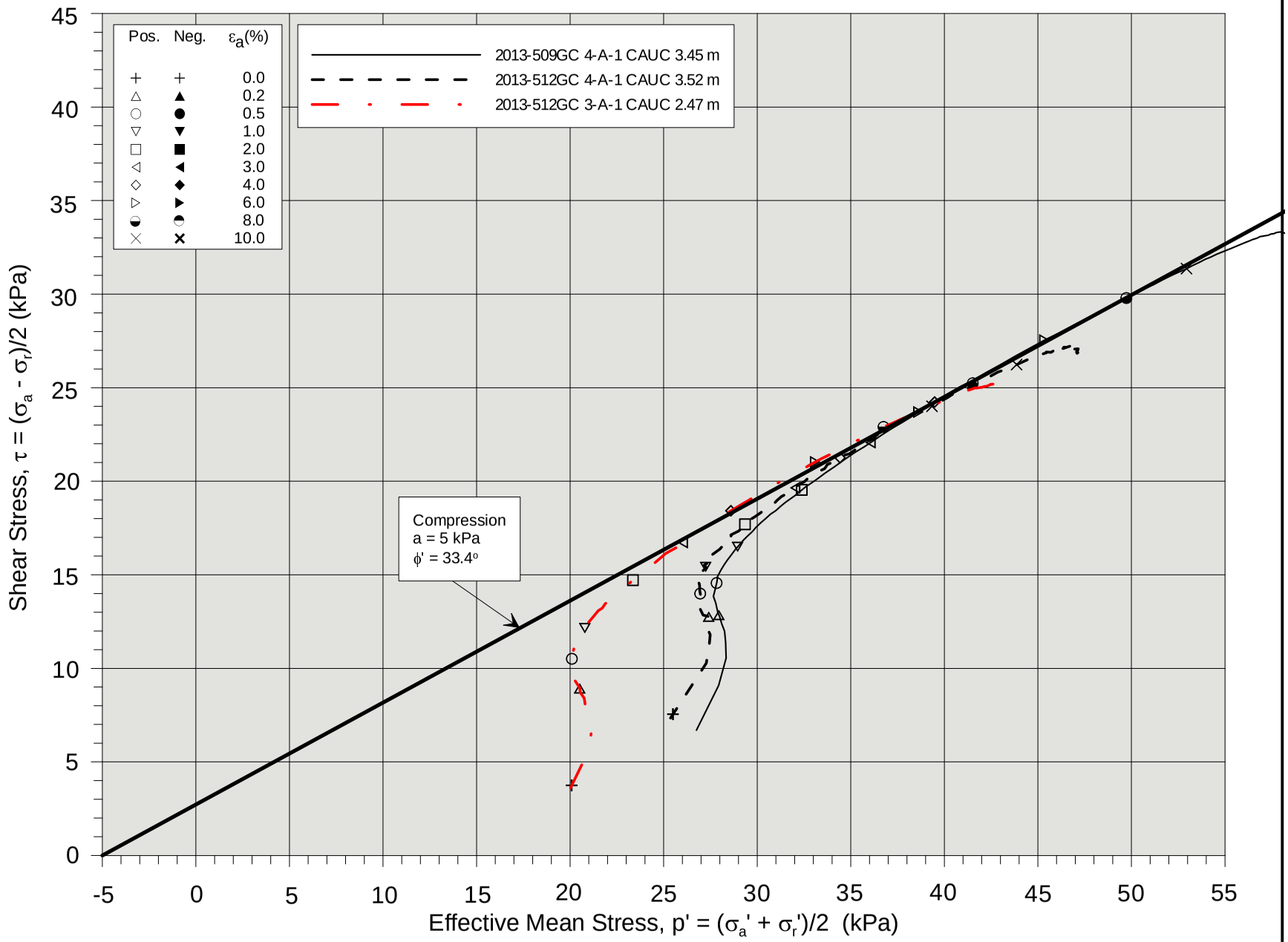


CAU triaxial stress paths

**U-864 - 2013 SOIL SURVEY**

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# Part A3 - List of Symbols and Classification System used

## Contents

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A3.3.4 Grain size distribution 9
A3.3.5 Plasticity 10

## A3.1 List of symbols

ENGLISH

| | | |
|---|---|---|
| a | = | attraction (= c' cot $\phi$', 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 |
| $N_f$ | | |
| $N_q$ | | |
| $N_q$* | | |
| $N_{fq}$ | = | cone factors |
| $N_p$ | | |
| $N_k$ | | |
| $N_{ke}$ | | |
| $N_{kt}$ | | |
| $N_m$ | = | cone resistance number |
| $N_u$ | = | pore pressure factor |
| $p_o'$ | = | effective overburden pressure |
| $p_o$ | = | total overburden pressure |
| $p_c'$ | = | effective preconsolidation pressure |
| $\Delta p$ | = | 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 |
| $\Delta u$ | = | 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

| | | |
|---|---|---|
| $\alpha$ | = | angle |
| $\alpha$ | = | "constant" |
| $\alpha$ | = | coefficient converting undrained shear strength to wall friction $q_w$ or unit skin friction f |
| $\alpha$ | = | area ratio (CPT) |
| $\alpha_m$ | = | factor converting undrained shear strength to $E_u$ |
| ß | = | angle |
| ß | = | "constant" |
| ß | = | correction factor |
| $\gamma'$ | = | effective unit weight |
| $\gamma_d$ | = | dry unit weight |
| $\gamma_s$ | = | unit weight of solid particles |
| $\gamma_w$ | = | unit weight of water |
| $\gamma$ | = | shear strain |
| $\gamma_a$ | = | average shear strain |
| $\gamma_{cy}$ | = | cyclic shear strain |
| $\gamma_f$ | = | shear strain at failure |
| $\gamma_h$ | = | horizontal shear strain |
| $\gamma_N$ | = | cyclic shear strain after N cycles |
| $\delta$ | = | settlement |
| $\delta$ | = | displacement |
| $\delta$ | = | rate of settlement |
| $\Delta$ | = | change, e.g. $\Delta\sigma$ |
| $\varepsilon$ | = | normal strain |
| $\varepsilon_a$ | = | axial strain |
| $\varepsilon_{ac}$ | = | axial consolidation strain |
| $\varepsilon_{acy}$ | = | axial cyclic strain |
| $\varepsilon_{df}$ | = | axial strain at failure |
| $\varepsilon_{ap}$ | = | permanent axial strain |
| $\varepsilon_{cy}$ | = | cyclic strain |
| $\varepsilon_h$ | = | horizontal strain |
| $\varepsilon_N$ | = | axial strain after N cycles |
| $\varepsilon_v$ | = | vertical strain |
| $\varepsilon_{vol}$ | = | volumetric strain |
| | | |
| $\lambda$ | = | rate factor |
| $\lambda$ | = | skin friction factor |
| $\upsilon$ | = | Poisson's ratio |
| $\upsilon$ | = | coefficient of variation |
| $\rho$ | = | specific resistivity |
| $\rho$ | = | density |
| $\rho$ | = | mobilized total friction angle |
| $\rho'$ | = | mobilized effective friction angle |
| $\rho_s$ | = | density of solid particles |
| $\Sigma$ | = | sum |
| $\sigma,\sigma'$ | = | normal stress (total, effective) |
| $\sigma_1,\sigma_1'$ | = | major principal stress |

| | | |
|---|---|---|
| $\sigma_2,\sigma_2'$ | = | intermediate principal stress |
| $\sigma_3,\sigma_3'$ | = | minor principal stress |
| $\sigma_a$ | = | reference stress (atmospheric pressure) = 100 kPa |
| $\sigma_a,\sigma_a'$ | = | axial stress (total, effective) |
| $\sigma_{ac},\sigma_{ac}'$ | = | axial consolidation stress |
| $\sigma_{acy},\sigma_{acy}'$ | = | axial cyclic stress |
| $\sigma_c,\sigma_c'$ | = | consolidation stress |
| $\sigma_h,\sigma_h'$ | = | horizontal stress |
| $\sigma_{oct},\sigma_{oct}'$ | = | octahedral stress |
| $\sigma_r,\sigma_r'$ | = | radial stress |
| $\sigma_{rc},\sigma_{rc}'$ | = | radial consolidation stress |
| $\sigma_v,\sigma_v'$ | = | vertical stress |
| $\tau$ | = | shear stress |
| $\tau_a$ | = | average shear stress |
| $\tau_{cy}$ | = | cyclic shear stress |
| $\tau_f$ | = | undrained shear strength |
| $\tau_h$ | = | horizontal shear stress |
| $\tau_{ha}$ | = | average cyclic horizontal shear stress |
| $\tau_{hcy}$ | = | cyclic horizontal shear stress |
| $\tau_{hf}$ | = | horizontal shear stress at failure |
| $\tau_{hfcy}$ | = | horizontal shear stress at failure after cycling |
| $\Phi$ | = | total friction angle |
| $\Phi'$ | = | effective friction angle |
| $\Phi_{mob}'$ | = | mobilized effective friction angle |
| $\Phi_d$ | = | drained friction angle |
| $\Phi_u$ | = | 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.

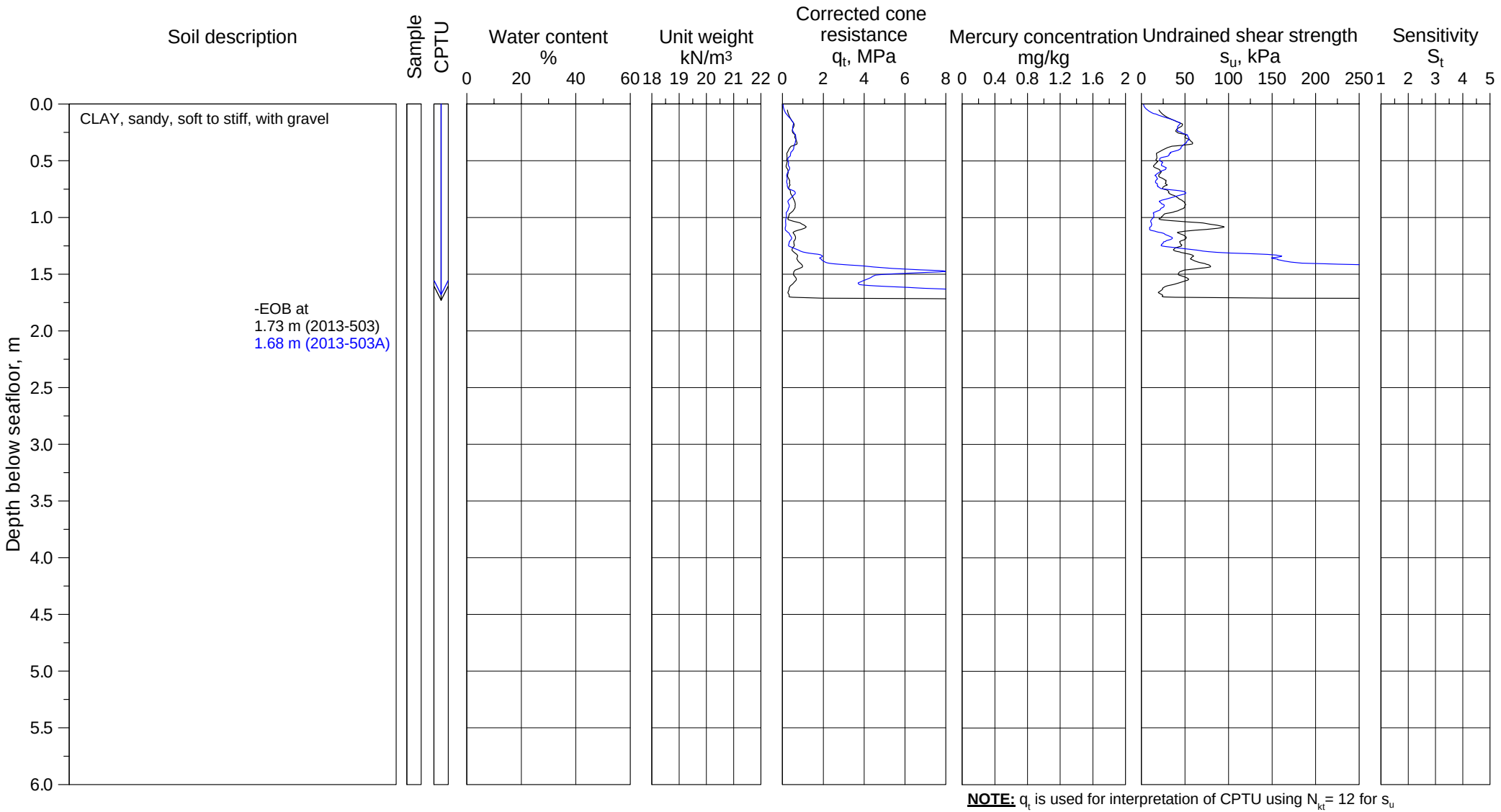
Note that the laboratory testing of the mercury concentration was performed by NIVA. The borehole locations are shown in Part A1.

## 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)
✤ $\gamma_t$ (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, $\gamma_t$ (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 |
|---|---|---|---|
| 2013-503CPT | 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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NGI

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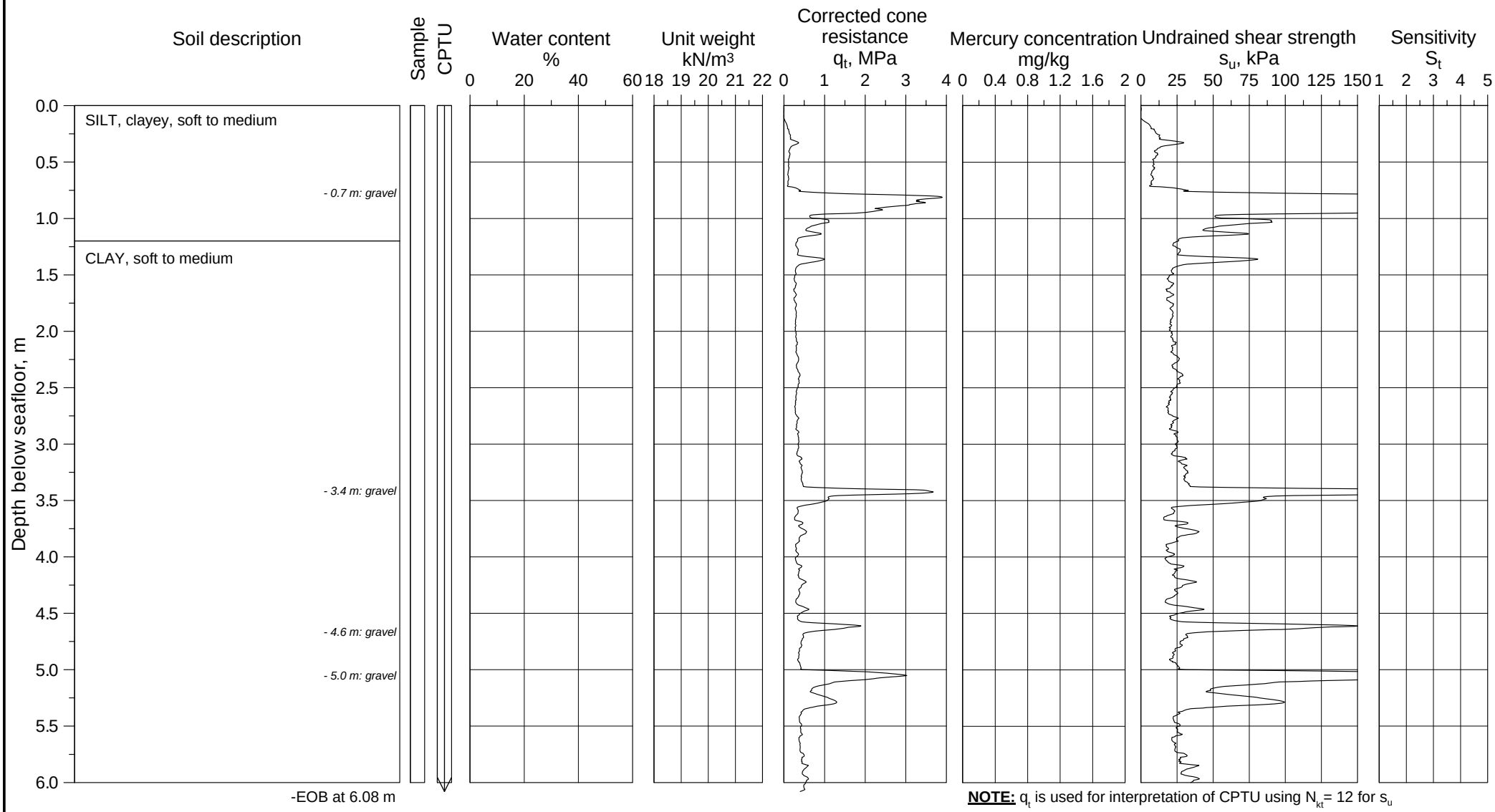


**NOTE:** $q_t$ is used for interpretation of CPTU using $N_{kt}$ = 12 for $s_u$

■ /□ 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)
✣ $\gamma_t$ (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, $\gamma_t$ (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"*

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Date 2013-04-16
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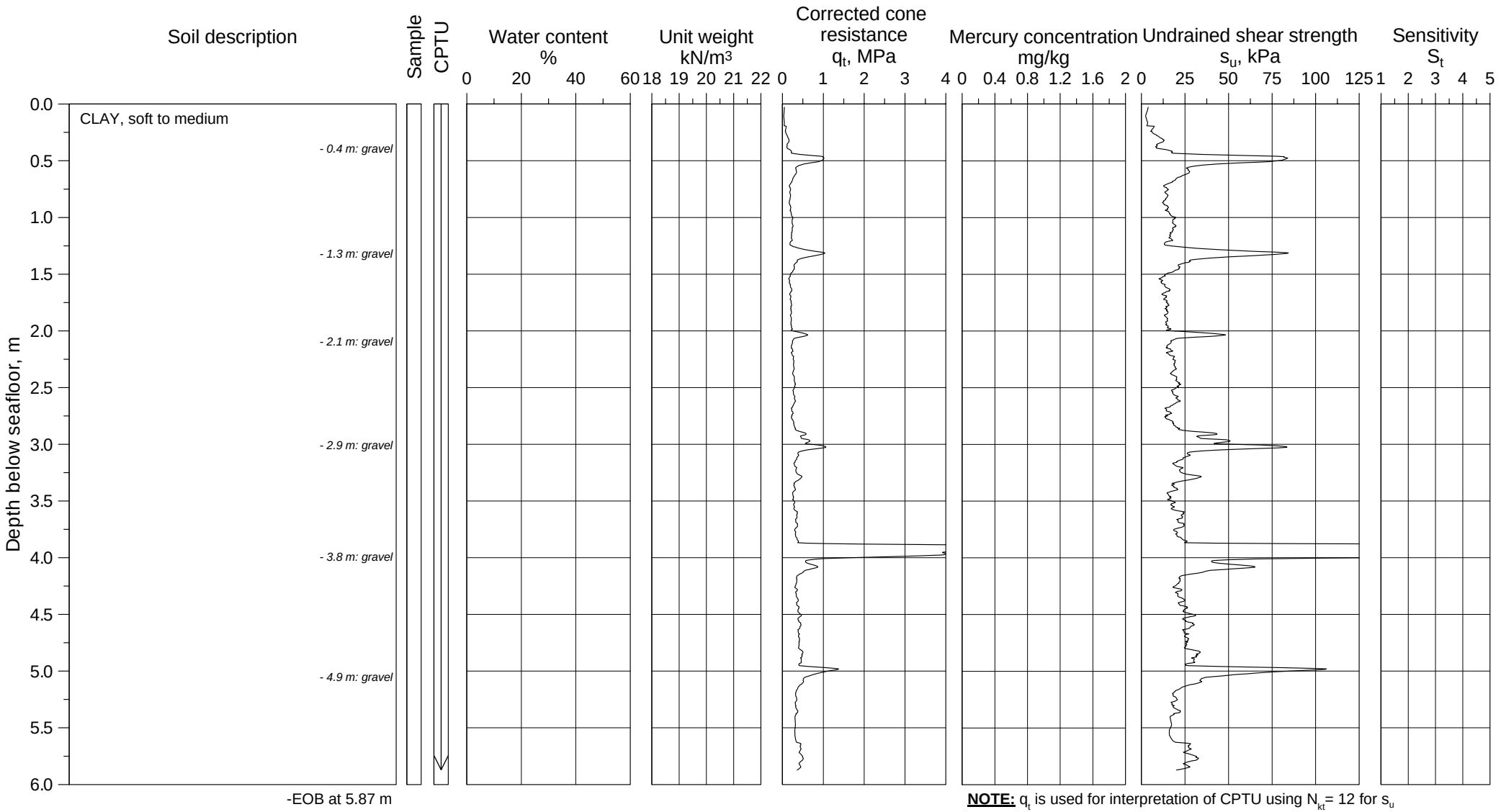


**NOTE:** $q_t$ is used for interpretation of CPTU using $N_{kt}$= 12 for $s_u$

■ /□ 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)
✣ $\gamma_t$ (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, $\gamma_t$ (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
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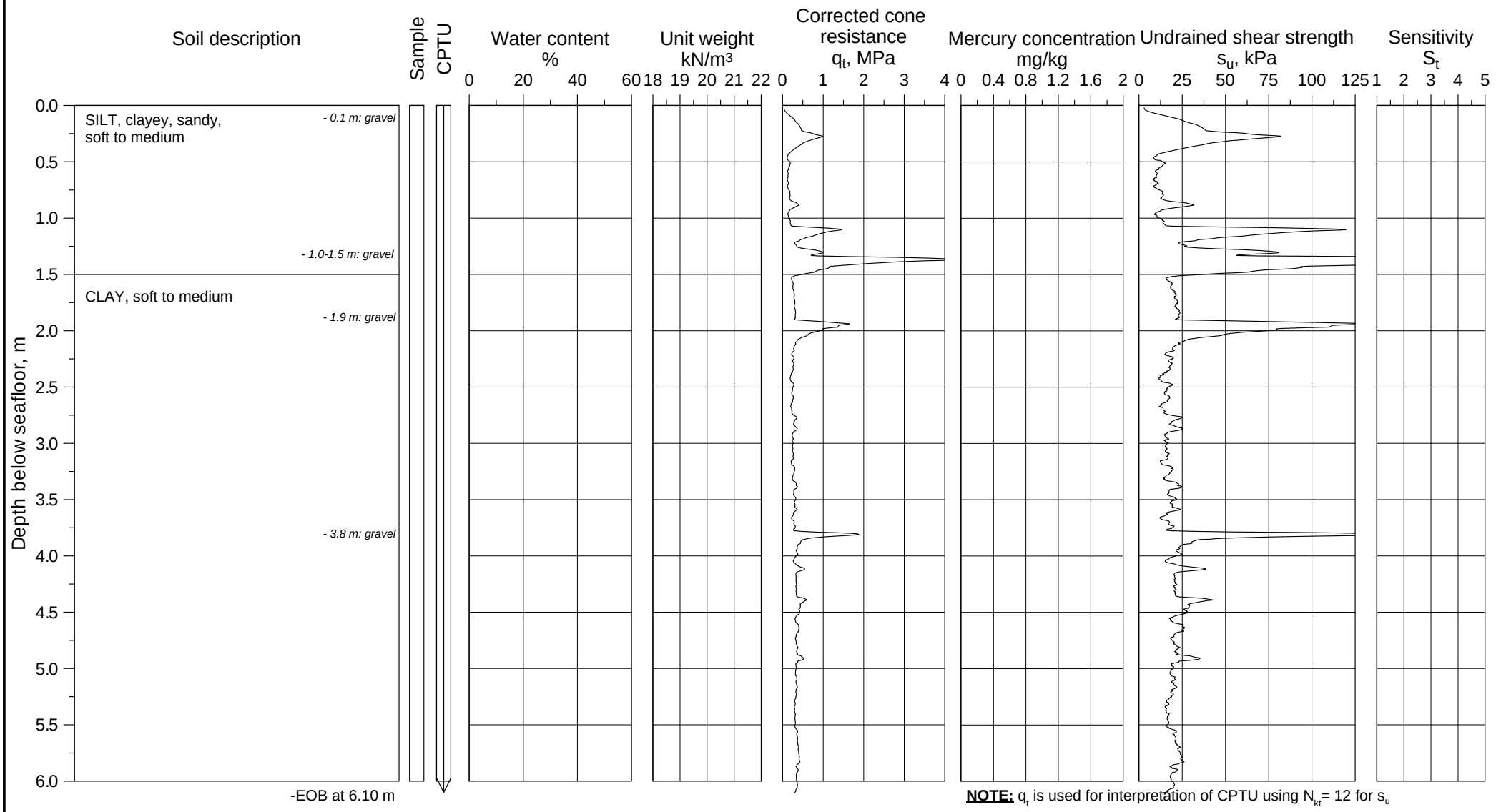


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## U-864 - 2013 SOIL SURVEY

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

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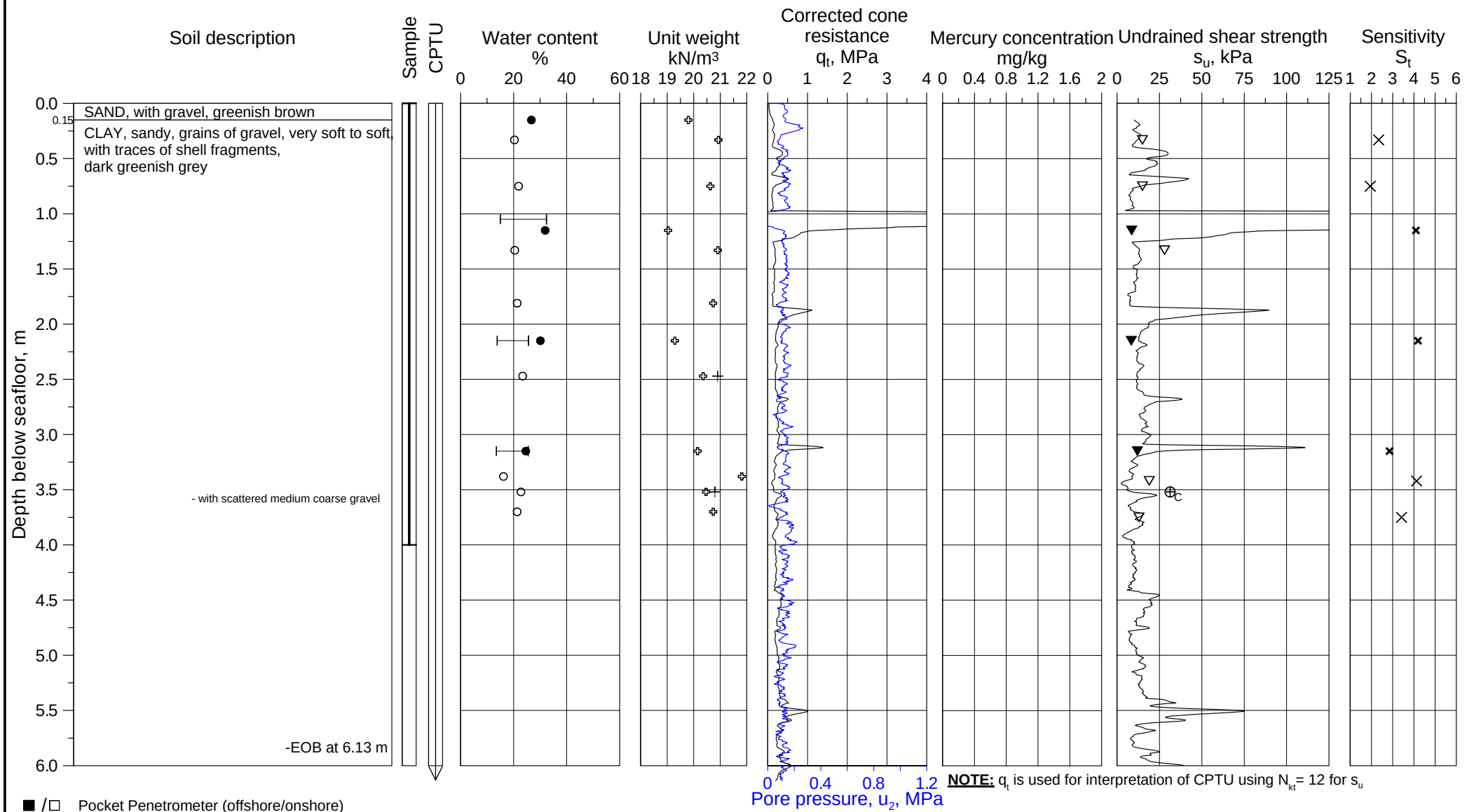


# U-864 - 2013 SOIL SURVEY

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

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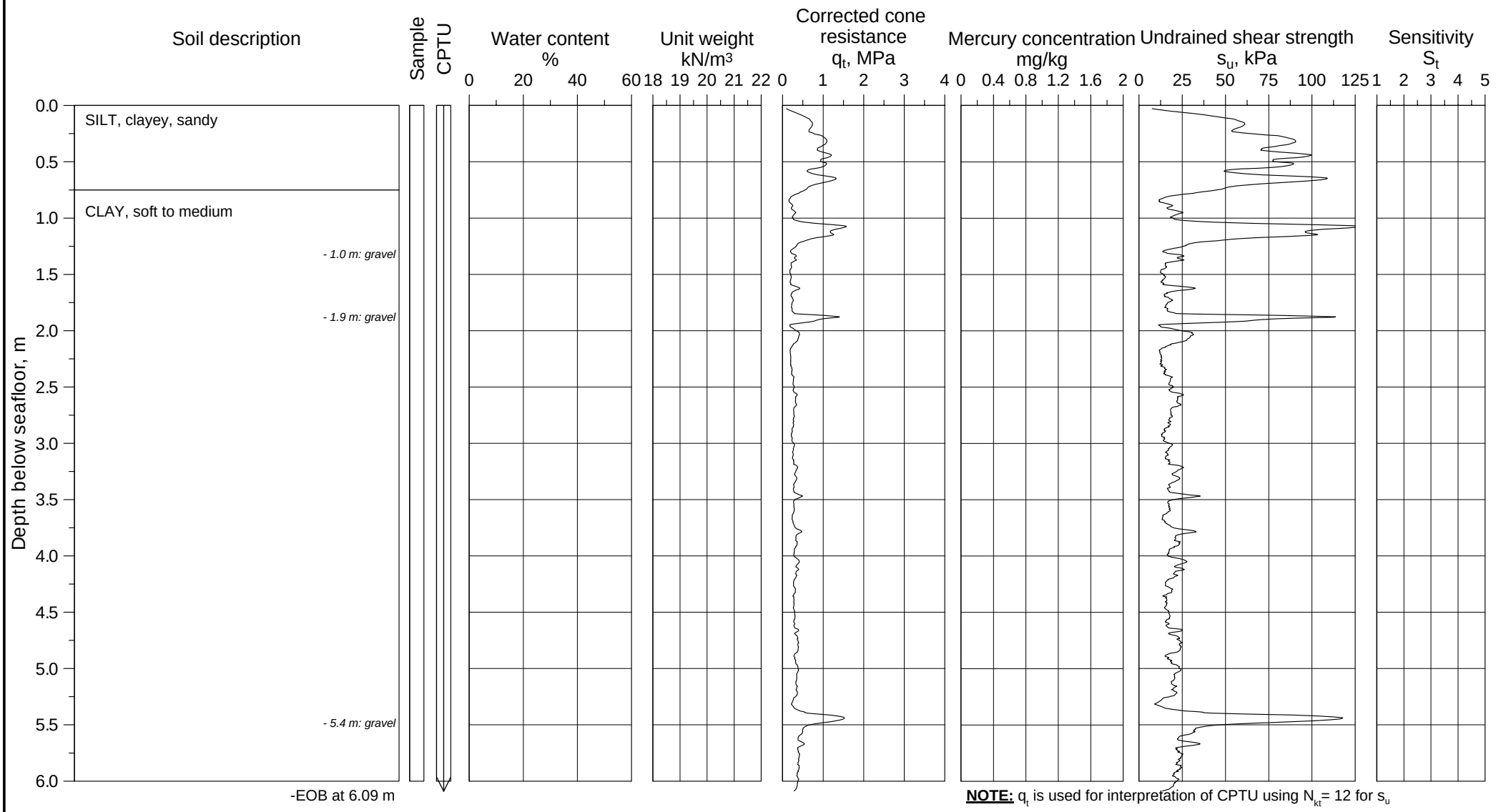


■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /⧫ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✣ γt (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, 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 |
|---|---|---|---|
| 2013-510CPT | 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
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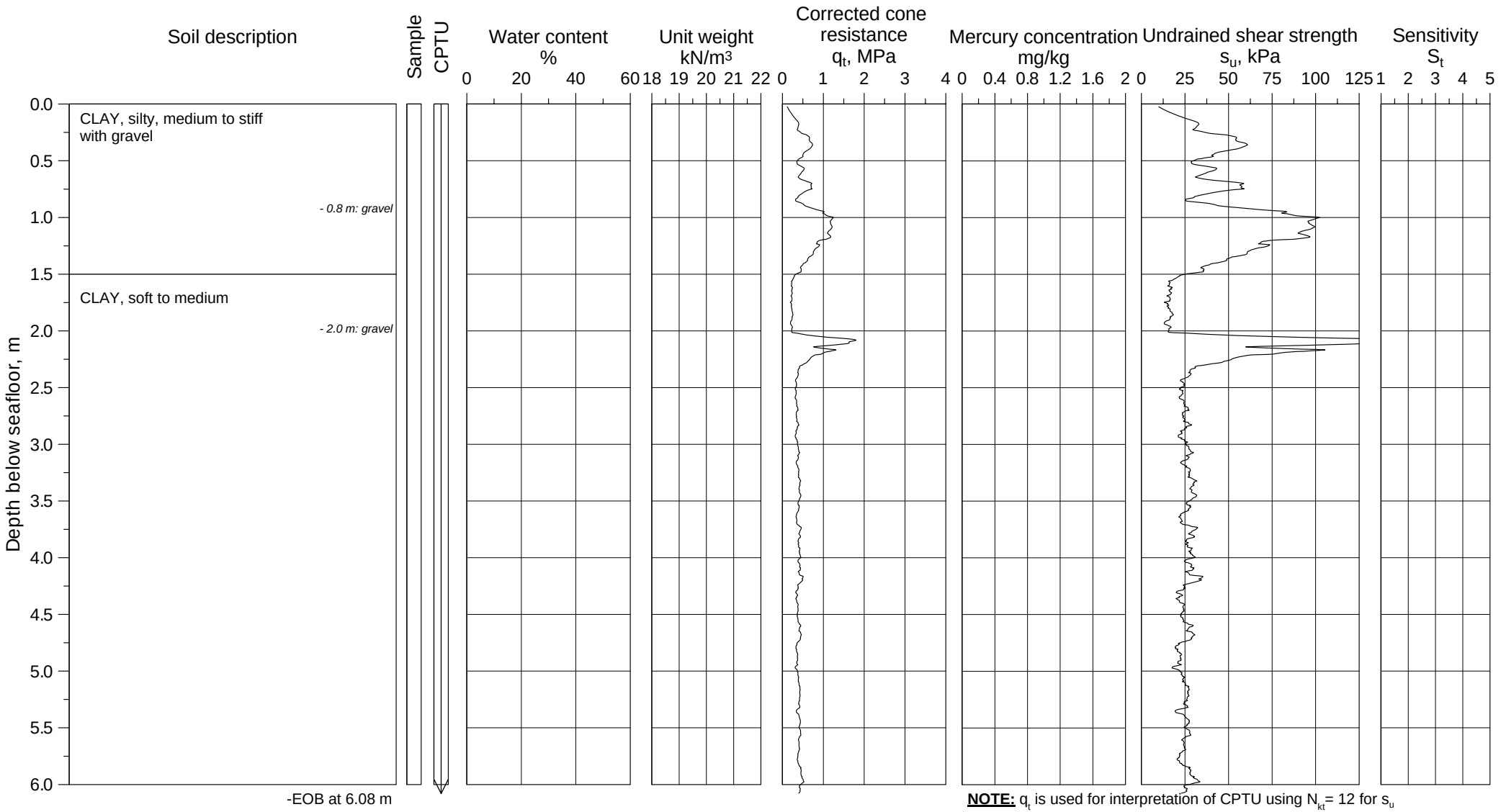


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★ /☆ Torvane (offshore/onshore)
✳ /⧫ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✣ γt (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, γt (offshore/onshore)
✖ /× 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 |
|---|---|---|---|
| 2013-511CPT | 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
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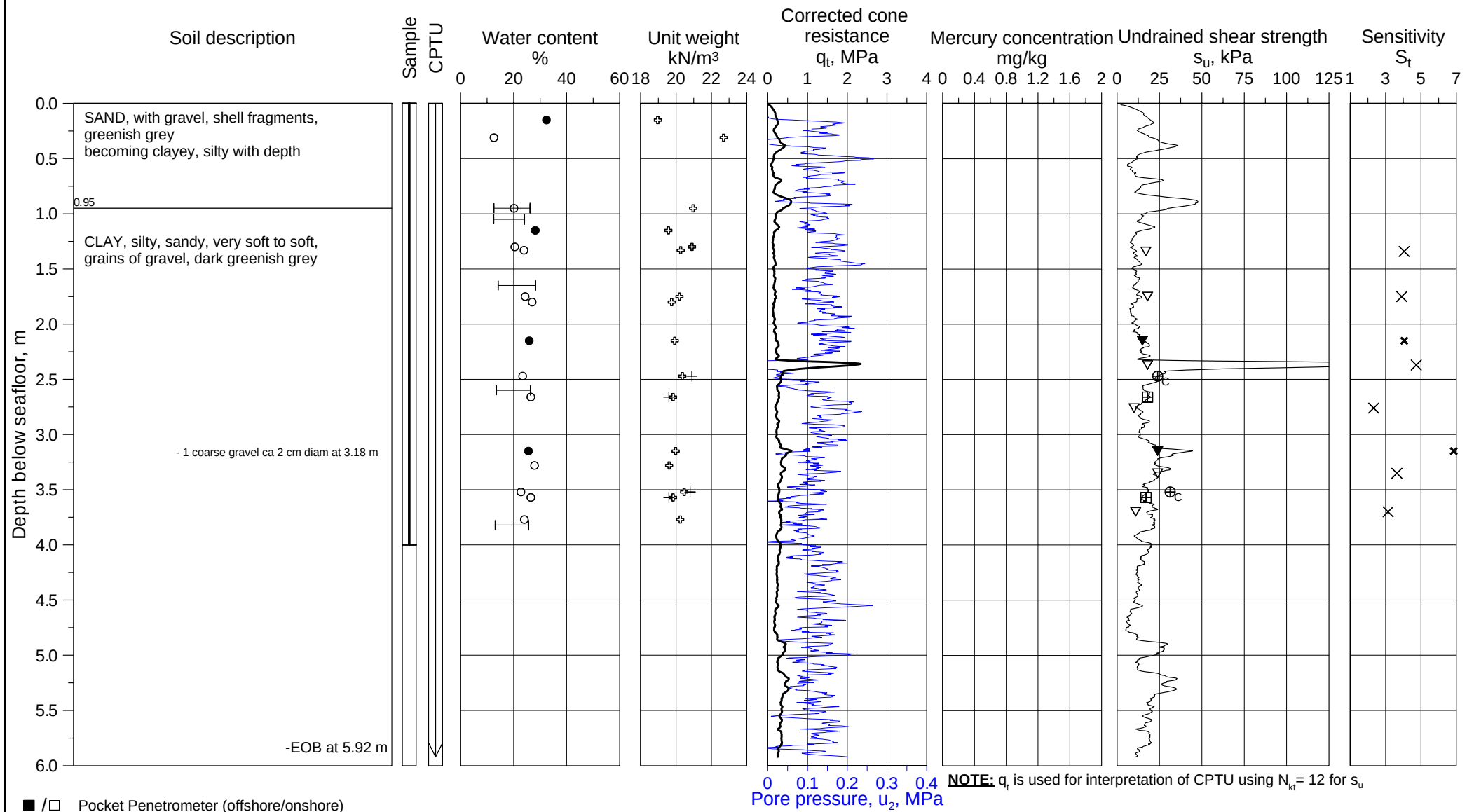


■ /□ Pocket Penetrometer (offshore/onshore)
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✳ /⧫ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✤ $\gamma_t$ (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, $\gamma_t$ (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
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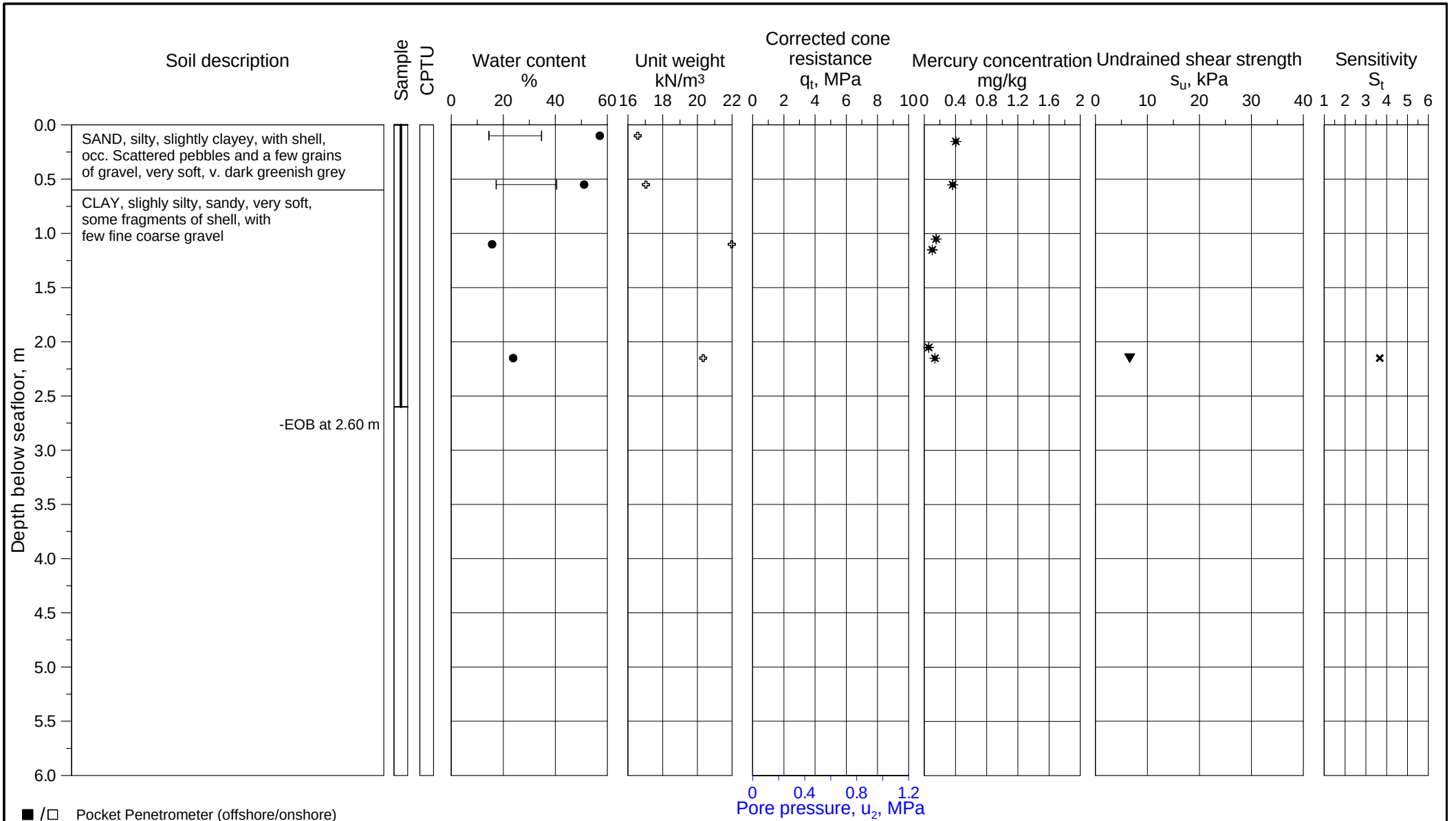


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## U-864 - 2013 SOIL SURVEY

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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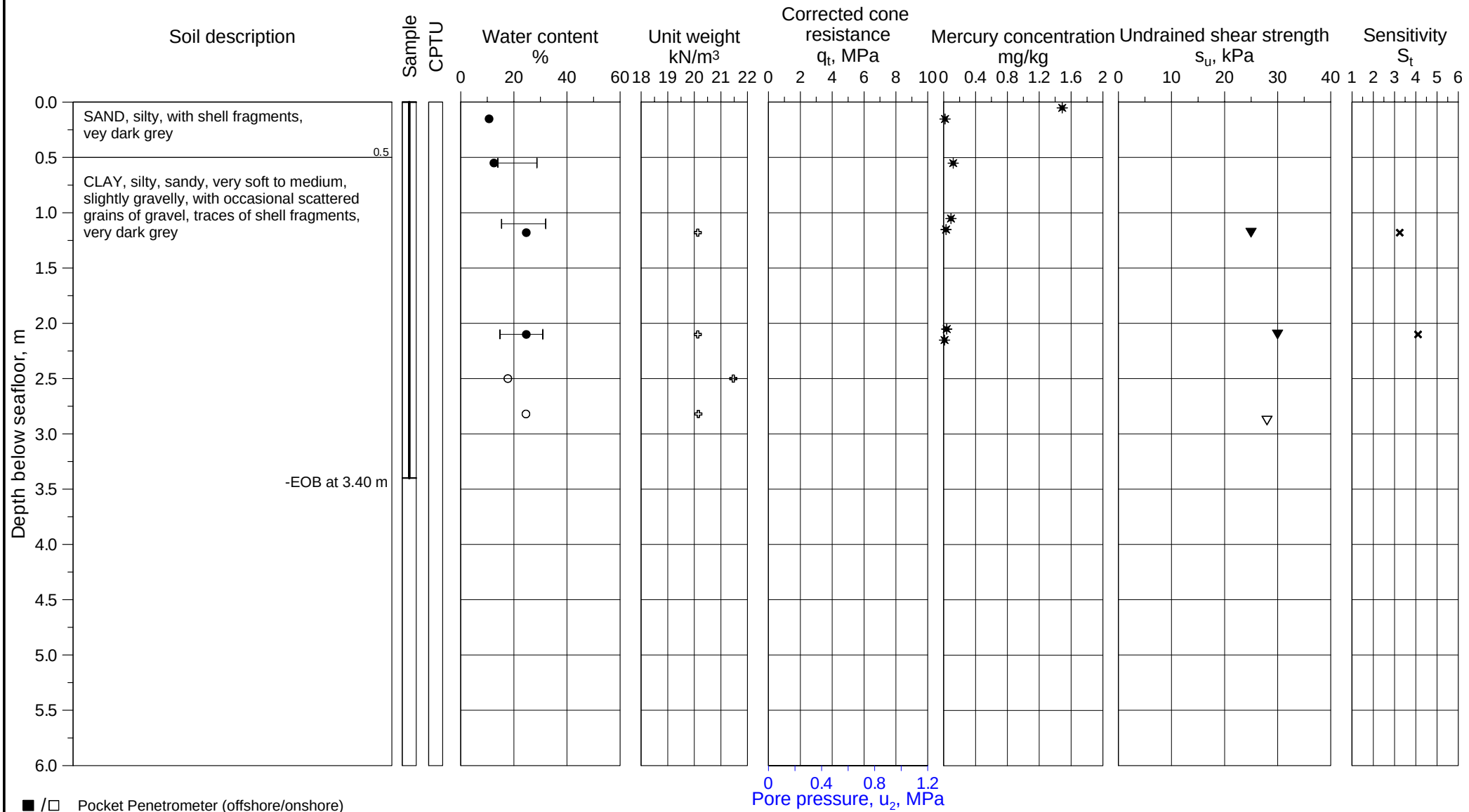


■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /⧫ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✣ γt (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, 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 |
|---|---|---|---|
| 2013-402VC | 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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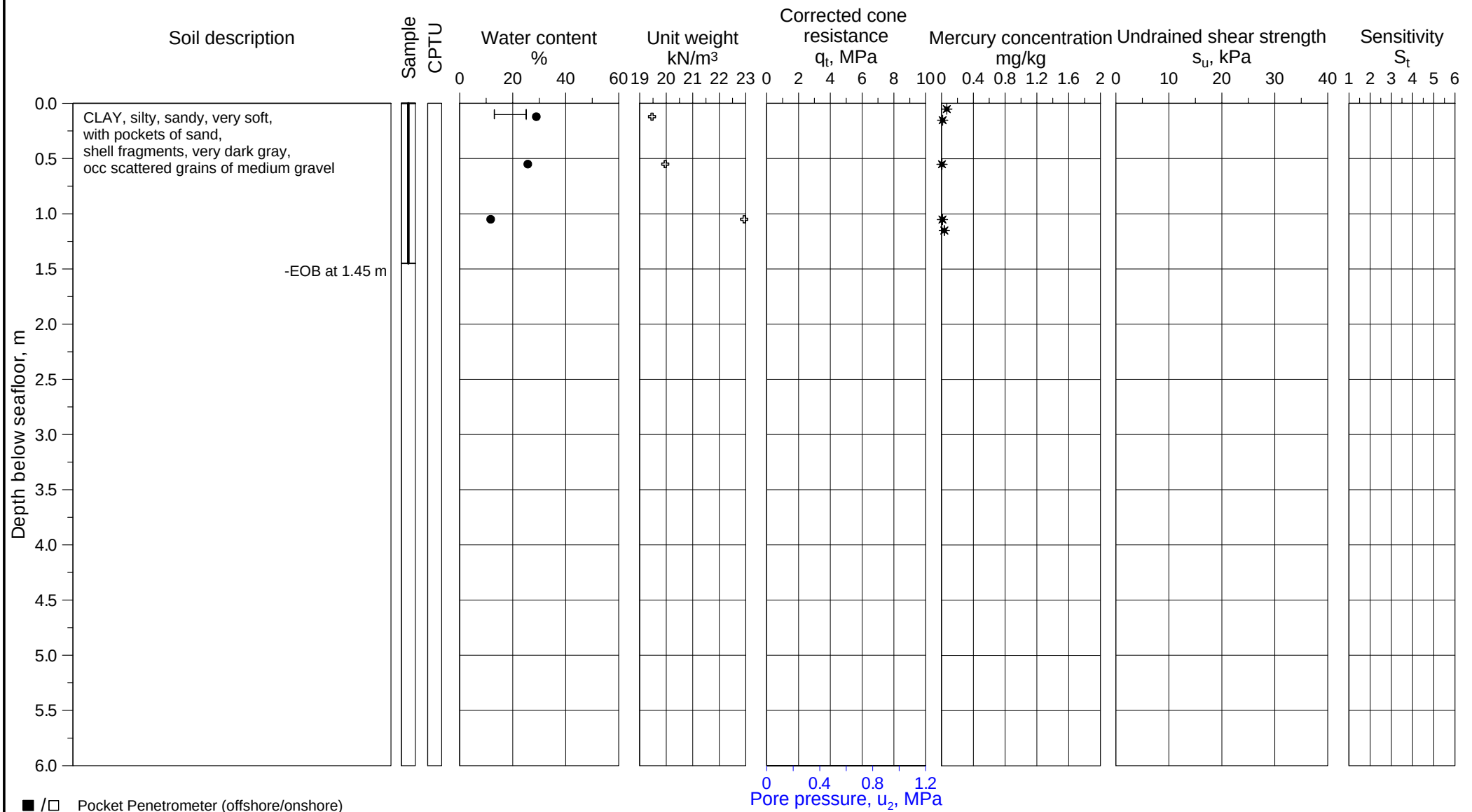


■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✷ /⧫ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✣ γt (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, 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
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Drawn by ES

NGI

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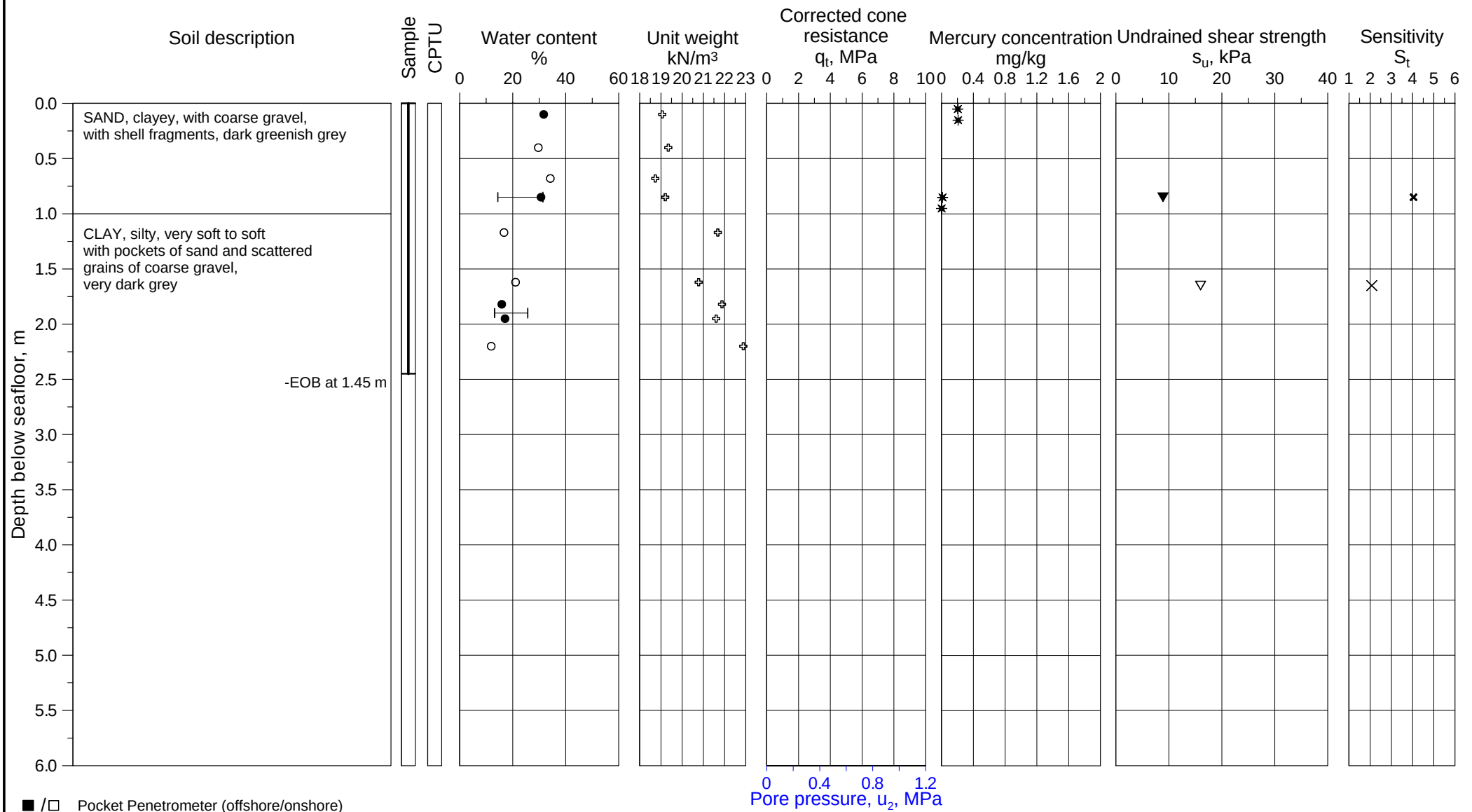


■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /⧫ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✣ γt (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, 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 |
|---|---|---|---|
| 2013-404VC | 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
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NGI

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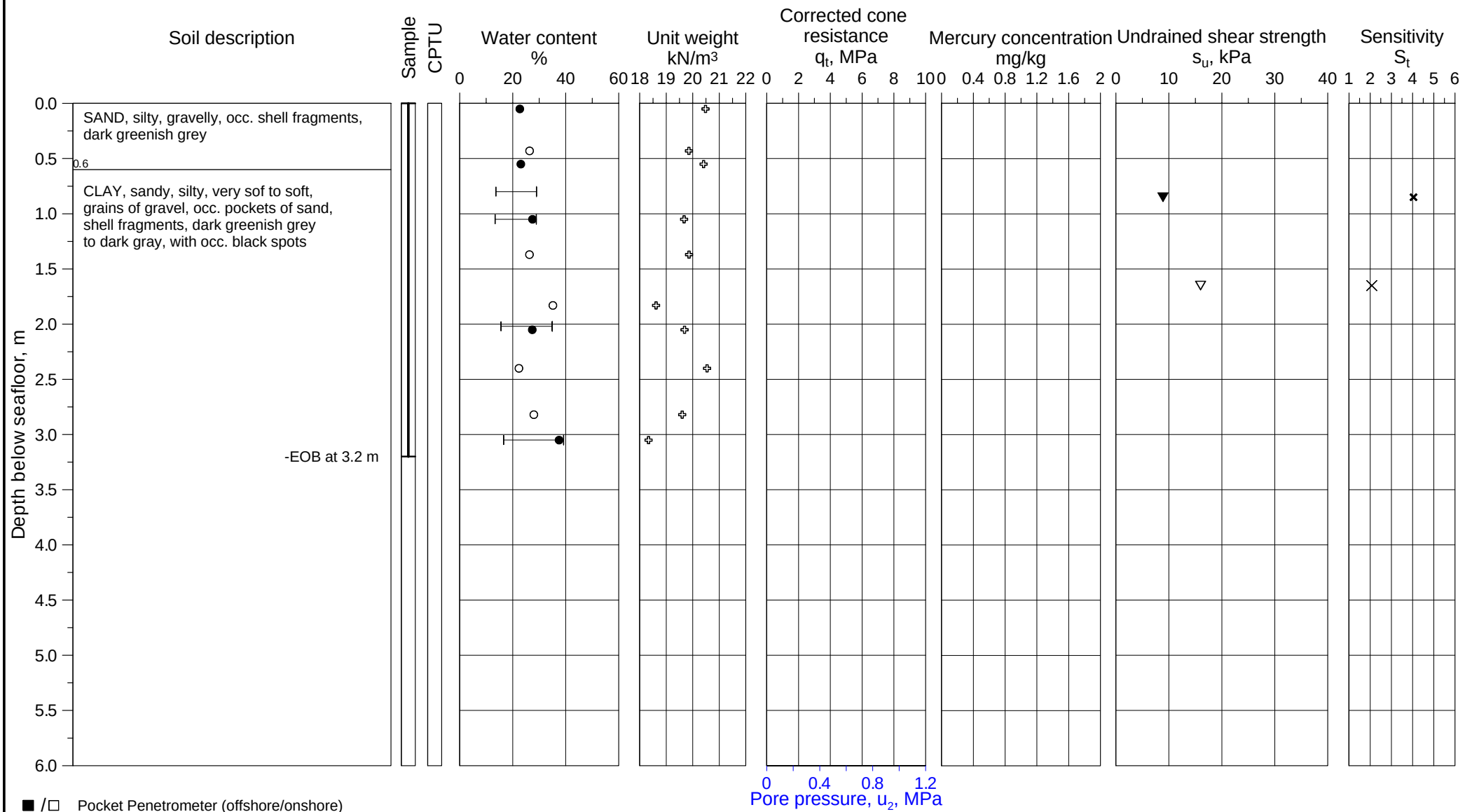


■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /⧫ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✣ γt (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, 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 |
|---|---|---|---|
| 2013-405VC | 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
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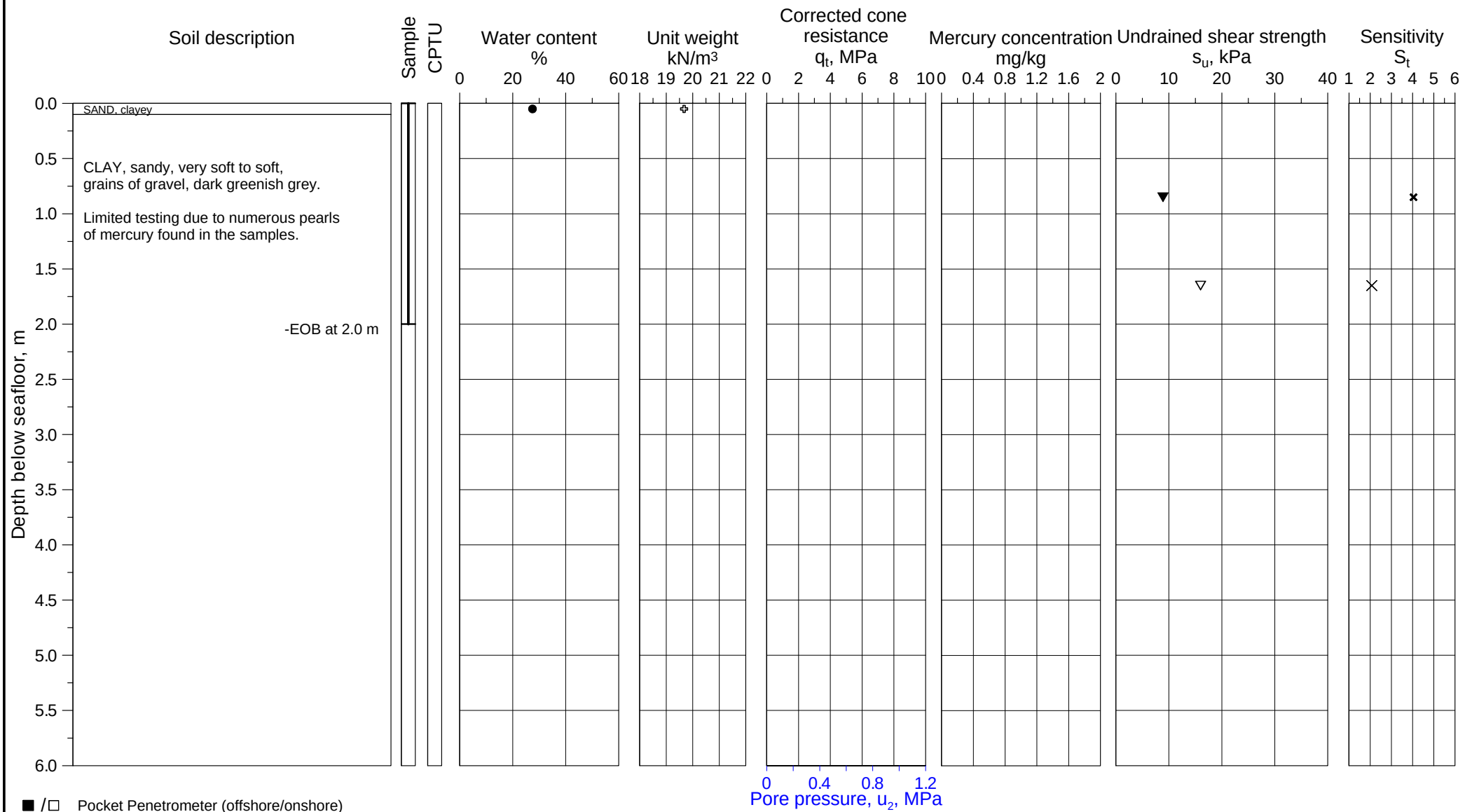


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# U-864 - 2013 SOIL SURVEY

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.
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ES

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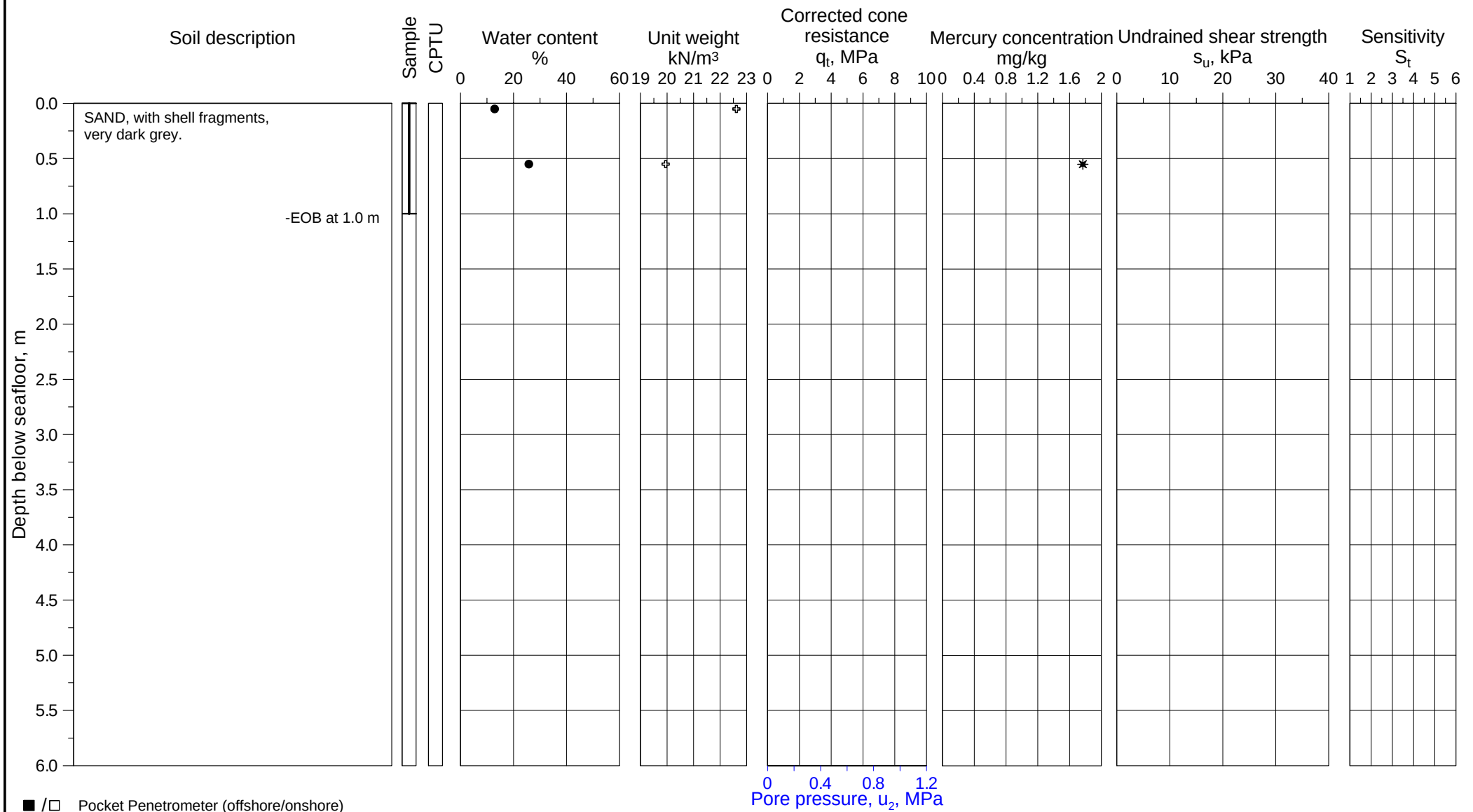


# U-864 - 2013 SOIL SURVEY

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

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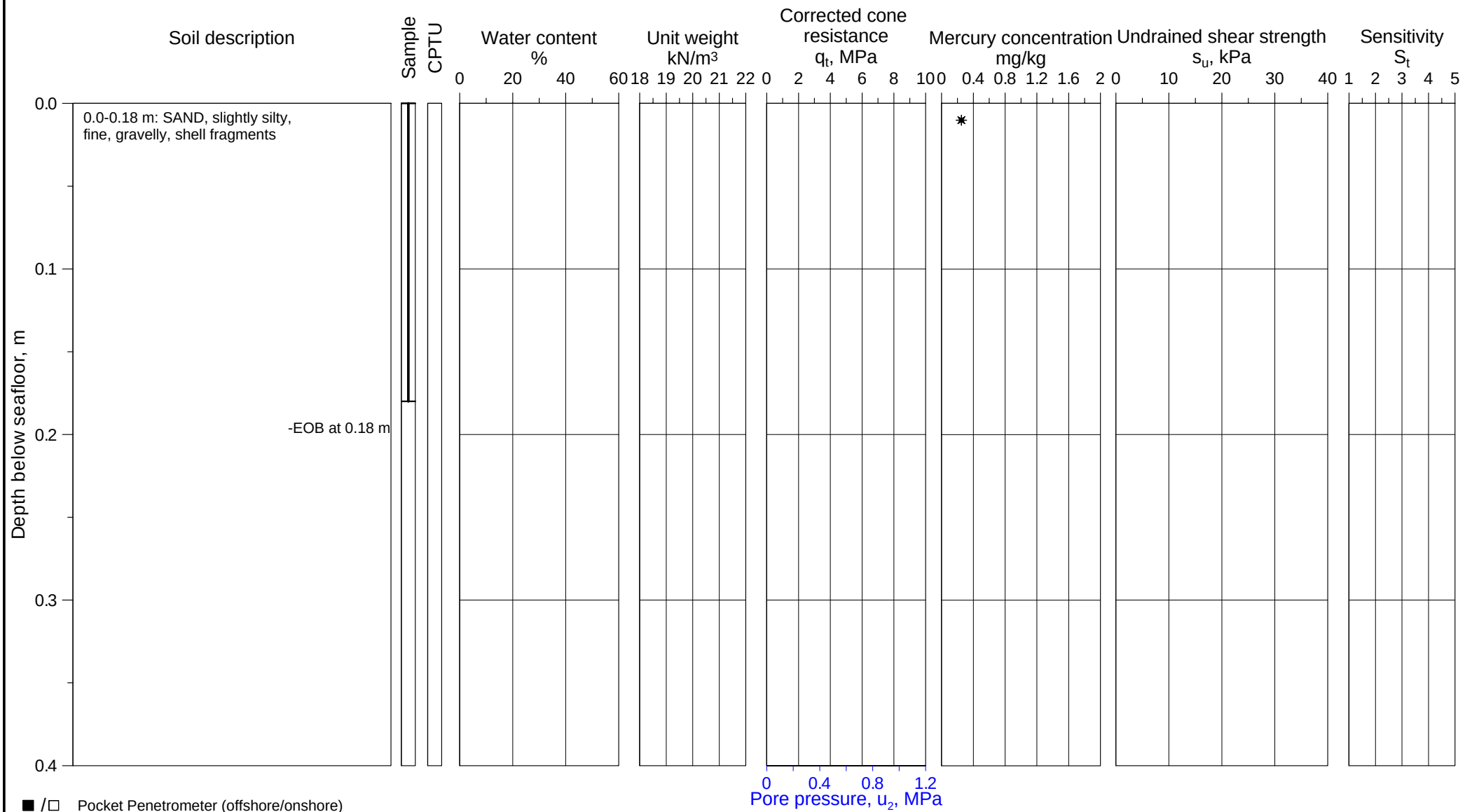


**U-864 - 2013 SOIL SURVEY**

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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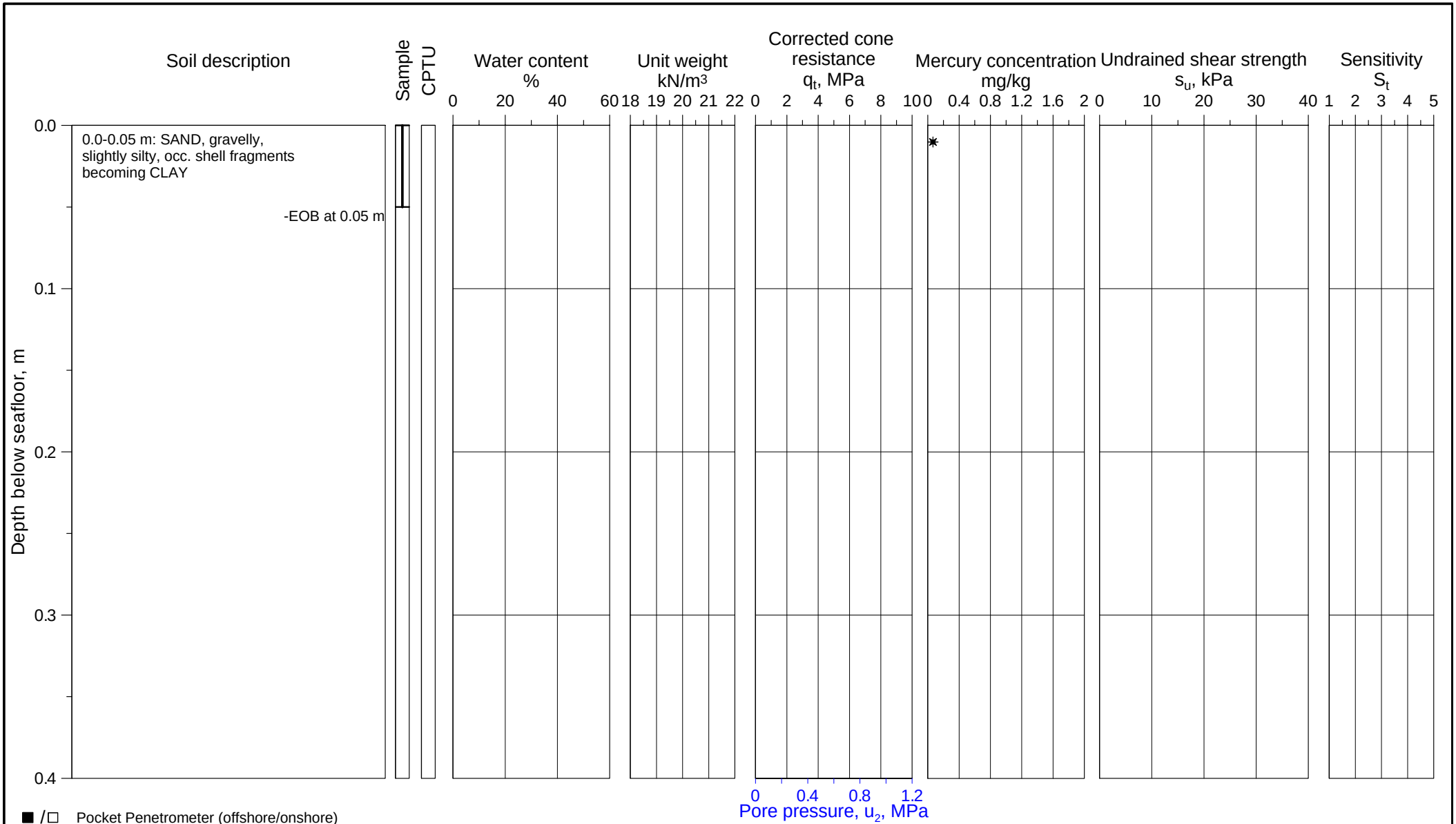


P:\2012\07\20120738\Feltarbeid\2013-28\Fig B1_17 2013-28.grf

## 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

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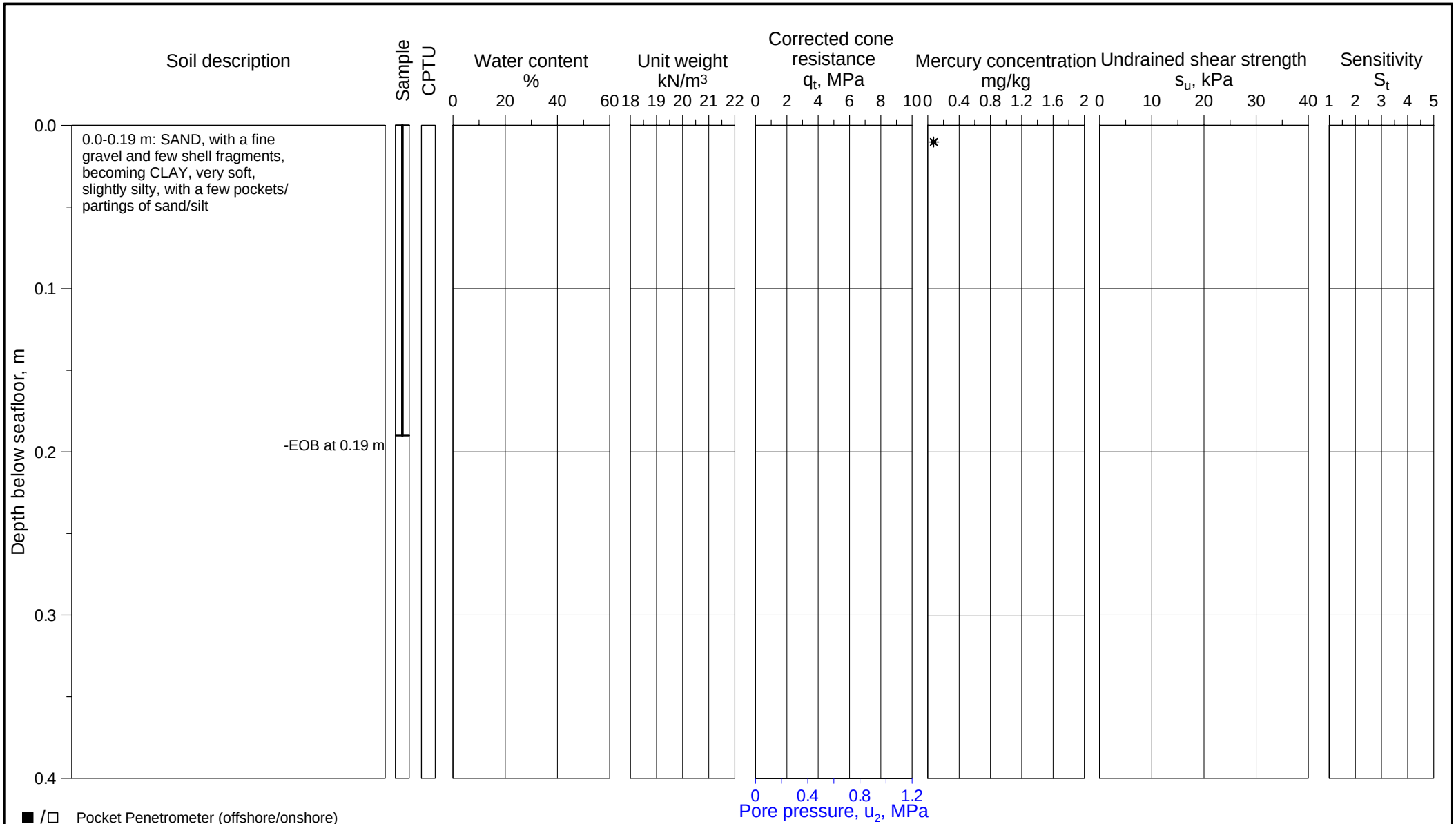


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# U-864 - 2013 SOIL SURVEY

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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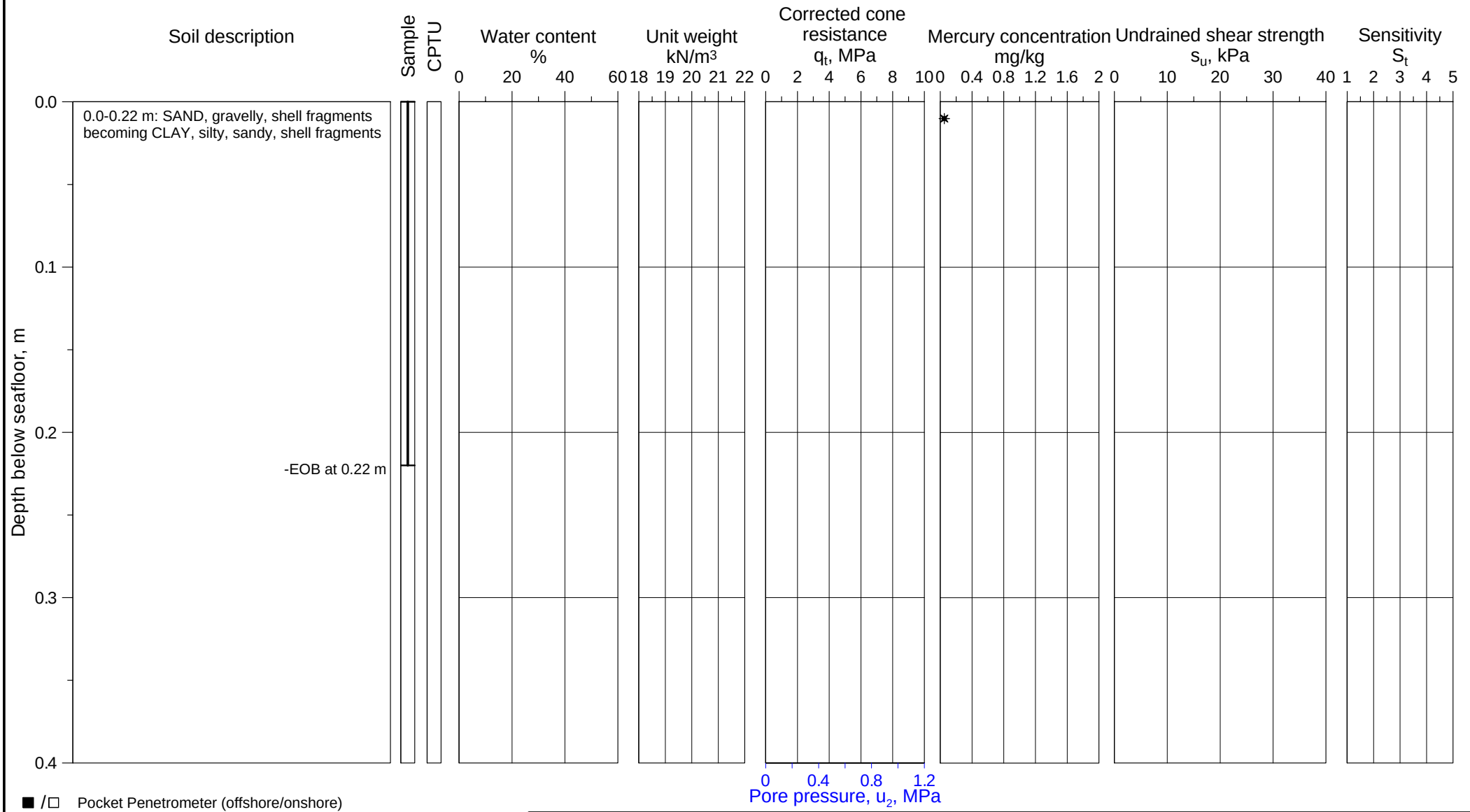


■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /⧫ Vane (lab offshore/in situ)
$\oplus_C$ CAUC/CIUC
$\oplus_E$ CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✥ $\gamma_t$ (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, $\gamma_t$ (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*

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20120738-01-R

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2013-03-15

Figure No.
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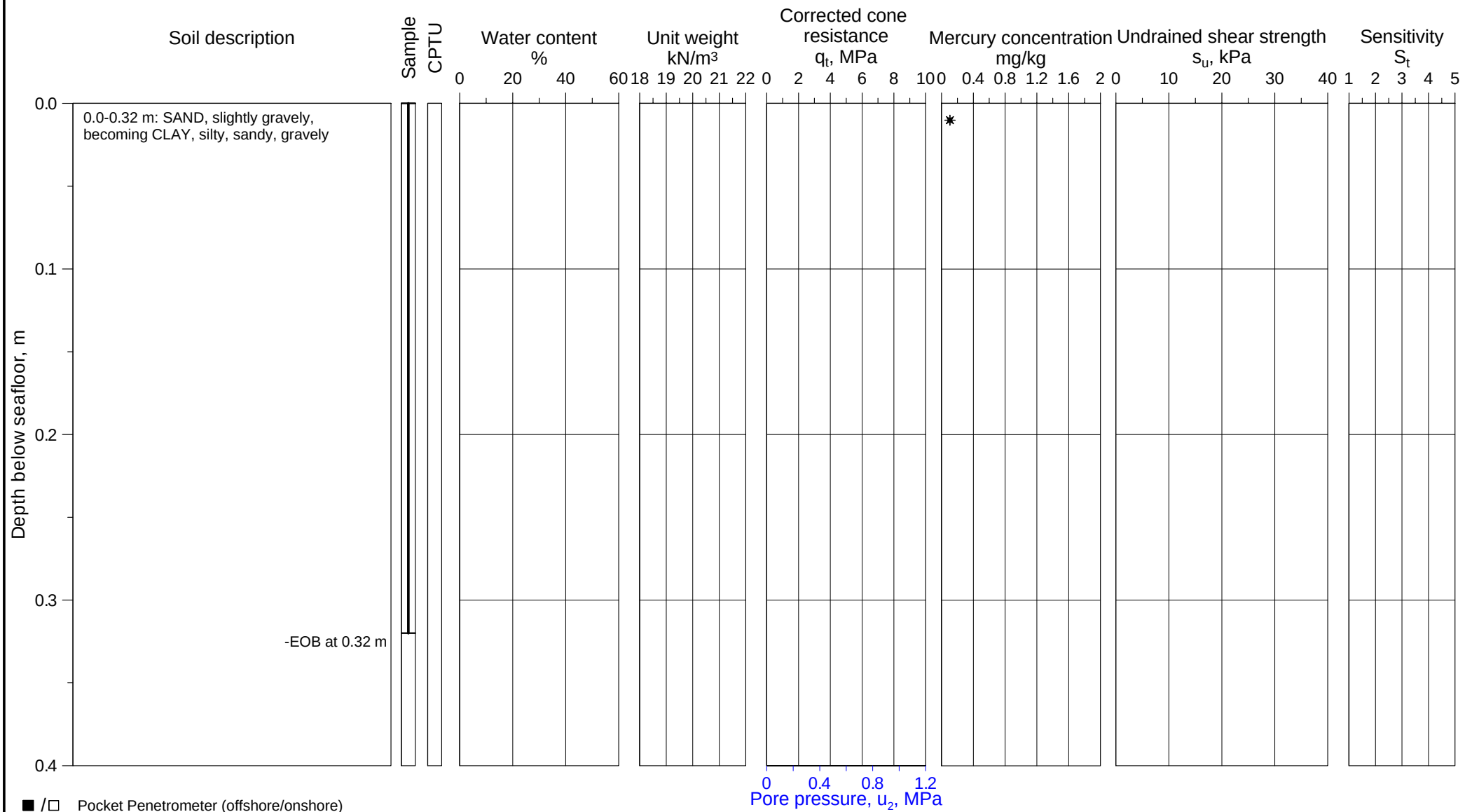


■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /⧫ Vane (lab offshore/in situ)
$\oplus_C$ CAUC/CIUC
$\oplus_E$ CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✣ $\gamma_t$ (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, $\gamma_t$ (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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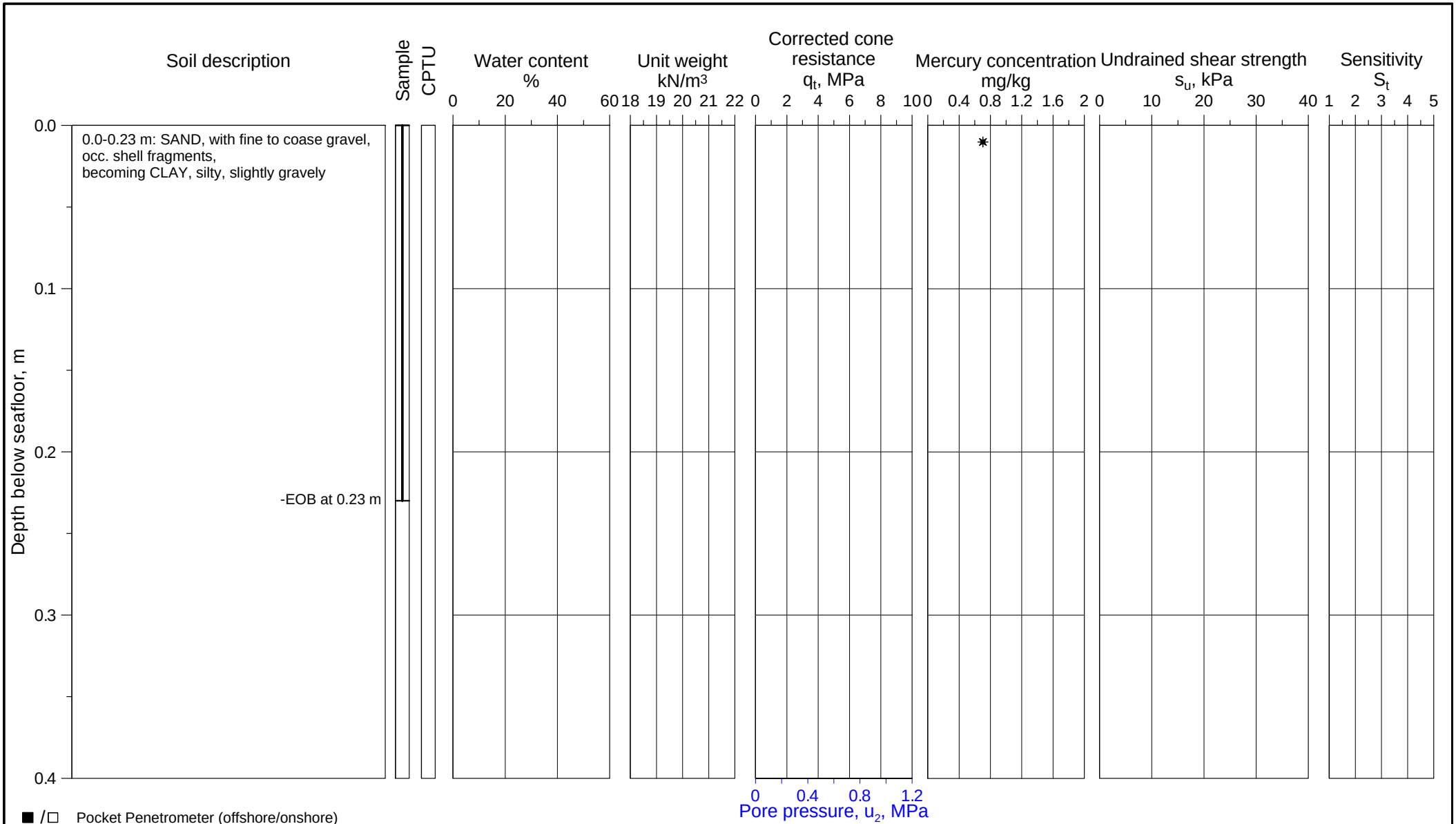


**U-864 - 2013 SOIL SURVEY**

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

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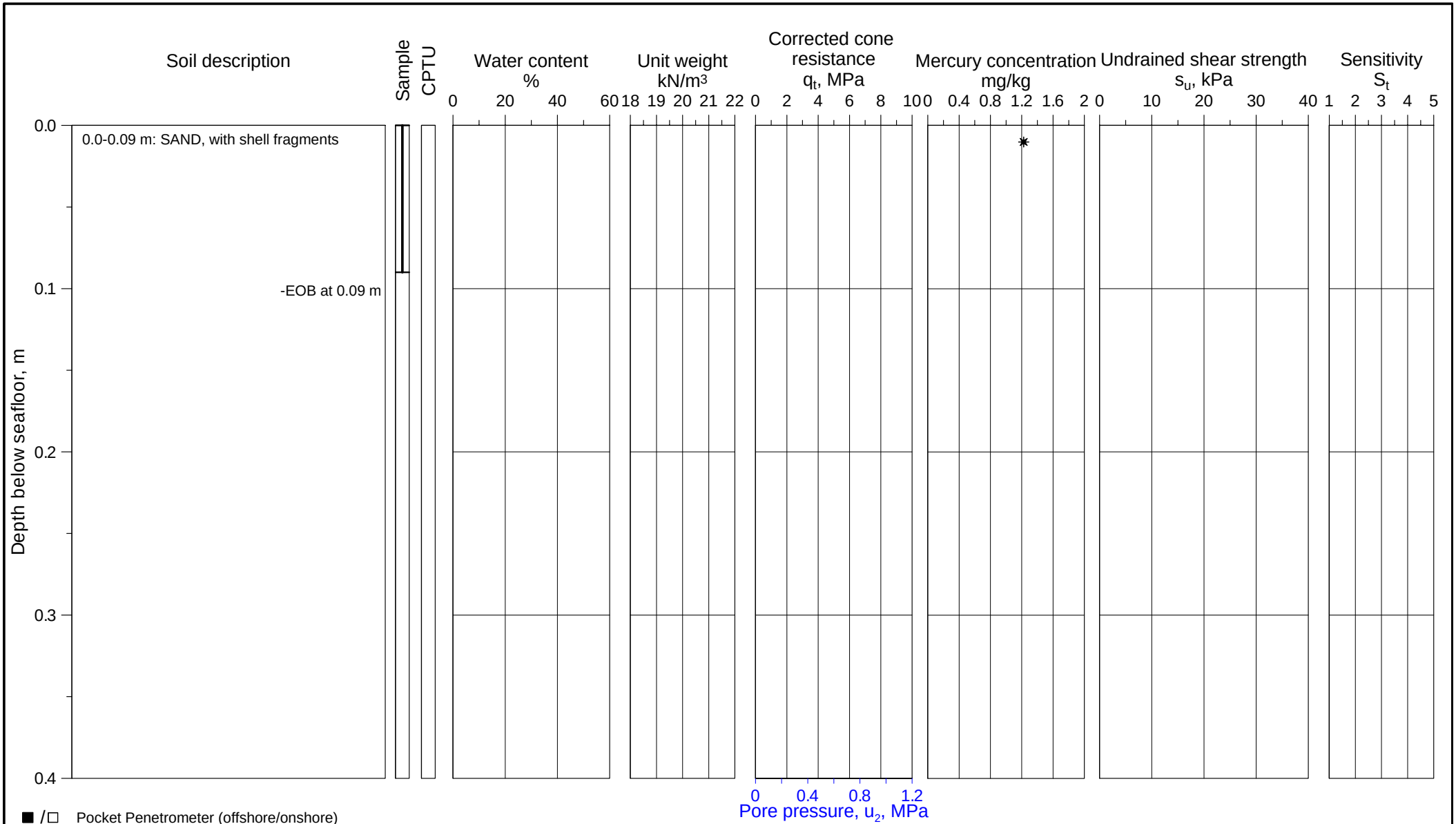


■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /⧫ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✣ $\gamma_t$ (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, $\gamma_t$ (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

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ES

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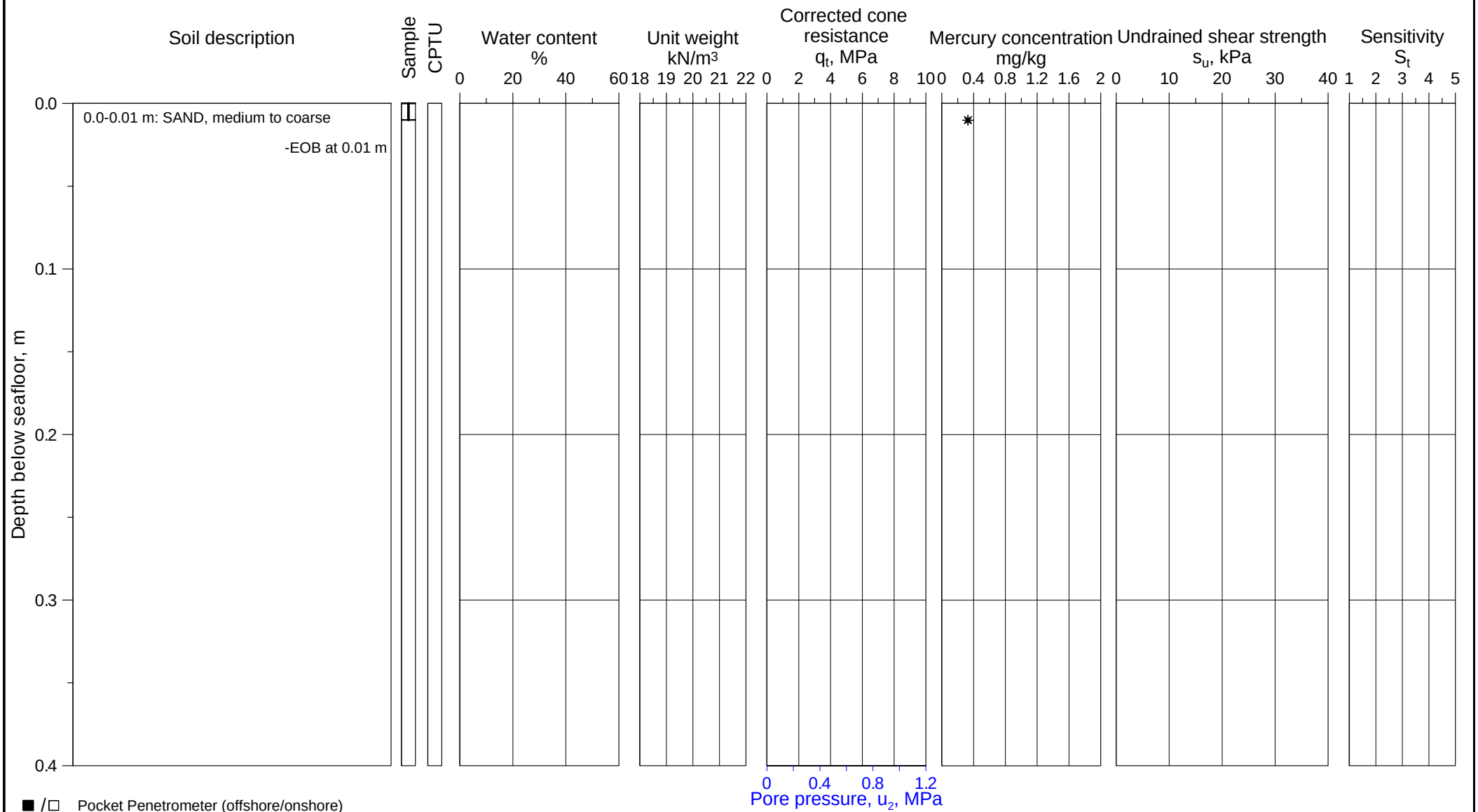
P:\2012\07\20120738\Feltarbeid\2013-35\Fig B1_22 2013-35.grf




■ /□ 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)
✣ $\gamma_t$ (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, $\gamma_t$ (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

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ES

NGI

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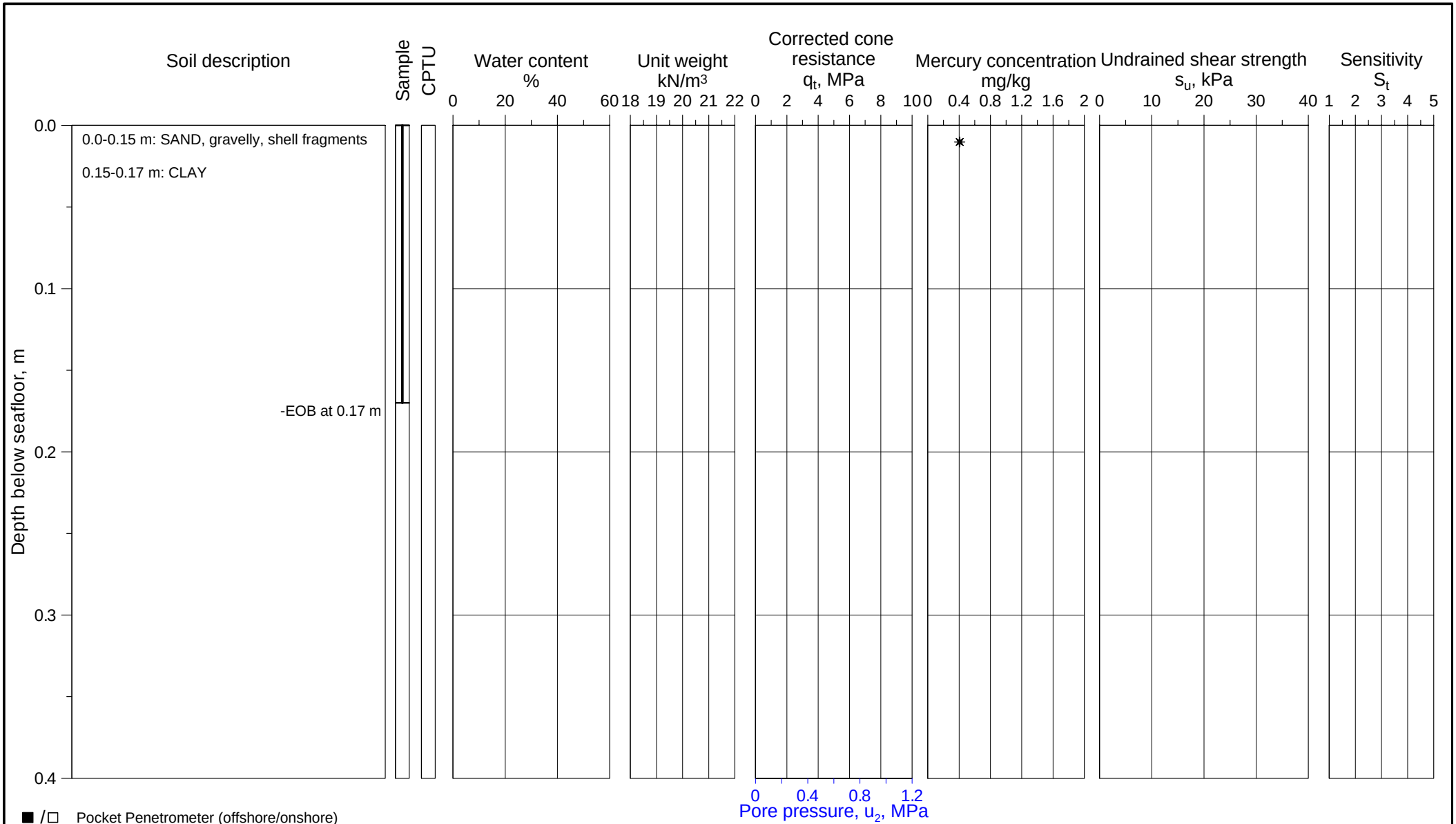


**U-864 - 2013 SOIL SURVEY**

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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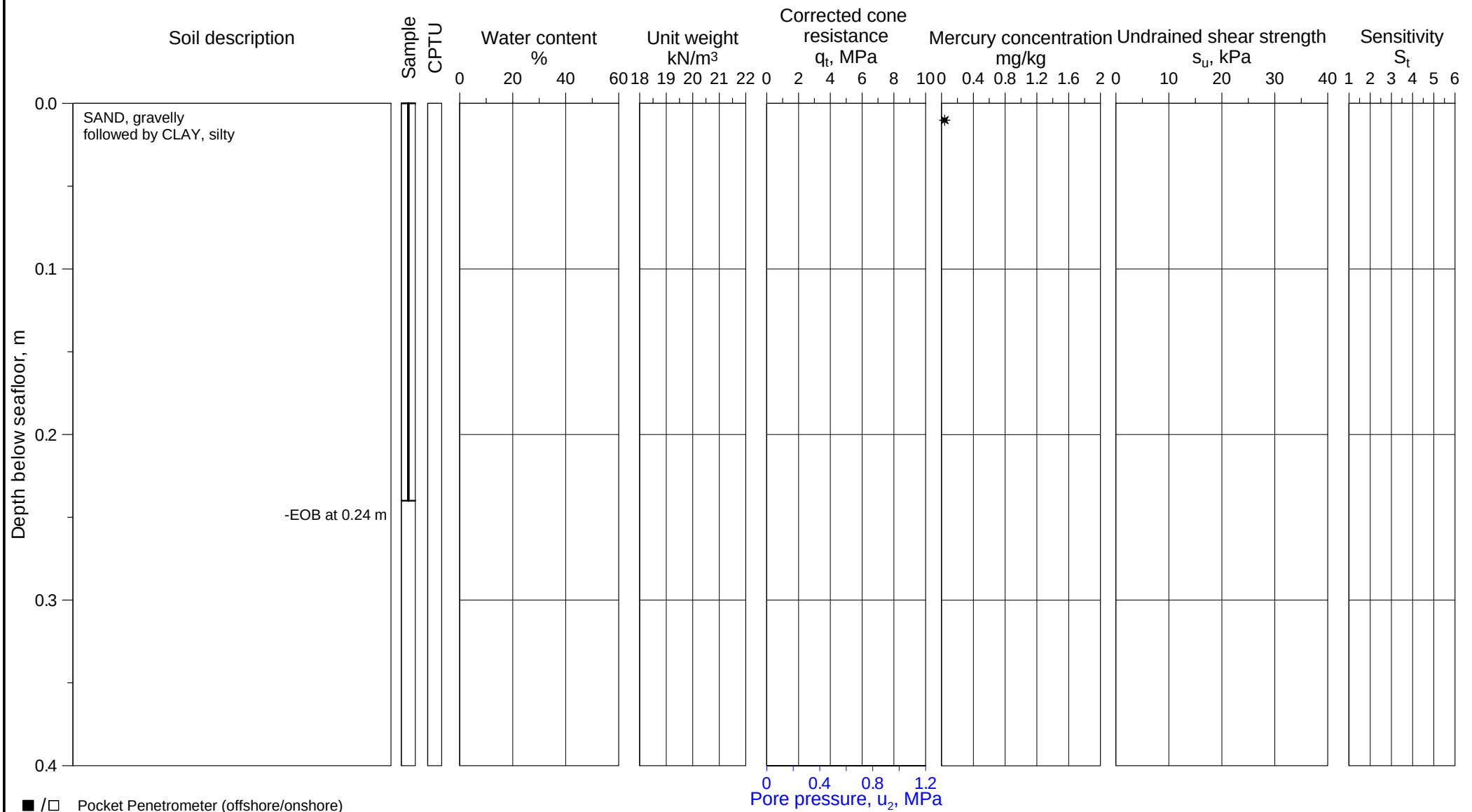


■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /⧫ Vane (lab offshore/in situ)
$\oplus_C$ CAUC/CIUC
$\oplus_E$ CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✣ $\gamma_t$ (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, $\gamma_t$ (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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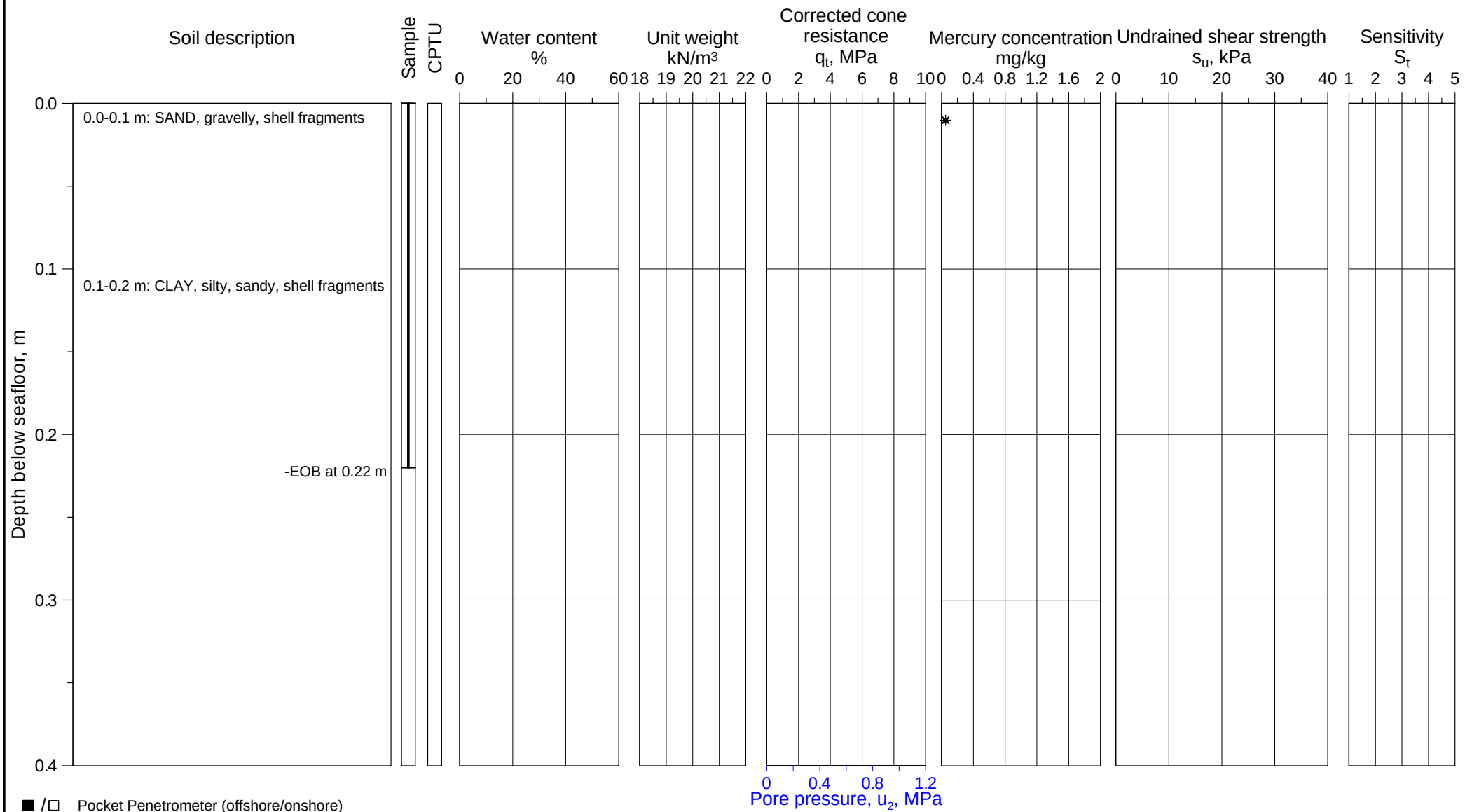
P:\2012\07\20120738\Feltarbeid\2013-83\Fig B1_25 2013-83.grf




■ /□ 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 |
|---|---|---|---|
| 2013-31 | 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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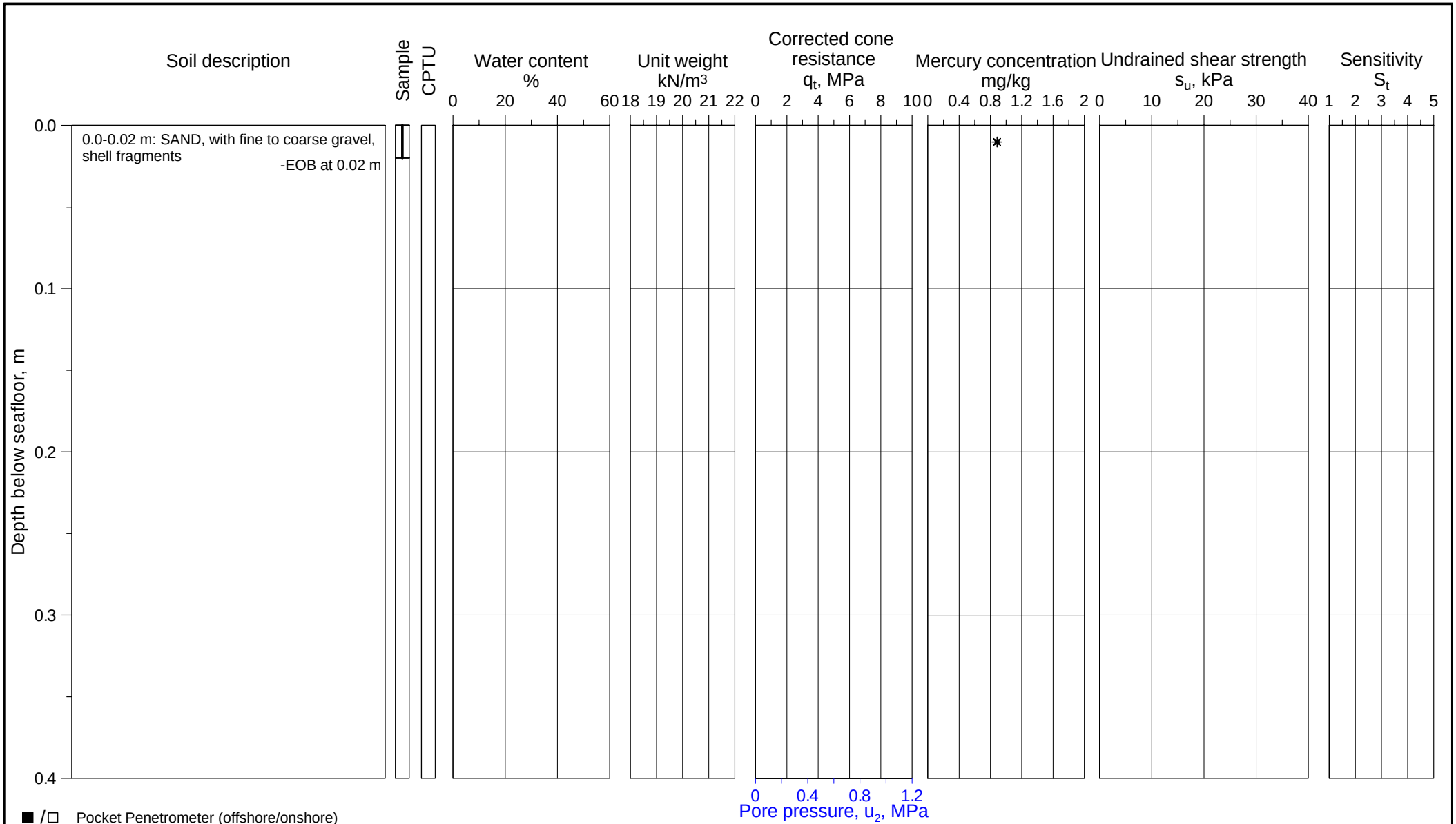


# U-864 - 2013 SOIL SURVEY

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

Drawn by ES

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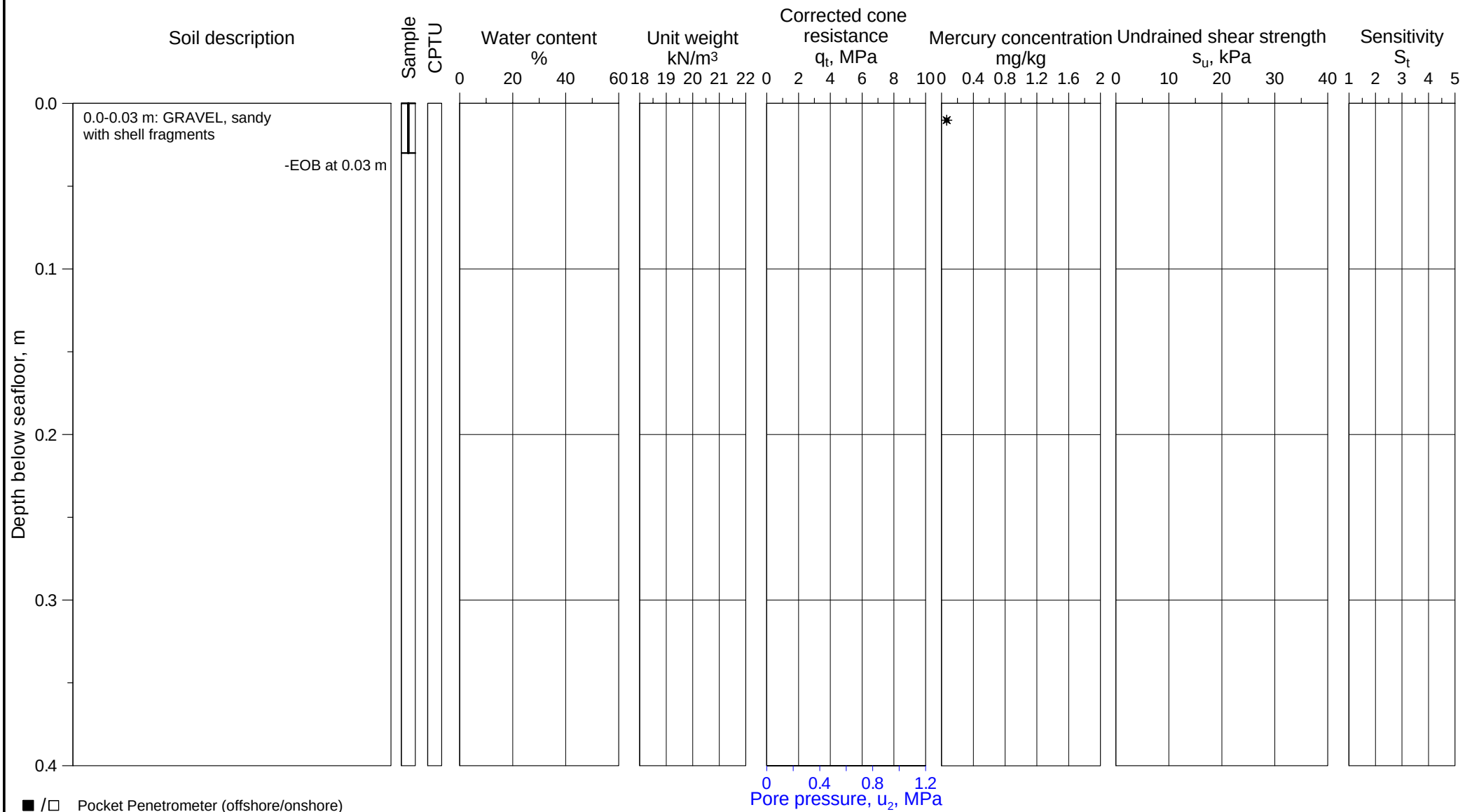


■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /⧫ Vane (lab offshore/in situ)
$\oplus_C$ CAUC/CIUC
$\oplus_E$ CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✣ $\gamma_t$ (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, $\gamma_t$ (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.
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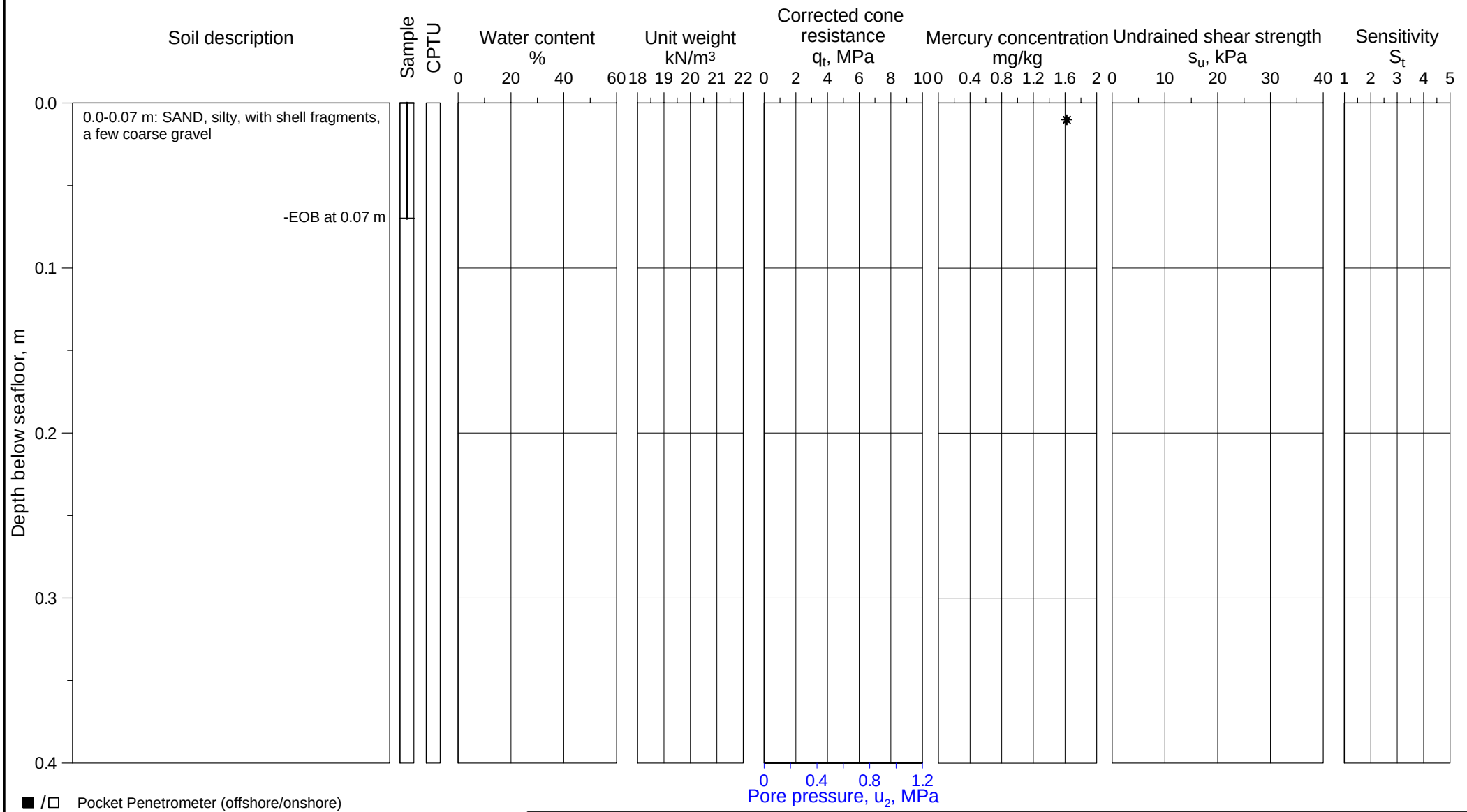


■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /⧫ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✥ γt (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, 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 |
|---|---|---|---|
| 2013-146 | 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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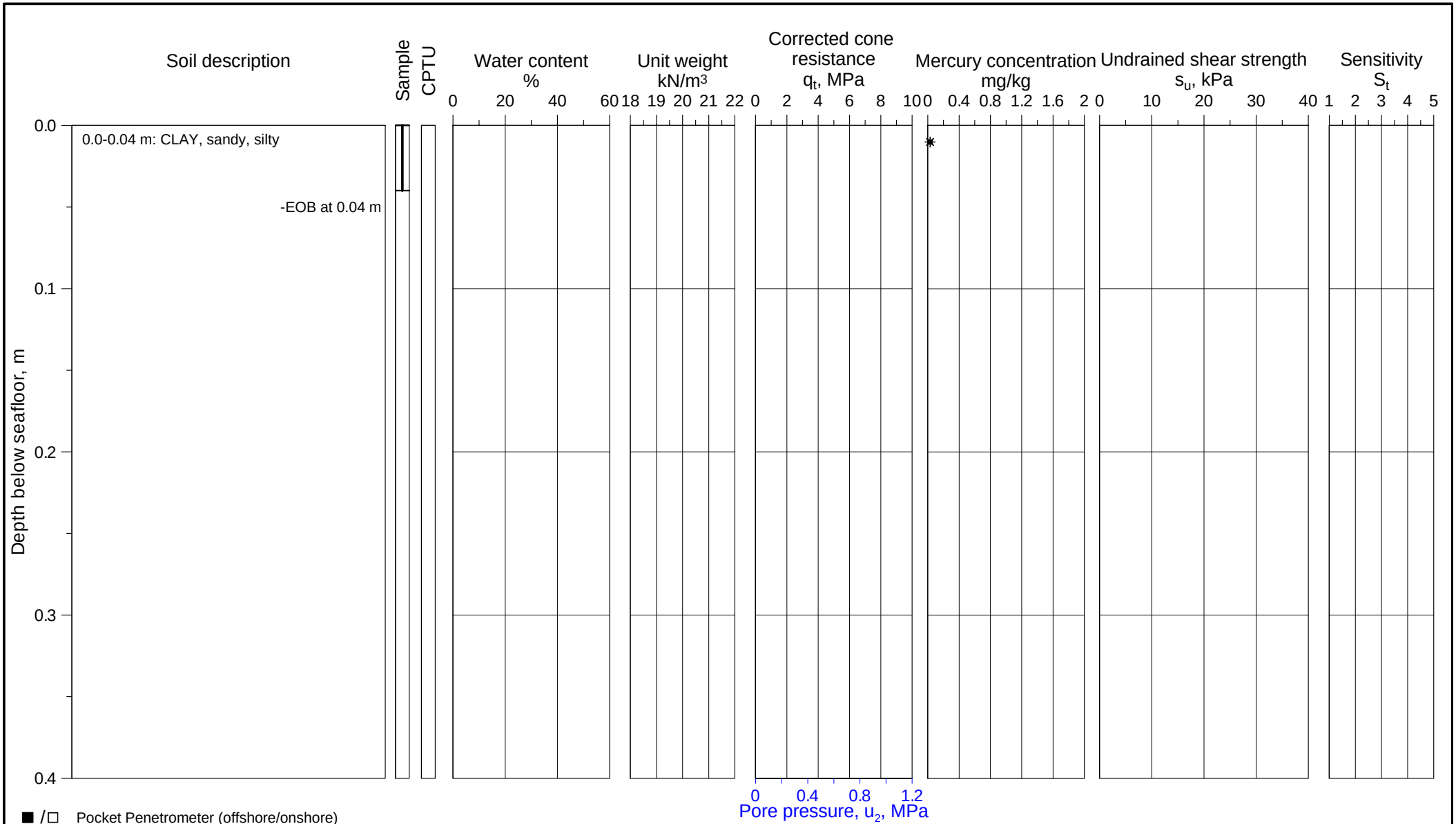


# U-864 - 2013 SOIL SURVEY

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

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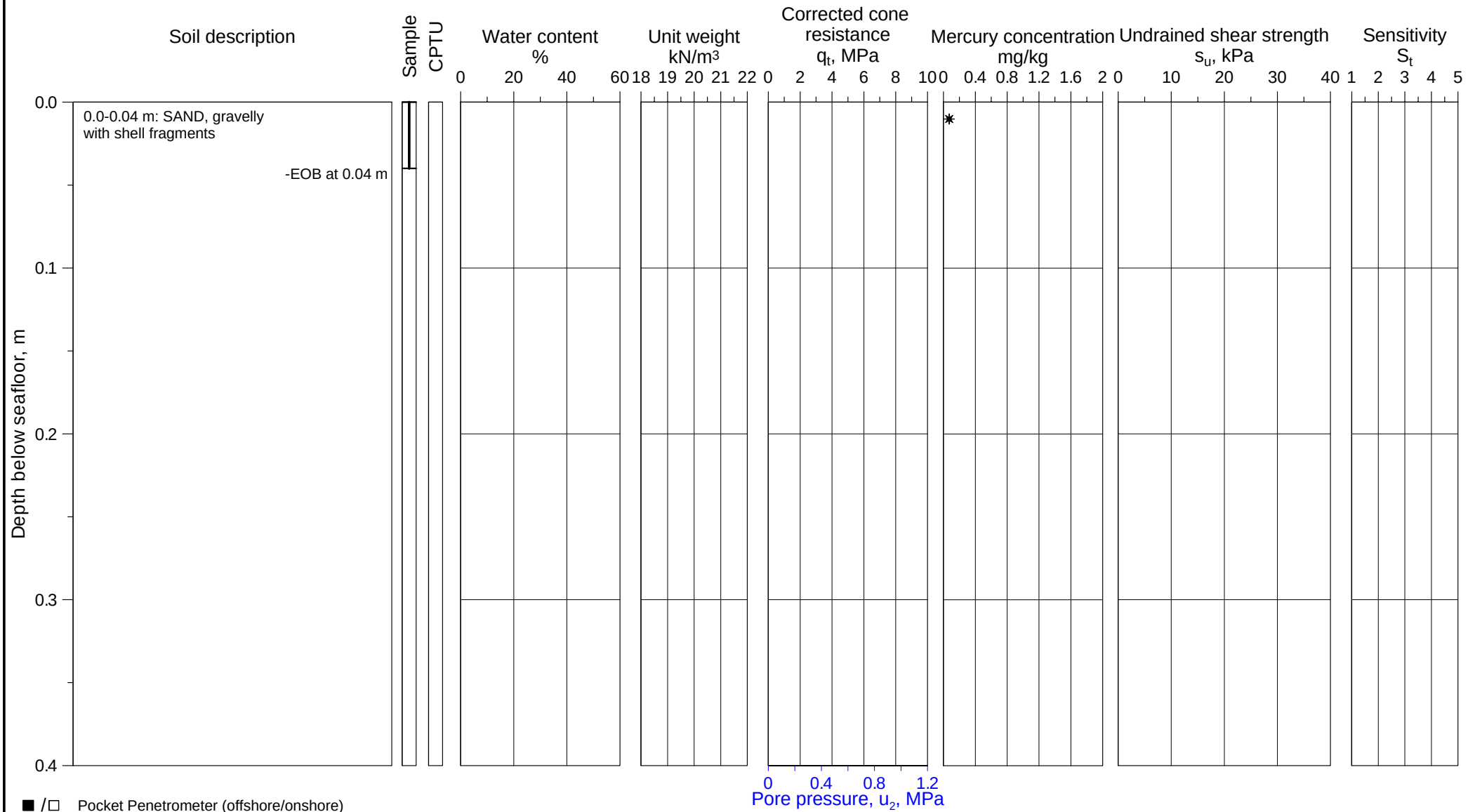


■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /⧫ Vane (lab offshore/in situ)
$\oplus_C$ CAUC/CIUC
$\oplus_E$ CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✣ $\gamma_t$ (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, $\gamma_t$ (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
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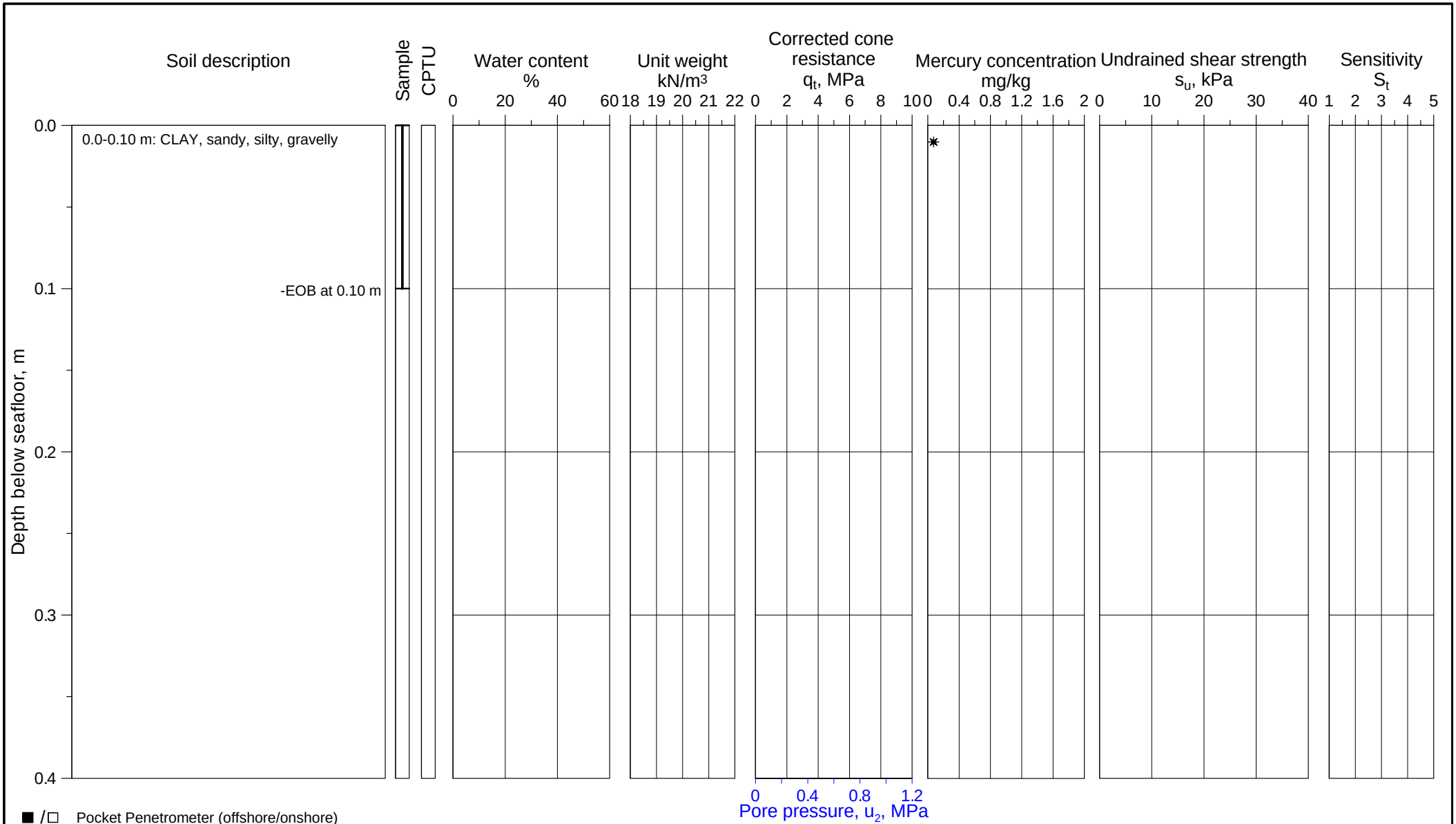
P:\2012\07\20120738\Feltarbeid\2013-204\Fig B1_31 2013-204.grf




# 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

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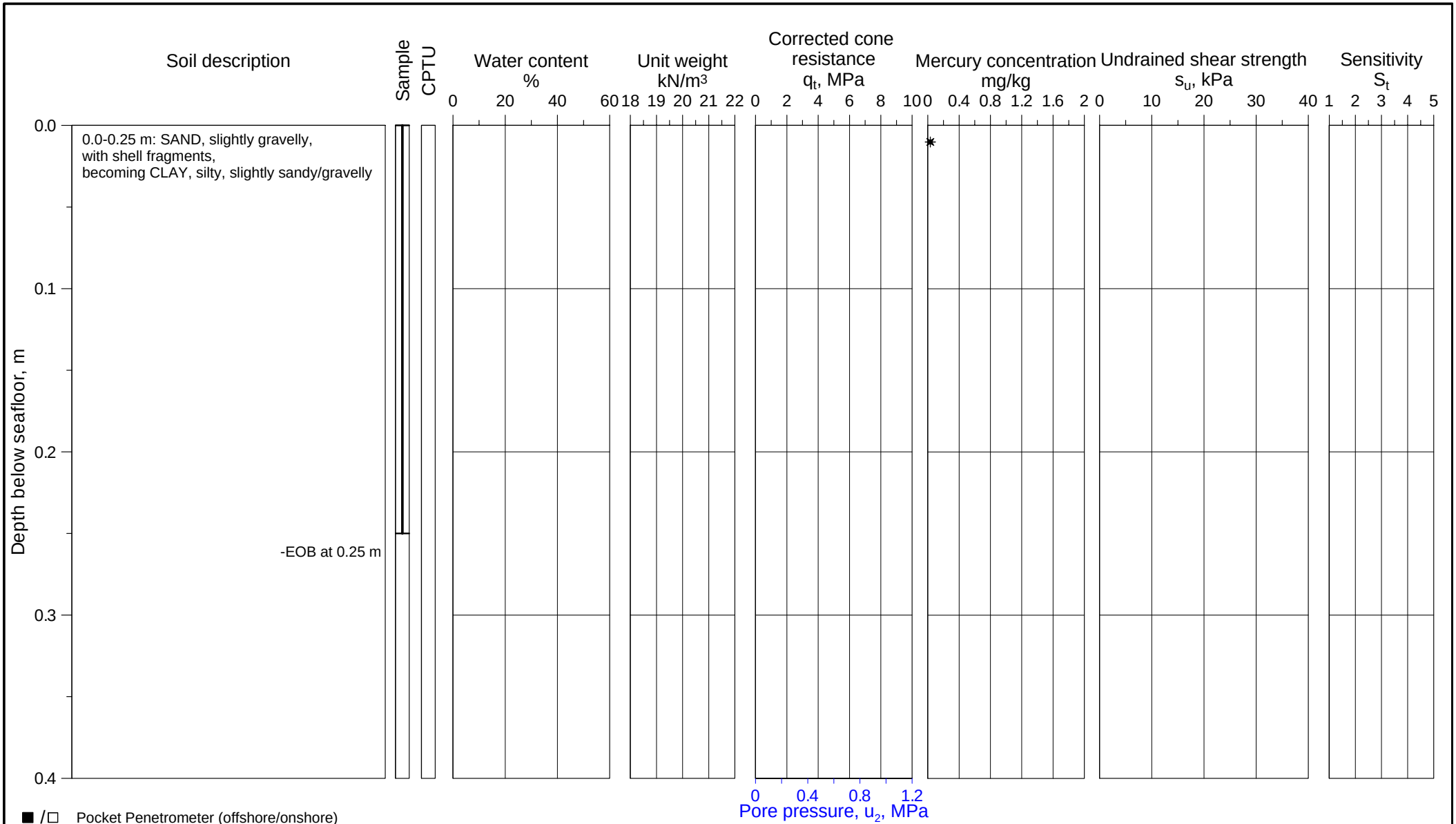
P:\2012\07\20120738\Feltarbeid\2013-206\Fig B1_32 2013-206.grf




**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

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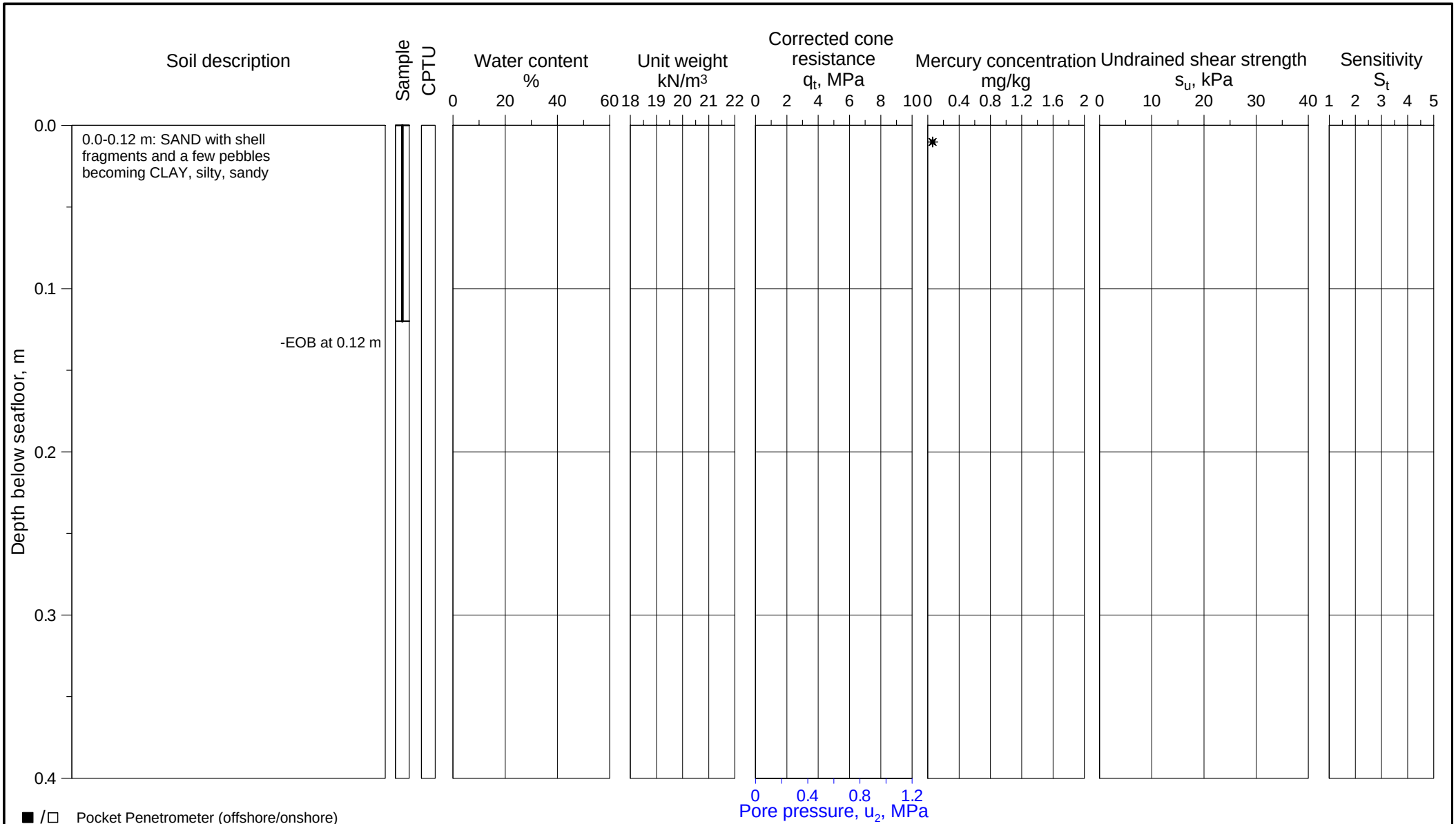
P:\2012\07\20120738\Feltarbeid\2013-210\Fig B1_33 2013-210.grf




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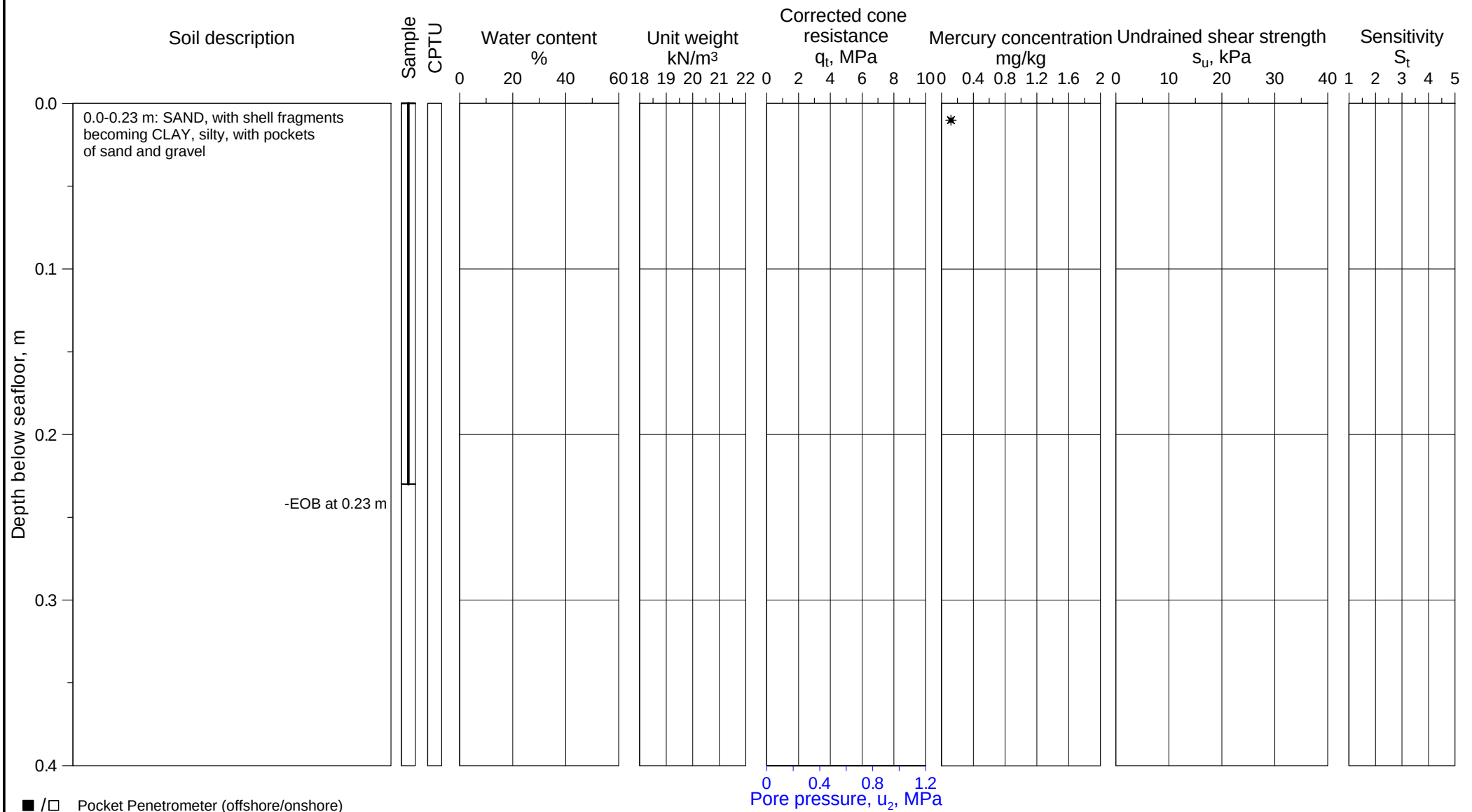
P:\2012\07\20120738\Feltarbeid\2013-211\Fig B1_34 2013-211.grf




■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /⧫ Vane (lab offshore/in situ)
$\oplus_C$ CAUC/CIUC
$\oplus_E$ CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✣ $\gamma_t$ (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, $\gamma_t$ (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 |
|---|---|---|---|
| 2013-213 | 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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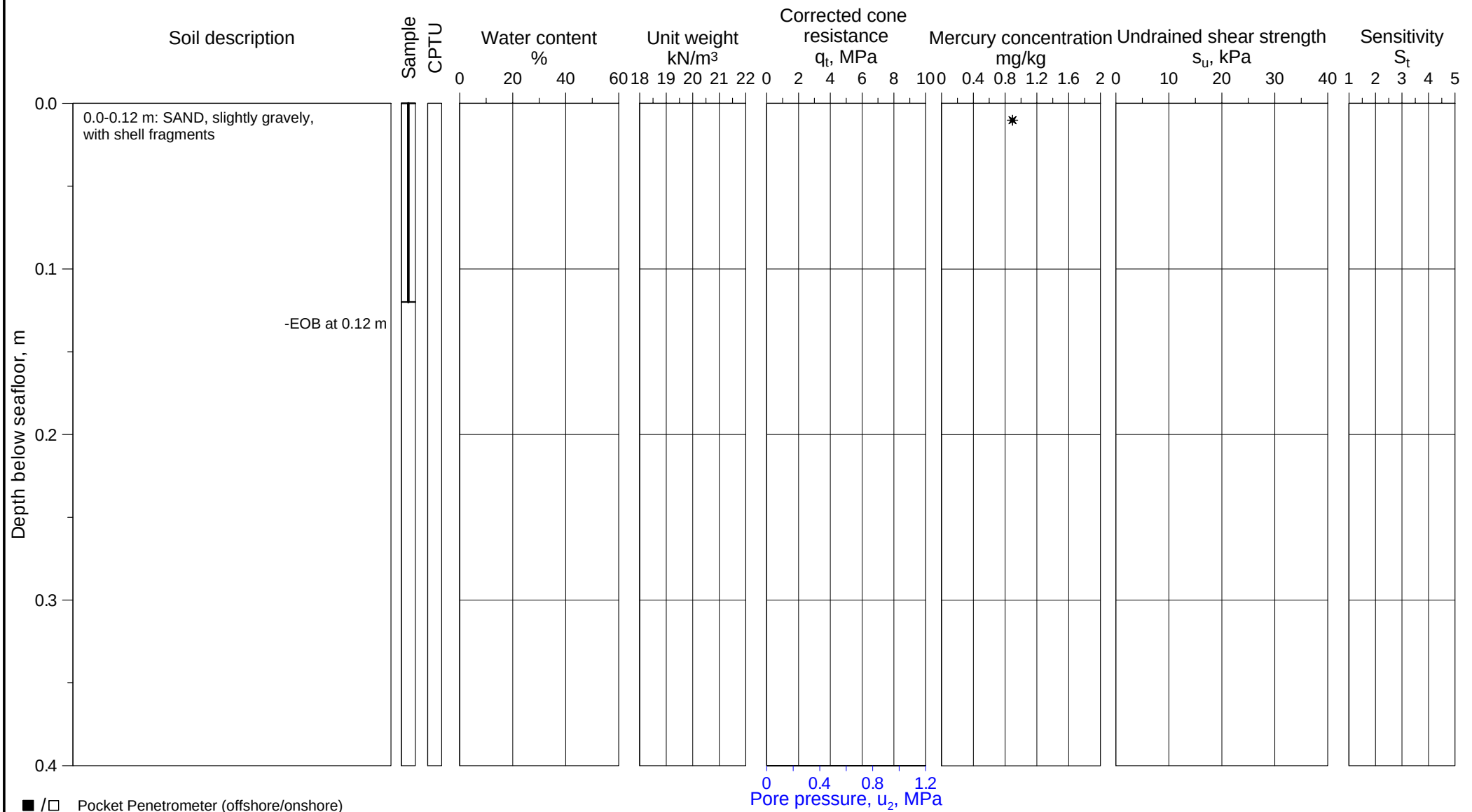
P:\2012\07\20120738\Feltarbeid\2013-213\Fig B1_35 2013-213.grf




■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /⧫ Vane (lab offshore/in situ)
$\oplus_C$ CAUC/CIUC
$\oplus_E$ CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✣ $\gamma_t$ (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, $\gamma_t$ (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

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2013-03-15

Figure No.
B1.36

Drawn by
ES

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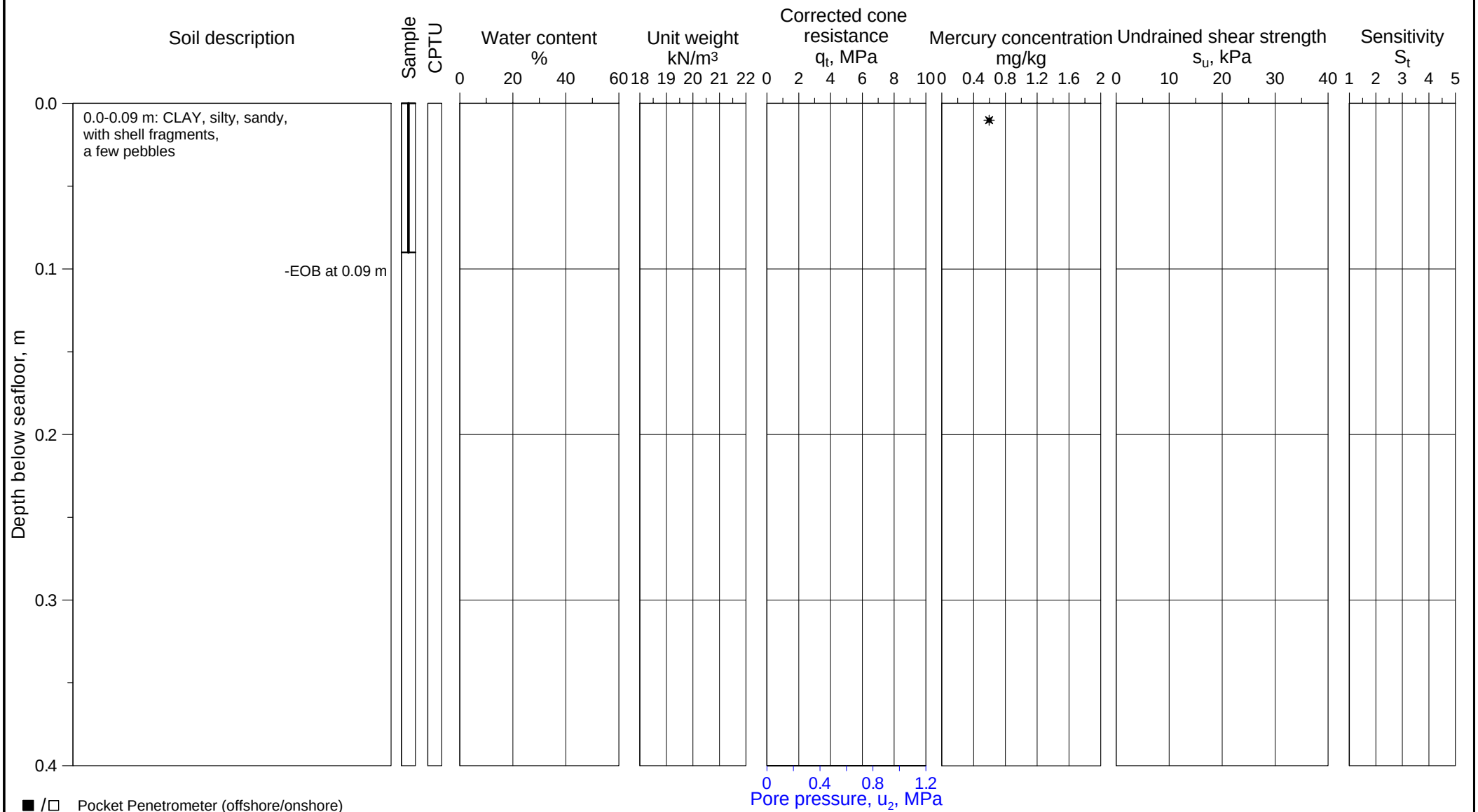
P:\2012\07\20120738\Feltarbeid\2013-301\Fig B1_36 2013-301.grf




■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /⧫ Vane (lab offshore/in situ)
$\oplus_C$ CAUC/CIUC
$\oplus_E$ CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✣ $\gamma_t$ (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, $\gamma_t$ (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 |
|---|---|---|---|
| 2013-302 | 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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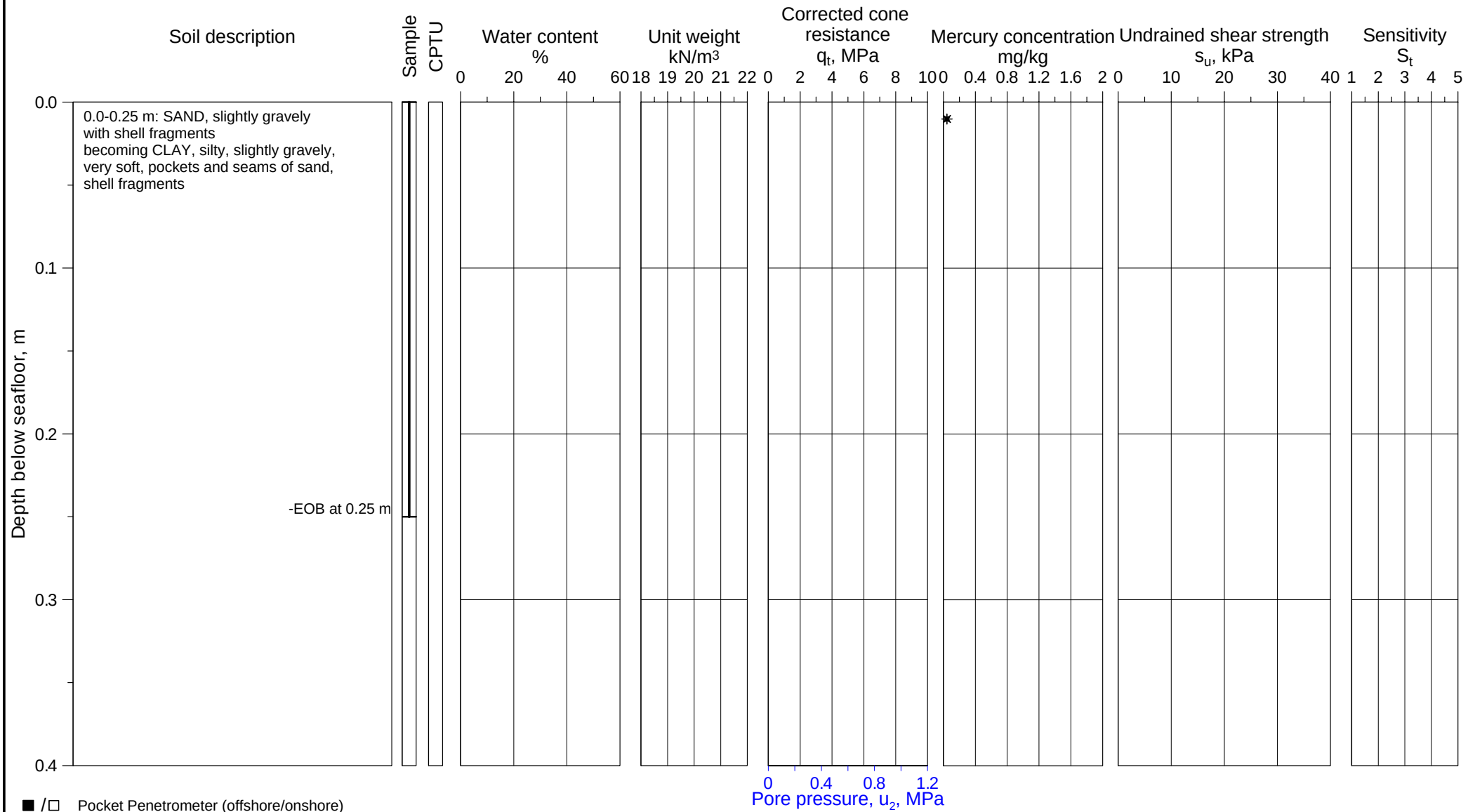
P:\2012\07\20120738\Feltarbeid\2013-302\Fig B1_37 2013-302.grf




■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /⧫ Vane (lab offshore/in situ)
$\oplus_C$ CAUC/CIUC
$\oplus_E$ CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✥ $\gamma_t$ (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, $\gamma_t$ (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 |
|---|---|---|---|
| 2013-306 | 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

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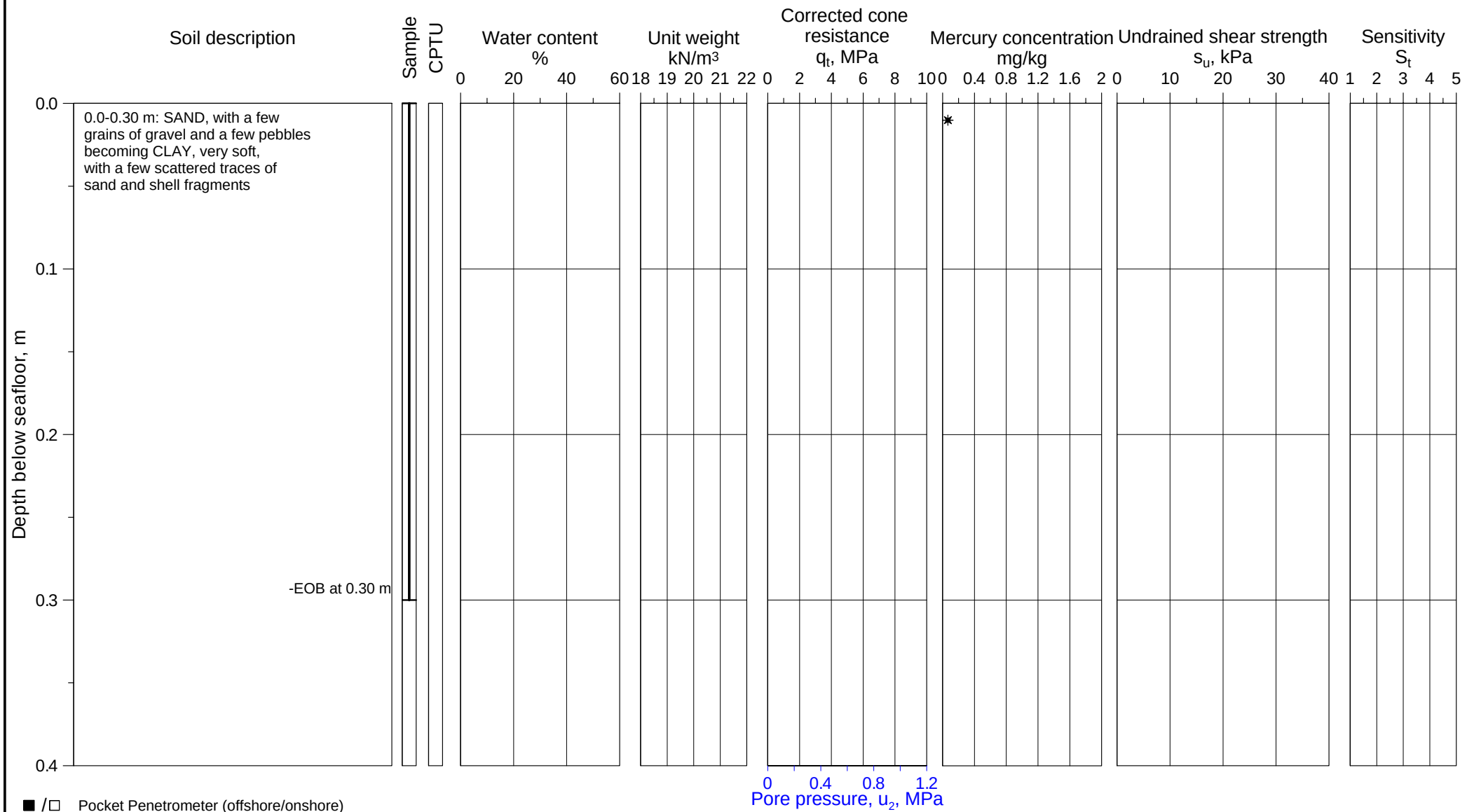
P:\2012\07\20120738\Feltarbeid\2013-306\Fig B1_38 2013-306.grf




■ /□ 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)
✣ $\gamma_t$ (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, $\gamma_t$ (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

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ES

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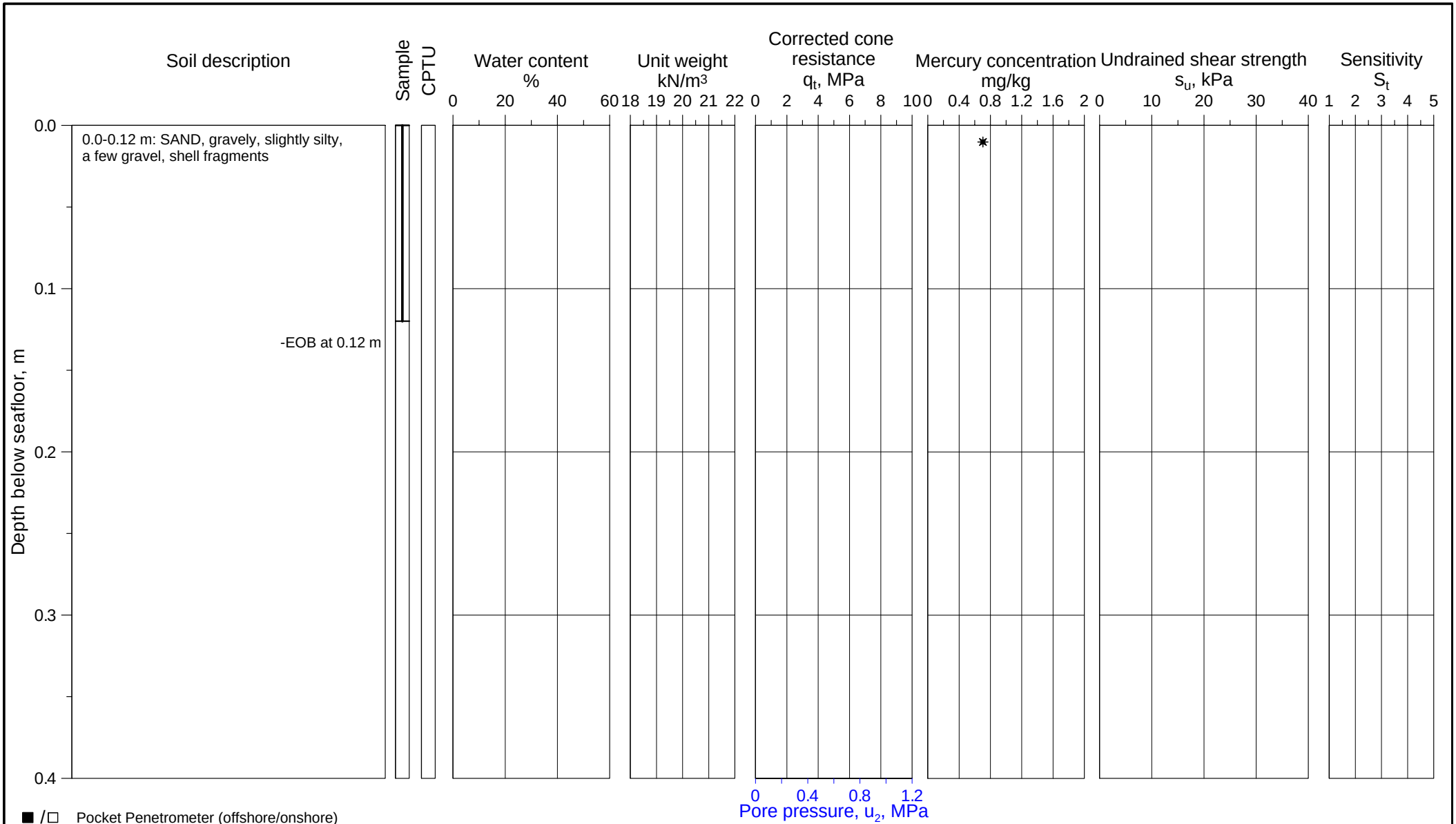
P:\2012\07\20120738\Feltarbeid\2013-308\Fig B1_39 2013-308.grf




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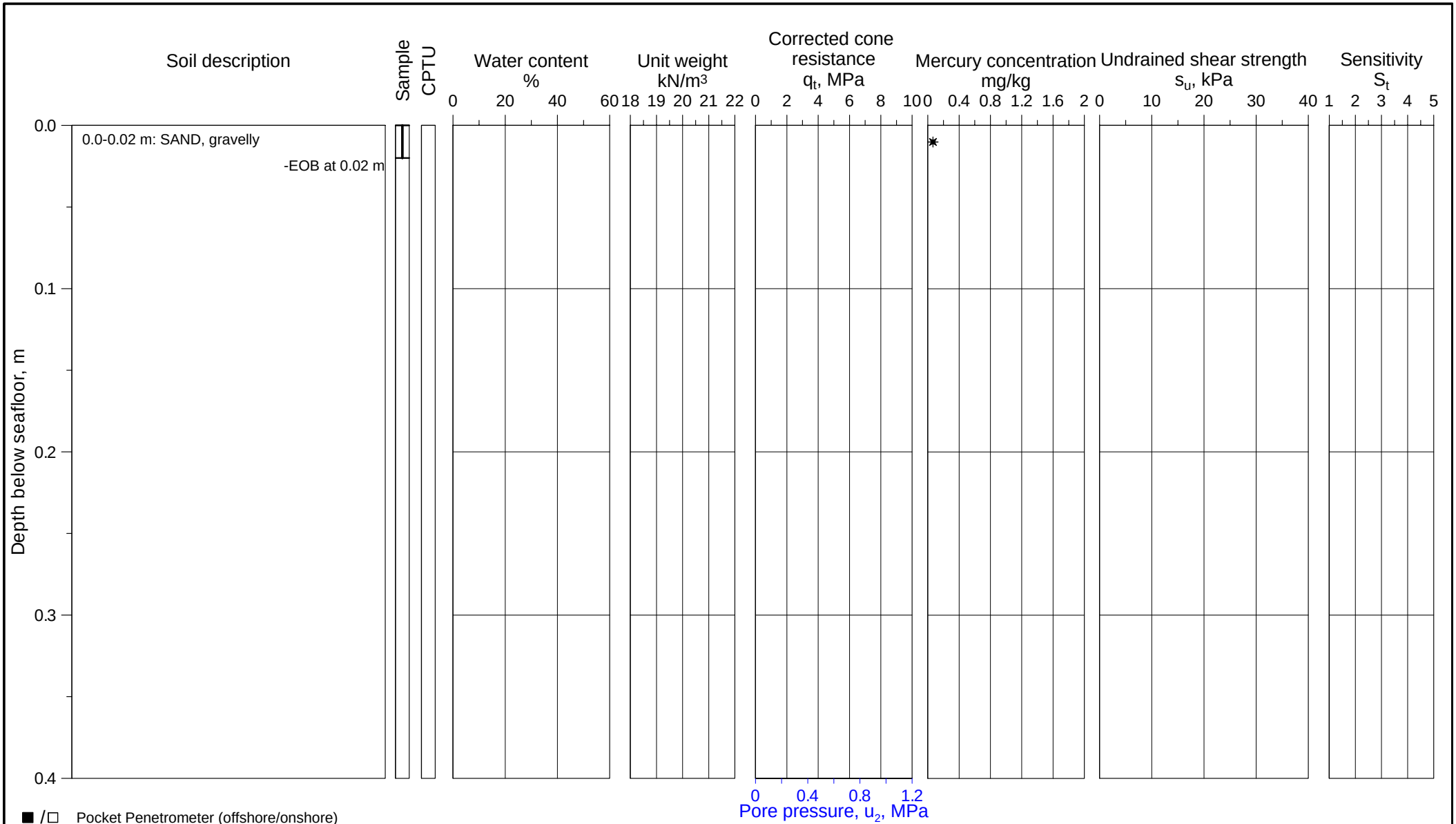
P:\2012\07\20120738\Feltarbeid\2013-312\Fig B1_40 2013-312.grf




# 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

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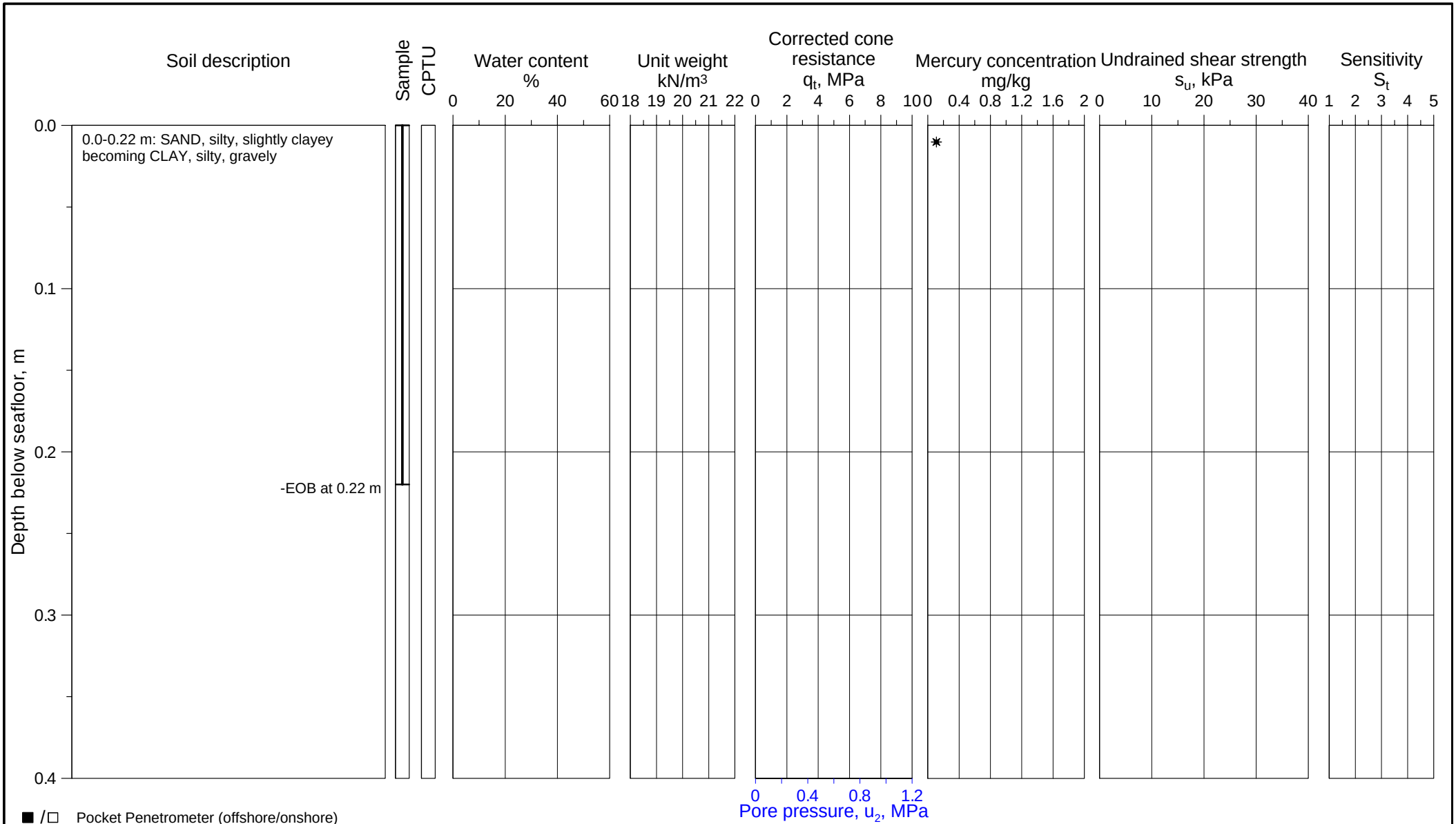
P:\2012\07\20120738\Feltarbeid\2013-313\Fig B1_41 2013-313.grf




■ /□ 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 |
|---|---|---|---|
| 2013-315 | 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

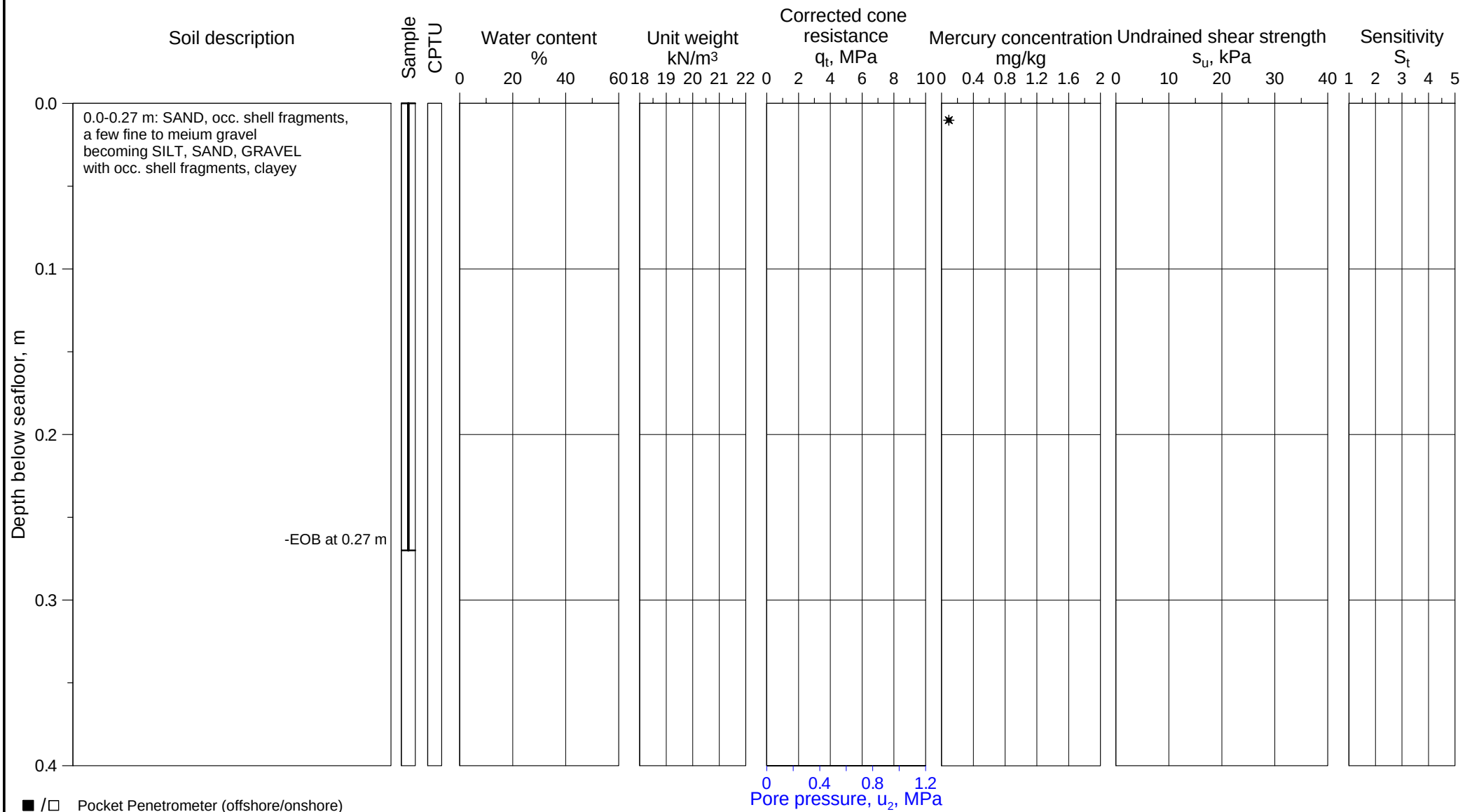
Date
2013-03-15

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)
$\oplus_C$ CAUC/CIUC
$\oplus_E$ CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✣ $\gamma_t$ (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, $\gamma_t$ (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

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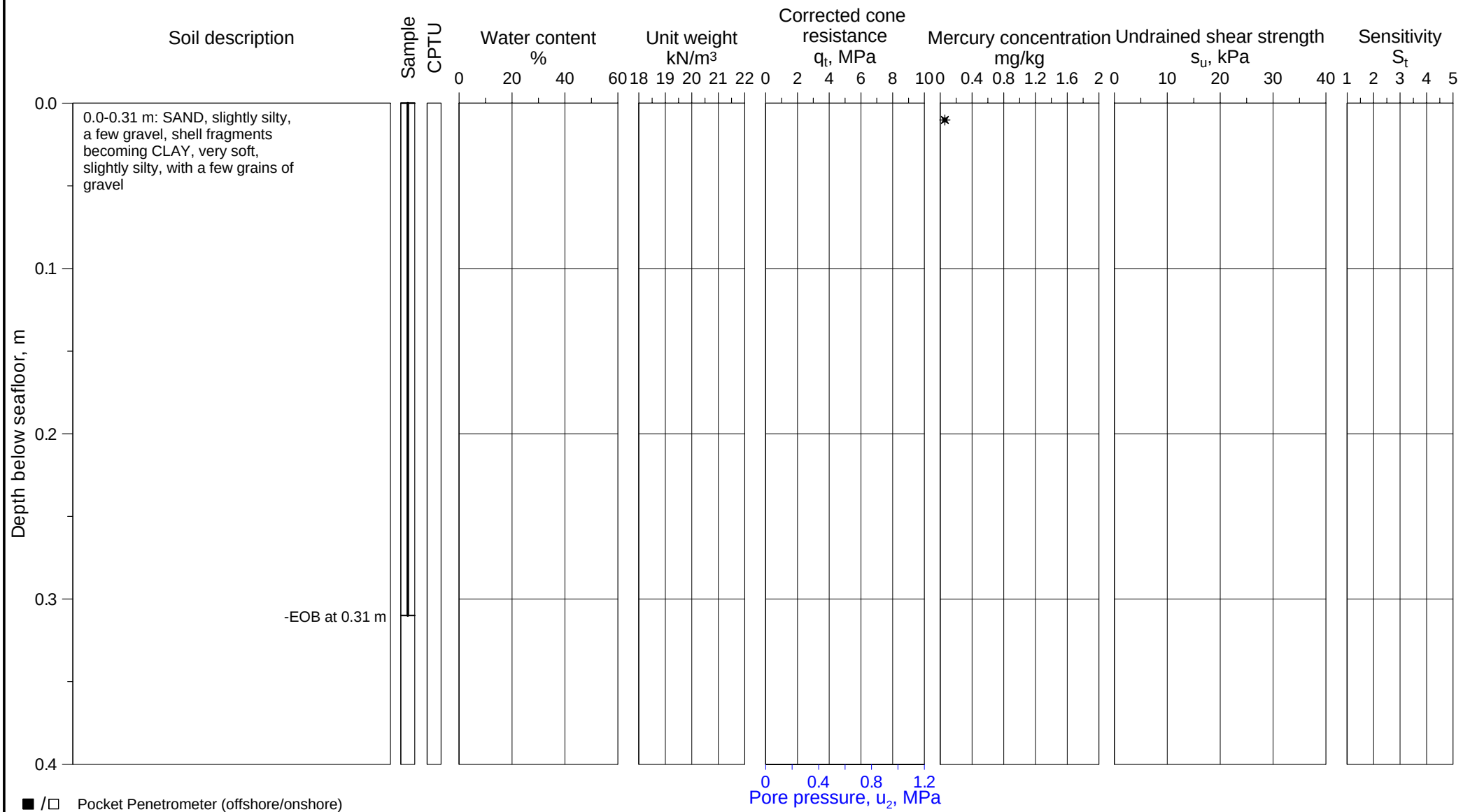
P:\2012\07\20120738\Feltarbeid\2013-316\Fig B1_43 2013-316.grf




■ /□ 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)
✣ 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 |
|---|---|---|---|
| 2013-317 | 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

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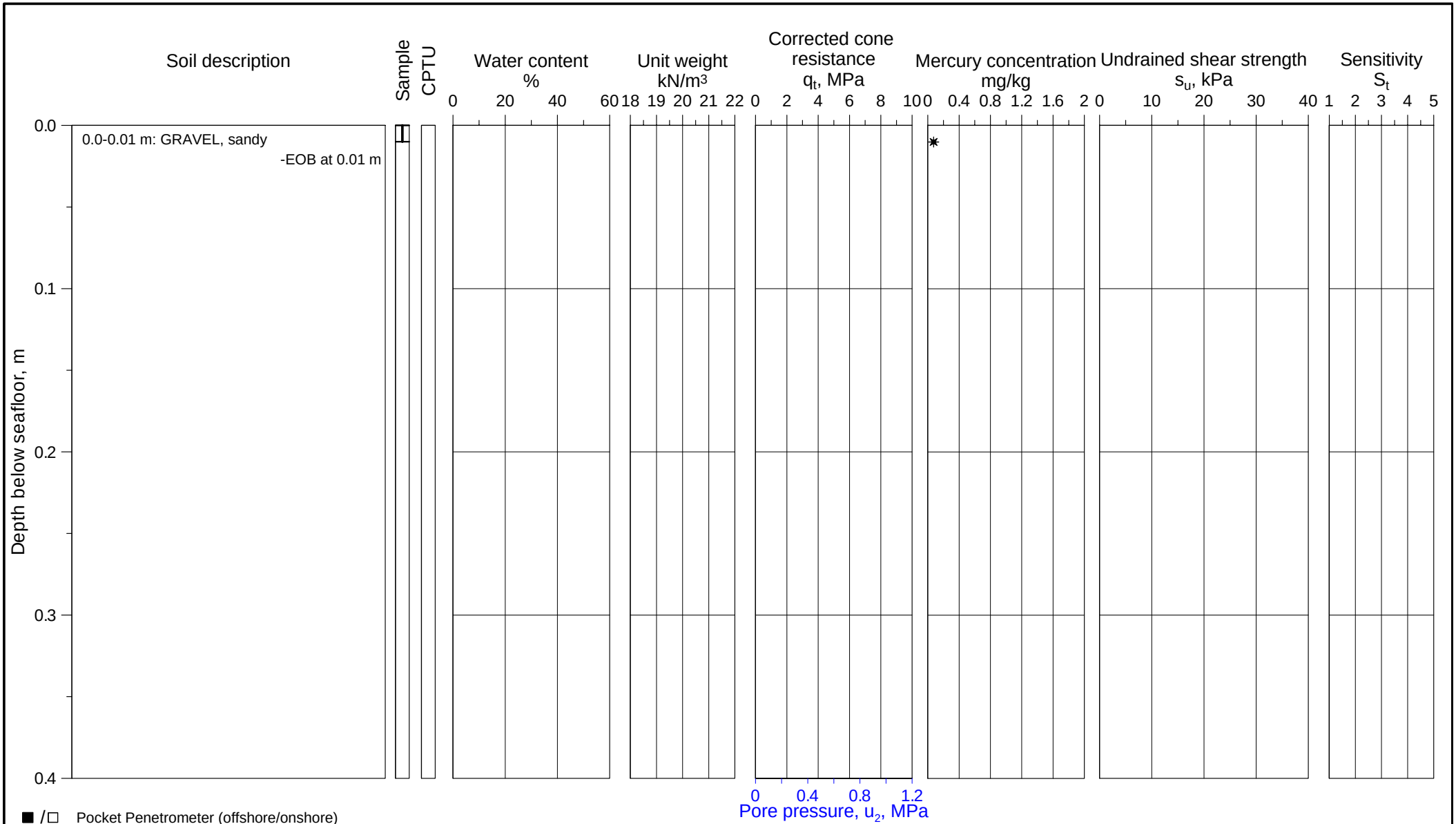
P:\2012\07\20120738\Feltarbeid\2013-317\Fig B1_44 2013-317.grf




■ /□ 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)
✣ $\gamma_t$ (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, $\gamma_t$ (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 |
|---|---|---|---|
| 2013-320 | 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

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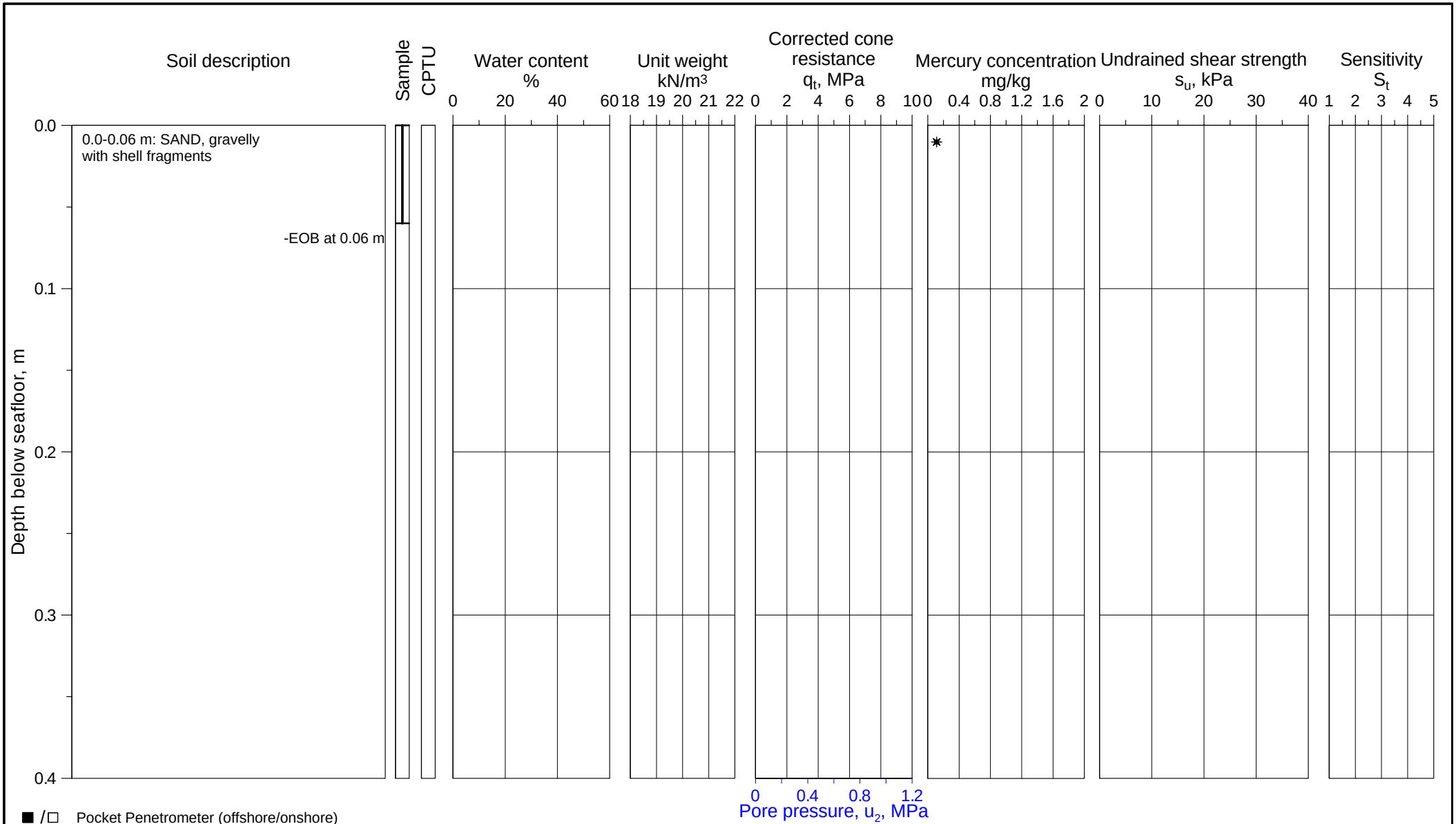
P:\2012\07\20120738\Feltarbeid\2013-320\Fig B1_45 2013-320.grf




**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

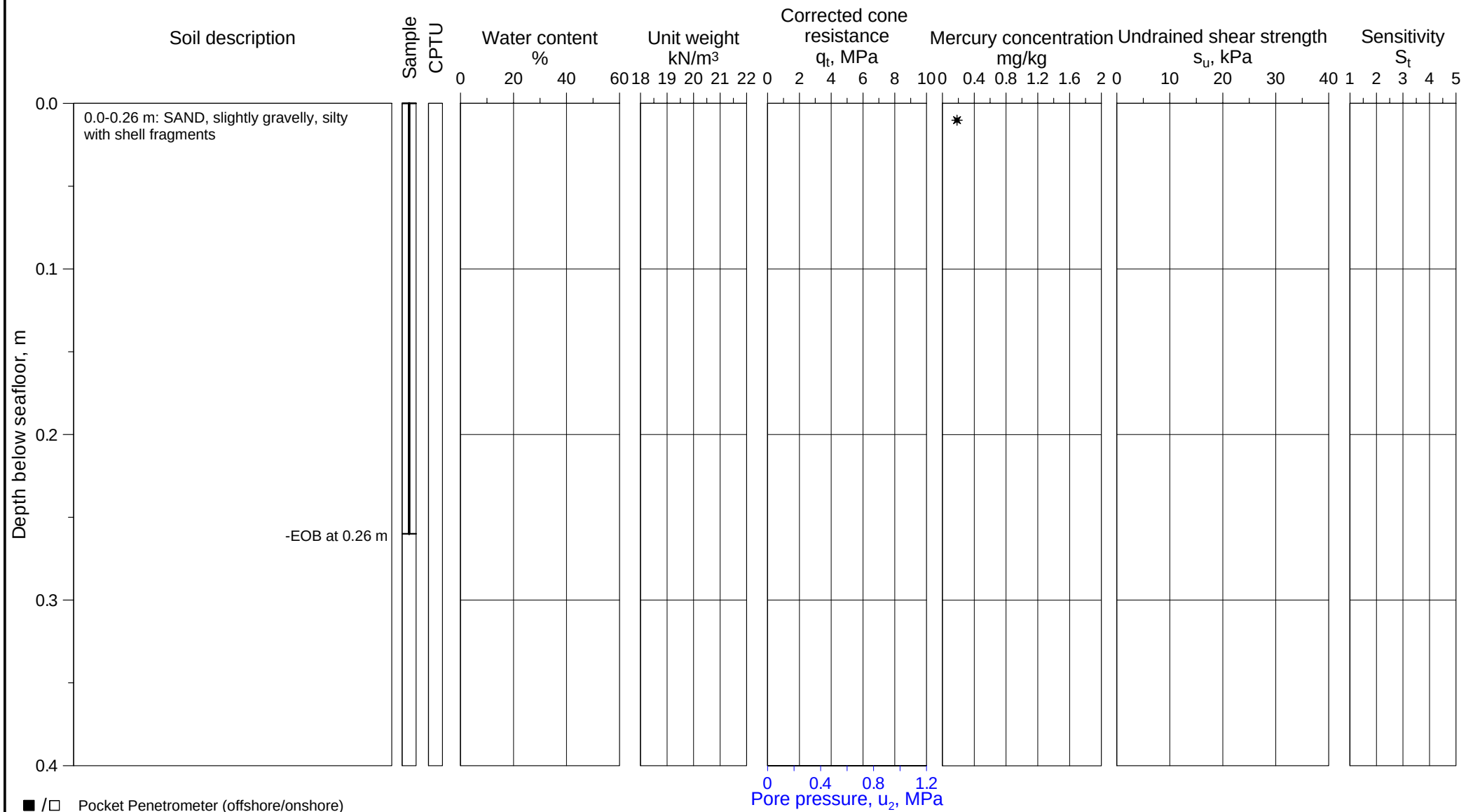
Date 2013-03-15

Figure No. B1.46

Drawn by ES

NGI

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)
⊕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 |
|---|---|---|---|
| 2013-331 | 261 600.3 mE | 6 745 036.7 mN | 147.6 m |

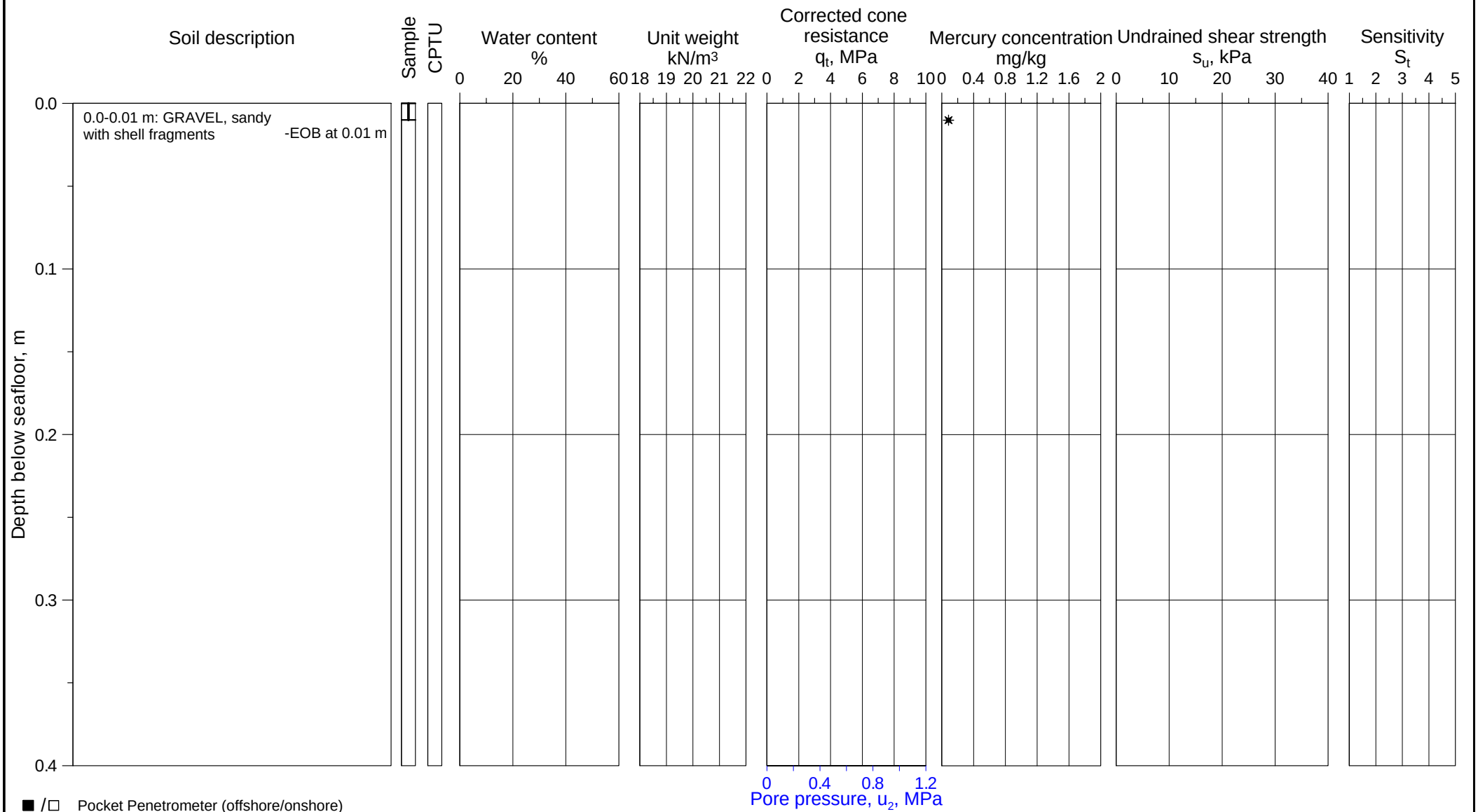
Coordinate system WGS-84, UTM Zone 32N, CM 9°E

*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)
✣ 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 |
|---|---|---|---|
| 2013-332 | 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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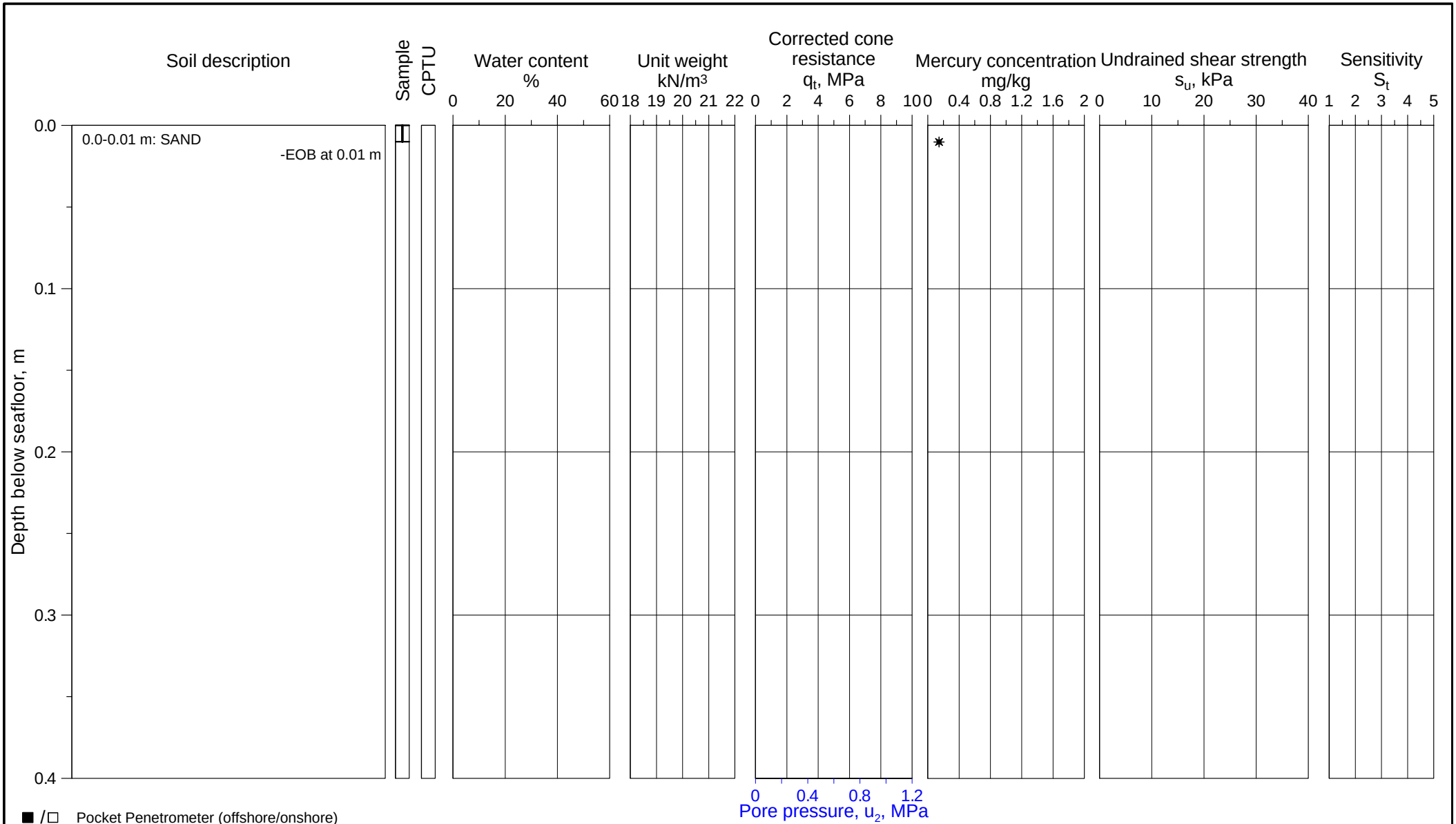


# U-864 - 2013 SOIL SURVEY

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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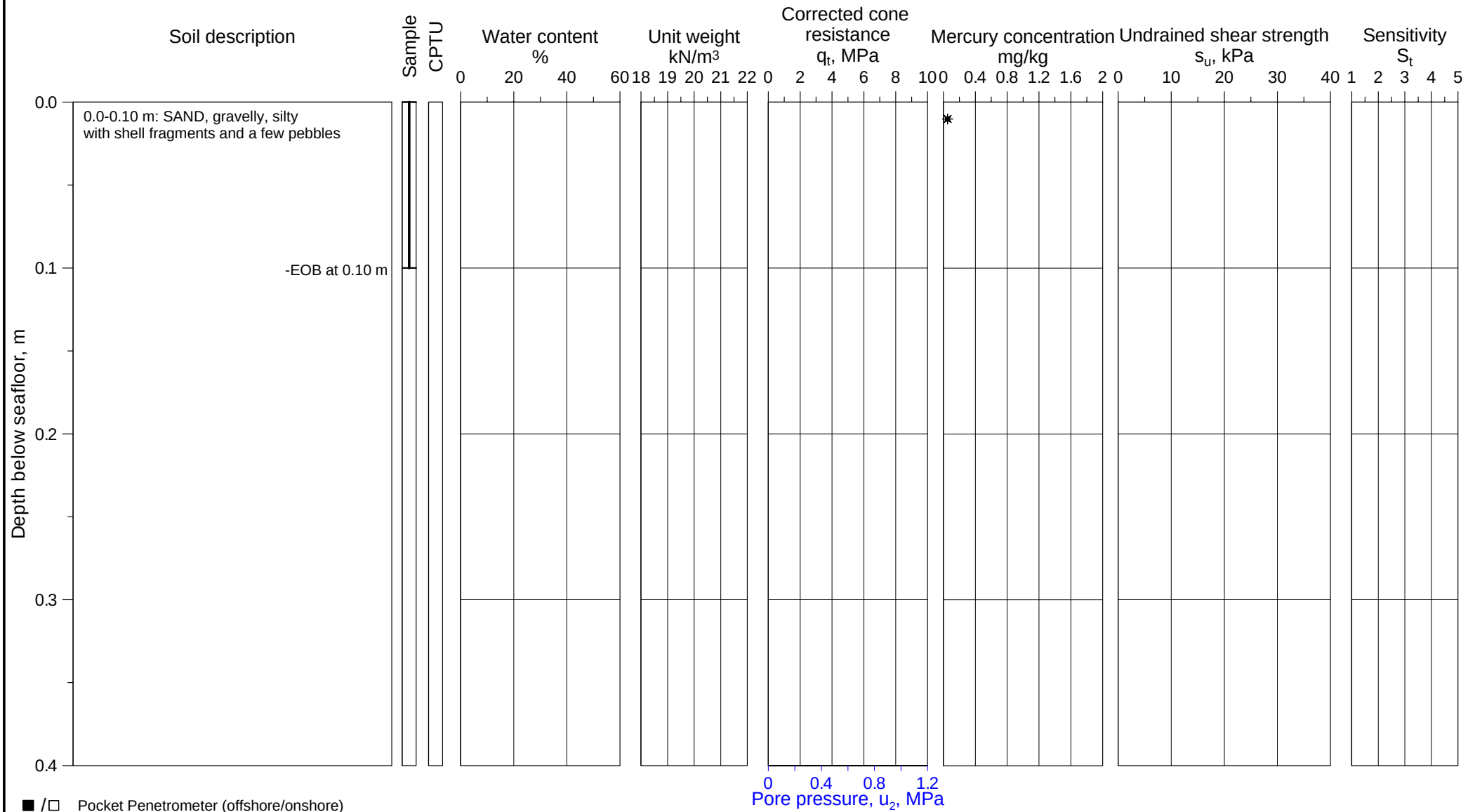


■ /□ Pocket Penetrometer (offshore/onshore)
▼ /▽ Fall cone (offshore/onshore)
★ /☆ Torvane (offshore/onshore)
✳ /⧫ Vane (lab offshore/in situ)
⊕C CAUC/CIUC
⊕E CAUE/CIUE
⊞ DSS test
◆ /◇ UU (offshore/onshore)
✣ γt (Based on water content)
● /○ Water content, w (offshore/onshore)
✚ /+ Total unit weight, 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 |
|---|---|---|---|
| 2013-334 | 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

| | | |
|---|---|---|
| **B2.1** | **General** | **2** |
| **B2.2** | **Water content** | **2** |
| **B2.3** | **Total unit weight** | **2** |
| **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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## Tables

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, $\gamma_s$, 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 | | $\gamma$ (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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Document No.: 20120738-01-R

# 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 % | $\gamma$ kN/m$^3$ | $\gamma_s$ 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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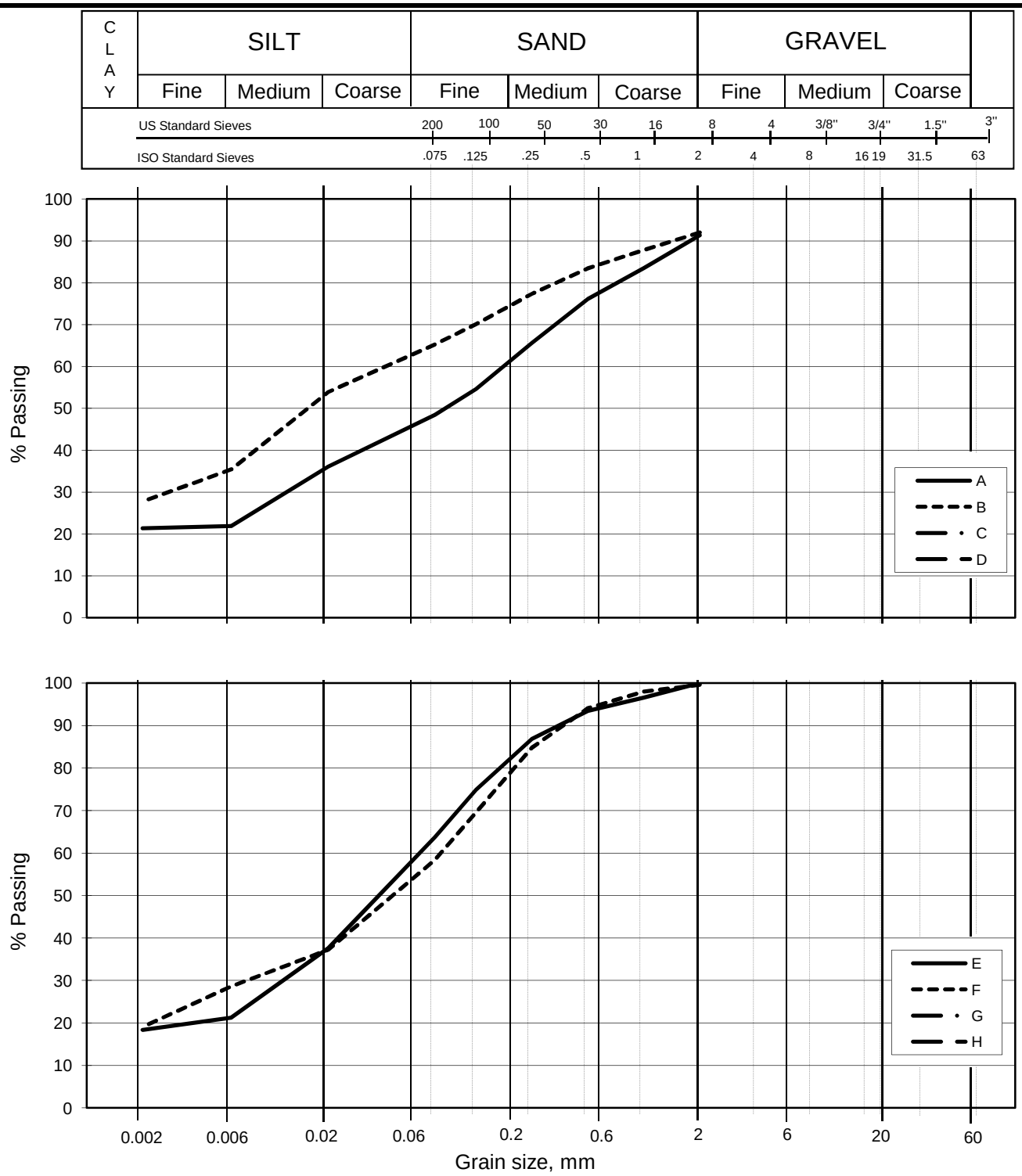


| Curve | Boring No. | Sample No. | Depth m | $D_{10}$ mm | $D_{60}$ mm | Clay cont. % | Soil Description | Method dry/wet-sieving |
|---|---|---|---|---|---|---|---|---|
| A | 2013-509GC | 1 | 0.17 | | 0.175 | 21.4 | CLAY, sandy, silty | Fall |
| B | 2013-509GC | 2 | 1.05 | | 0.041 | 27.8 | CLAY, silty, 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 | | | | | | | | |



**U-864 2013 Soil survey**

Grain size distribution curves.

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2013-03-06

Figure No.
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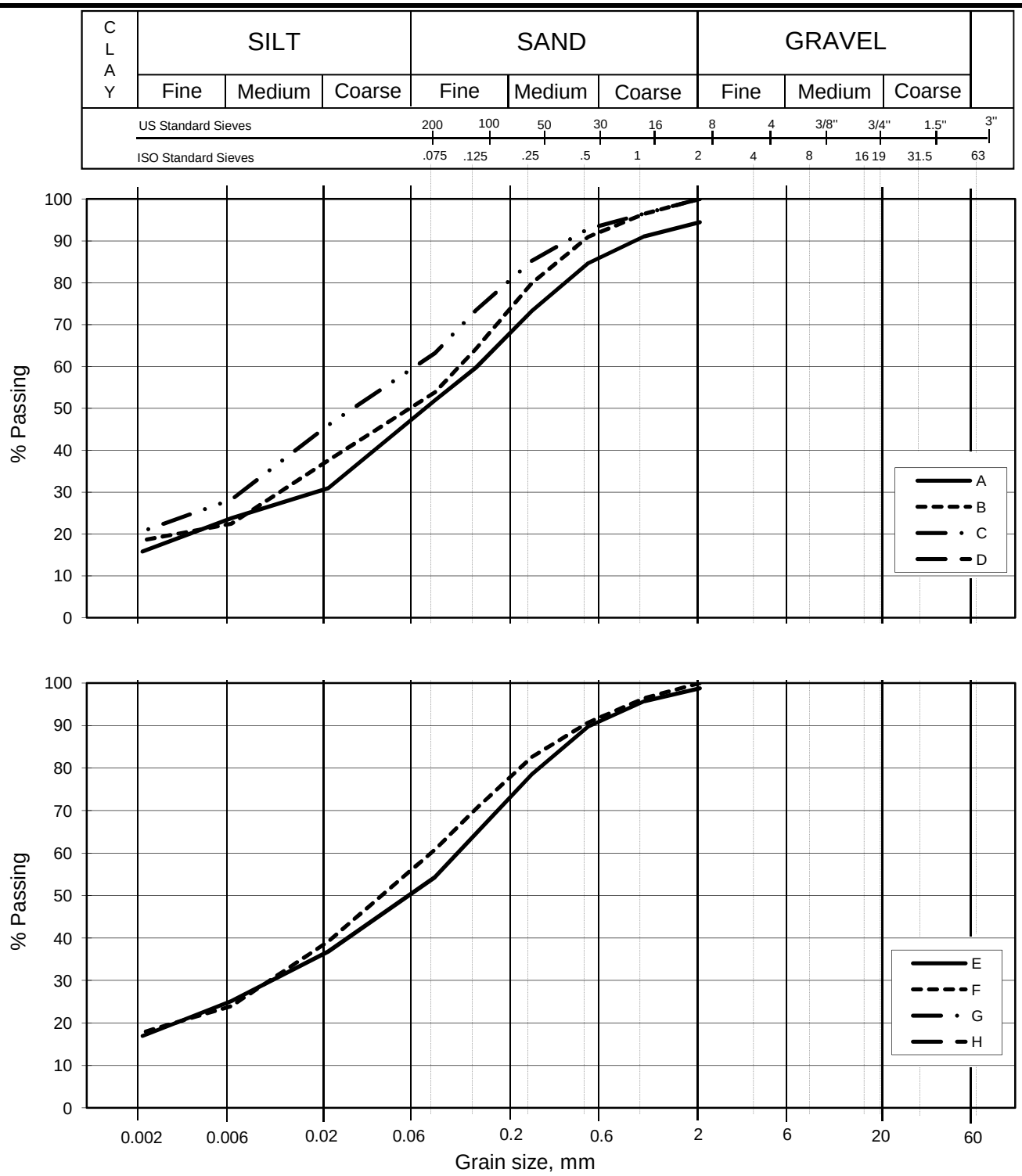


| Curve | Boring No. | Sample No. | Depth m | $D_{10}$ mm | $D_{60}$ mm | Clay cont. % | Soil Description | Method dry/wet-sieving |
|---|---|---|---|---|---|---|---|---|
| A | 2013-512GC | 1 | 0.95 | | 0.126 | 15.8 | CLAY, sandy, silty | Fall |
| B | 2013-512GC | 2 | 1.05 | | 0.101 | 18.5 | CLAY, sandy, 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 | | | | | | | | |



**U-864 2013 Soil survey**

Grain size distribution curves.

Document No.
20120738-01-R

Date
2013-03-06

Figure No.
B2.2

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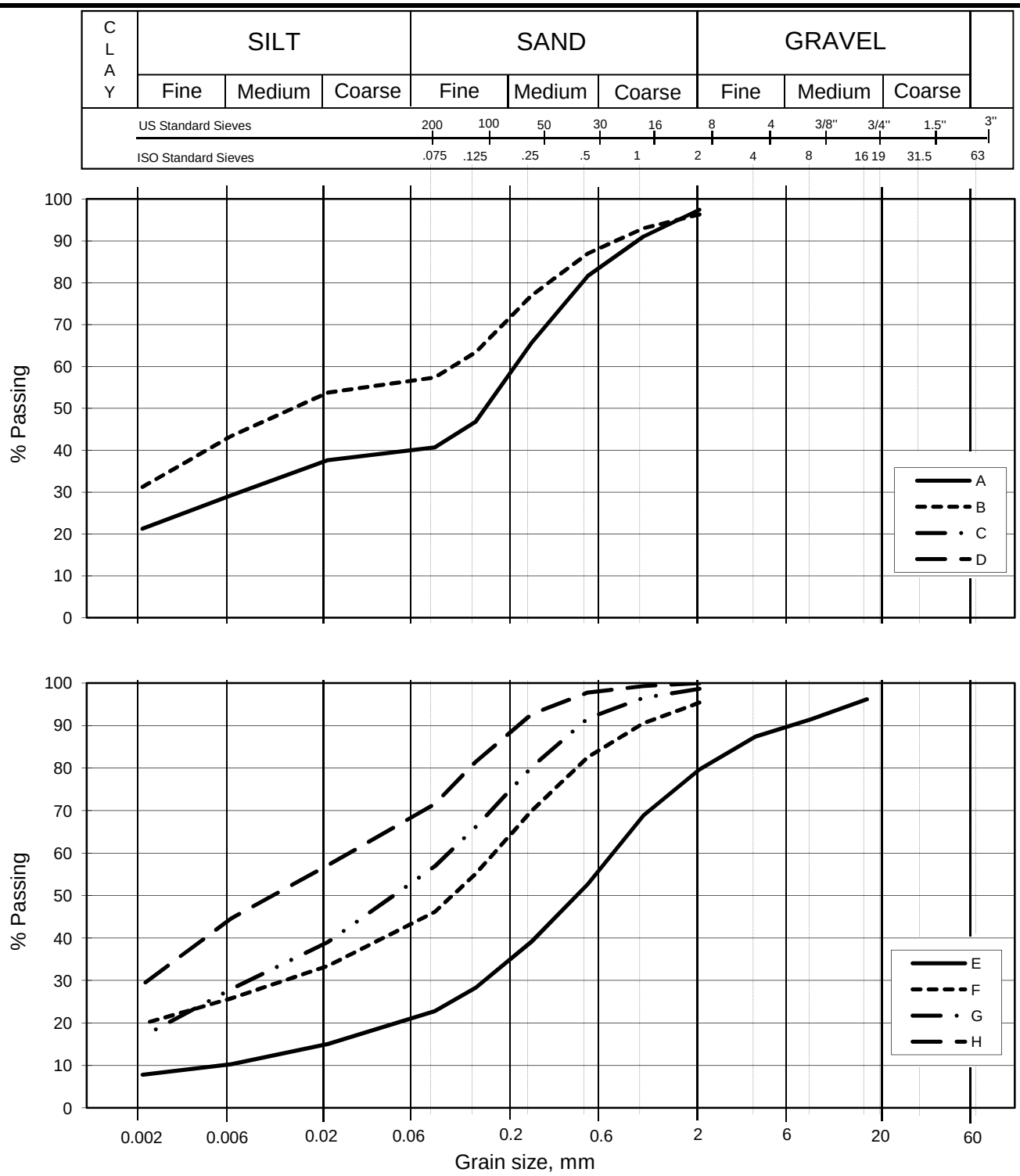


| Curve | Boring No. | Sample No. | Depth m | $D_{10}$ mm | $D_{60}$ mm | Clay cont. % | Soil Description | Method dry/wet-sieving |
|---|---|---|---|---|---|---|---|---|
| A | 2013-401VC | 1 | 0.1 | | 0.203 | 21.2 | CLAY, sandy, silty | Fall |
| B | 2013-401VC | 1 | 0.55 | | 0.094 | 31.2 | CLAY | Fall |
| 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 |



**U-864 2013 Soil survey**

Grain size distribution curves.

Document No.
20120738-01-R

Date
2013-03-06

Figure No.
B2.3

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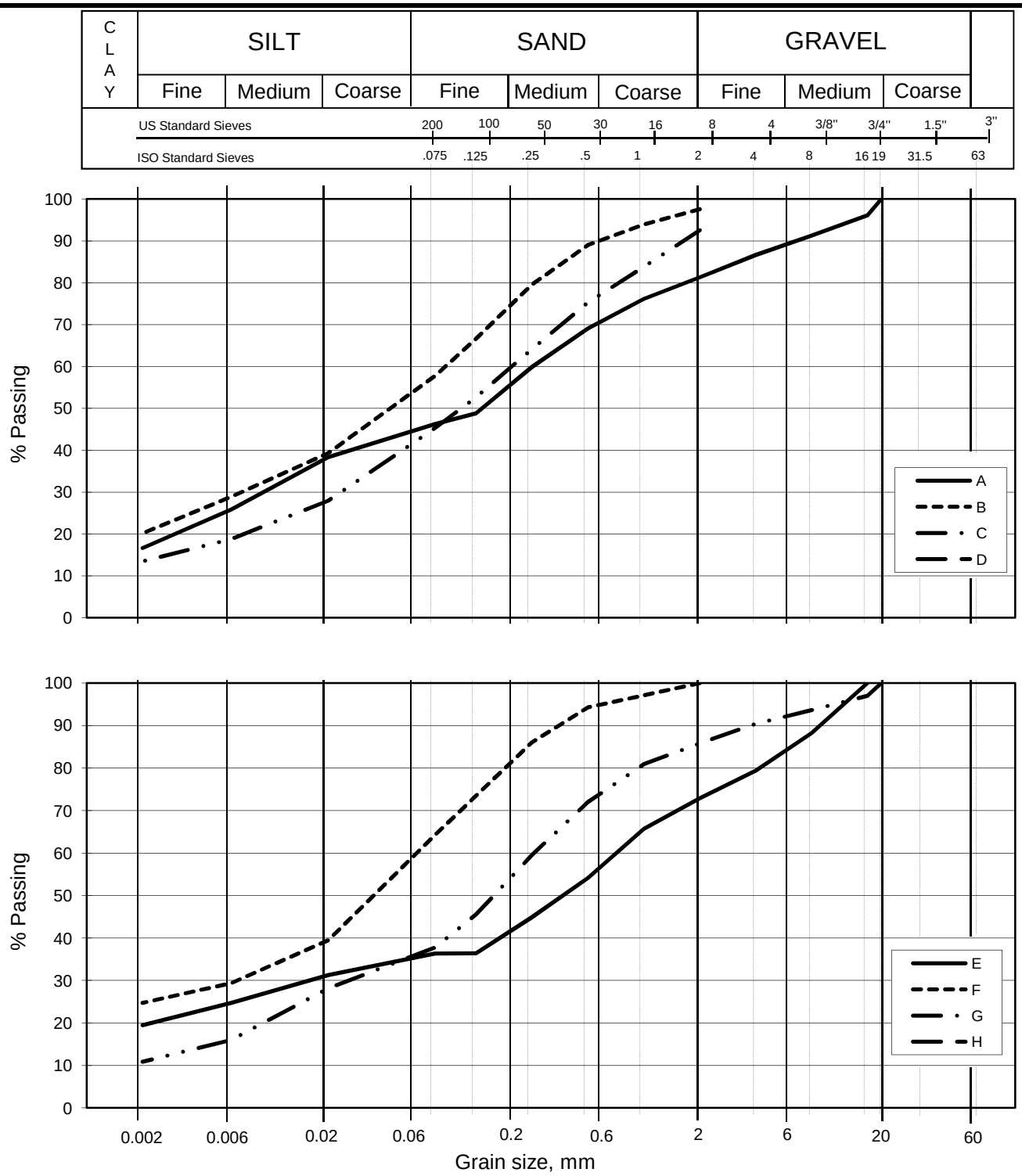


| Curve | Boring No. | Sample No. | Depth m | $D_{10}$ mm | $D_{60}$ mm | Clay cont. % | Soil Description | Method dry/wet-sieving |
|---|---|---|---|---|---|---|---|---|
| A | 2013-403VC | 1 | 0.1 | | 0.252 | 16.7 | CLAY, sandy, silty | Wet/Fall |
| B | 2013-403VC | 1 | 0.55 | | 0.085 | 20.2 | CLAY, 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 | | | | | | | | |



**U-864 2013 Soil survey**

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

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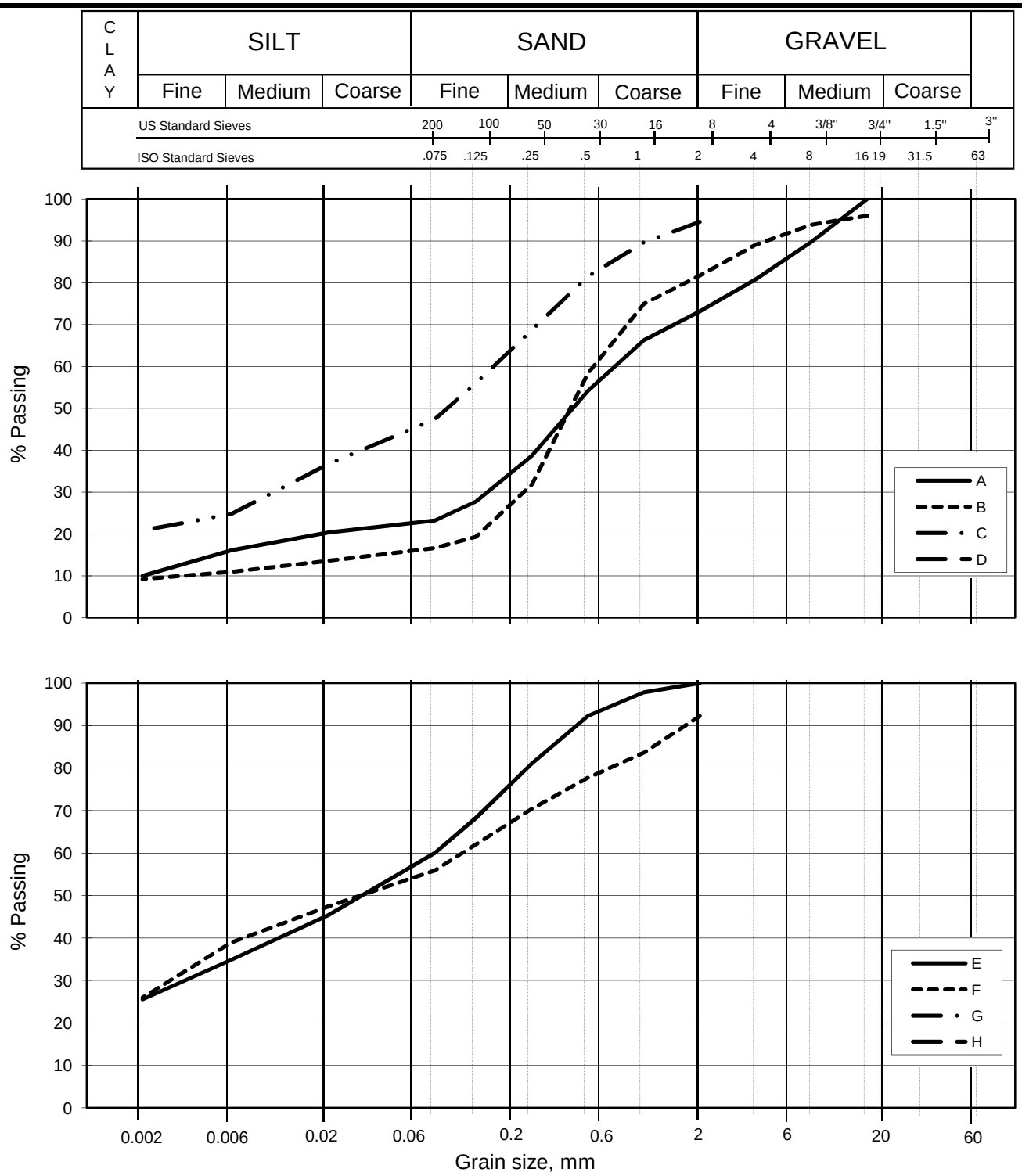


| Curve | Boring No. | Sample No. | Depth m | $D_{10}$ mm | $D_{60}$ mm | Clay cont. % | Soil Description | Method dry/wet-sieving |
|---|---|---|---|---|---|---|---|---|
| A | 2013-405VC | 1 | 0.05 | | 0.696 | 10.0 | Sandy, gravelly, clayey | Wet/Fall |
| B | 2013-405VC | 1 | 0.55 | 0.003 | 0.535 | 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 | | | | | | | | |



**U-864 2013 Soil survey**

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

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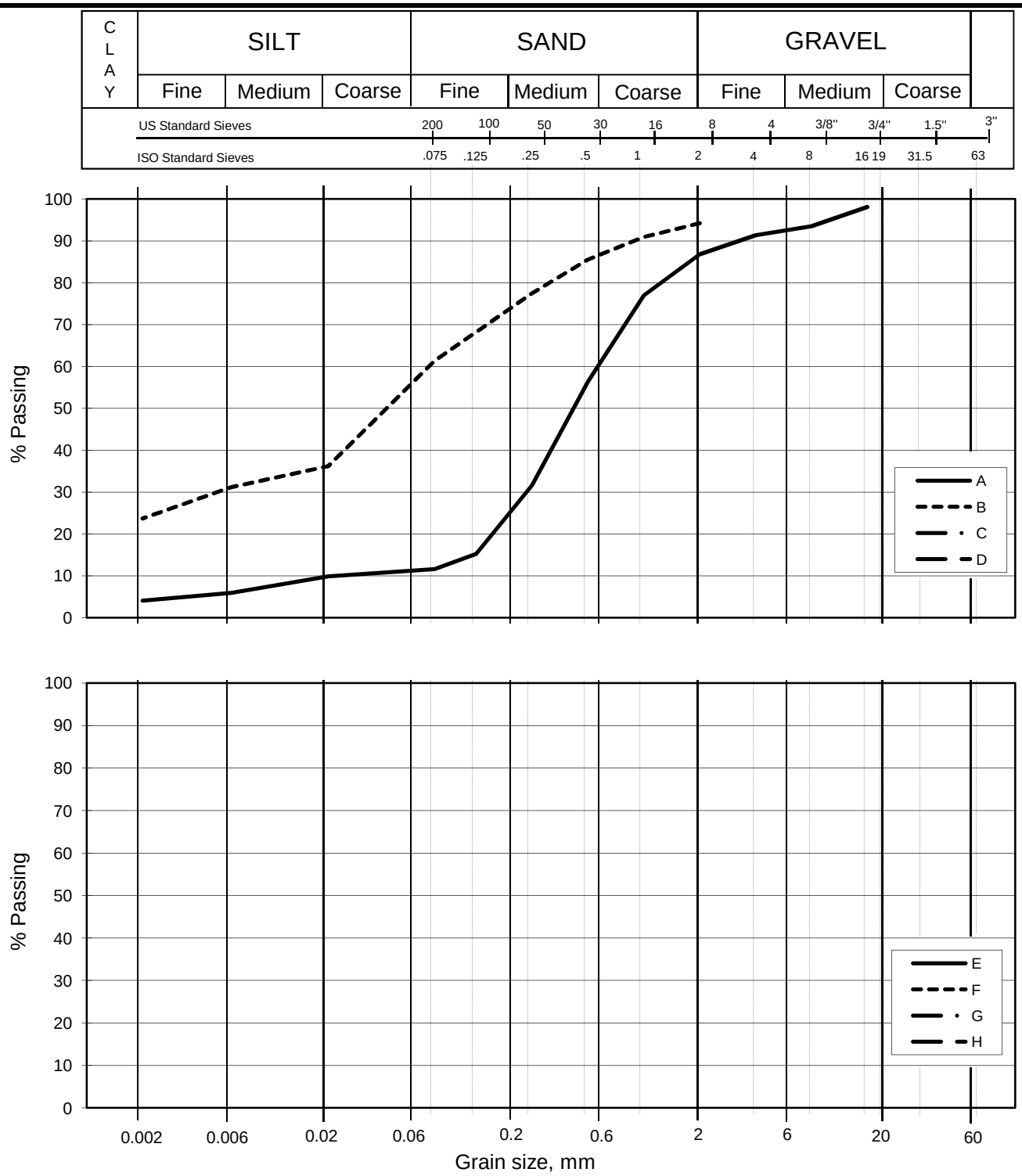


| Curve | Boring No. | Sample No. | Depth m | $D_{10}$ mm | $D_{60}$ mm | Clay cont. % | Soil Description | Method dry/wet-sieving |
|---|---|---|---|---|---|---|---|---|
| A | 2013-407VC | 1 | 0.15 | 0.022 | 0.564 | 4.1 | SAND, coarse to fine | Wet/Fall |
| B | 2013-407VC | 1 | 0.55 | | 0.070 | 23.7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



**U-864 2013 Soil survey**

Grain size distribution curves.

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# Part B3 - Piezocone Penetration Tests

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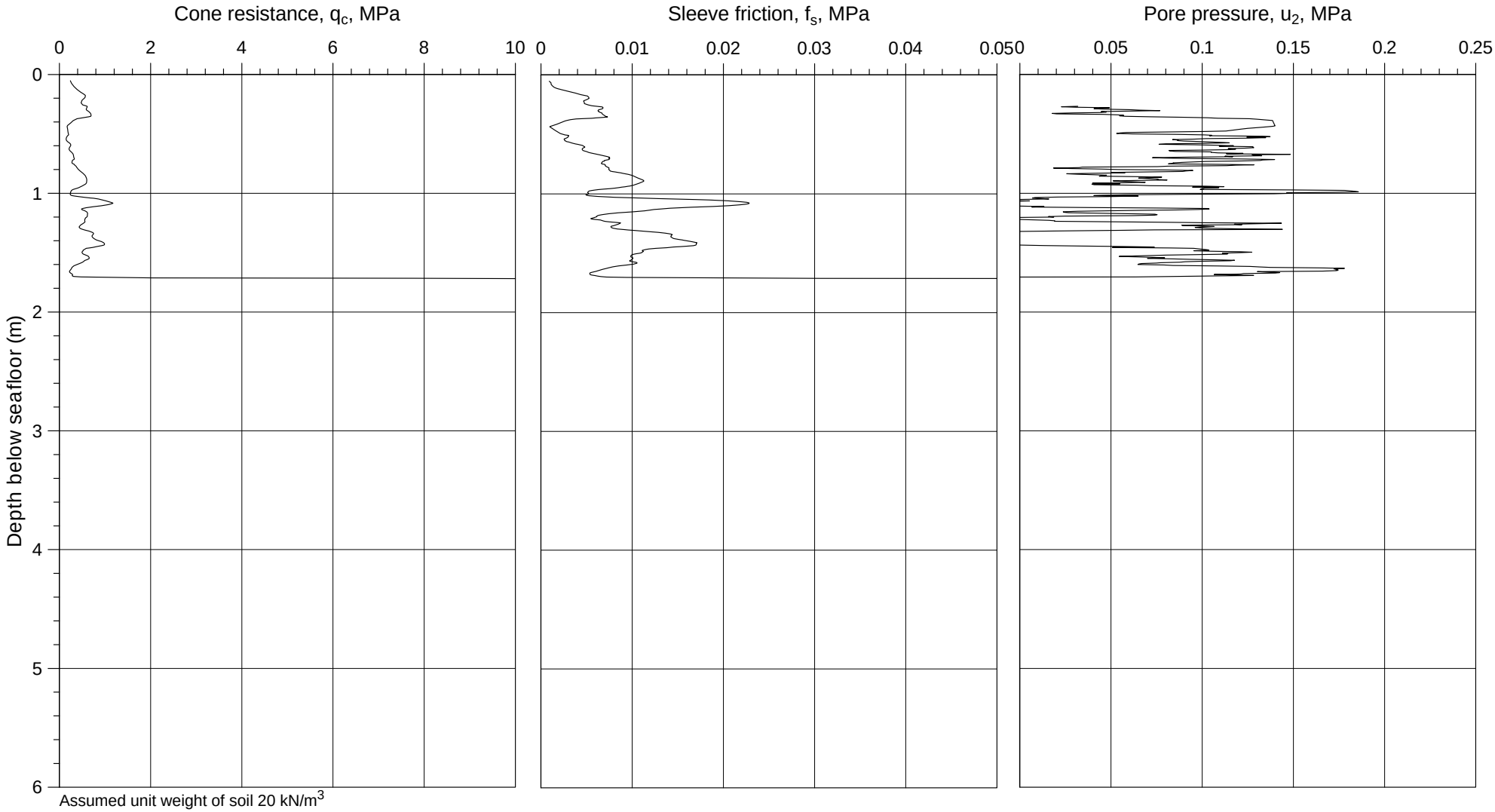
## B3.1 Summary

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 |

WGS-84, UTM Zone 32N, CM 9°E

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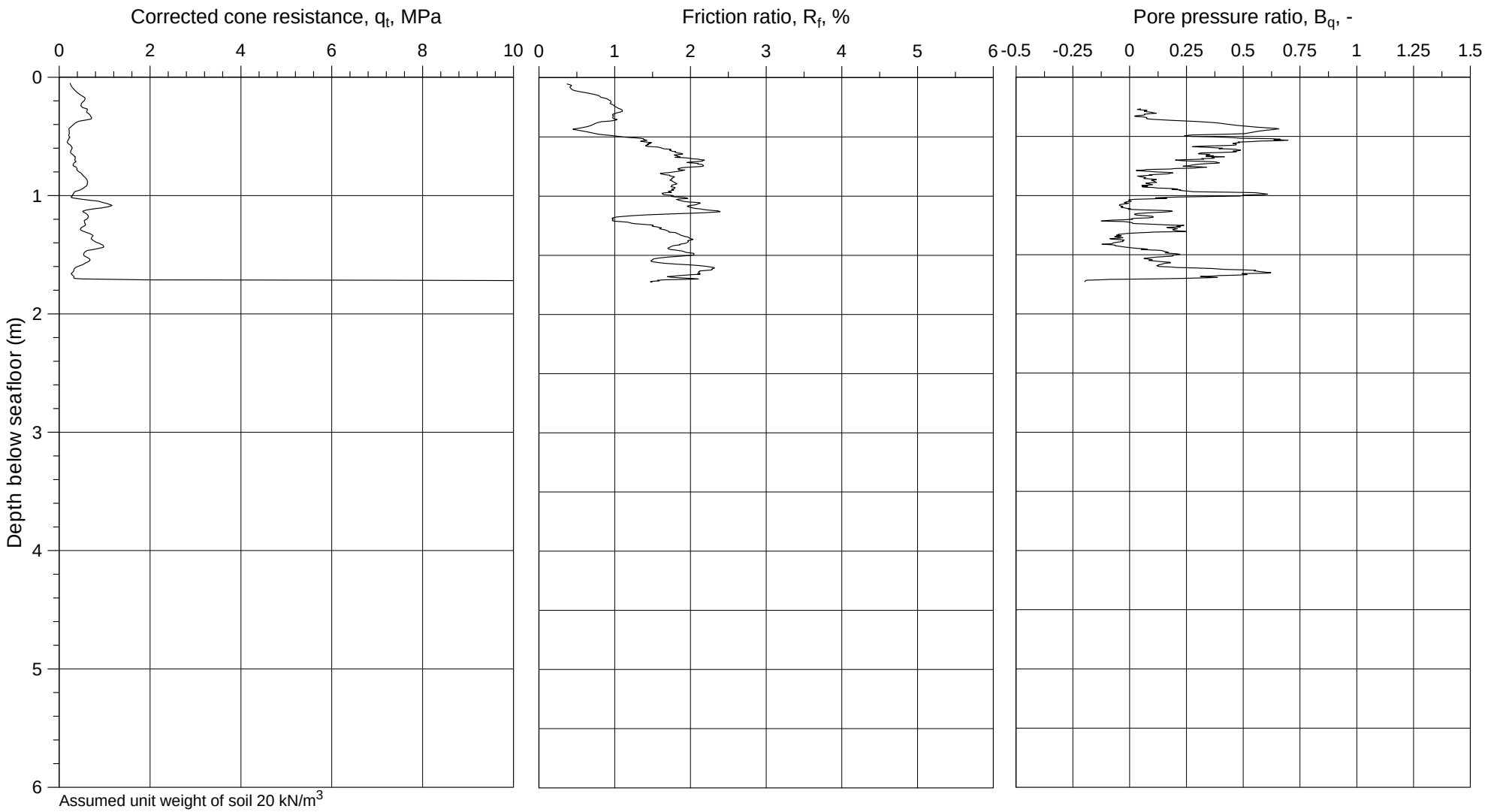


# U-864 - 2013 SOIL SURVEY

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

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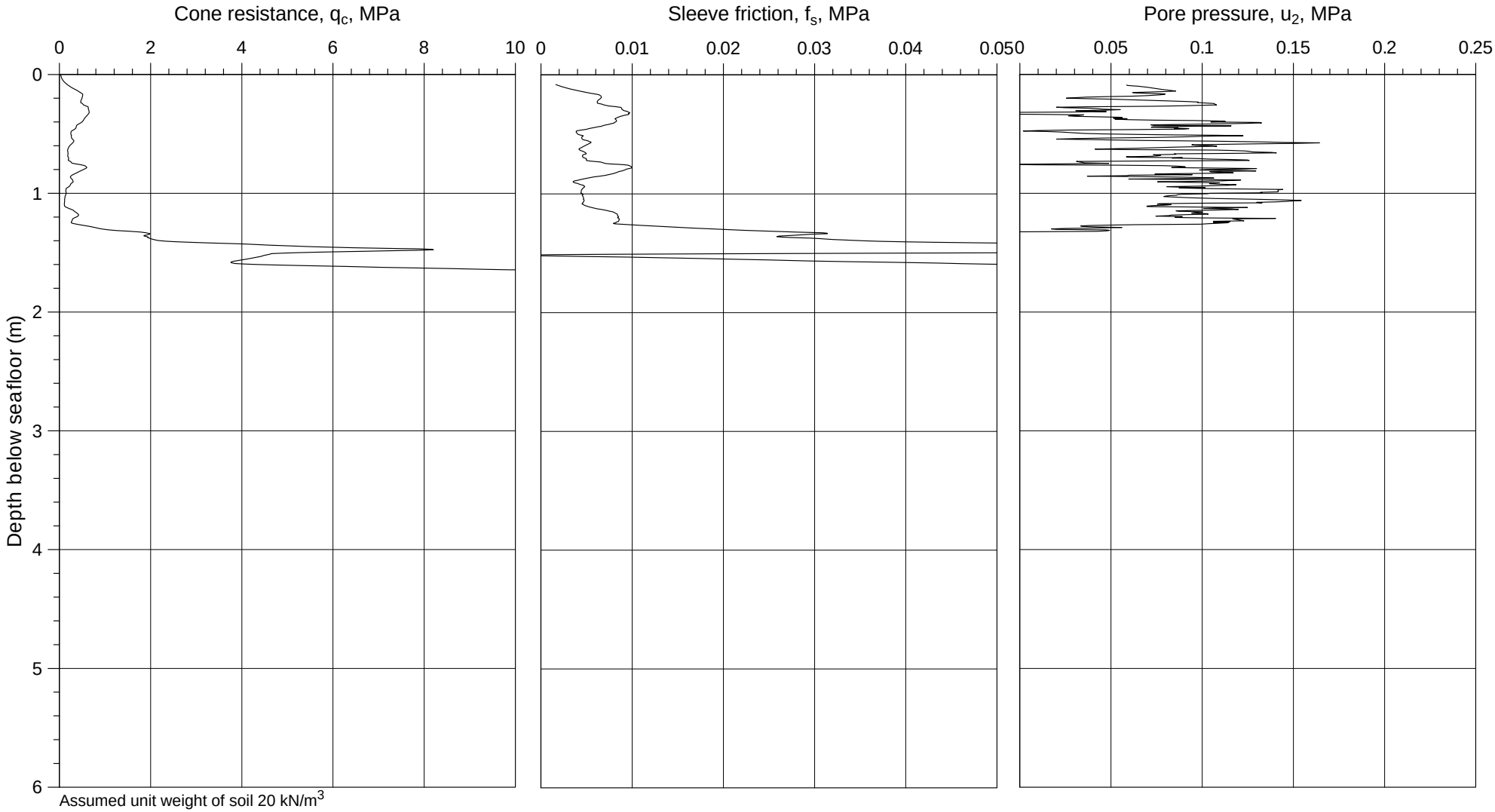


# U-864 - 2013 SOIL SURVEY

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

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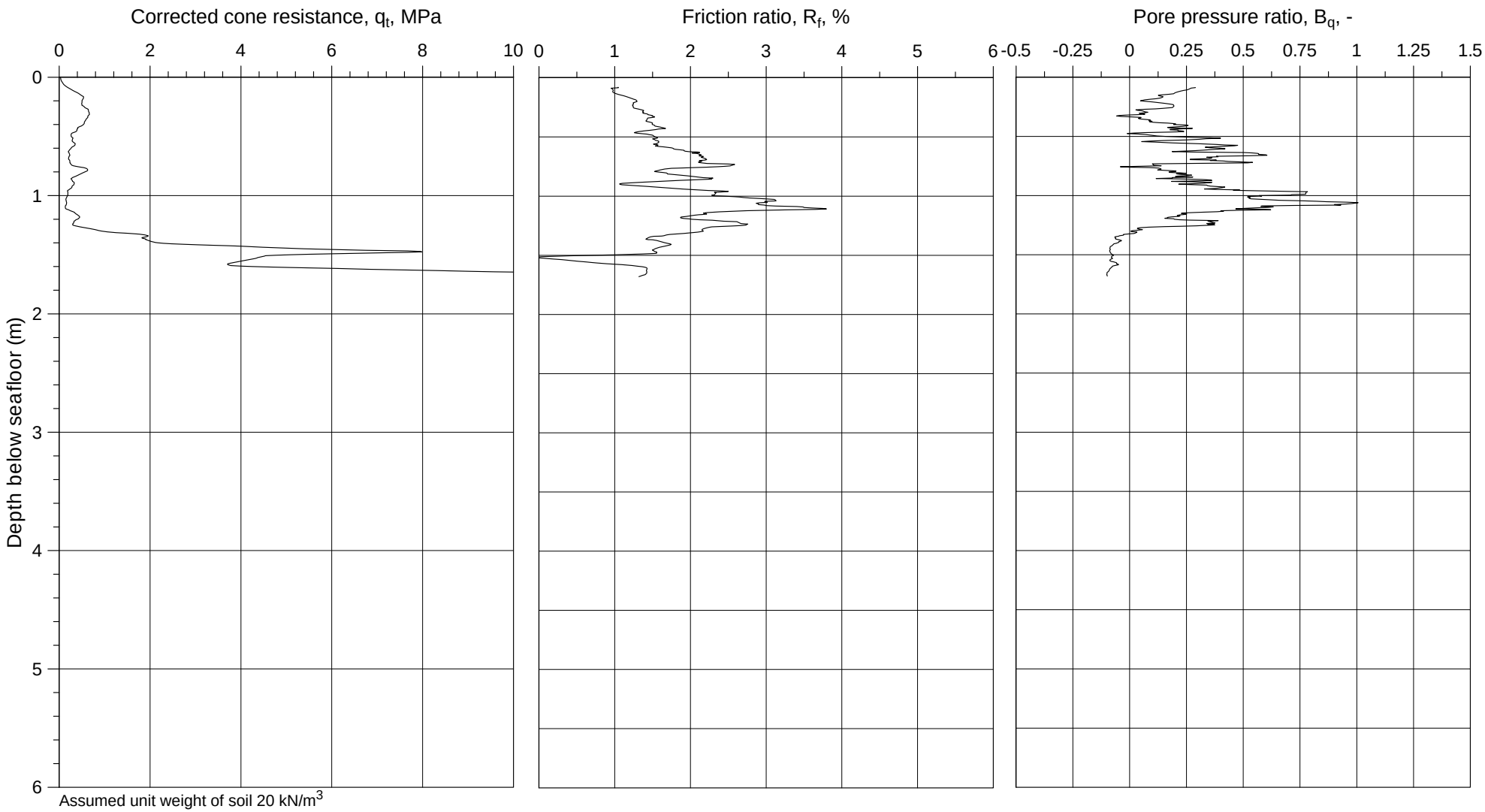


## U-864 - 2013 SOIL SURVEY

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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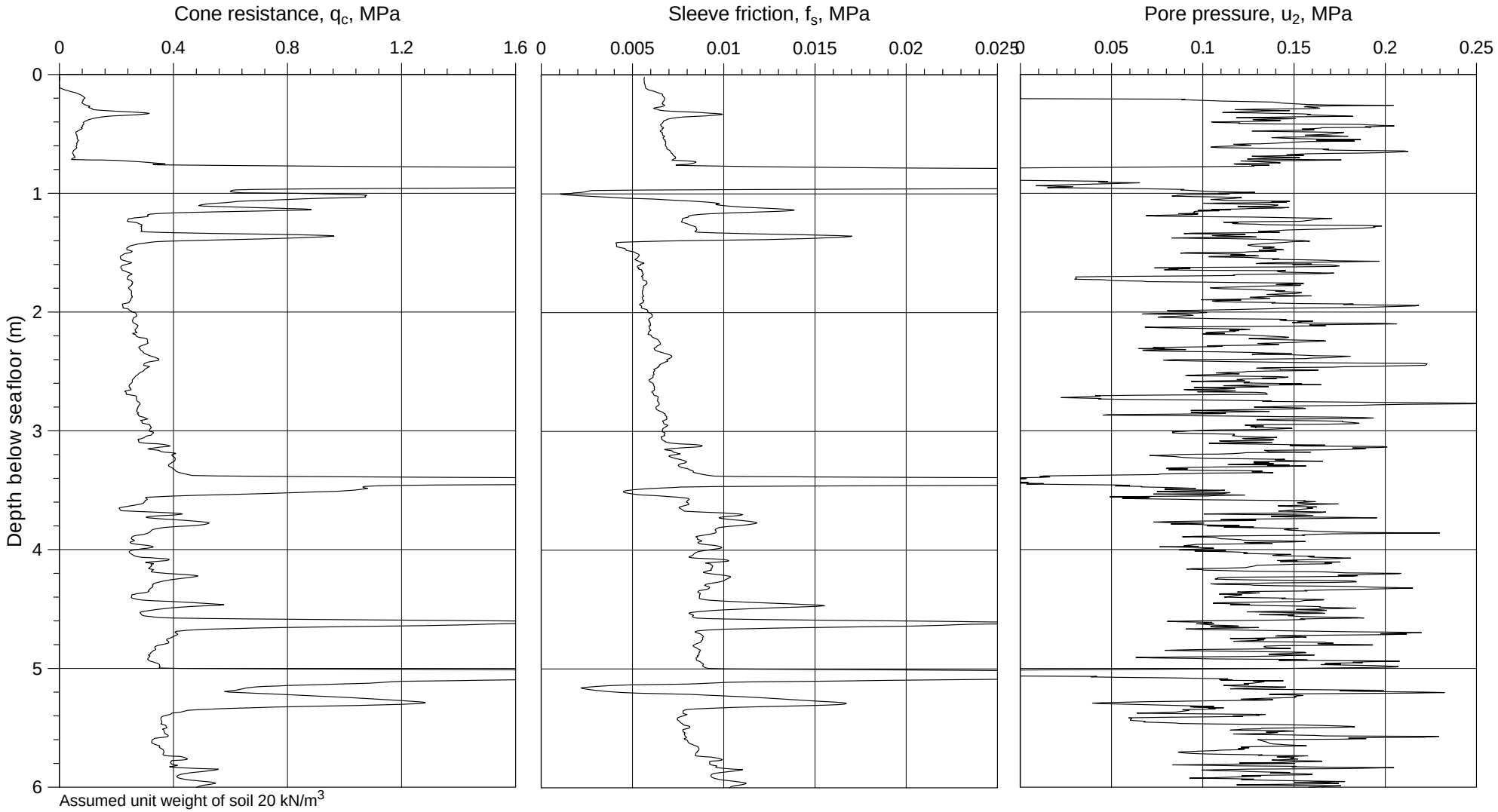


## U-864 - 2013 SOIL SURVEY

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 |

WGS-84, UTM Zone 32N, CM 9°E

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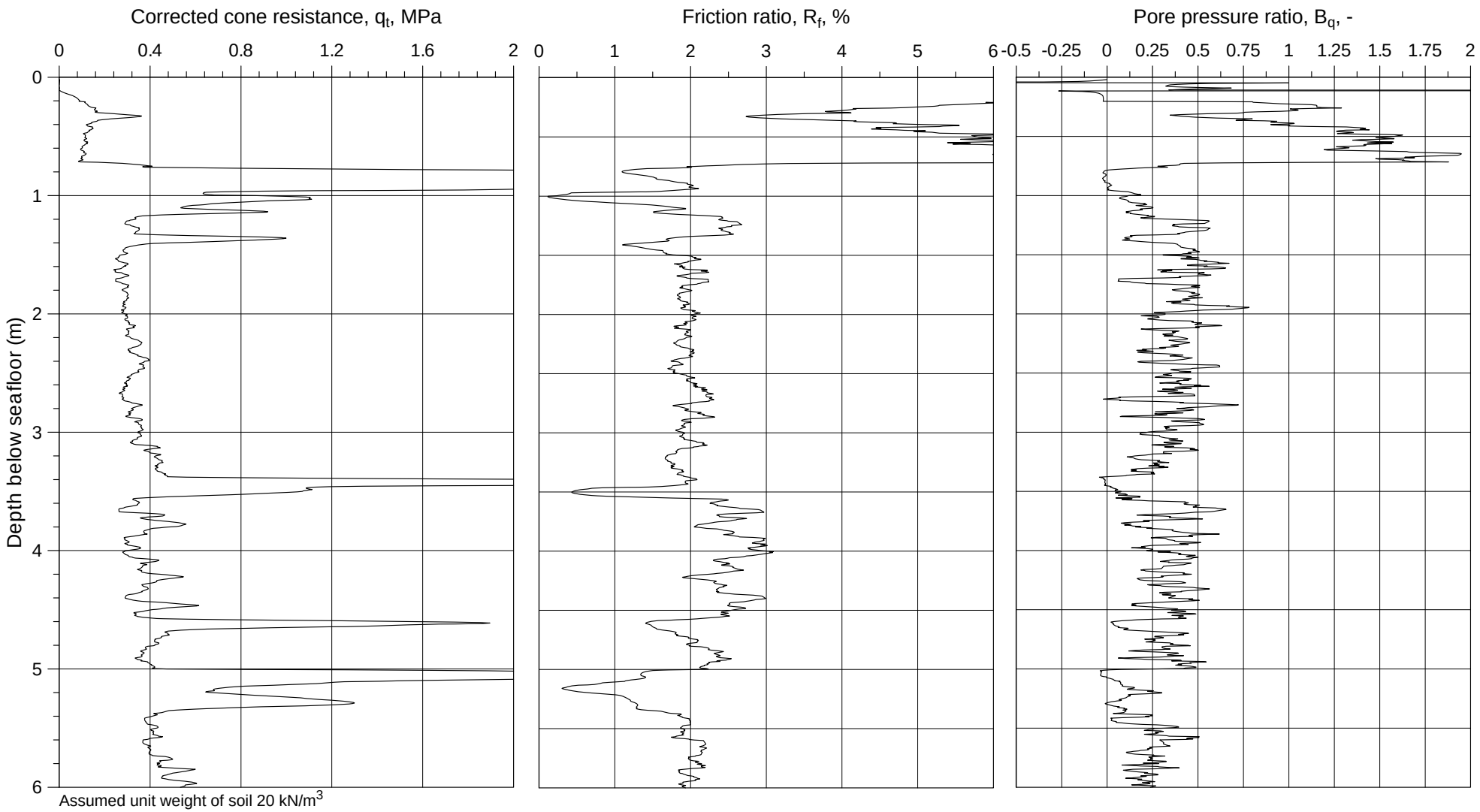


## U-864 - 2013 SOIL SURVEY

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 |

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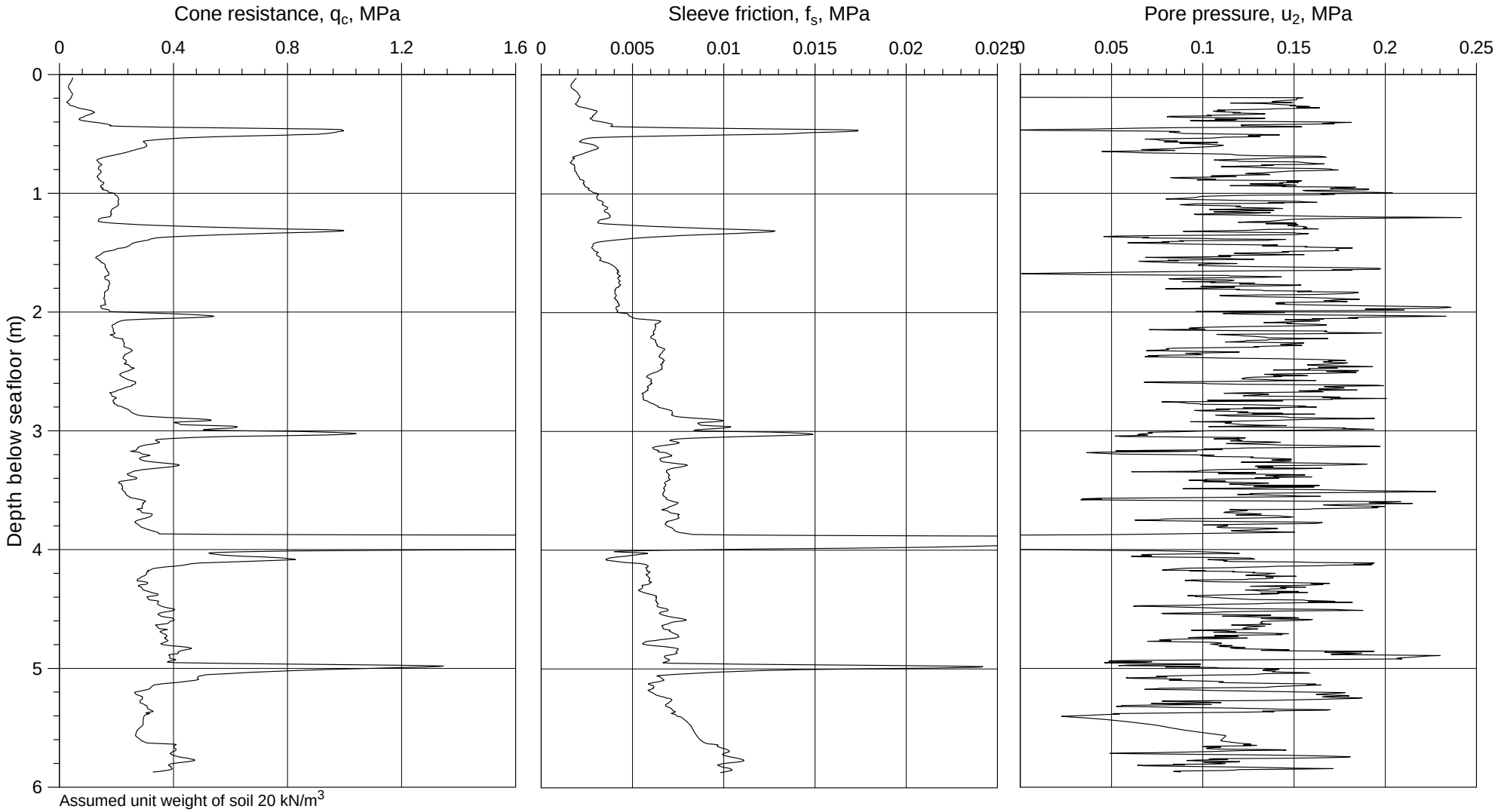


## U-864 - 2013 SOIL SURVEY

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 |

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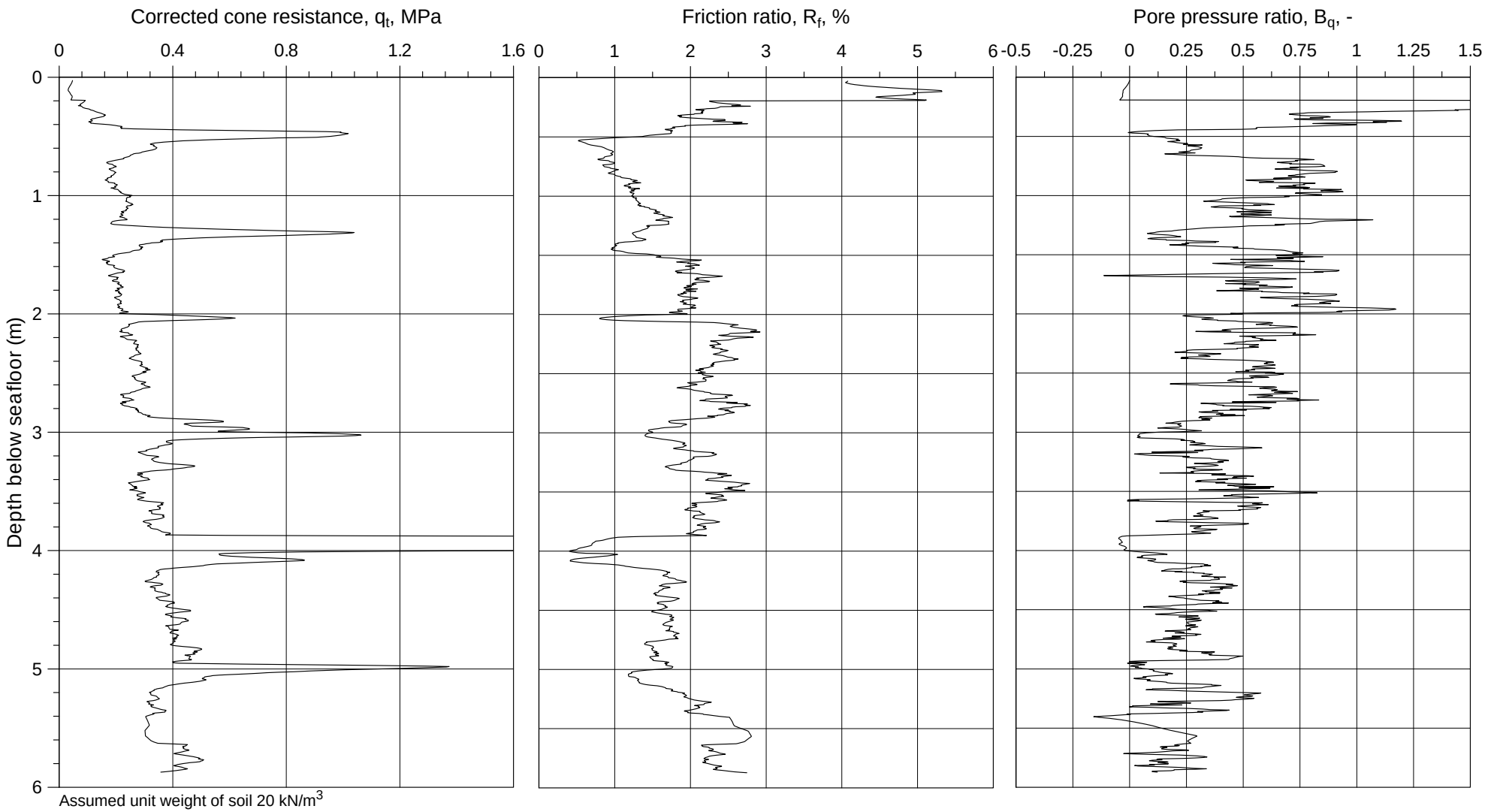


**U-864 - 2013 SOIL SURVEY**

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 |

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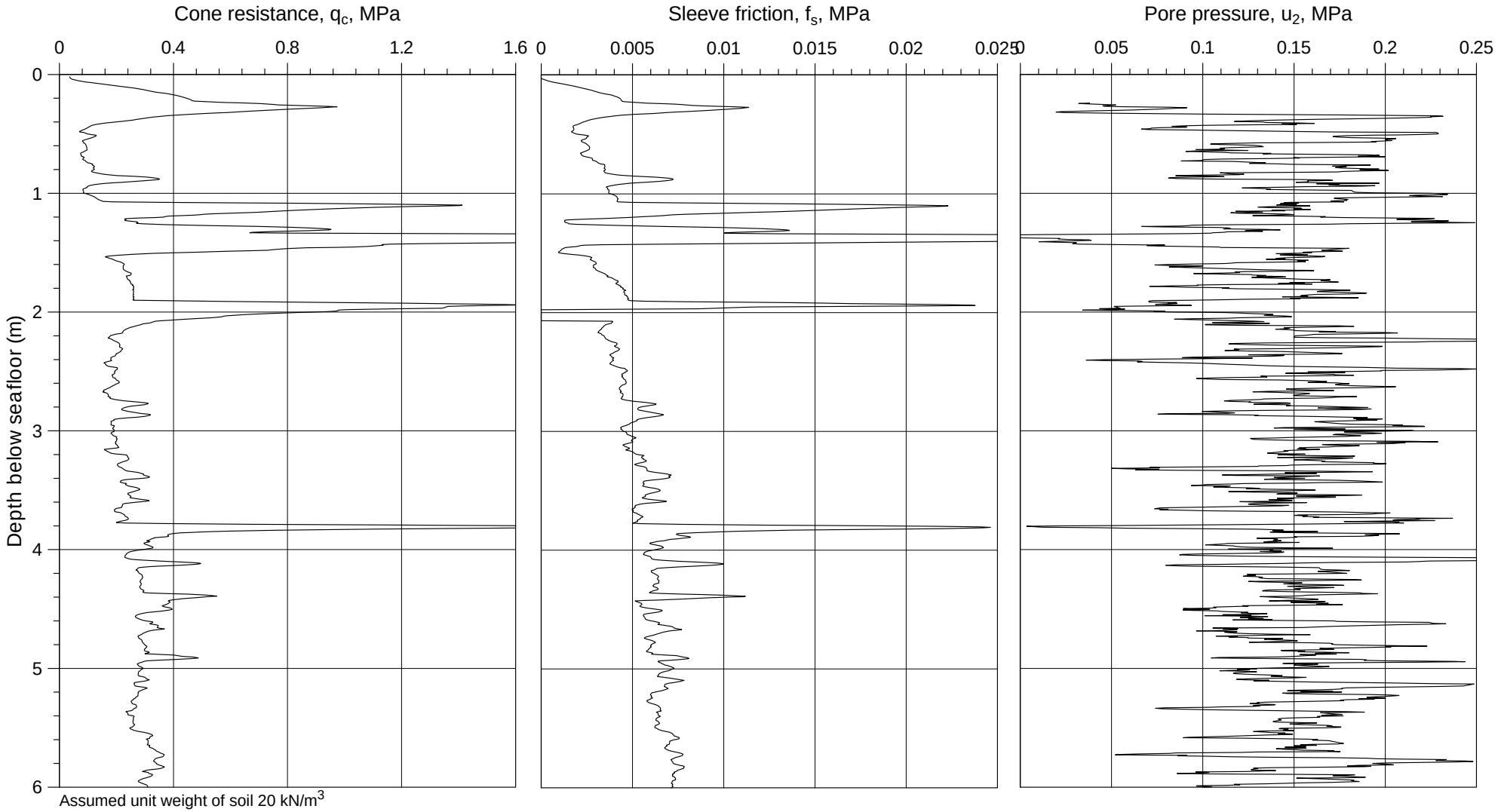


## U-864 - 2013 SOIL SURVEY

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 |

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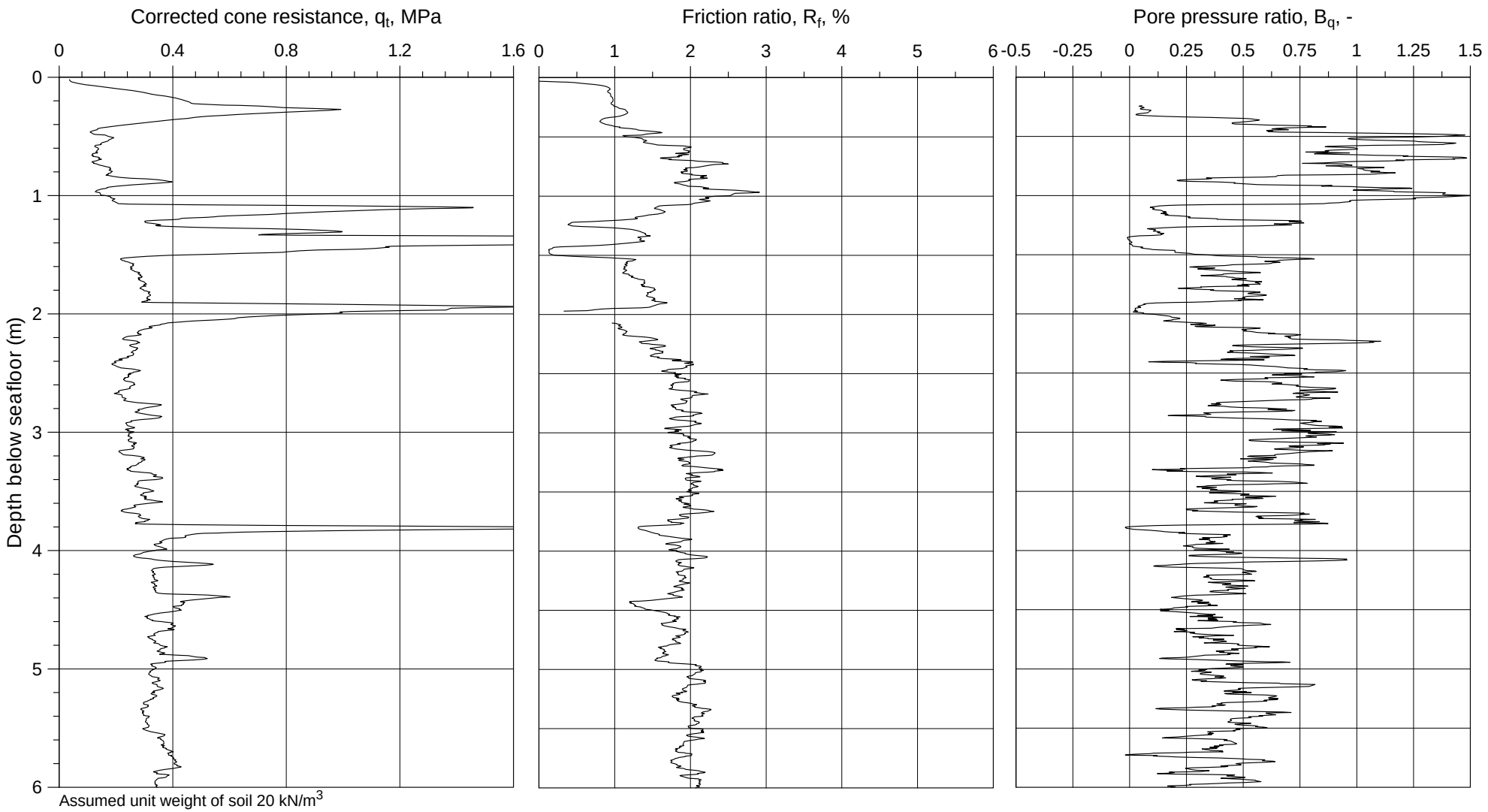


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## U-864 - 2013 SOIL SURVEY

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 |

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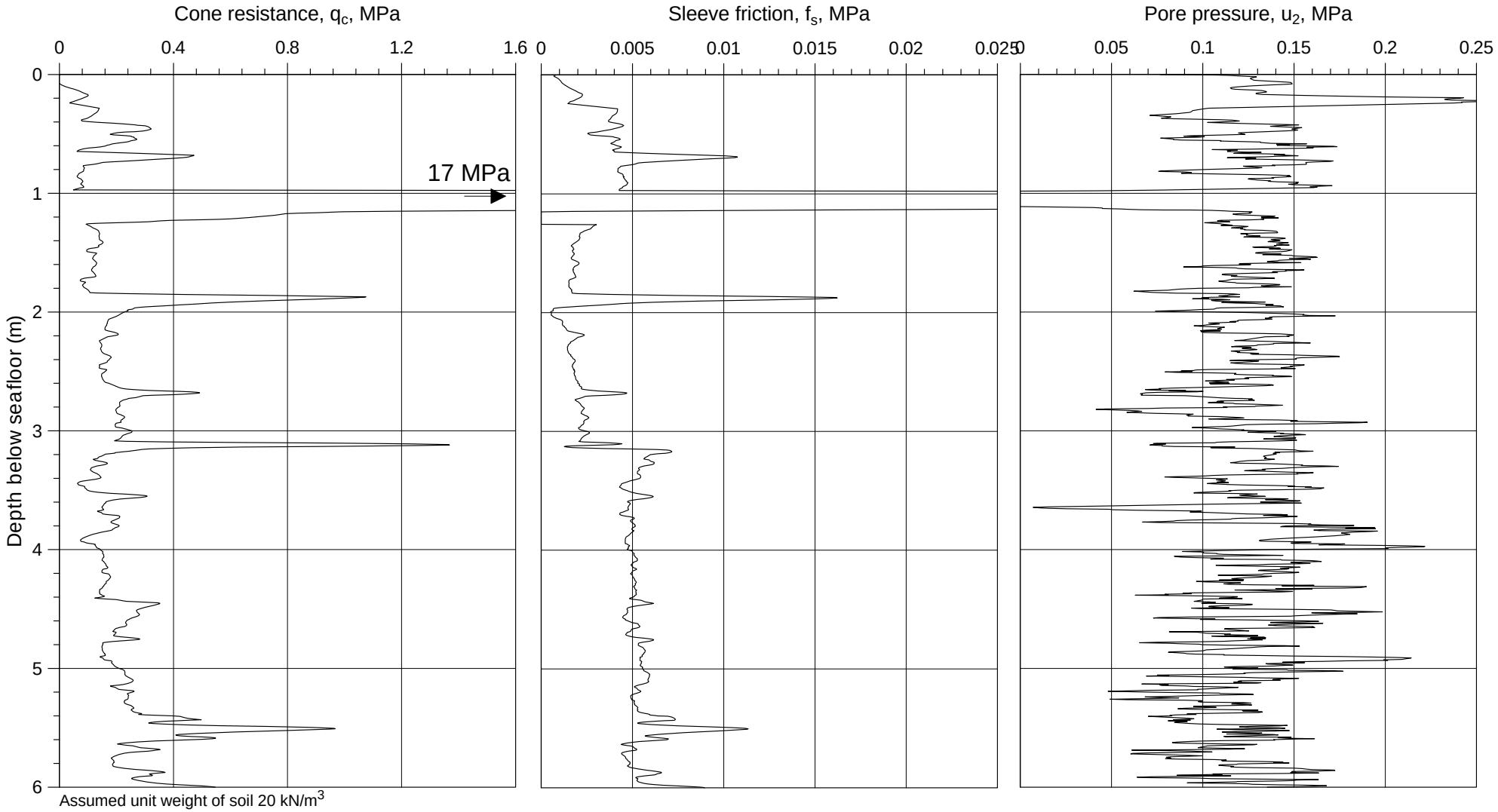


## U-864 - 2013 SOIL SURVEY

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 |

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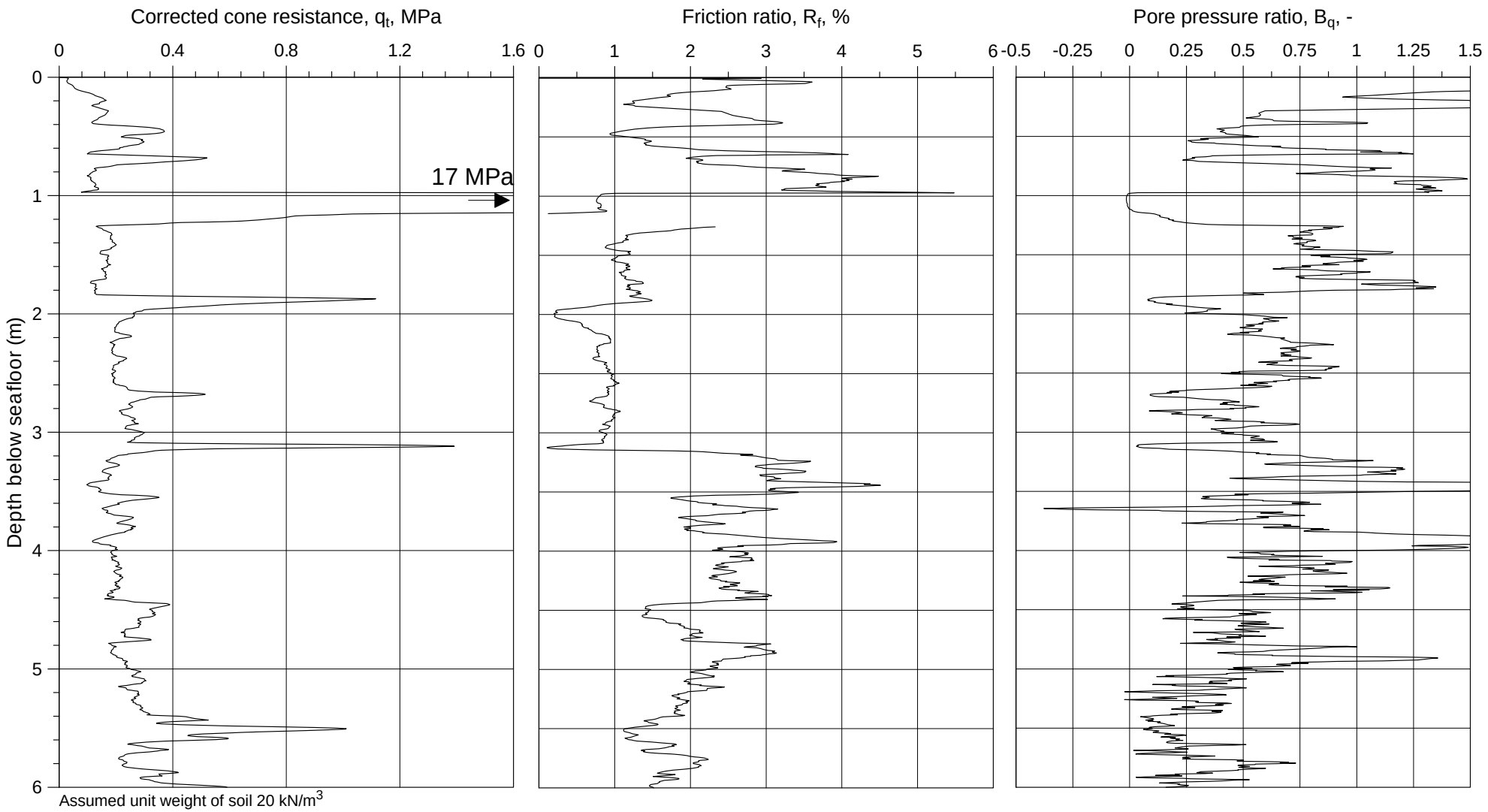


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## U-864 - 2013 SOIL SURVEY

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

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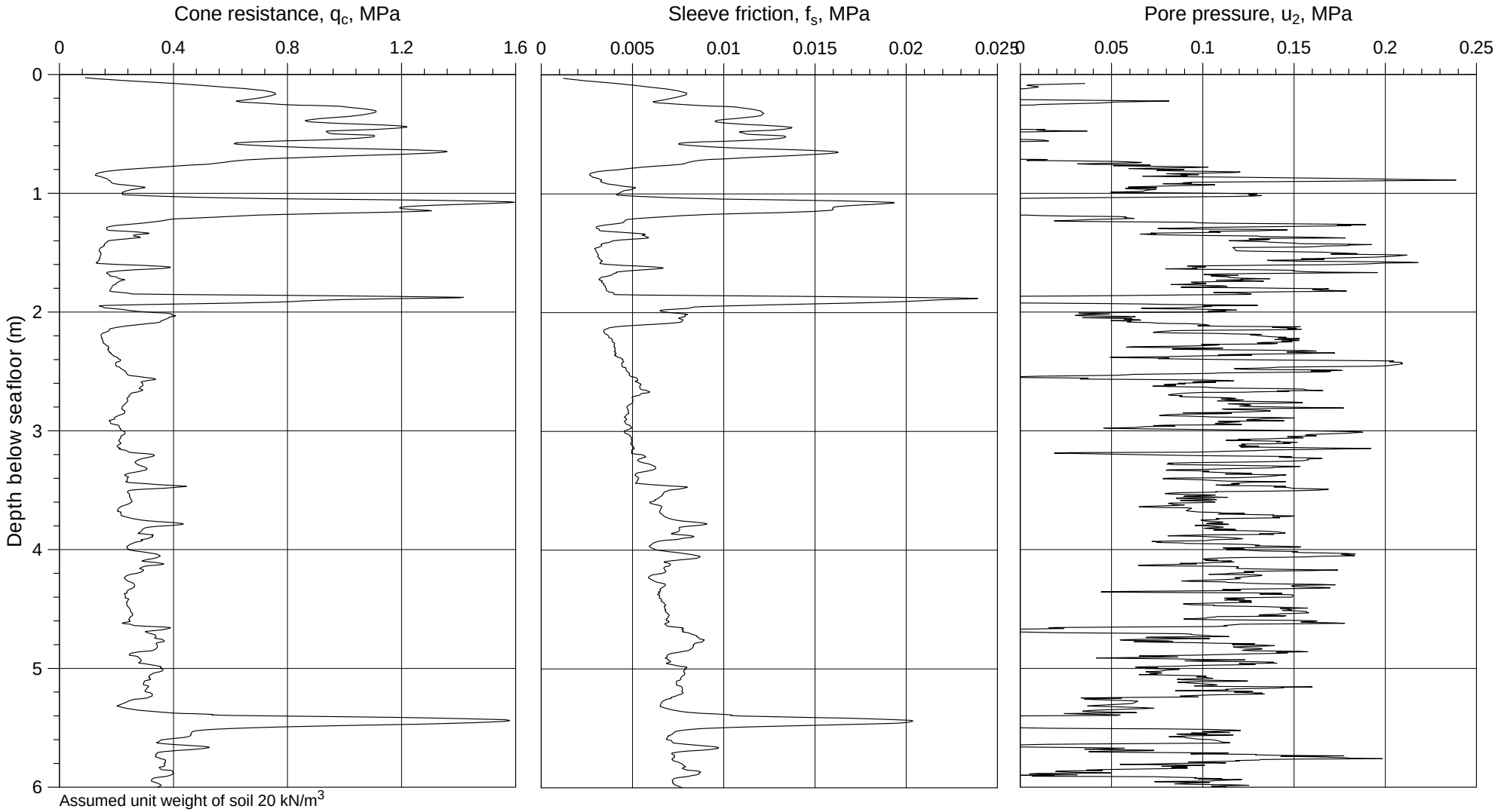


**U-864 - 2013 SOIL SURVEY**

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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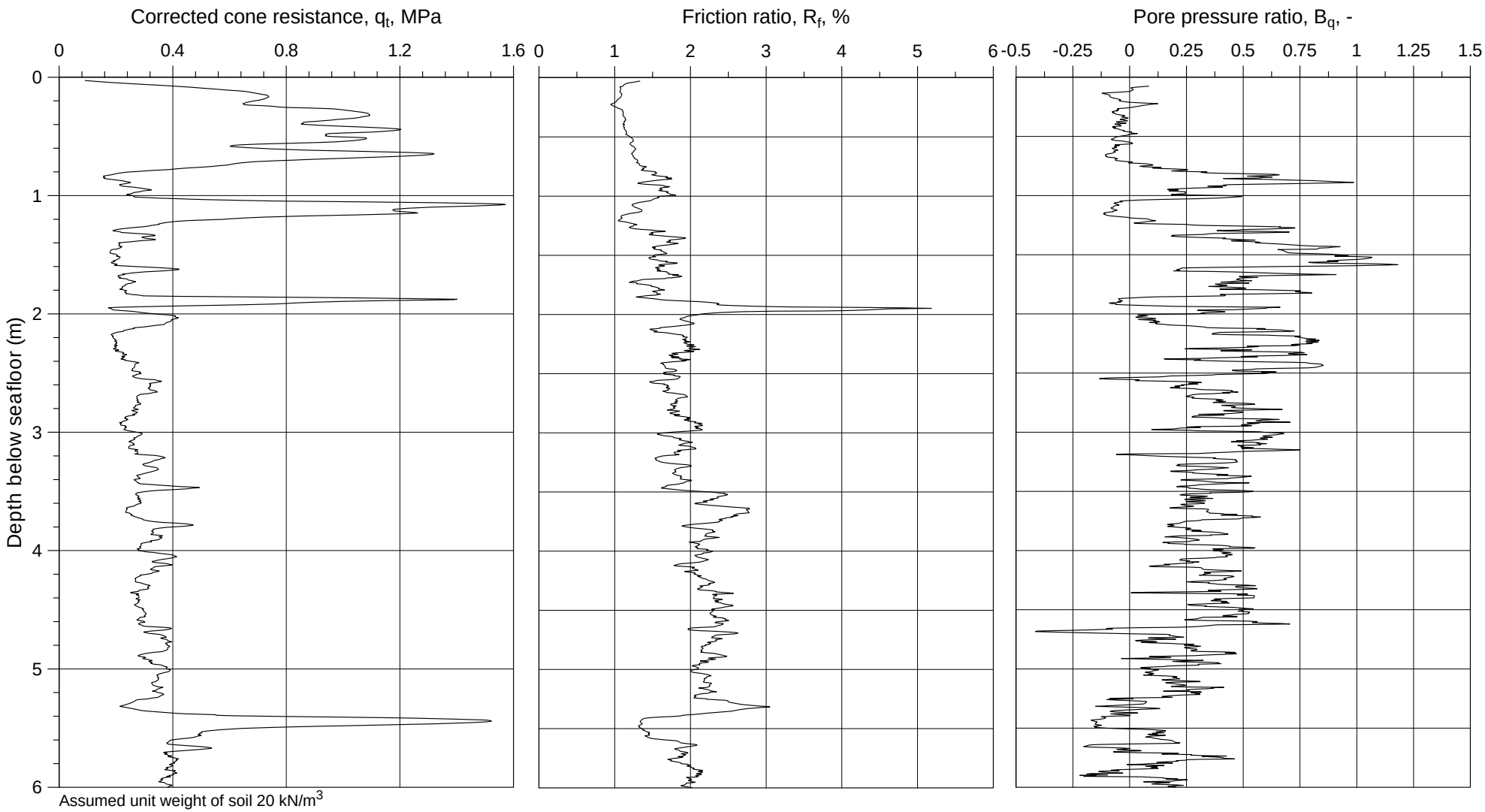


**U-864 - 2013 SOIL SURVEY**

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 |

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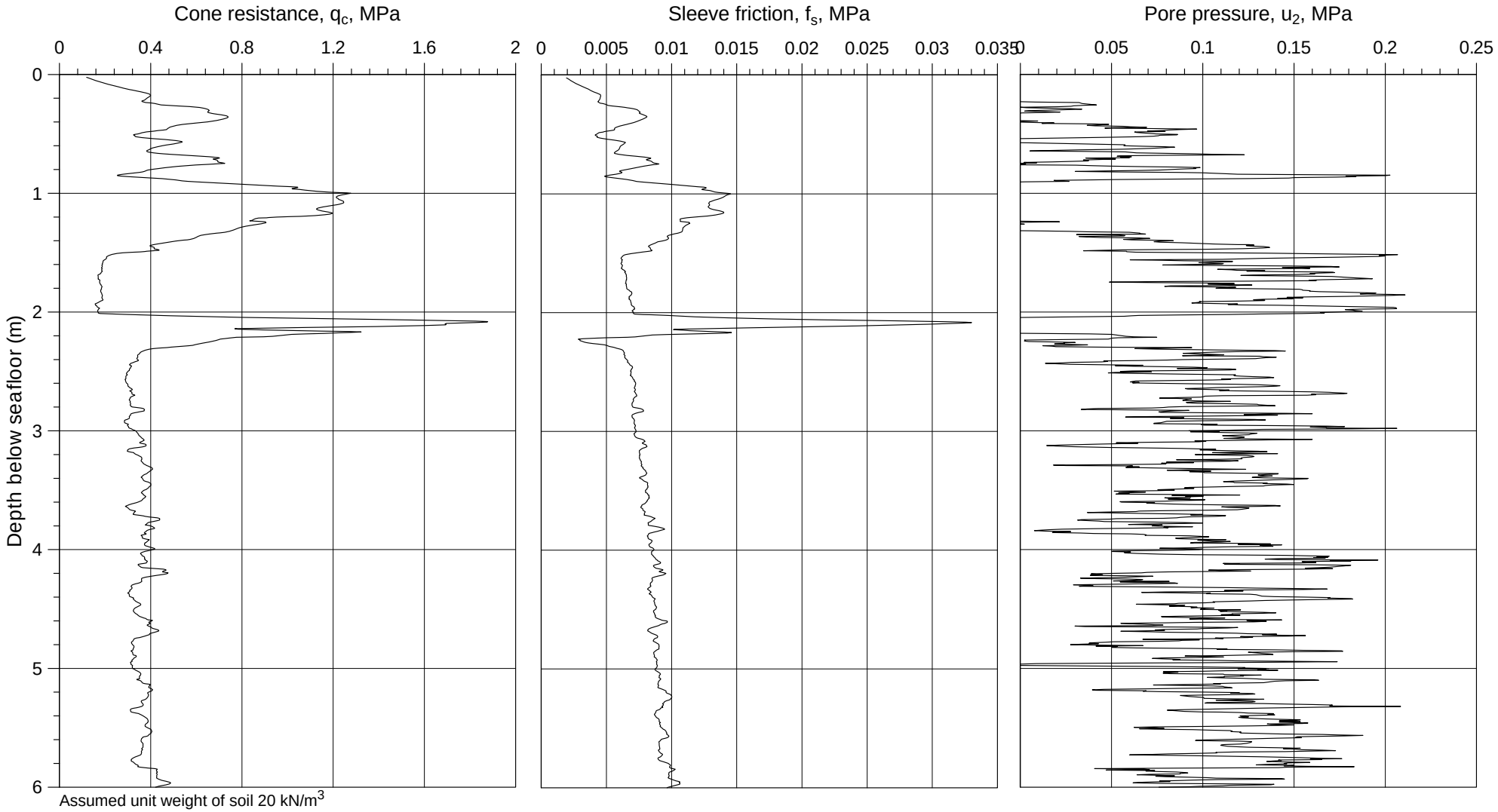


## U-864 - 2013 SOIL SURVEY

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 |

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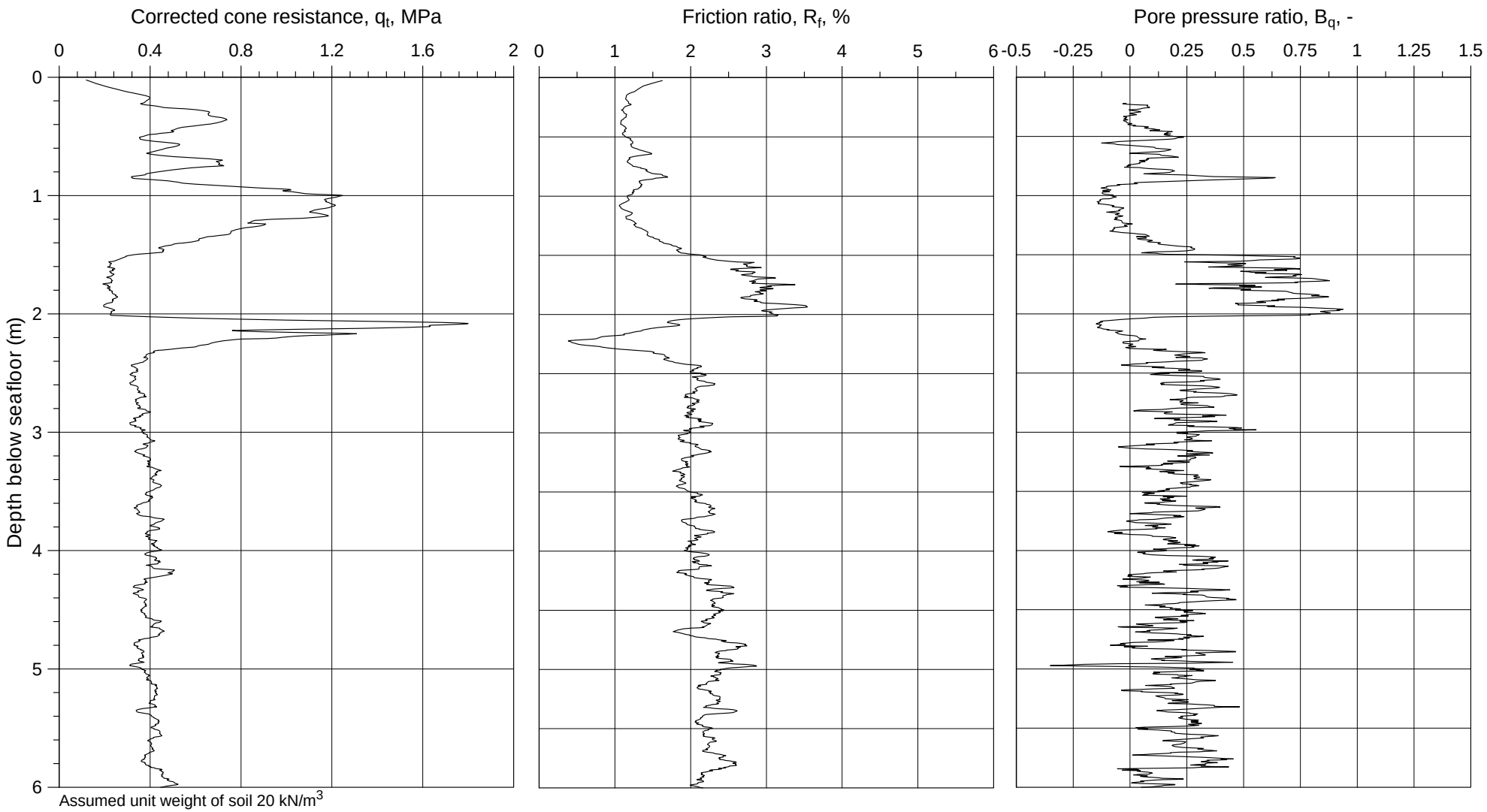


## U-864 - 2013 SOIL SURVEY

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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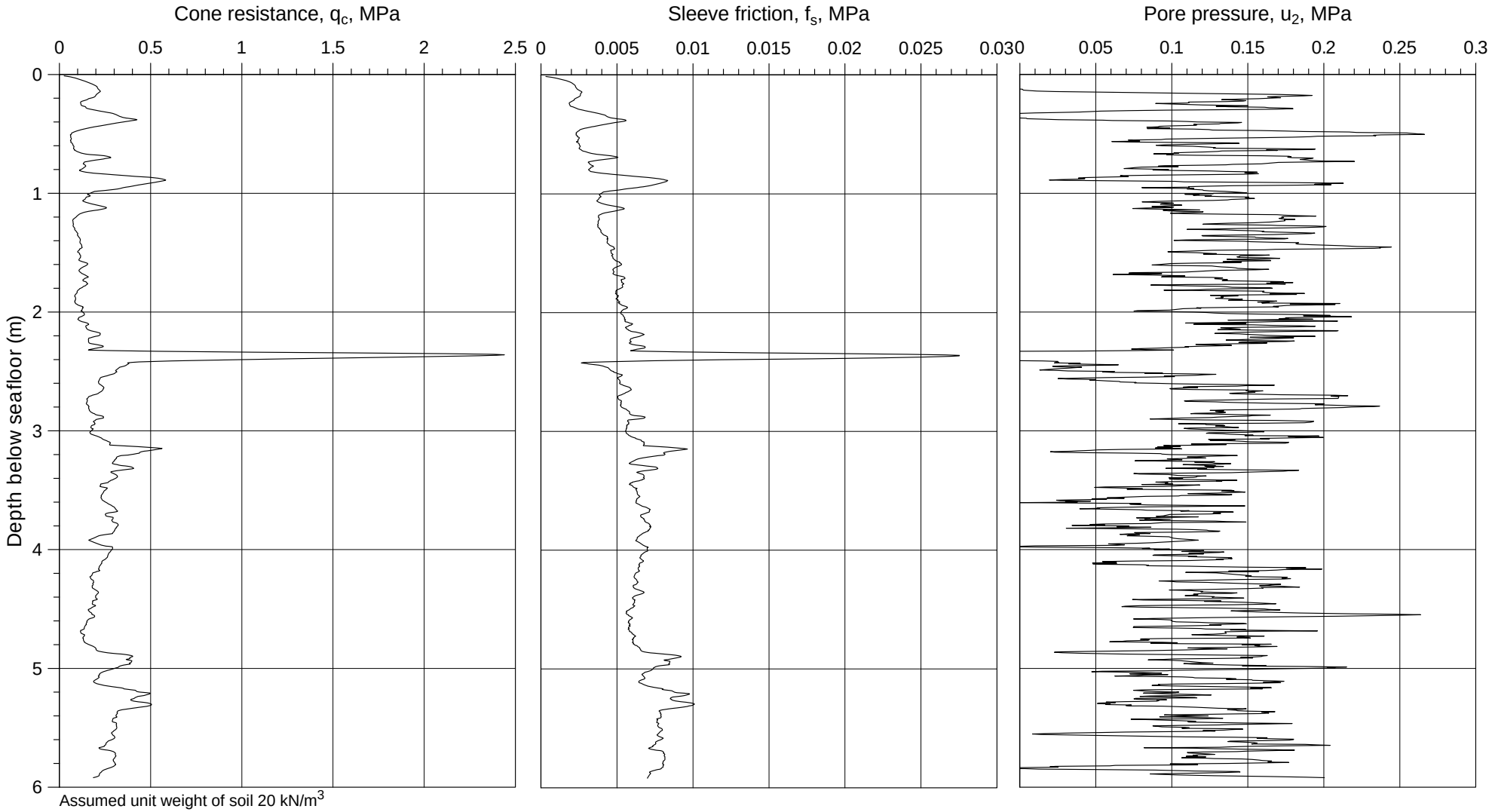


**U-864 - 2013 SOIL SURVEY**

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

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2013-03-06

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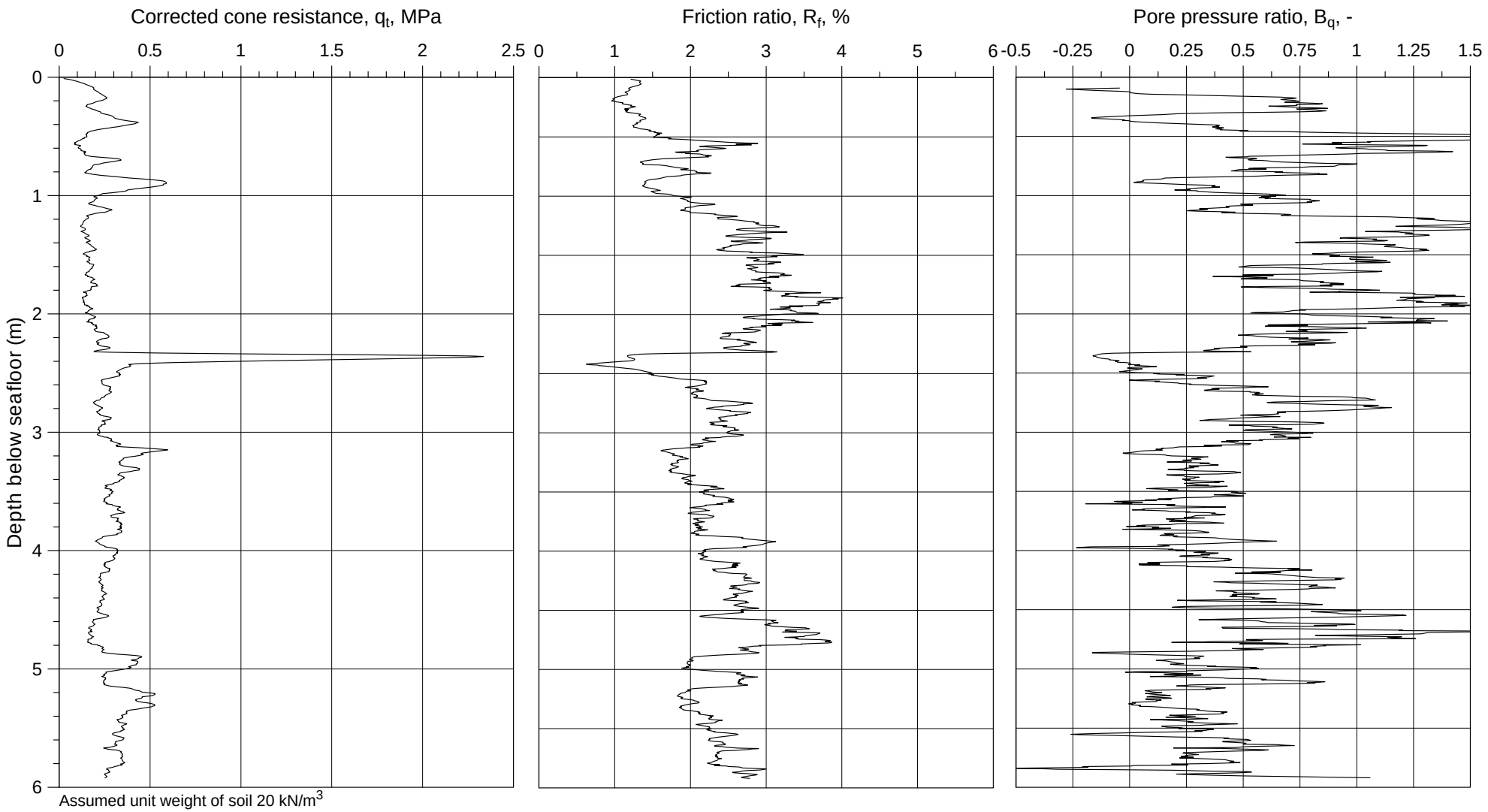


## U-864 - 2013 SOIL SURVEY

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

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# Part B4 - Oedometer Tests

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**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 $s_u$, $\sigma_{v0}$' 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 ($\Delta e$), 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 $w_i$ % | Water content $w_f$ % | $I_p$ % | 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 | Loading $M_1$ MPa | m - | $p_r'$ kPa | COEFF. OF CONS. Loading $c_{v0}$ $m^2/s*10^{-7}$ | Loading $c_{v1}$ $m^2/s*10^{-7}$ | 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

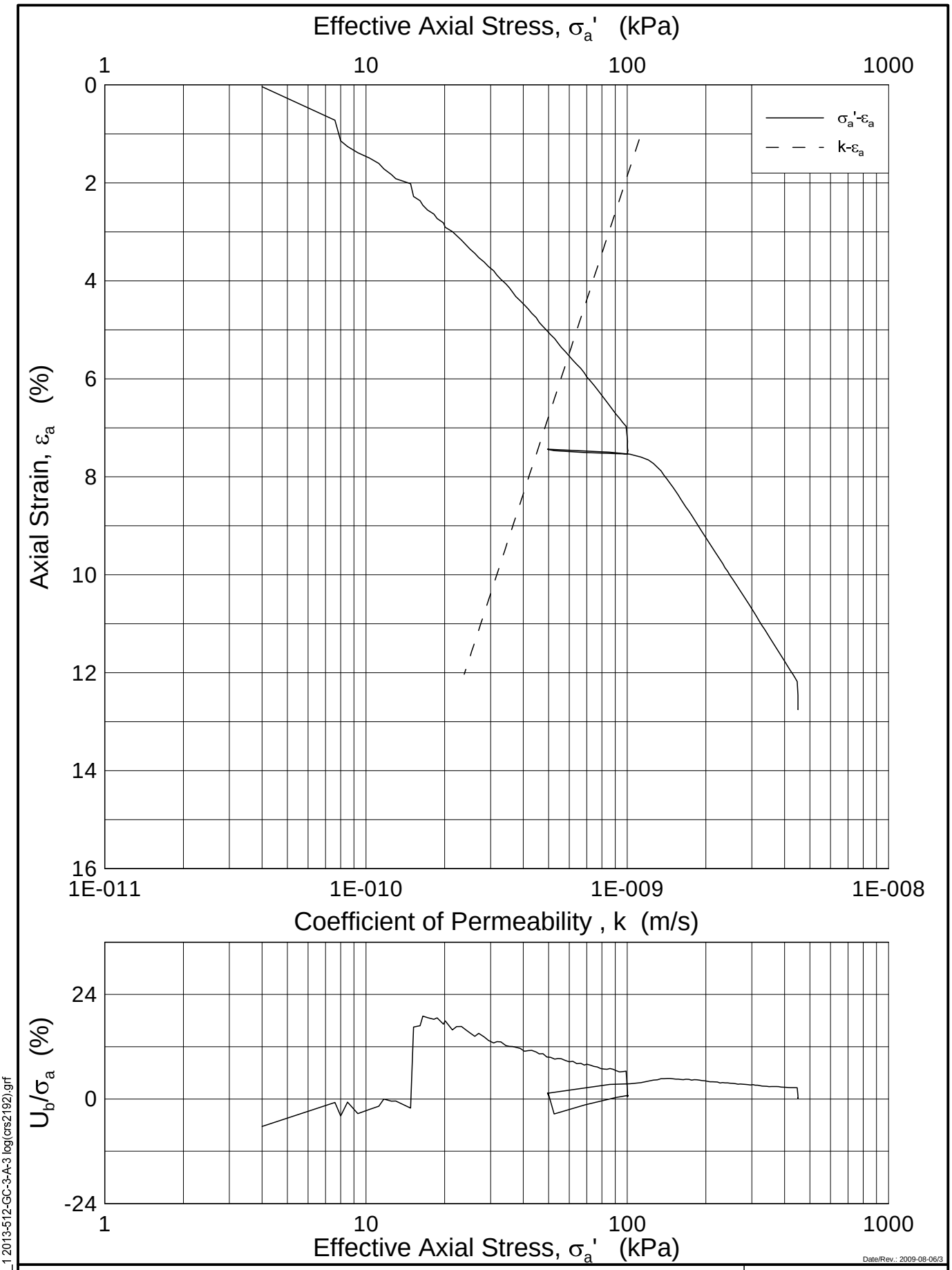
3) Using the Becker interpretation

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)

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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

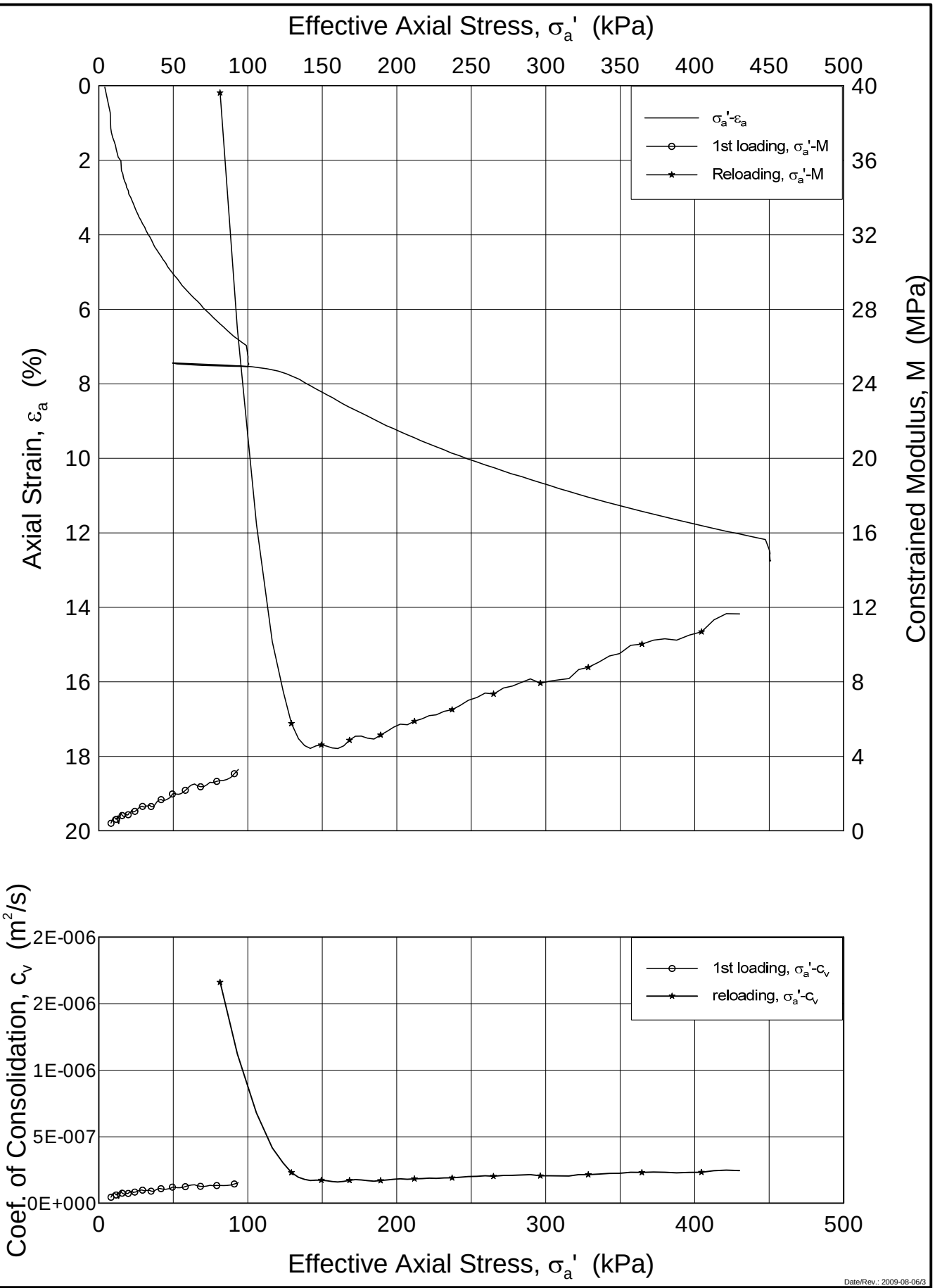
$w_i$ = 24.99 %

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

Date 2013-03-06

Oedometer test (CRSC)

Depth = 2.70 m

Boring: 2013-512GC Tube: 3

$p_o'$ = 25.7 kPa

Part: A Test: 3

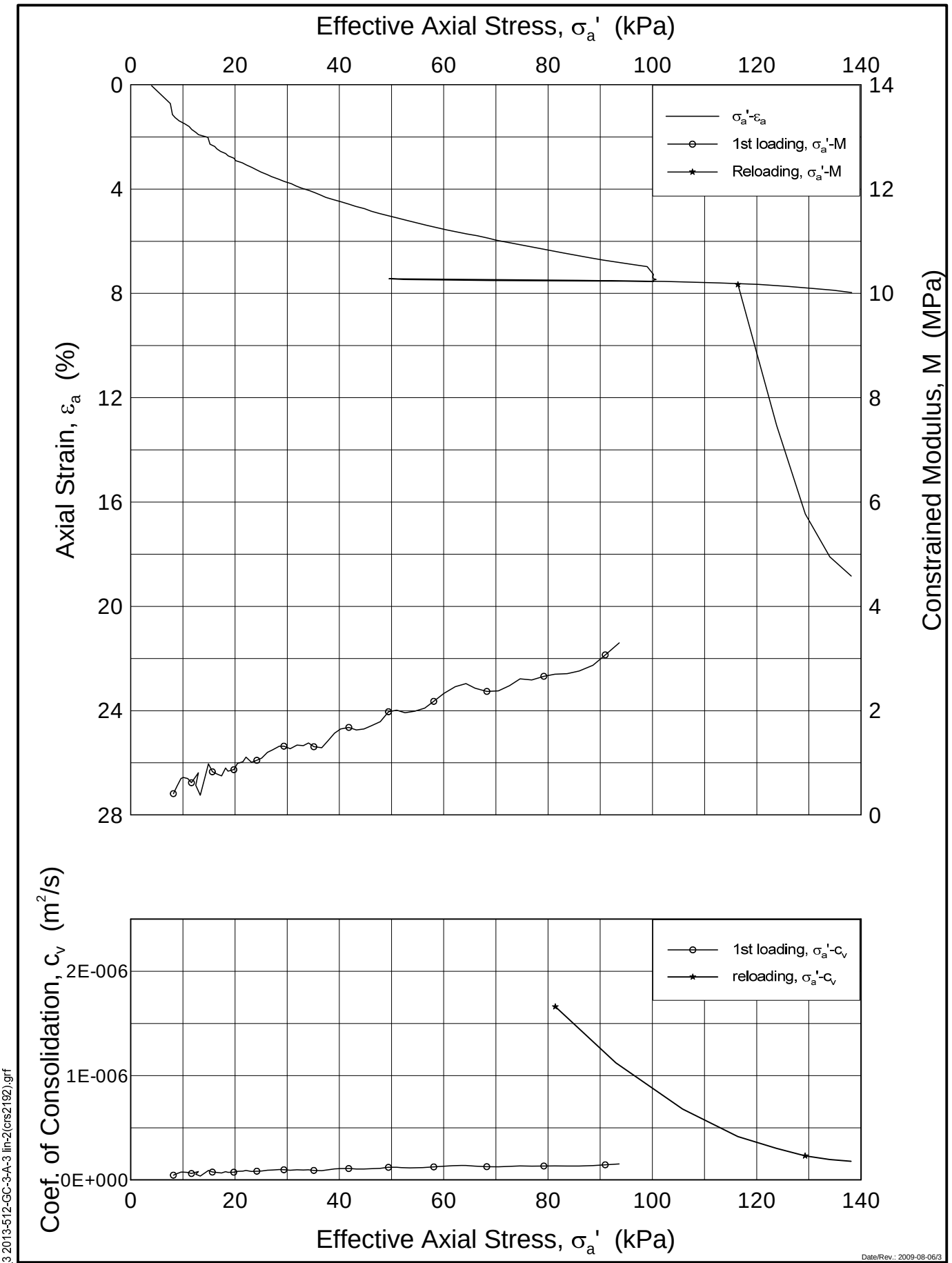
$w_i$ = 24.99 %

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)

Boring: 2013-512GC Tube: 3

Part: A Test: 3

Depth = 2.70 m

$p_o'$ = 25.7 kPa

$w_i$ = 24.99 %

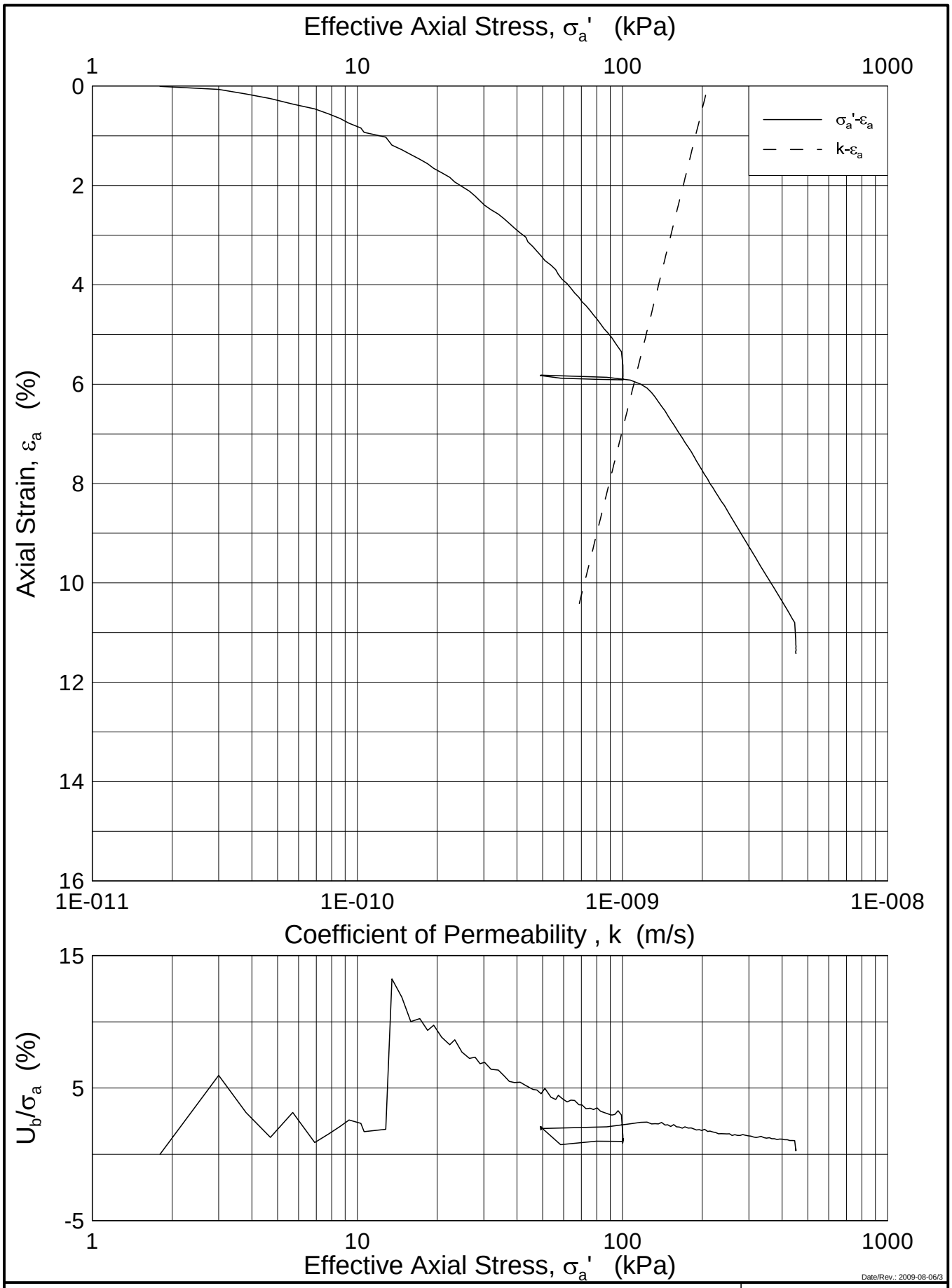
Date: 2013-03-06

Figure No.: B4.3

Drawn by: FP/

NGI

P:\2012\07\20120738\Lab\Oedom\Fig B4_3 2013-512-GC-3-A-3 lin-2(crs2192).grf




Date/Rev.: 2009-08-06/3

**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

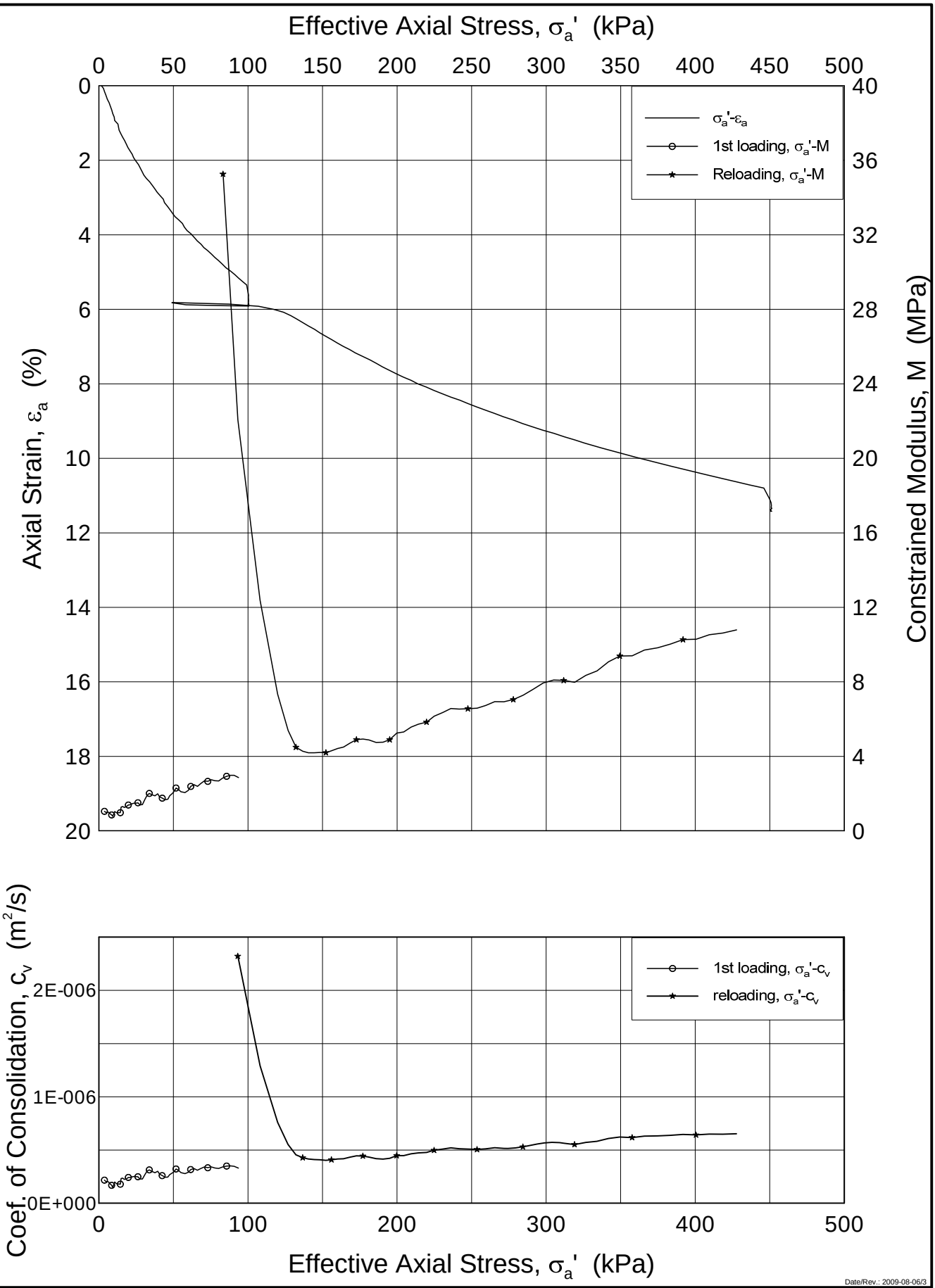
$w_i$ = 25.33 %

Figure No.: B4.4

Drawn by: FP

NGI

P:\2012\07\20120738\Lab\Oedom\Fig B4_4 2013-512-GC-4-A-3 log(crs2193).grf




Date/Rev.: 2009-08-06/3

**U-864 2013 Soil survey**

Document No.: 20120738-01-R

Oedometer test (CRSC)

Boring: 2013-512GC Tube: 4

Part: A Test: 3

Depth = 3.60 m

$p_o'$ = 34.20 kPa

$w_i$ = 25.33 %

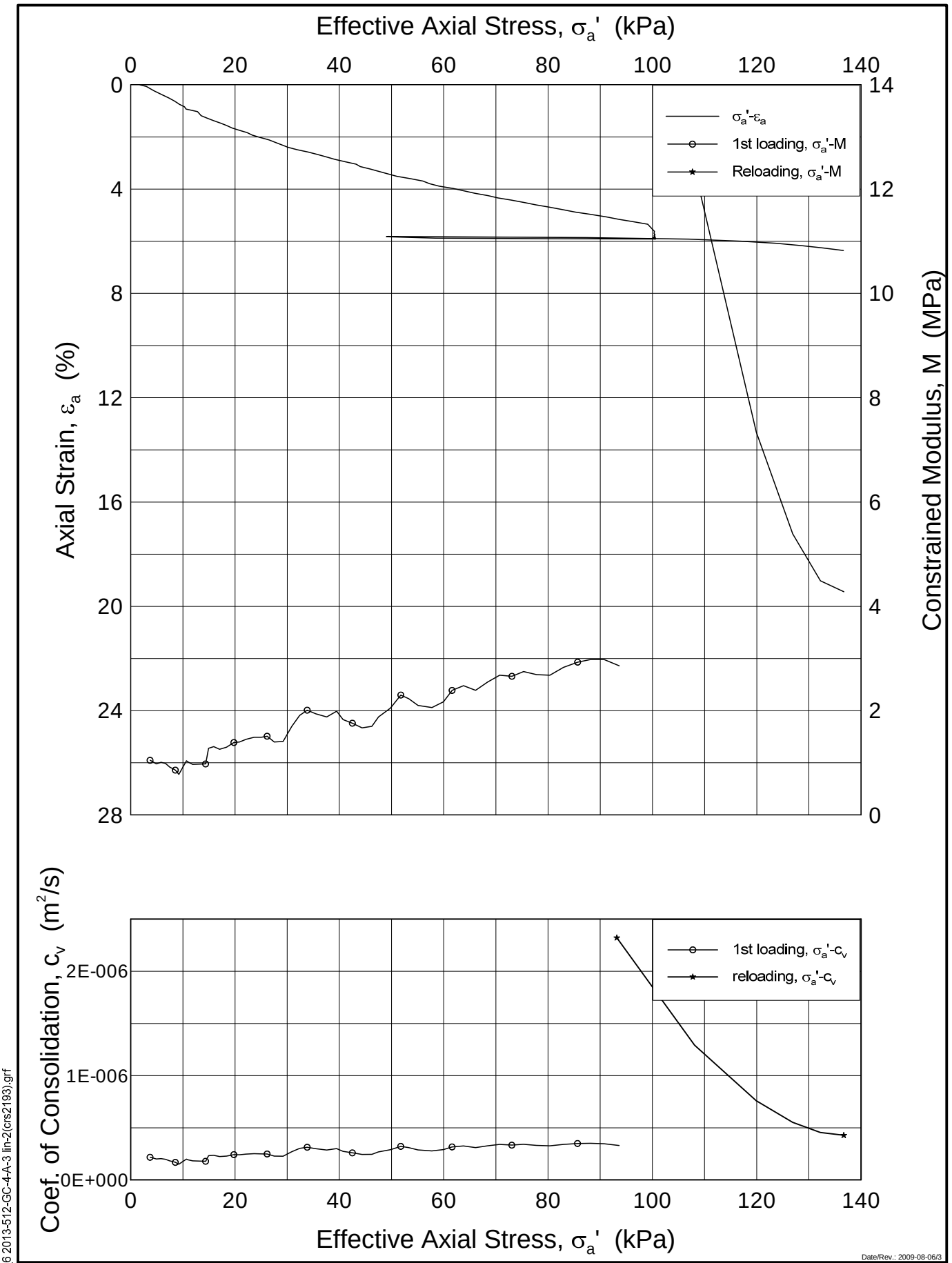
Date: 2013-03-06

Figure No.: B4.5

Drawn by: FP/

NGI

P:\2012\07\20120738\Lab\Oedom\Fig B4_5 2013-512-GC-4-A-3 lin(crs2193).grf




Date/Rev.: 2009-08-06/3

**U-864 2013 Soil survey**

Document No.: 20120738-01-R

Oedometer test (CRSC)

Boring: 2013-512GC Tube: 4

Part: A Test: 3

Depth = 3.60 m

$p_o'$ = 34.20 kPa

$w_i$ = 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 ($\Delta e$), 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 $w_i$ % | Water content $w_f$ % | $I_p$ % | Clay cont. % | Unit weight kN/m$^3$ | Type of test 1) | CONSOLIDATION: Estim. $p_o'$ kPa | $\sigma_a'$ final kPa | $\sigma_r'$ final kPa | $\varepsilon_{vol}$ % | $\varepsilon_{ac}$ % | B % | UNDR. STATIC TESTING: $s_u$ kPa | $U_f$ kPa | $\varepsilon_f$ % | $s_u/\sigma'_{ac}$ - | $\Delta e/e_i$ 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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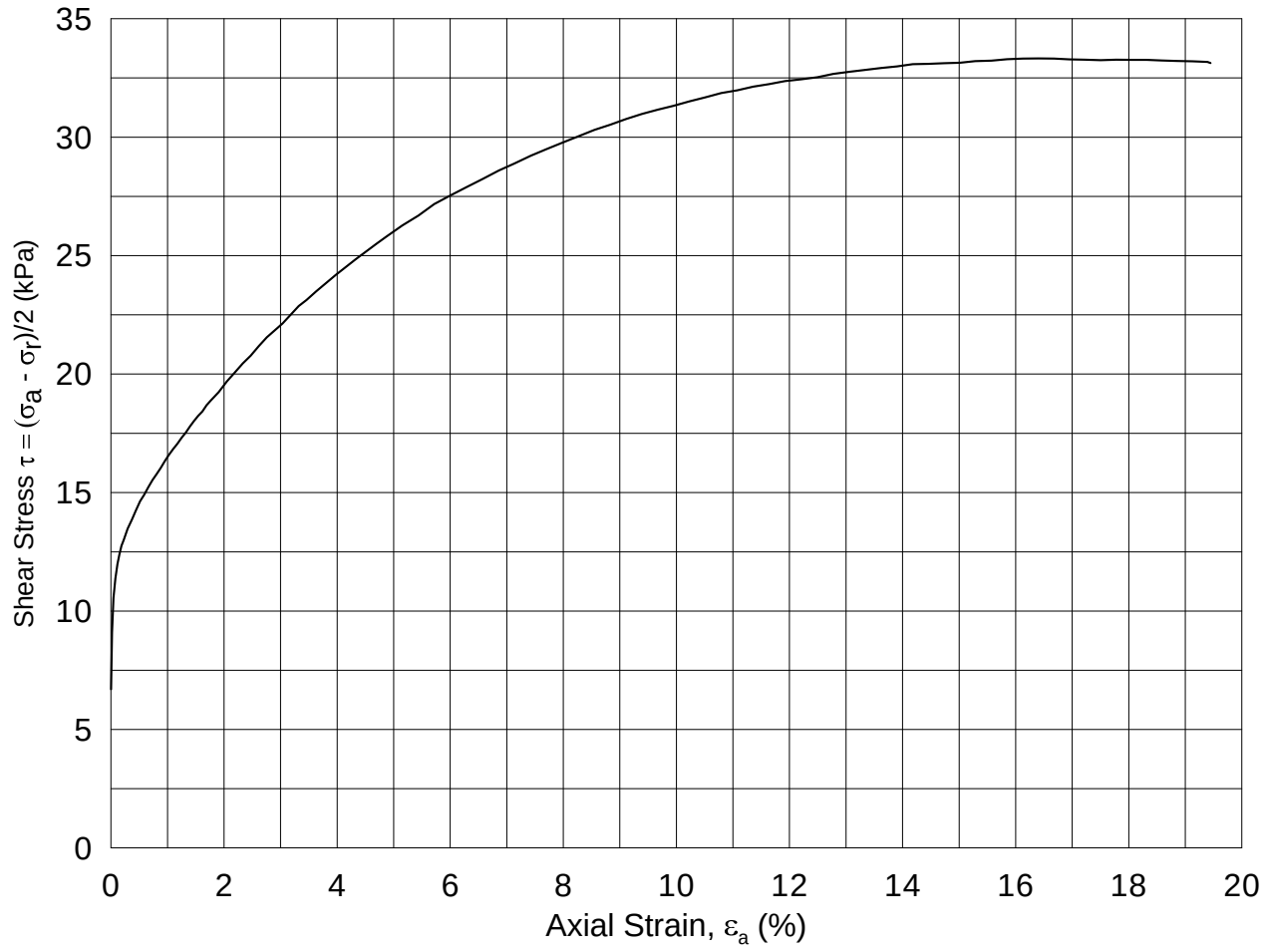
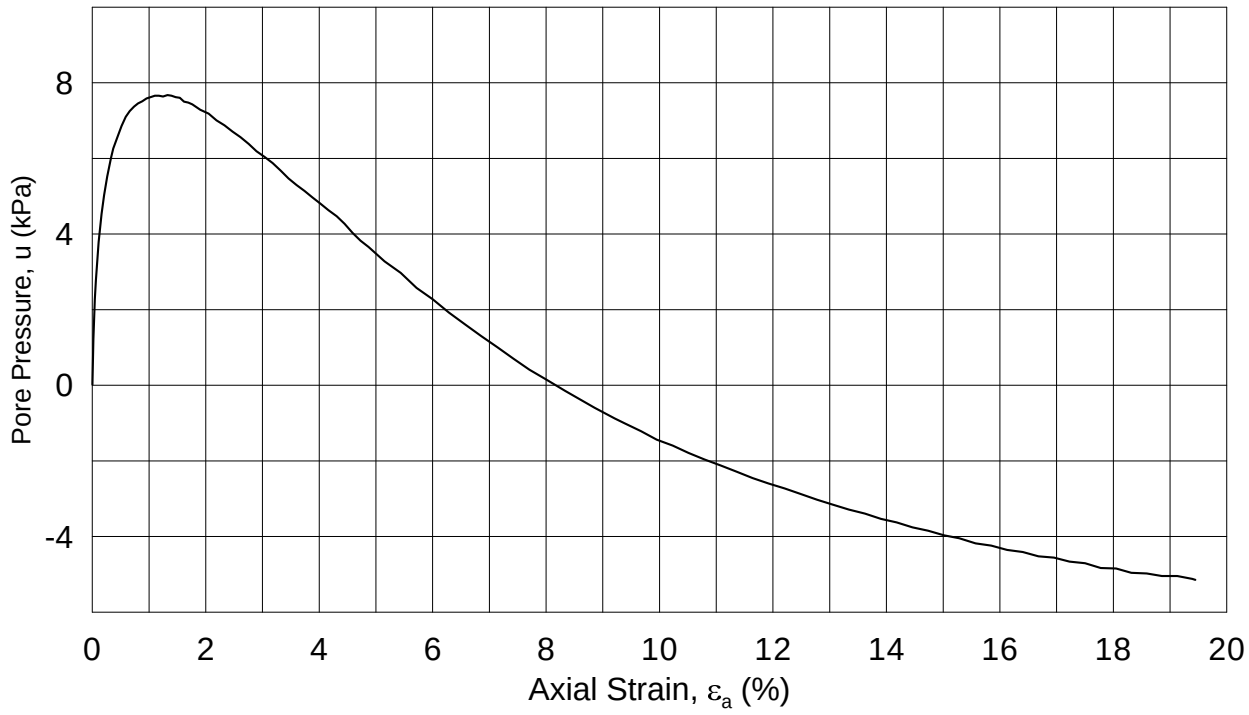
| NGI's criteria for sample quality | | | | |
|---|---|---|---|---|
| OCR | $\Delta e/e_i$ | | | |
| 1-2 | <0.04 | 0.04-0.07 | 0.07-0.14 | >0.14 |
| 2-4 | <0.03 | 0.03-0.05 | 0.05-0.10 | >0.10 |
| 4-6 | <0.02 | 0.02-0.035 | 0.035-0.07 | >0.07 |
| Quality: | 1 | 2 | 3 | 4 |

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**

Boring: **2013-509GC**

Tube: **4**

Part: **A**

Test: **1**

| | | | |
|---|---|---|---|
| Depth = | **3.52** | m | |
| $p_o'$ = | **33.4** | kPa | |
| $w_i$ = | **22.8** | % | |
| $w_c$ = | **21.9** | % | |

| Consolidation stresses (kPa) | max. | min. | final |
|---|---|---|---|
| $\sigma_{ac}'$ = | - | - | **33.4** |
| $\sigma_{rc}'$ = | - | - | **20.1** |

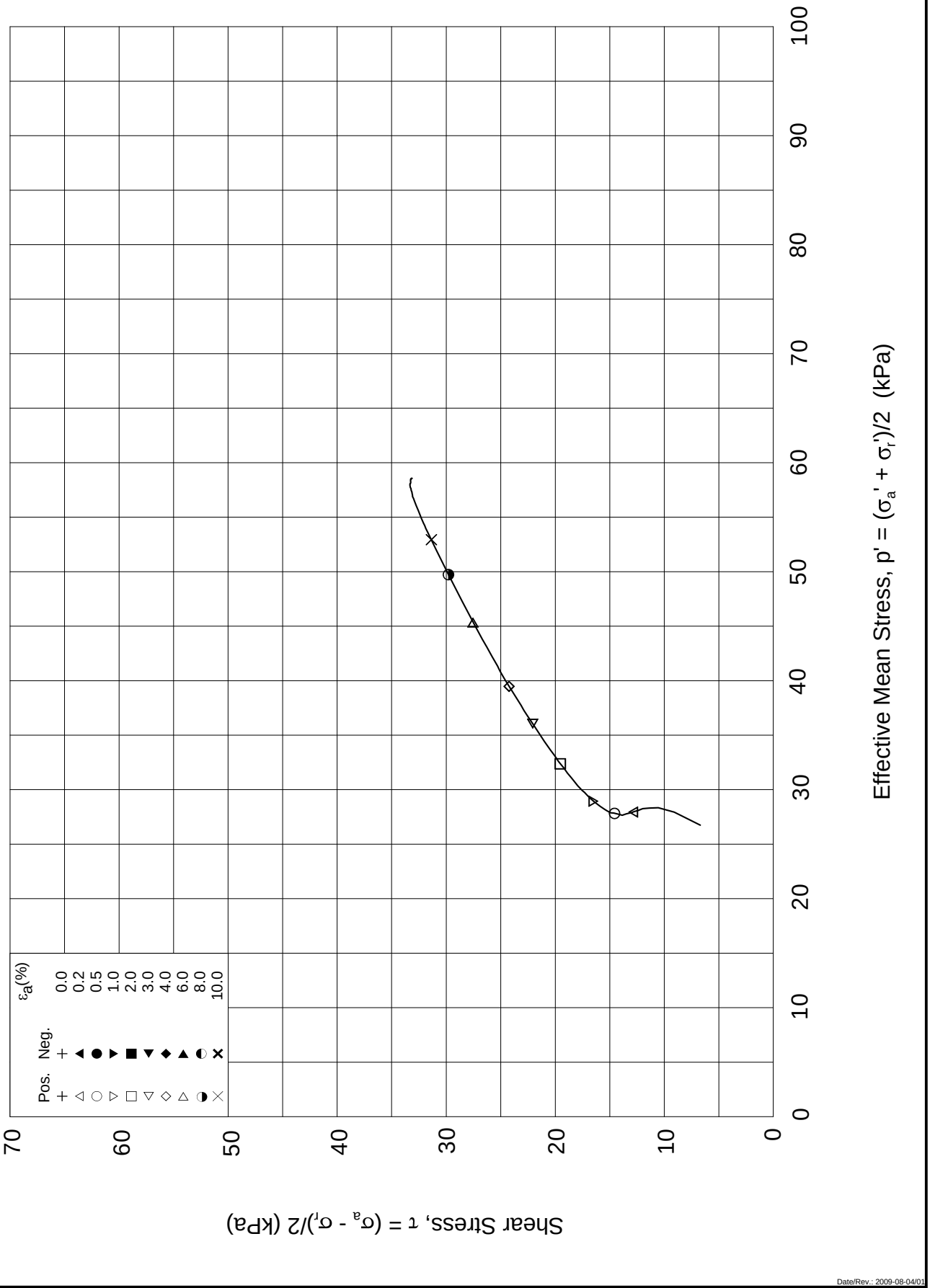
Date: 2013-03-06

Figure No.: B5.1

Drawn by: MAS

NGI

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**

Boring: **2013-509GC**

Tube: **4**

Part: **A**

Test: **1**

| | | | |
|---|---|---|---|
| Depth = | **3.52** | m | |
| $p_o'$ = | **33.4** | kPa | |
| $w_i$ = | **22.8** | % | |
| $w_c$ = | **21.9** | % | |

Consolidation stresses

| (kPa) | max. | min. | final |
|---|---|---|---|
| $\sigma_{ac}'$ = | - | - | **33.4** |
| $\sigma_{rc}'$ = | - | - | **20.1** |

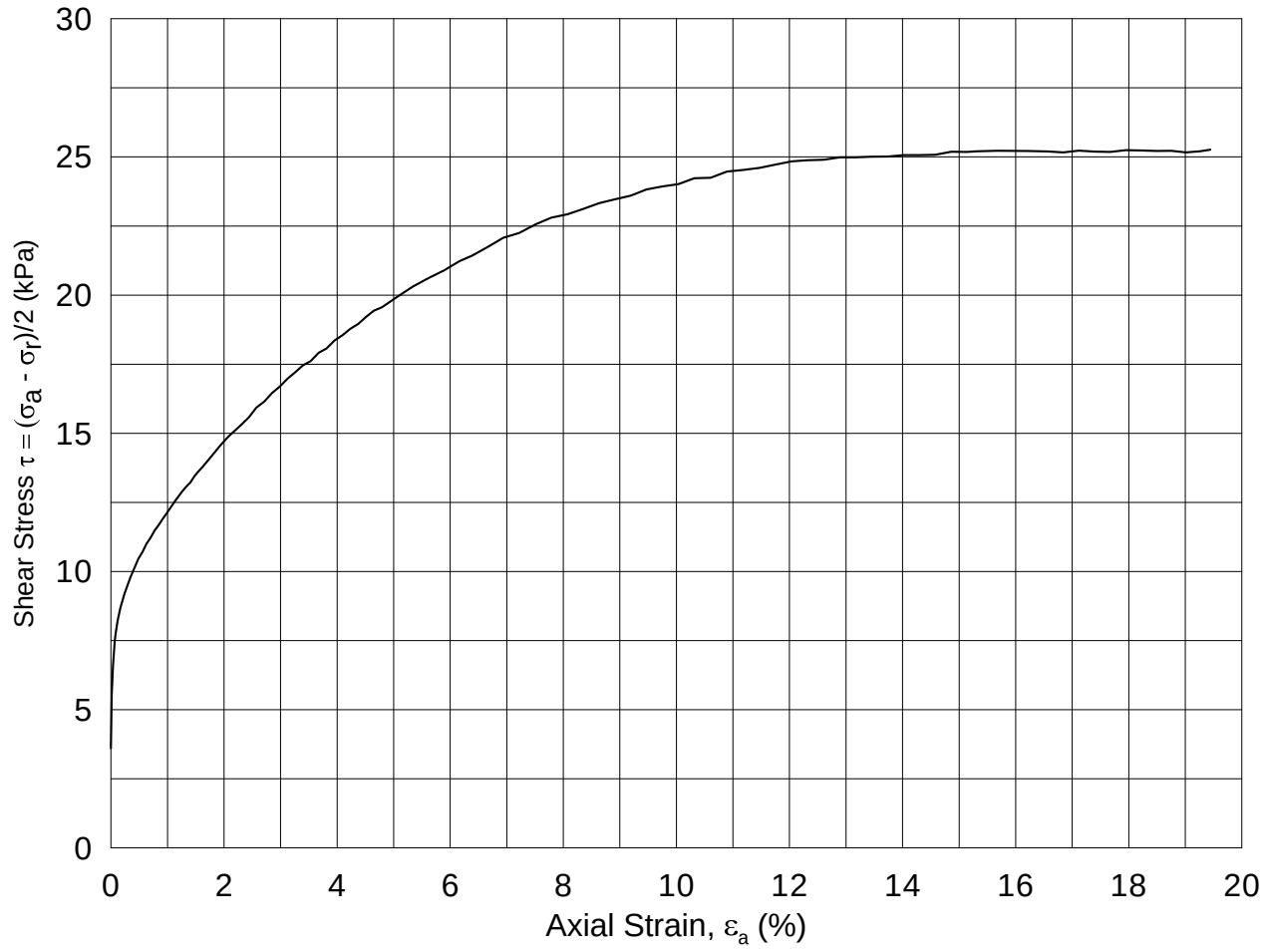
Date: 2013-03-06

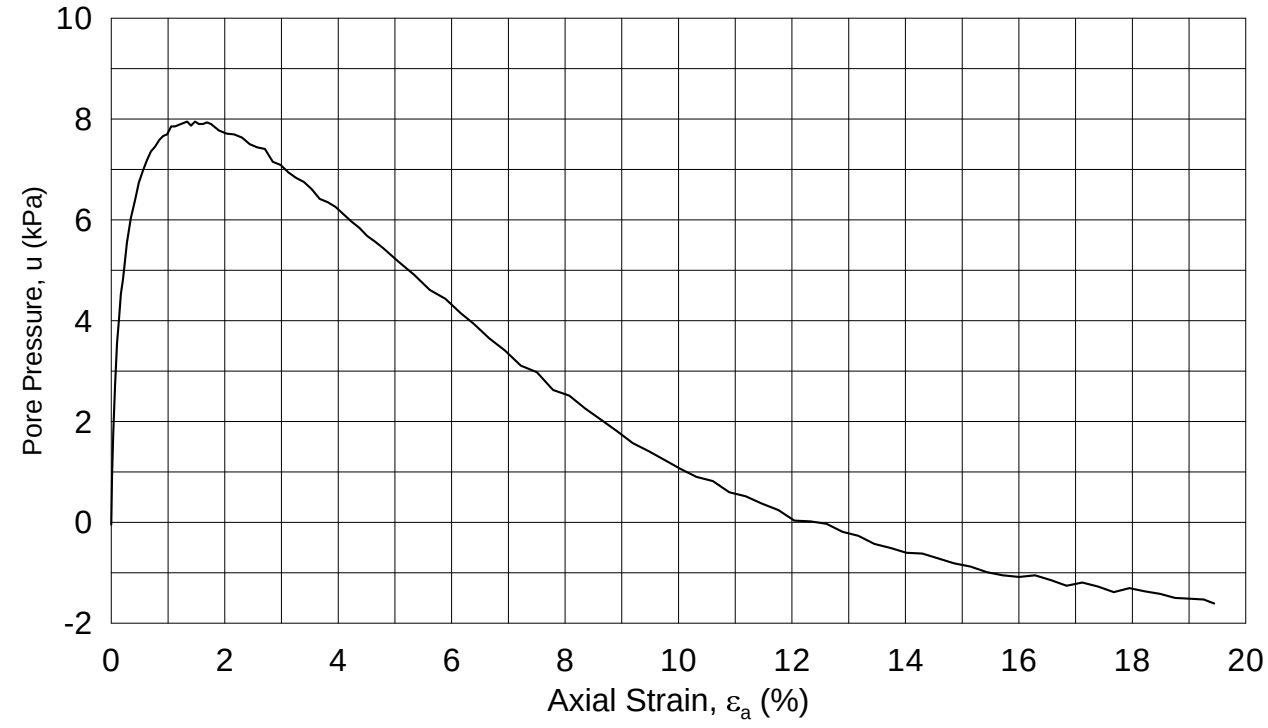
Figure No.: B5.2

Drawn by: MAS

NGI

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**

Boring: **2013-512GC**

Tube: **3**

Part: **A**

Test: **1**

| | | | |
|---|---|---|---|
| Depth = | **2.47** | m | |
| $p_o'$ = | **23.5** | kPa | |
| $w_i$ = | **23.4** | % | |
| $w_c$ = | **22.2** | % | |

Consolidation stresses

| (kPa) | max. | min. | final |
|---|---|---|---|
| $\sigma_{ac}'$ = | - | - | **23.5** |
| $\sigma_{rc}'$ = | - | - | **16.4** |

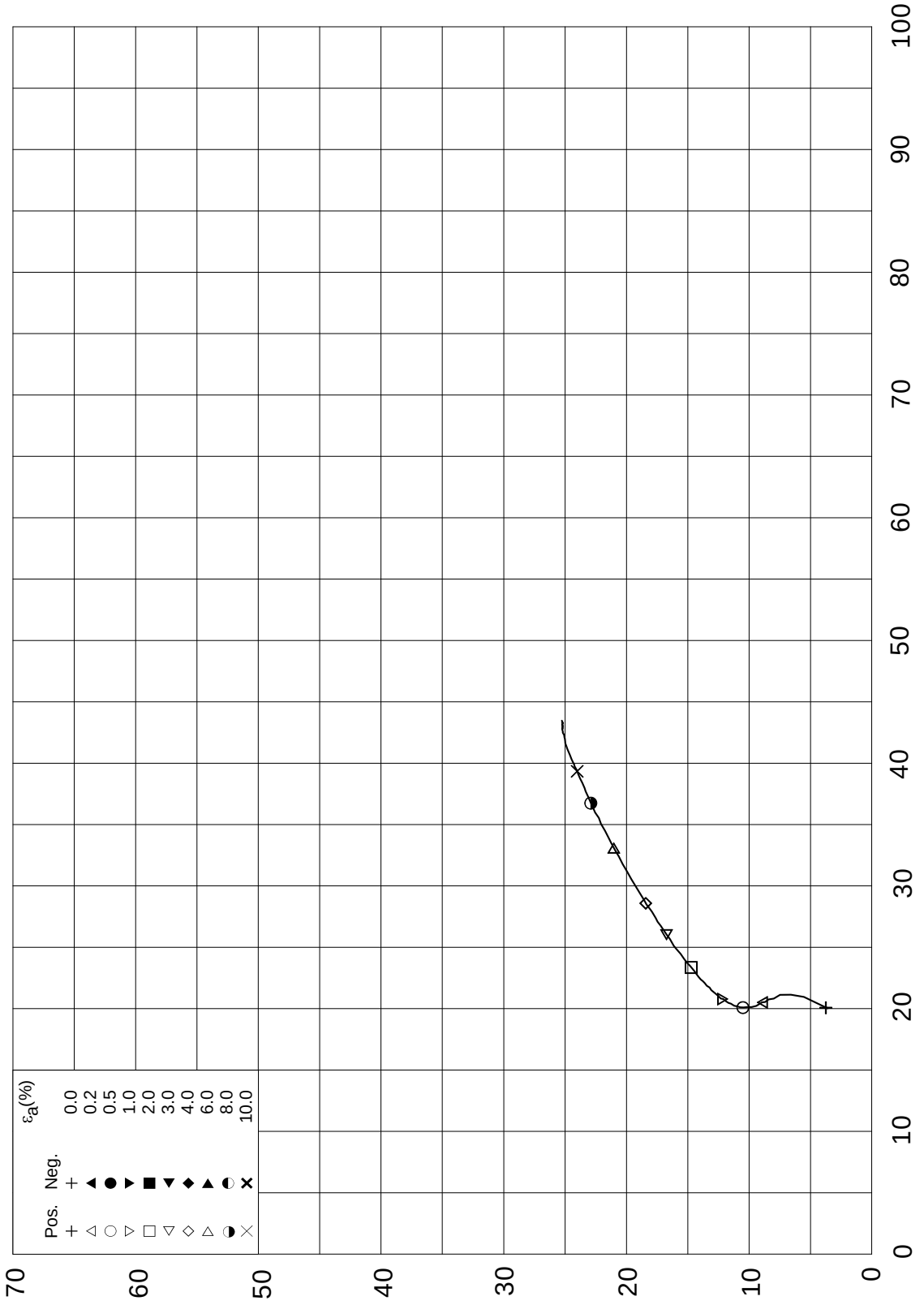
Date: 2013-03-06

Figure No. B5.3

Drawn by MAS

NGI

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**

Boring: **2013-512GC**

Tube: **3**

Part: **A**

Test: **1**

| | | | |
|---|---|---|---|
| Depth = | **2.47** | m | |
| $p_o'$ = | **23.5** | kPa | |
| $w_i$ = | **23.4** | % | |
| $w_c$ = | **22.2** | % | |

Consolidation stresses

| (kPa) | max. | min. | final |
|---|---|---|---|
| $\sigma_{ac}'$ = | - | - | **23.5** |
| $\sigma_{rc}'$ = | - | - | **16.4** |

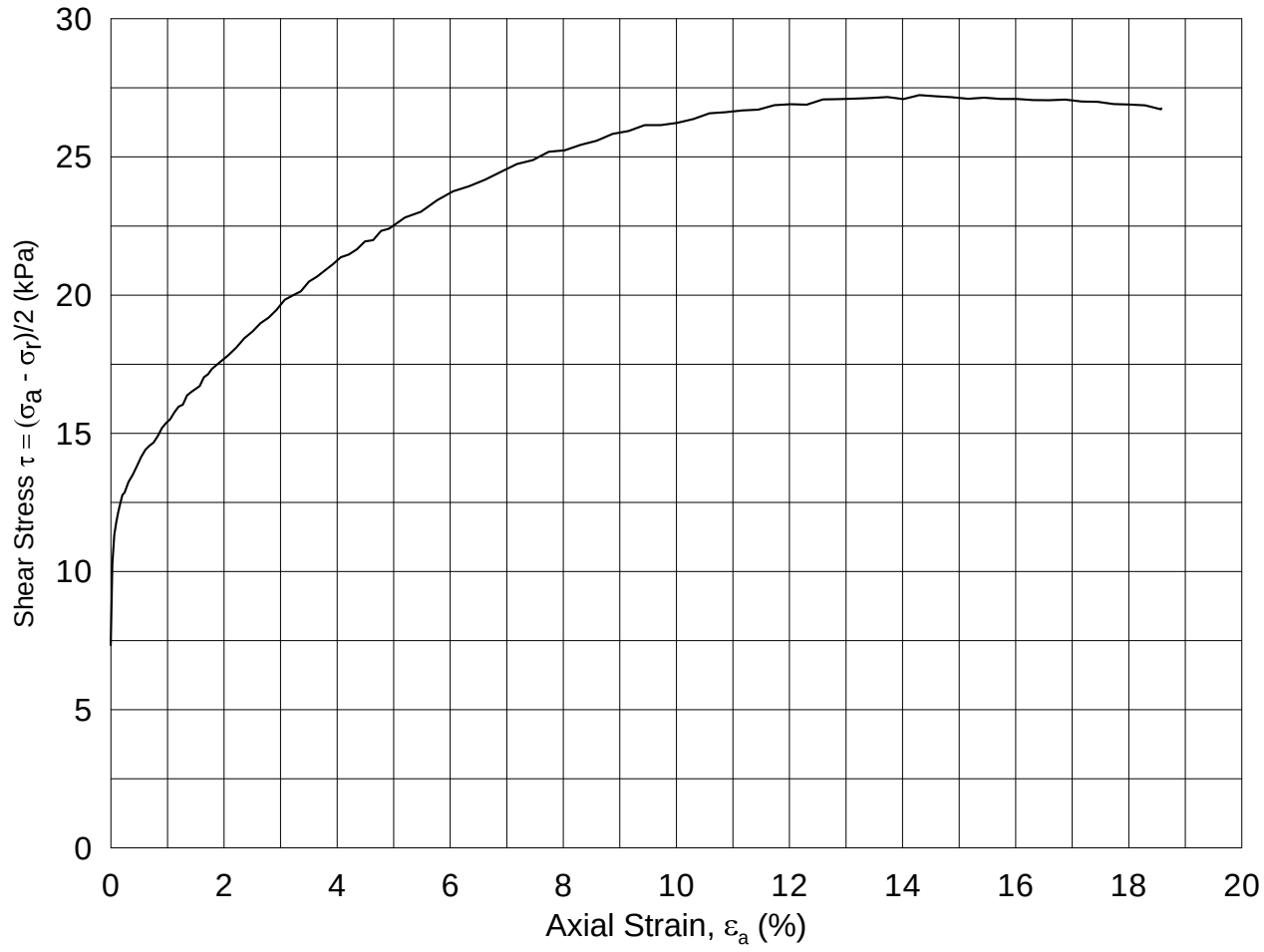
Date: 2013-03-06

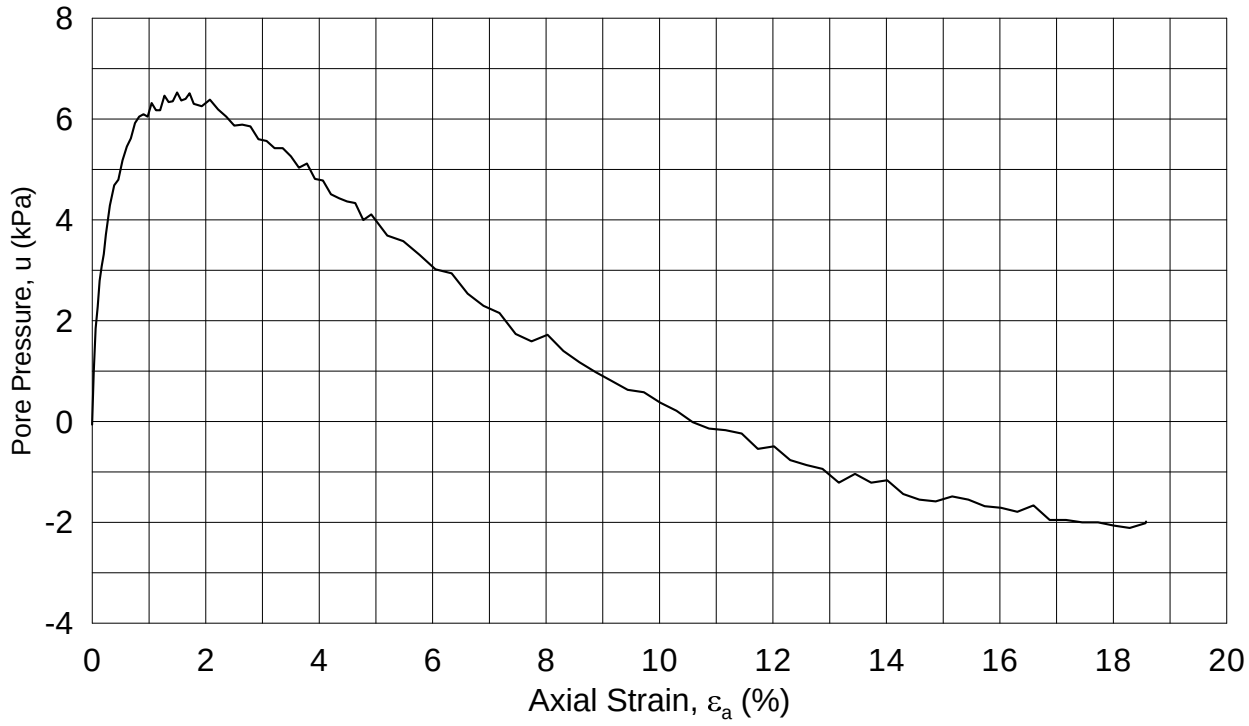
Figure No.: B5.4

Drawn by: MAS

NGI

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**

Boring: **2013-512GC**

Tube: **4**

Part: **A**

Test: **1**

| | | | |
|---|---|---|---|
| Depth = | **3.45** | m | |
| $p_o'$ = | **32.8** | kPa | |
| $w_i$ = | **24.5** | % | |
| $w_c$ = | **23.2** | % | |

Consolidation stresses

| (kPa) | max. | min. | final |
|---|---|---|---|
| $\sigma_{ac}'$ = | - | - | **32.7** |
| $\sigma_{rc}'$ = | - | - | **18.0** |

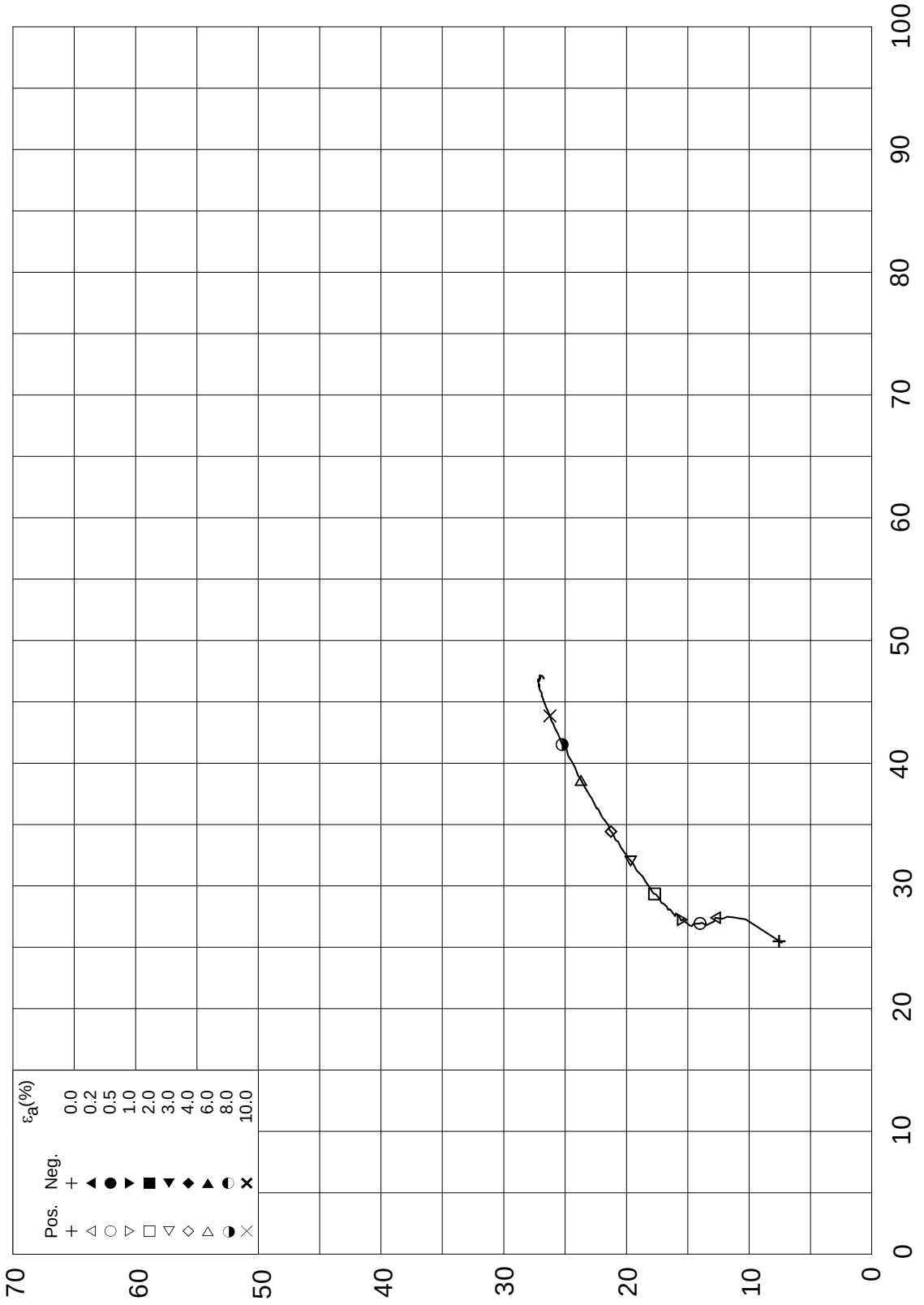
Date: 2013-03-06

Figure No. B5.5

Drawn by MAS

NGI

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**

Boring: **2013-512GC**

Tube: **4**

Part: **A**

Test: **1**

| | | | |
|---|---|---|---|
| Depth = | **3.45** | m | |
| $p_o'$ = | **32.8** | kPa | |
| $w_i$ = | **24.5** | % | |
| $w_c$ = | **23.2** | % | |

Consolidation stresses

| (kPa) | max. | min. | final |
|---|---|---|---|
| $\sigma_{ac}'$ = | - | - | **32.7** |
| $\sigma_{rc}'$ = | - | - | **18.0** |

Date: 2013-03-06

Figure No.: B5.6

Drawn by: MAS

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 $0.75 \times p_c$' 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. $\tau_f$) 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 $w_i$ % | Water content $w_f$ % | $I_p$ % | 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 | $\varepsilon_{ac}$ % | $\tau_c$ kPa | $\gamma_{hc}$ % | STATIC TESTING: $s_u^{DSS}$ kPa | $U_f$ kPa | $\gamma_f$ % | $s_u^{DSS}/\sigma'_{ac}$ - | $\Delta e/e_i$ 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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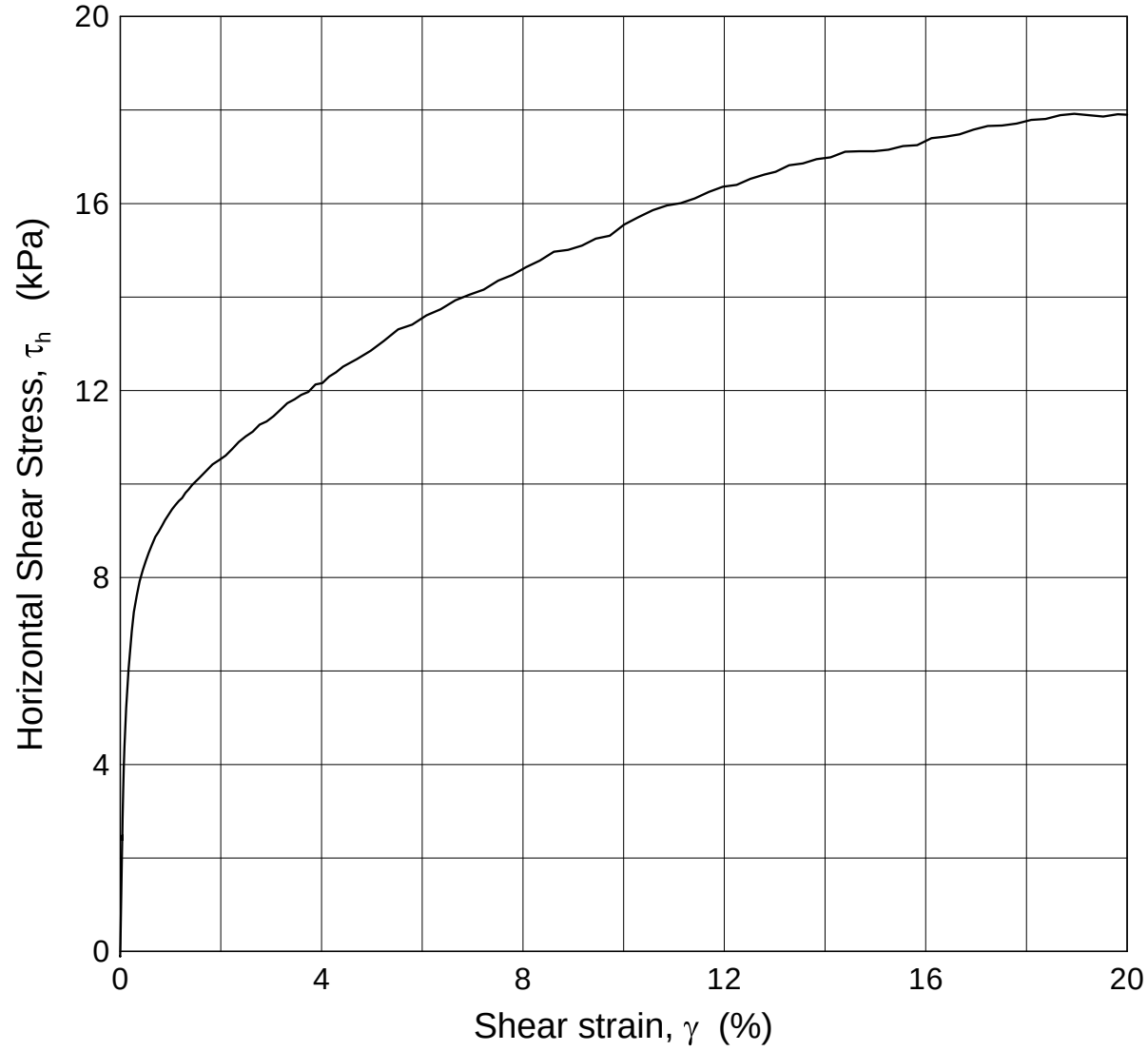
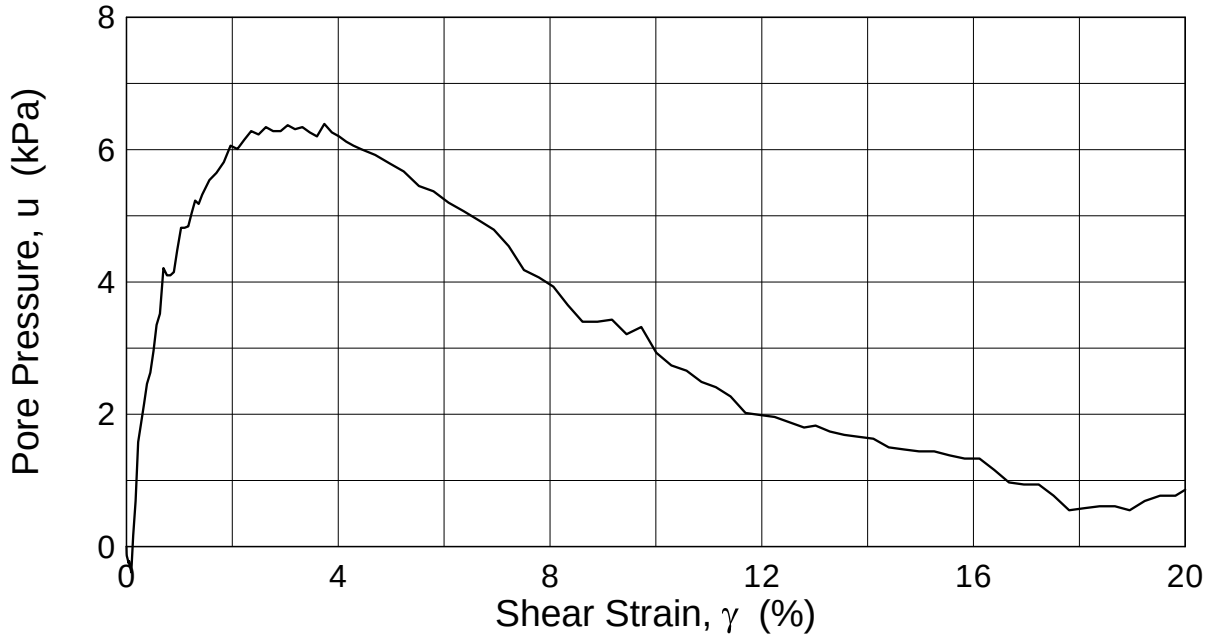
LEGEND

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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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** | % | $\sigma_{ac}'$ = | 33.0 | - | **25.3** | |
| Test: **2** | $\gamma_i$ = | **19.59** | kN/m³ | $\tau_c'$ = | - | - | **-** | |

Figure No. B6.1

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NGI

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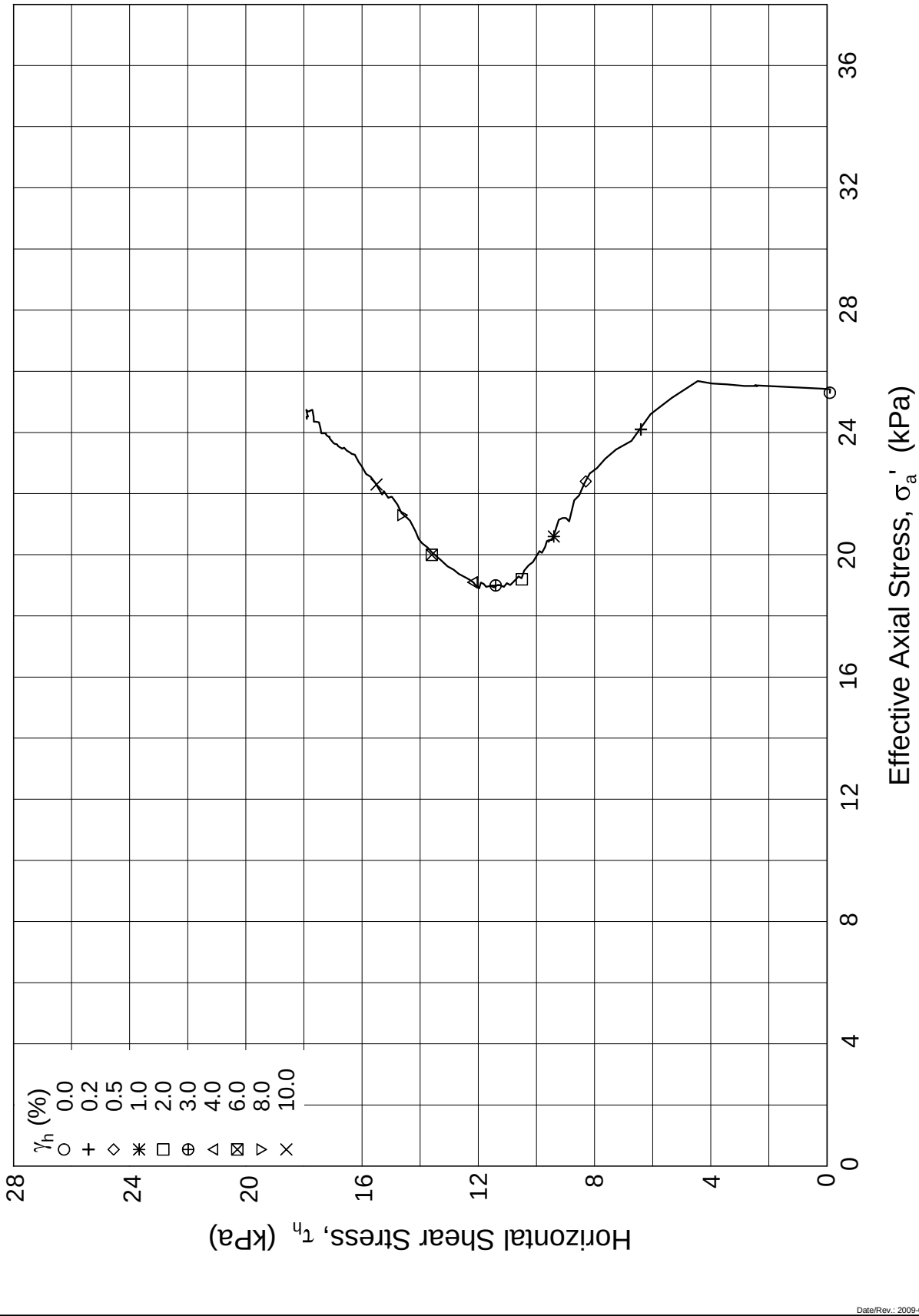


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**U-864-2013 SOIL SURVEY**

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** | % | $\sigma_{ac}'$ = | 33.0 | - | **25.3** | |
| Test: **2** | $\gamma_i$ = | **19.59** | kN/m³ | $\tau_c'$ = | - | - | **-** | |

Figure No. B6.2

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NGI

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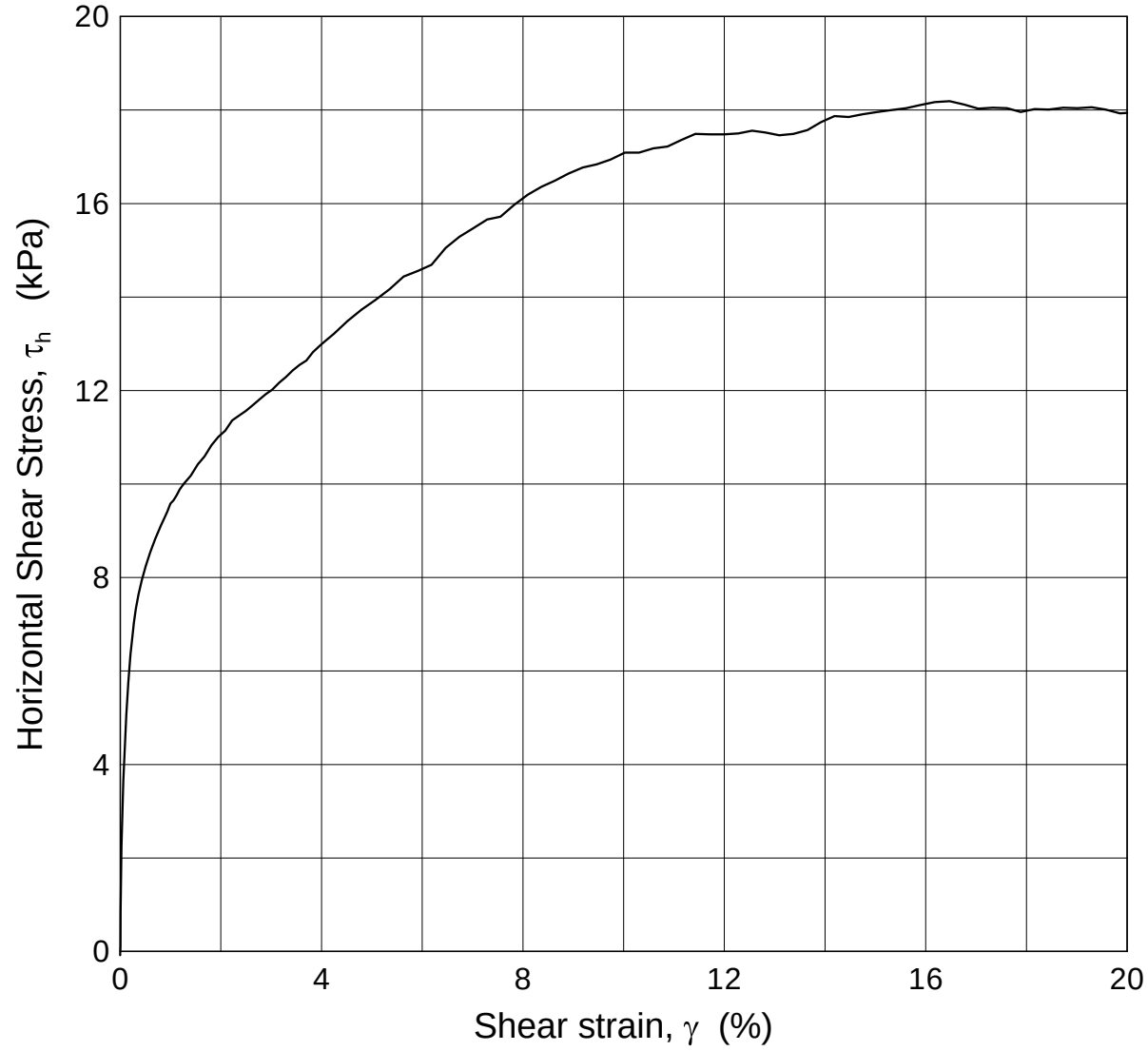


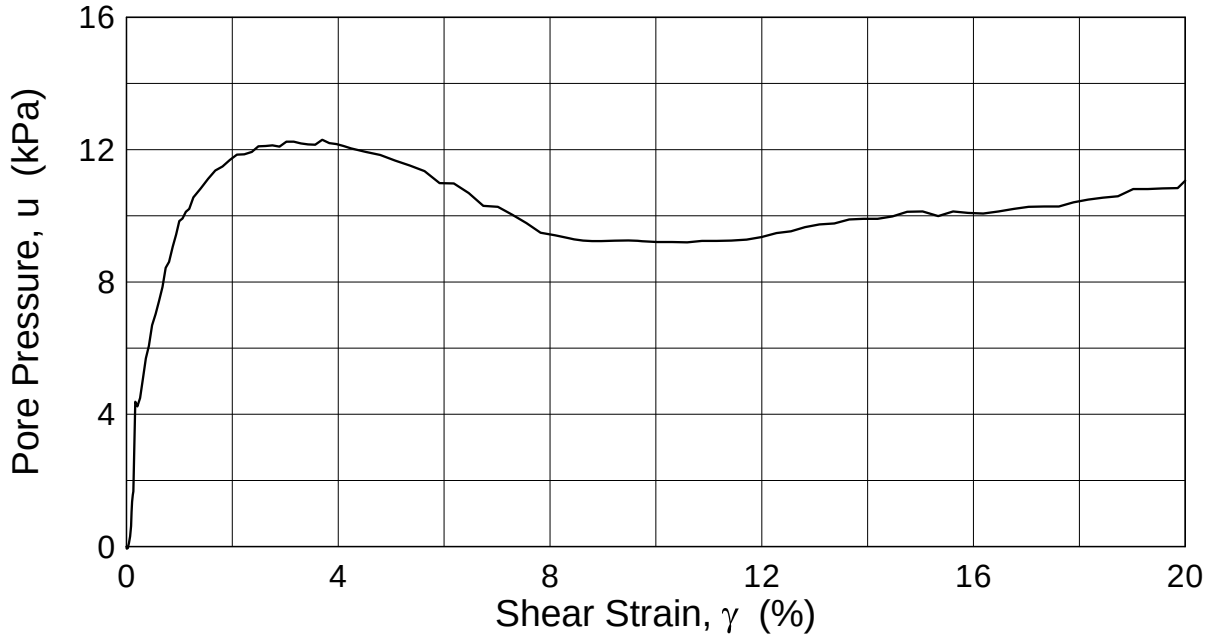


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Document No. 20120738-01-R

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** | % | $\sigma_{ac}'$ = | - | - | **33.9** | |
| Test: **2** | $\gamma_i$ = | **19.61** | kN/m³ | $\tau_c'$ = | - | - | **-** | |

Figure No. B6.3

Drawn by JLa/

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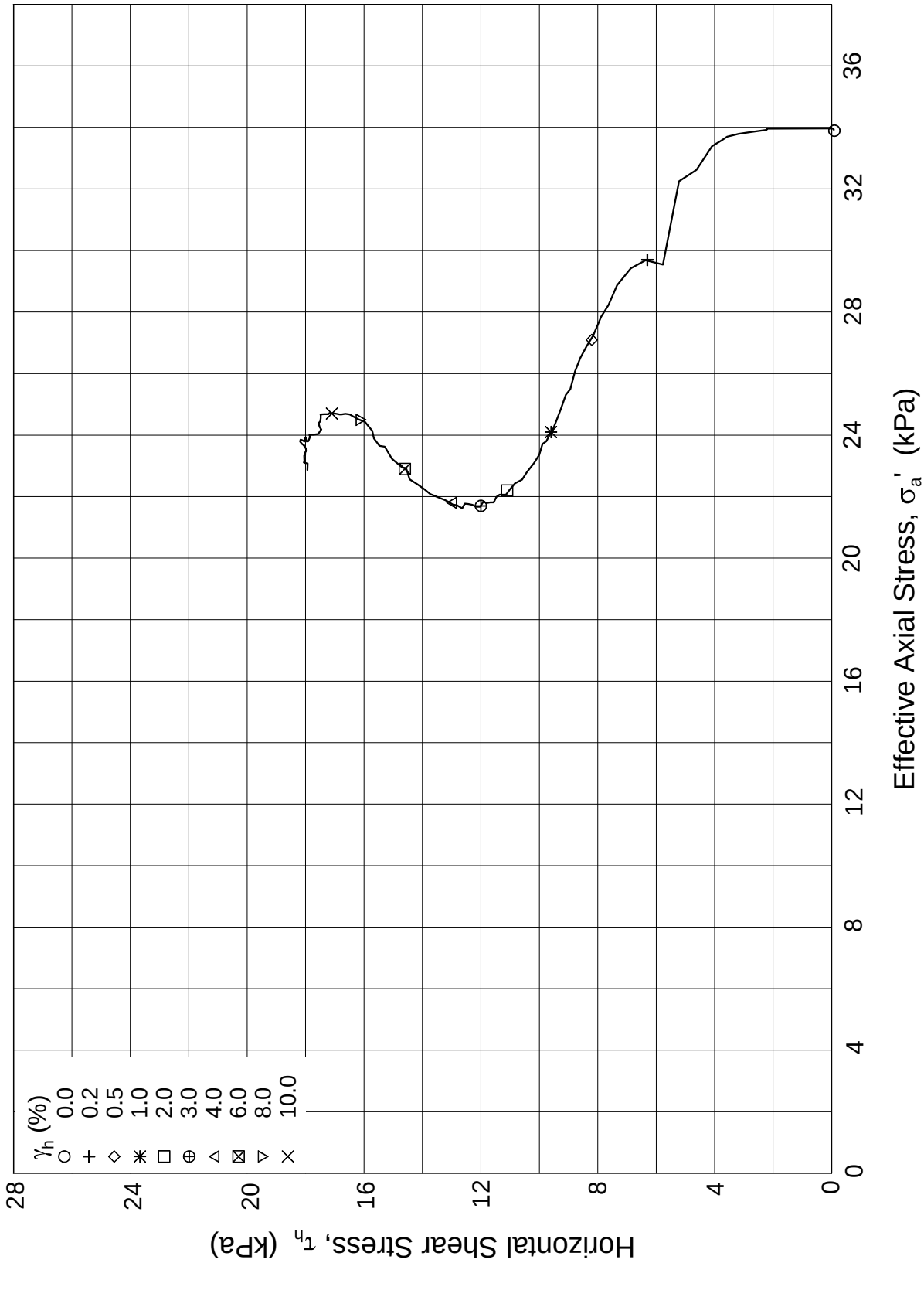


Date/Rev.: 2009-08-07/1

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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** | % | $\sigma_{ac}'$ = | - | - | **33.9** |
| Test: **2** | $\gamma_i$ = | **19.61** | kN/m³ | $\tau_c'$ = | - | - | **-** |

Figure No.: B6.4

Drawn by: JLa/

NGI

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# 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 $\rho \cdot g$. 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 ($m/s^2$)
$\rho_s$ 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, $\rho_s$, is measured by means of a density bottle. Unit weight of solid particles, $\gamma_s$, 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 $\sigma'_{max}$ and then unloaded to the specified axial stress before shearing. The reason for loading to $\sigma'_{max}$ before unloading to $\sigma'_{min}$ 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 ($\Delta e$), 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

## Contents

**B8.1 References 2**

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Geotechnical testing - Laboratory methods - Fall cone liquid limit

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Geotechnical testing, Laboratory methods. Plastic limit.

Norges Byggstandardiseringsråd (NBR). (1990) NS 8005
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Norges Byggstandardiseringsråd (NBR). (1982) NS 8012
Geotechnical testing, Laboratory methods. Density of solid particles.

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Geotechnical testing - Laboratory methods – Water content

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Geotechnical testing, Laboratory methods. Determination of undrained shear strength by fall-cone testing.

Norges Byggstandardiseringsråd (NBR). (1993) NS 8018
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Oedometer testing at the Norwegian Geotechnical Institute. Consolidation of soils: testing and evaluation: a symposium.
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# Part C - Field Operations

## Contents

Part C1 Coordinates (DOF Subsea)
Part C2 Sampling (HSE)
Part C3 Cone Penetration Testing (GeoEngineering)
Part C4 Field Laboratory (NGI)

# Part C1 - Coordinates (DOF Subsea)

## Contents

**C1.1 Summary 2**

## Table

C1-1 Sample locations ROV sampler
C1-2 Sample locations CPTU
C1-3 Sample locations vibro/gravity core

## 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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## 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) |

## Figures

Fig. 1: Chart of test locations for CPT work (Coordinates in UTM32, CM9°E, WGS84) ..... 4
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Fig. 3: Load winch provided by DOF Subsea ..... 6
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

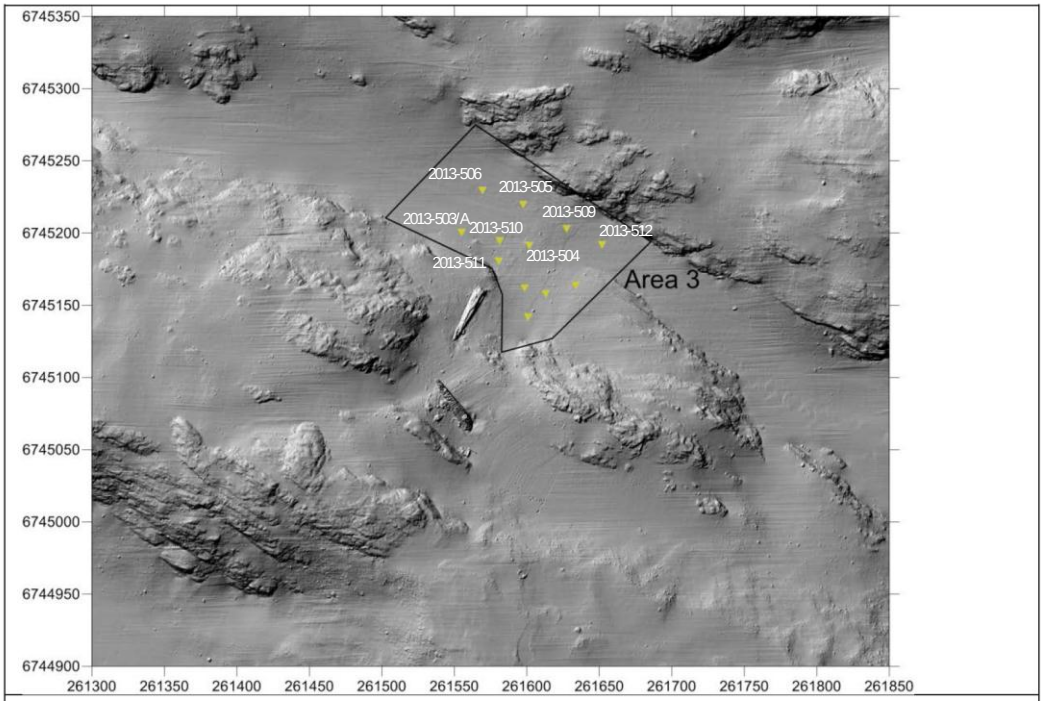


Fig. 1: Chart of test locations for CPT work (Coordinates in UTM32, CM9°E, WGS84)

## 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:<br>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

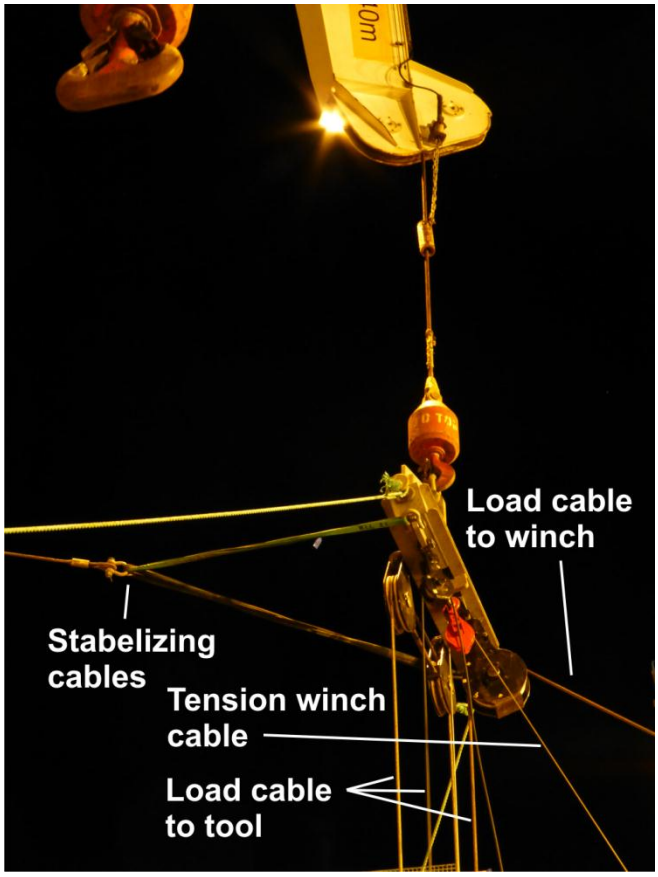


**Fig. 2: Rigging of CPT tool on crane.**

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.

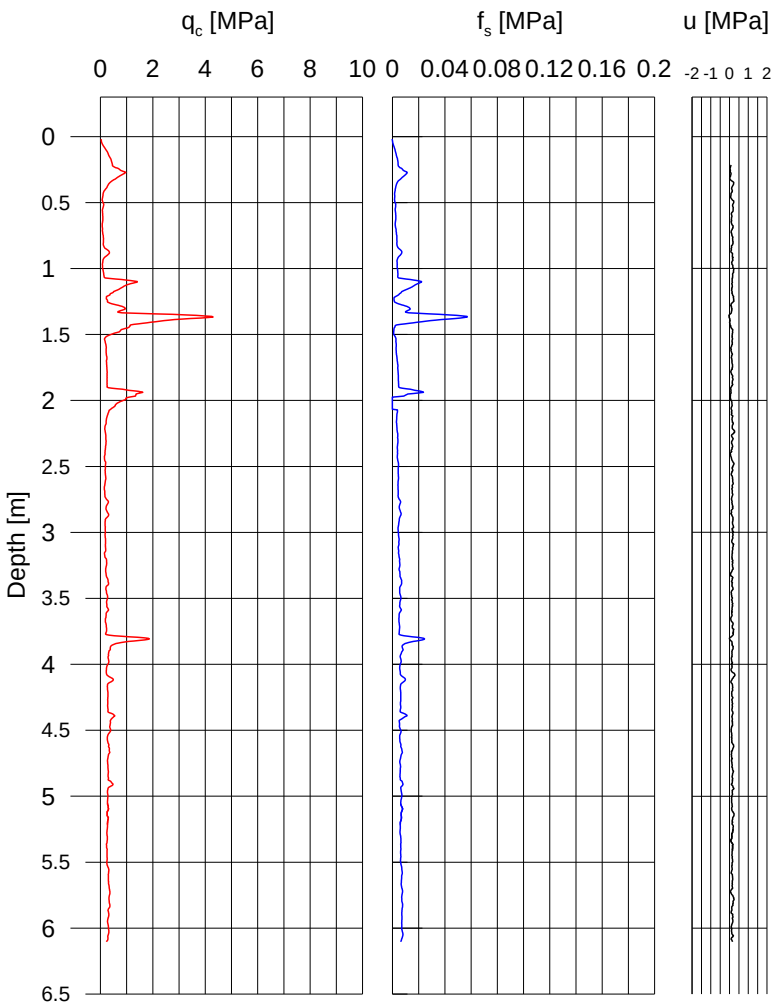


**Fig. 4: Data example of Site 2013-506.**

# 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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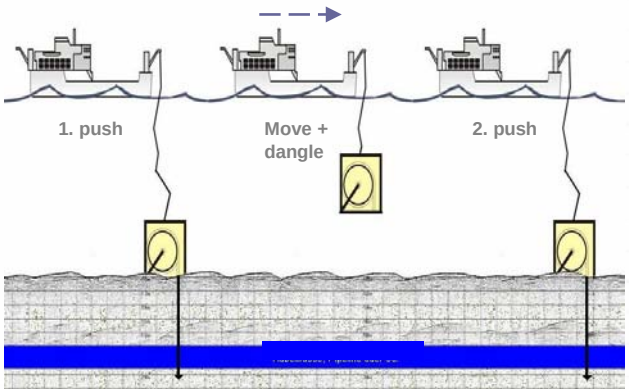
***Fields of Application***

- ***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<br>250Hz sampling rate |
| Processing: | Averaging of 10 values |
| Electrical Cutout: protection | Overvoltage and reverse-polarity |
| 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

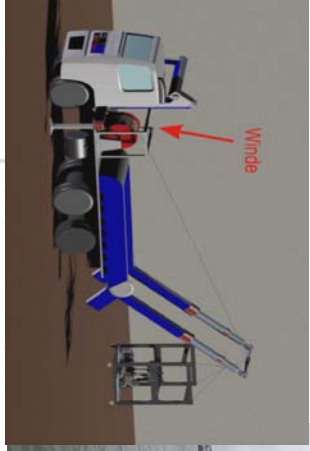
- o 8.000kg hydraulic push force
- o infinitely variable hydraulic pressure 0 – 200bar
- o pressure compensated hydraulic system
- o Powerful and fast MOOG servo-valve
- o dynamic push speed adaptation
- o Advanced modes: VIBRO, dissipation, remolding – plate loading testing
- o hydraulic leveling (optional)

### 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**

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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)<br>AST AE 703 (analog/digital converter)<br>LabView via USB (data aquisition unit/logger) |
| **HBM Certificate Number** | 1472828A – FL1194 |

| | **resolution [kN/digit]** | **zero offset [kN]** | **maximum Inaccuracy*<br>[% of maximum load]** |
|---|---|---|---|
| **Tip Resistance** | 0.00000842 | -0.77307 | + 0.36<br>- 0.25 |
| **Tip + Sleeve** | 0.00000919 | 1.3196 | + 0.56<br>- 0.3 |
| | **resolution [kPa/digit]** | **zero offset [kPa]** | **maximum Inaccuracy*<br>[% of maximum load]** |
| **Pore Pressure** | 0.000216 | 31.845 | + 0.5<br>- 0.5 |
| **Acceleration** | **resolution [m/s²/digit]** | **zero offset [m/s²]** | **nonlinearity [%]<br>interaxis alignment error [°]<br>cross axis sensitivity [%]** |
| x-axis | 0.070323 | -35.407 | ± 0.2<br>± 0.1<br>± 1 |
| y-axis | 0.068601 | -34.301 | ± 0.2<br>± 0.1<br>± 1 |
| z-axis | 0.068842 | -35.006 | ± 0.2<br>± 0.1<br>± 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

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**C4.2 Classification tests 3**
C4.2.1 Water content 3
C4.2.2 Total unit weight 3
C4.2.3 Index undrained shear strength and sensitivity 3
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C4.3.1 Water content 4
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 |
| | | | | | 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 |
| NOTE: Sample 2013-406 was not shipped to NGI Oslo due to high mercury content | | | | | 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 | # |

# Kontroll- og referanseside/
# *Review and reference page*

| **Dokumentinformasjon/*Document information*** | | |
|---|---|---|
| **Dokumenttittel/*Document title***<br>U-864 2013 Soil survey<br>Geotechnical Report | | **Dokument nr./*Document No.***<br>20120738-01-R |
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# Technical Note

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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.

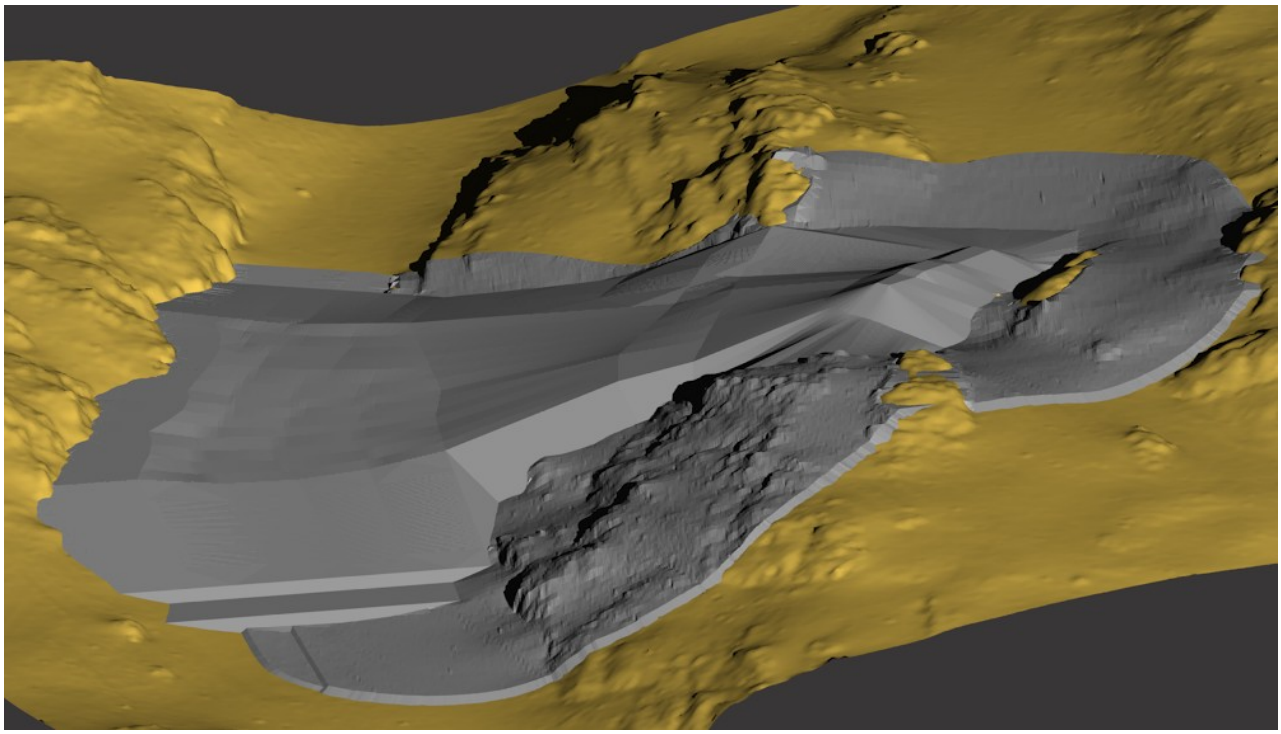

*Figure 2-1 3D view towards south-west of finalised encapsulation and capping.*

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: | $\gamma'_{rock}$ | = 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** |
|---|---|---|---|---|---|
| | | **$\gamma_L$ ULS-O** | **$\gamma_L$ ULS-E** | **$\gamma_L$ PLS-A** | **$\gamma_m$** |
| Static stability, weight of sand and rock reduces stability (acting load) | P | 1.3 | N/A<br>N/A | N/A<br>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<br>N/A | N/A<br>N/A | 1.5 in clay, 1.25 in rock and sand |

$\gamma_L$ = Load coefficient
$\gamma_m$ = 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 $\gamma_{cover}'$ 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.

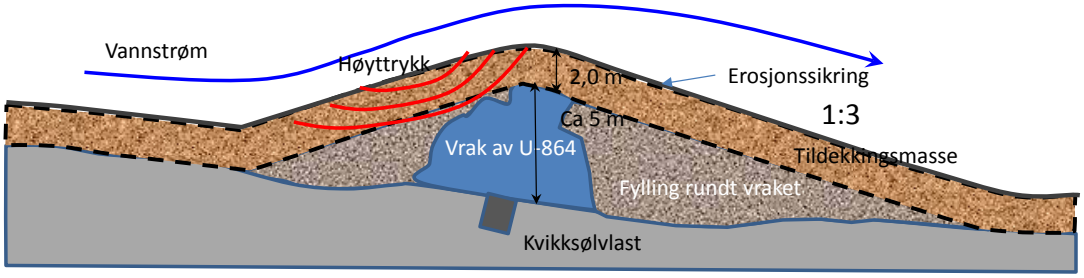


*Figure 4-1 Principle design of the capping layer from Ref /5/.*

# 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.

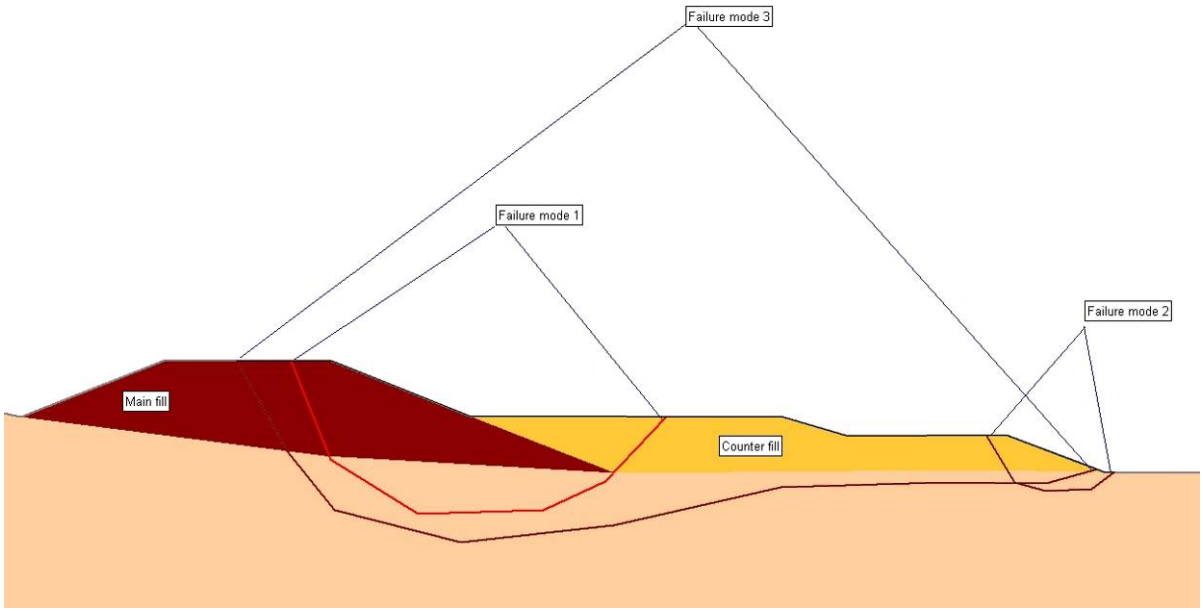


*Figure 5.1-1 Failure modes to be analyzed for determination of counterfill dimensions*

# 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.

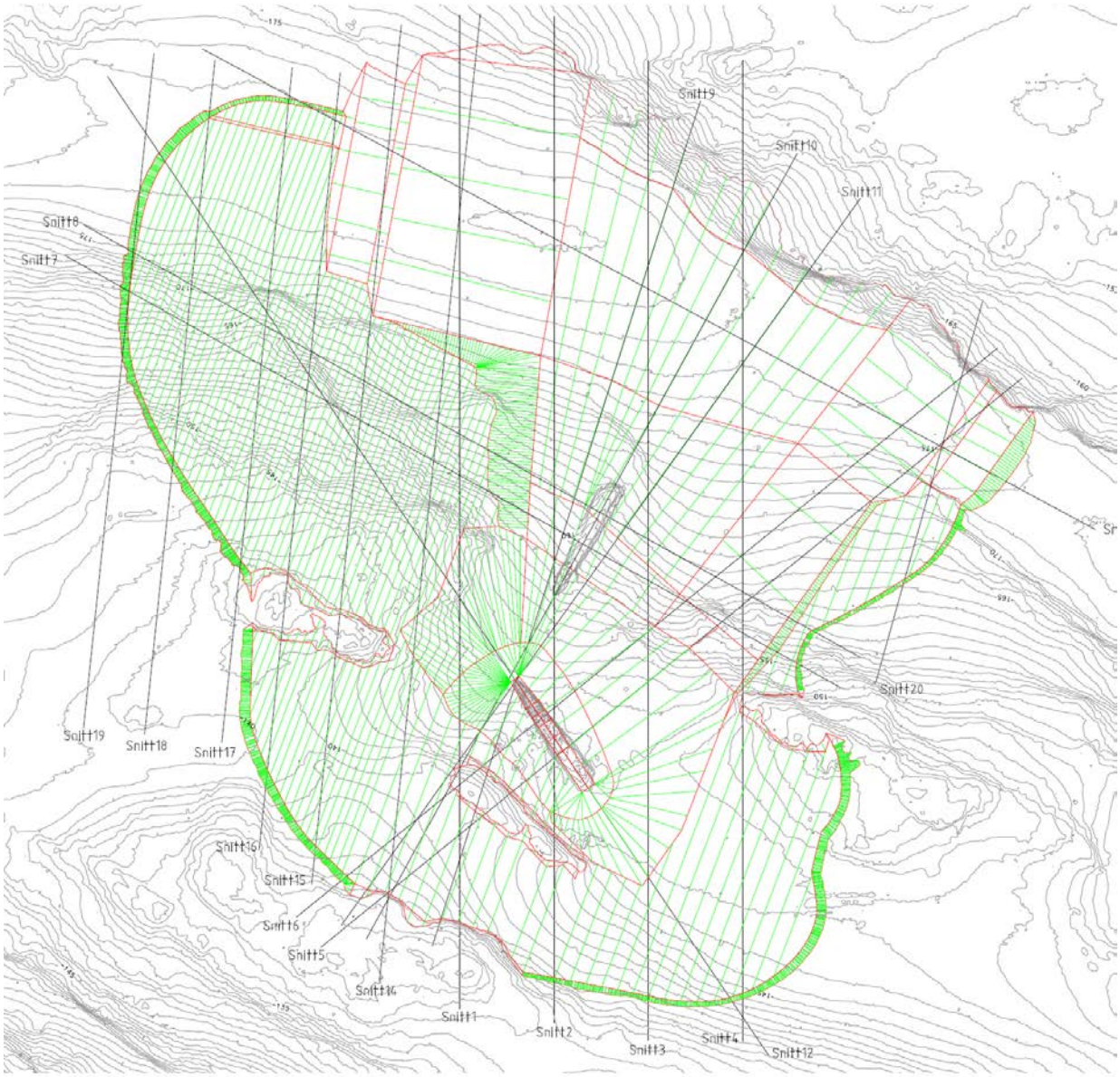


*Figure 6-1 Overview of sections for evaluation produced by the 3D model.*

## 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 $35^o$ 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.

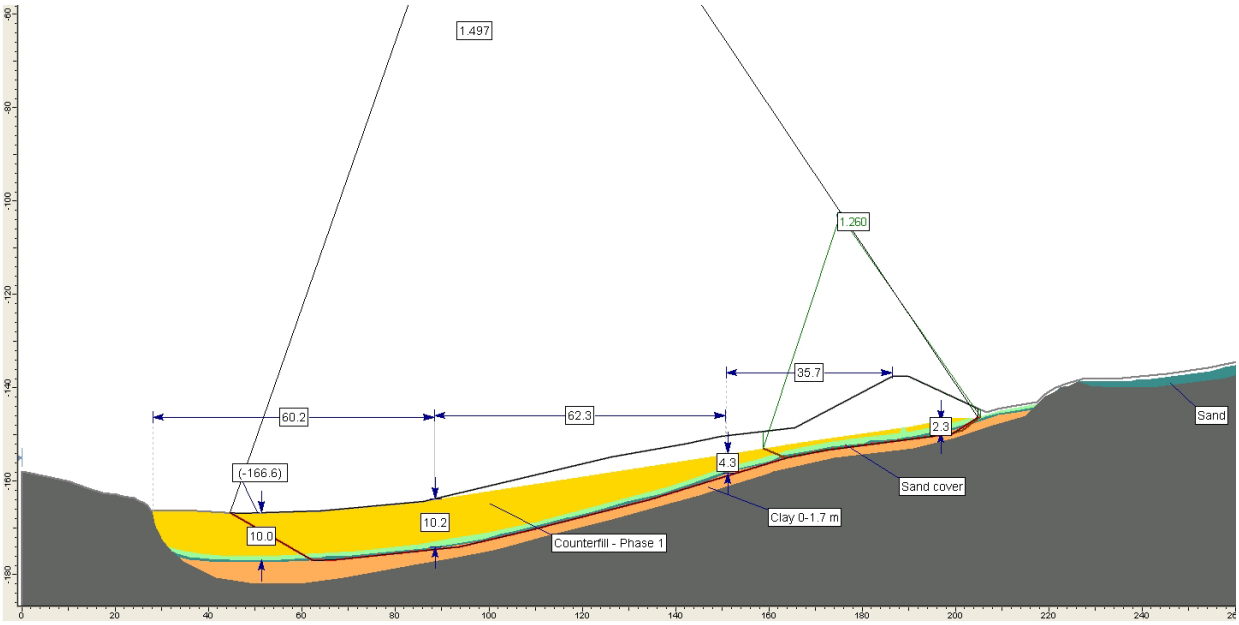


*Figure 6-2 Stability along Section No 11 Phase 1*

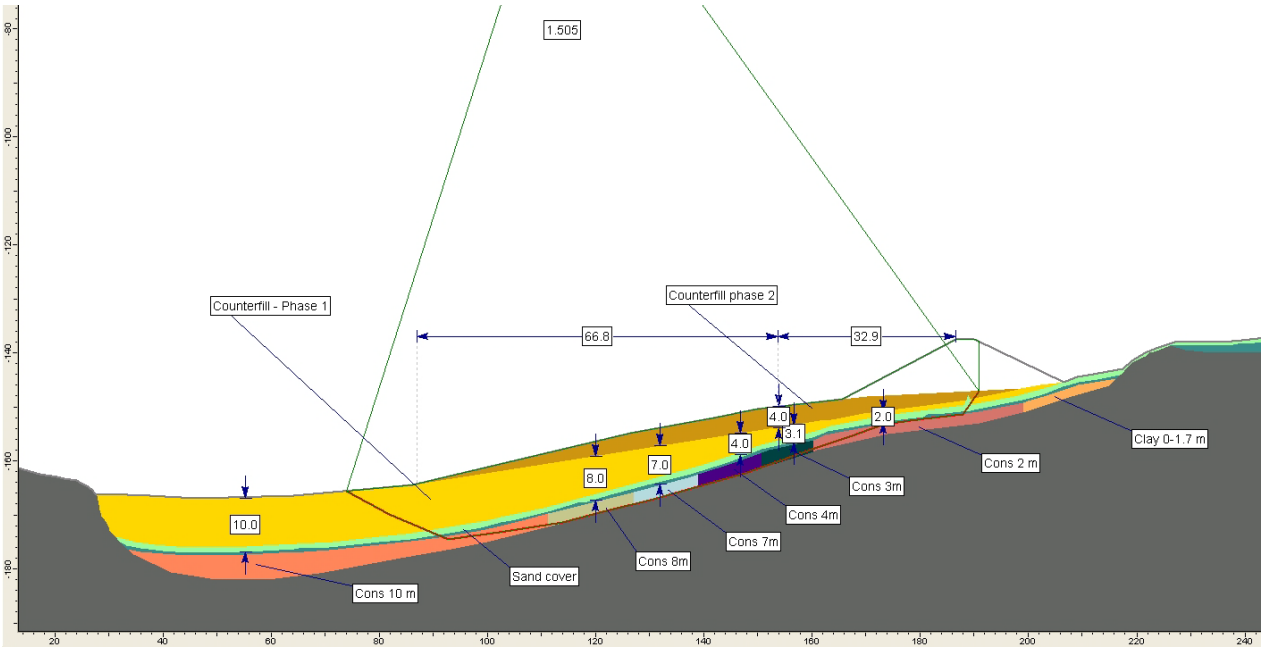


*Figure 6-3 Stability along Section No 11 Phase 2*

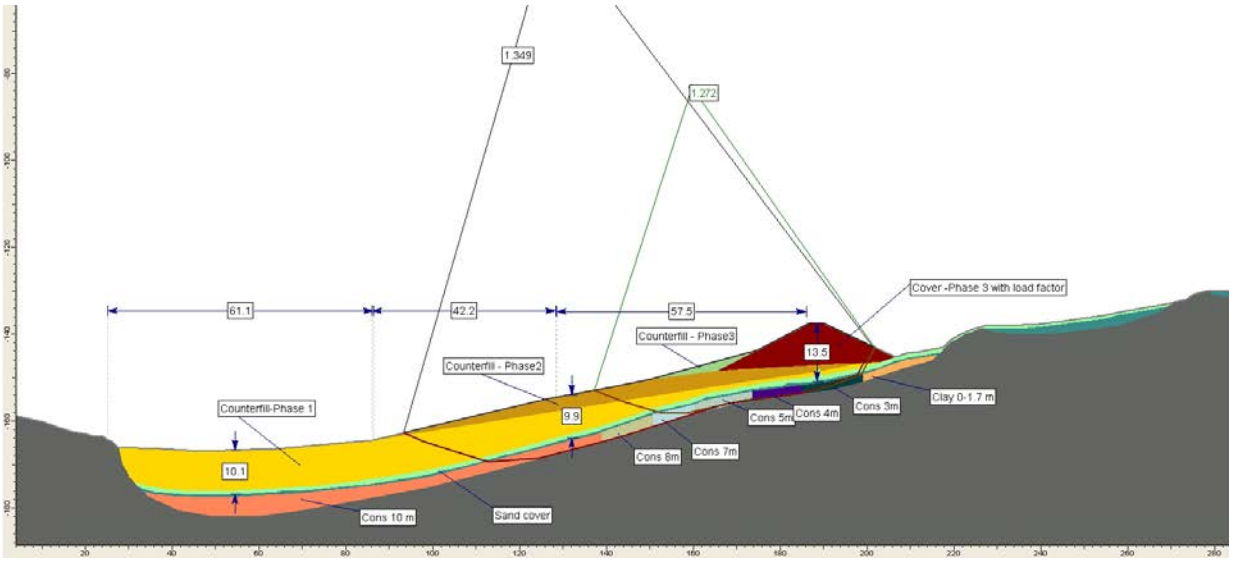


*Figure 6-4 Stability along Section No 11 Phase 3*

## 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/.

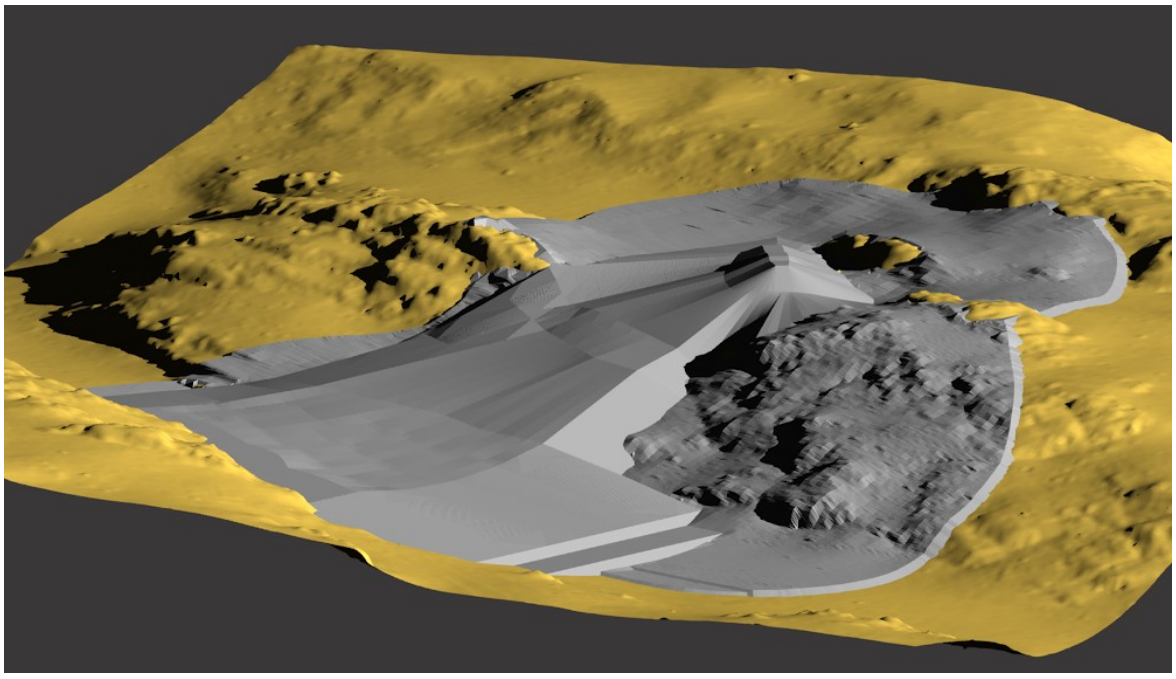

*Figure 6-5 3D view of the finalised encapsulation and seabed capping.*

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## Effect of consolidation on shear strength

## Contents

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**Review and reference page**

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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.

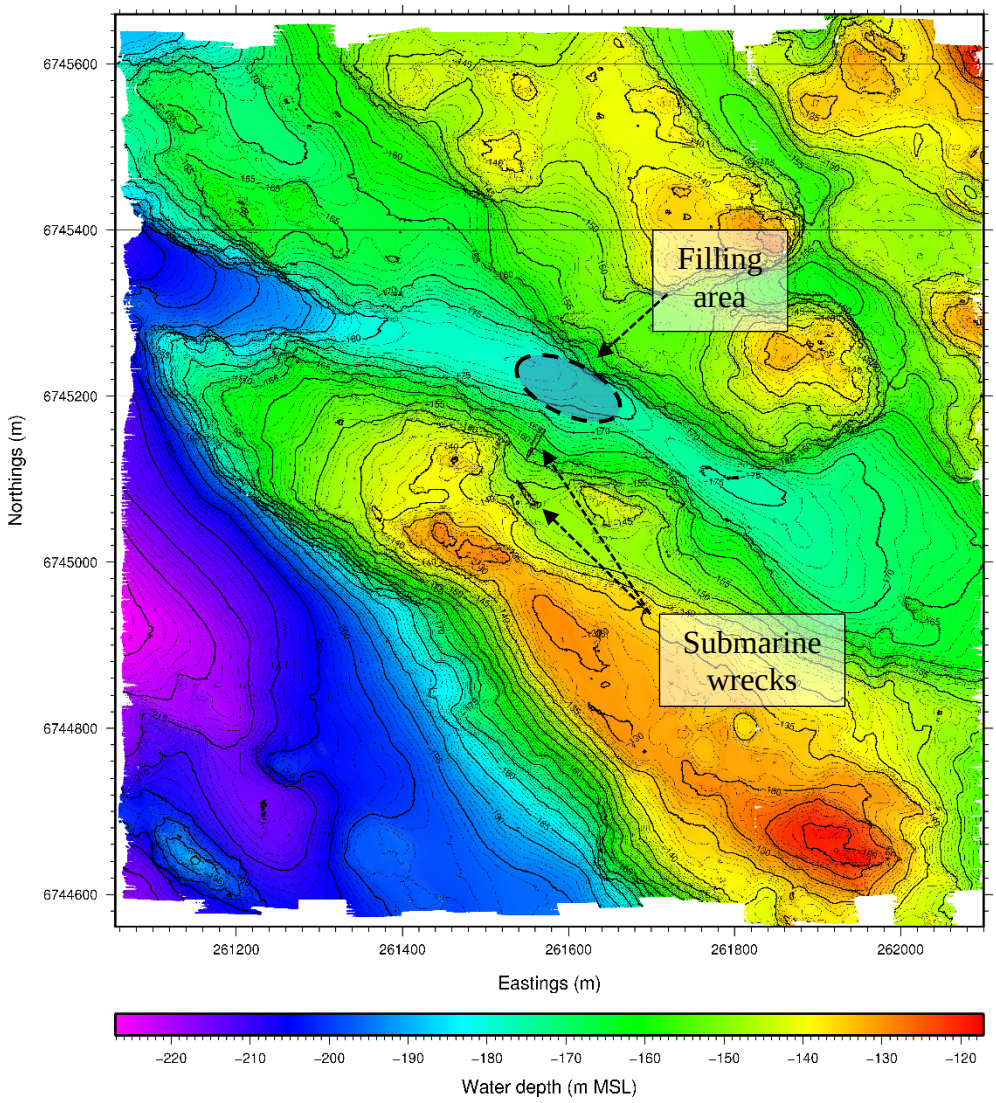


*Figure 1.1 Bathymetry date and wreck locations*

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.

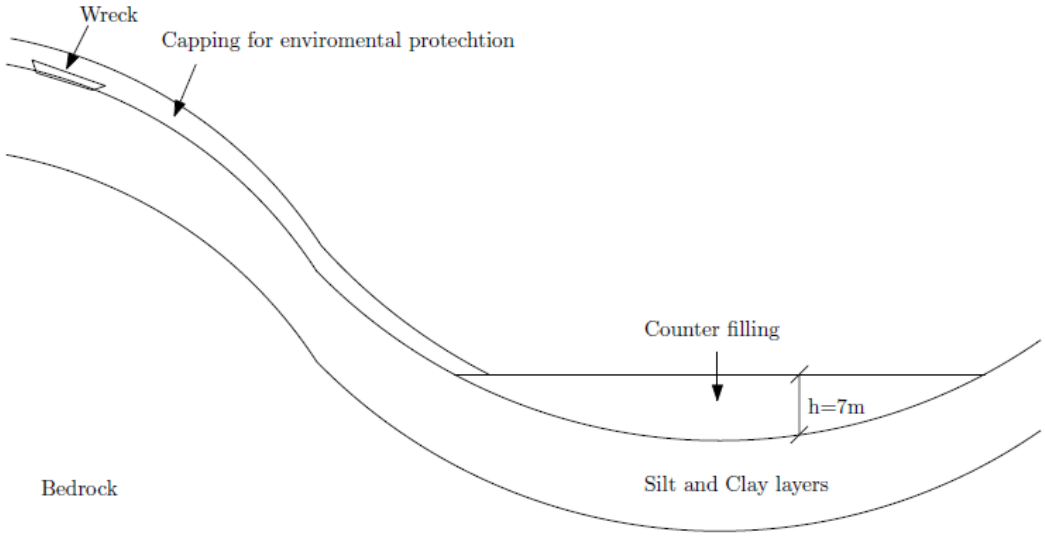


*Figure 1.2 Cross section sketch of slope with capping and counter filling*

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.

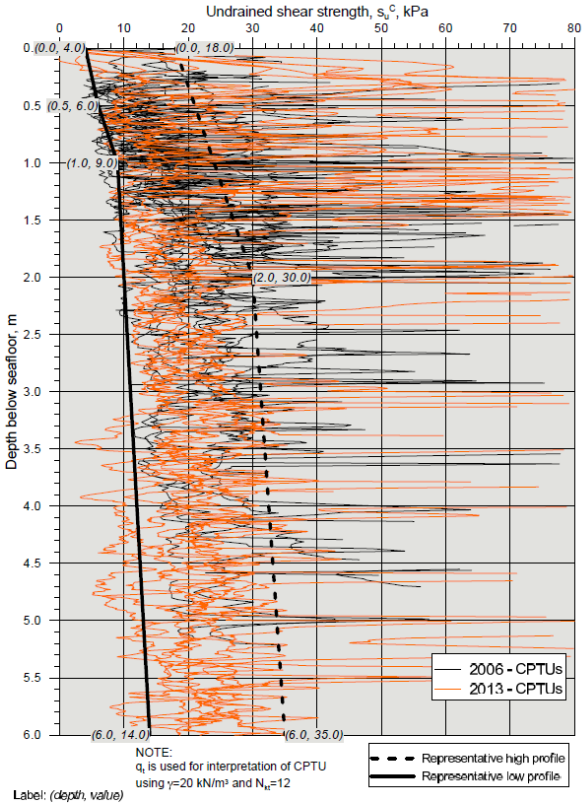


*Figure 2.1 Corrected cone resistance versus depth, from NGI (2013)*

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 $\gamma_w$ 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.

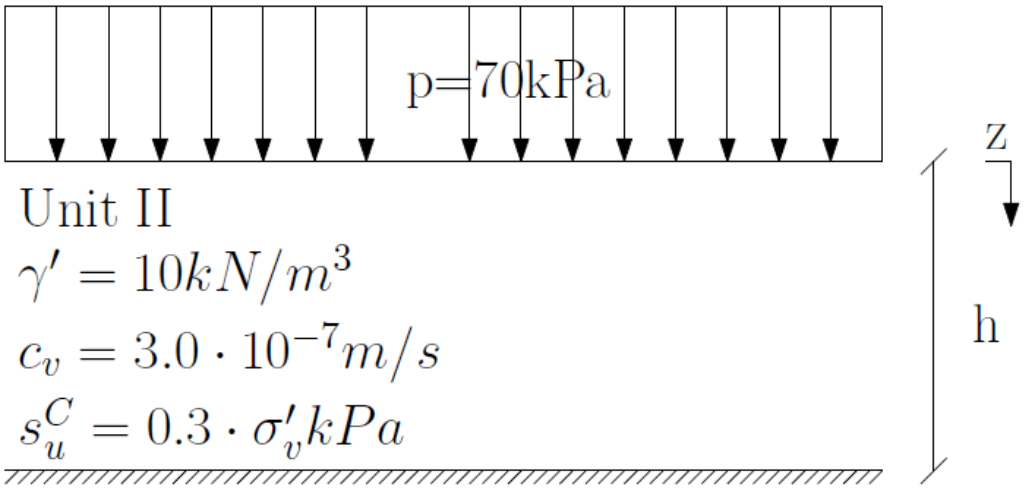


*Figure 3.1 Simplified model*

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):

$$\frac{\Delta u}{p} = \frac{4}{\pi} \sum_{j=1}^{\infty} \frac{(-1)^{j-1}}{2j-1} \cos\left((2j-1)\frac{\pi}{2}\frac{(h-z)}{h}\right) e^{\left(-(2j-1)^2 \cdot \frac{\pi^2}{4} T\right)}$$

*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.

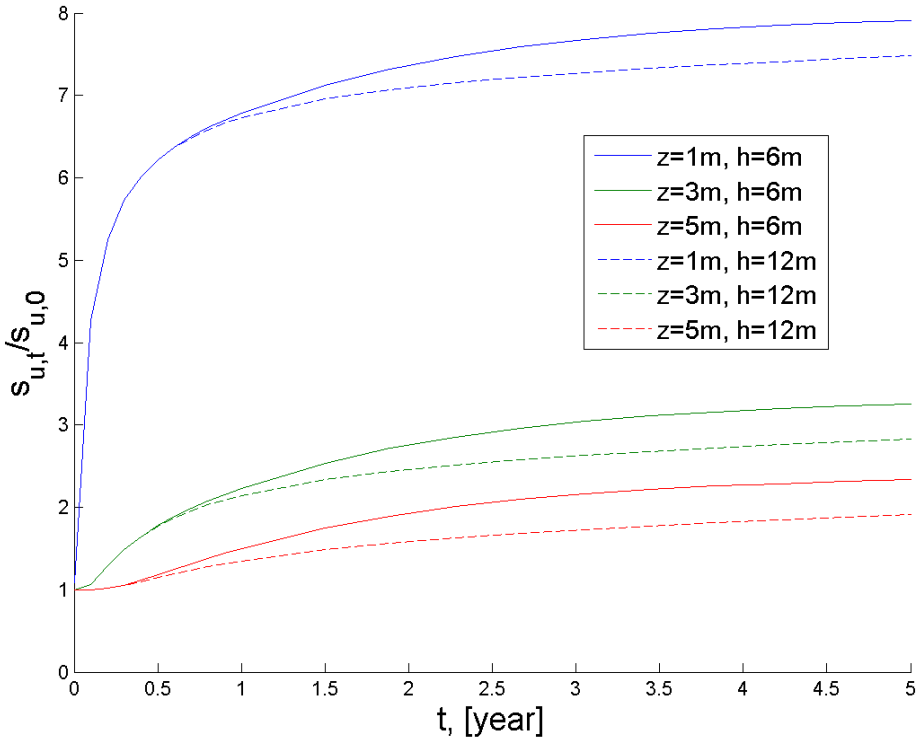


*Figure 3.2 Increase in undrained shear strength increase versus time for a clay layers with different thichness consolidated with a load of p=70kPa*

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.

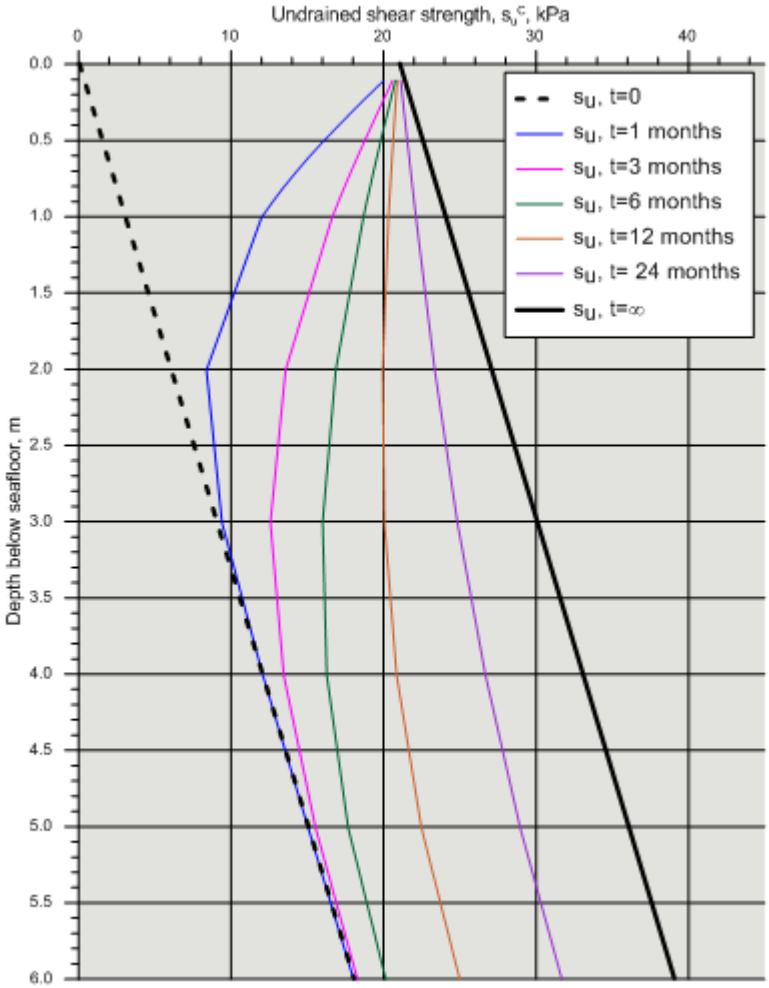


*Figure 3.3 Undrained compression shear strength for a clay layer with a thickness of h=6m as a function of consolidation time, for a consolidation load of p=70kPa.*

## 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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| V0.07.03 | Identification of oil leak and position verification of U-864 | DOF Subsea | 10 |
| V0.07.04 | U-864 2013 Soil servey<br>(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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# Contract 2012/2998 U-864

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# U-864 Phase 3A Survey and Geotechnical Campaign Survey Report

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# 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.

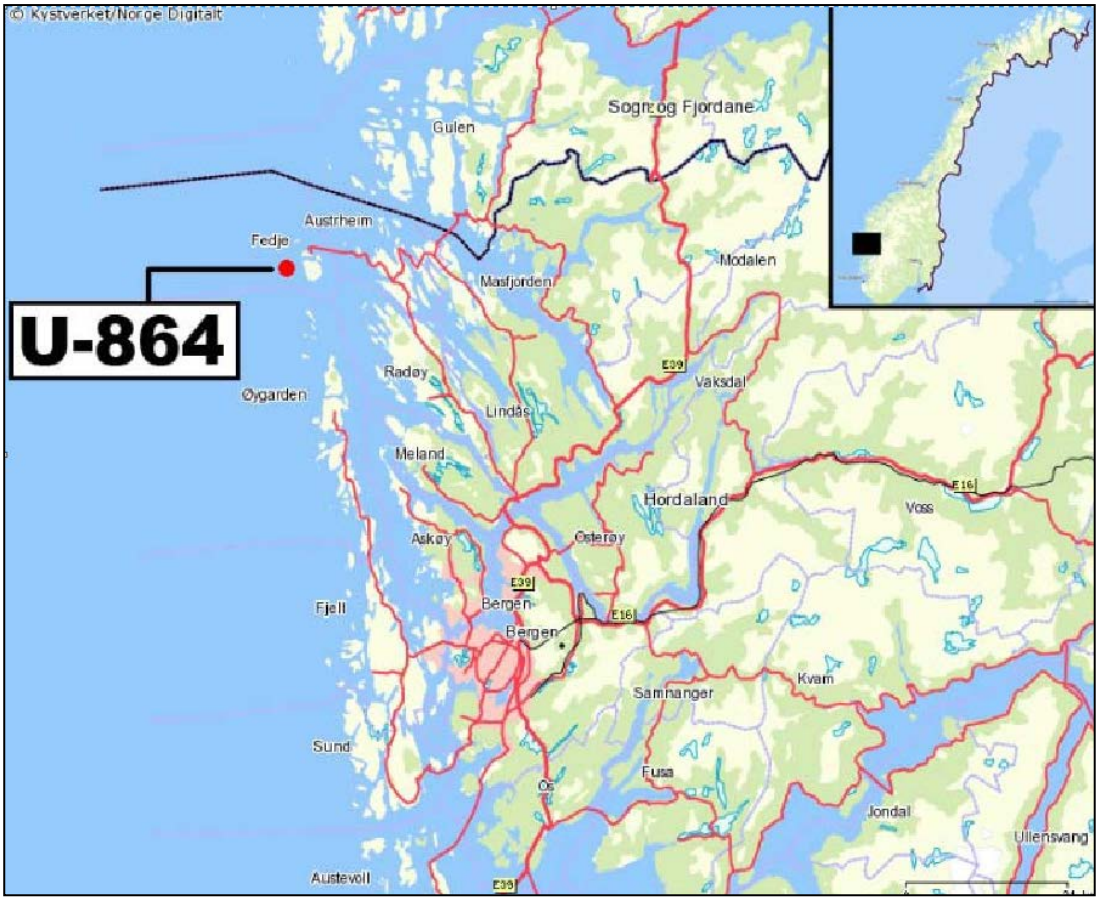



**Figure 1.1 Map of U-864 location**

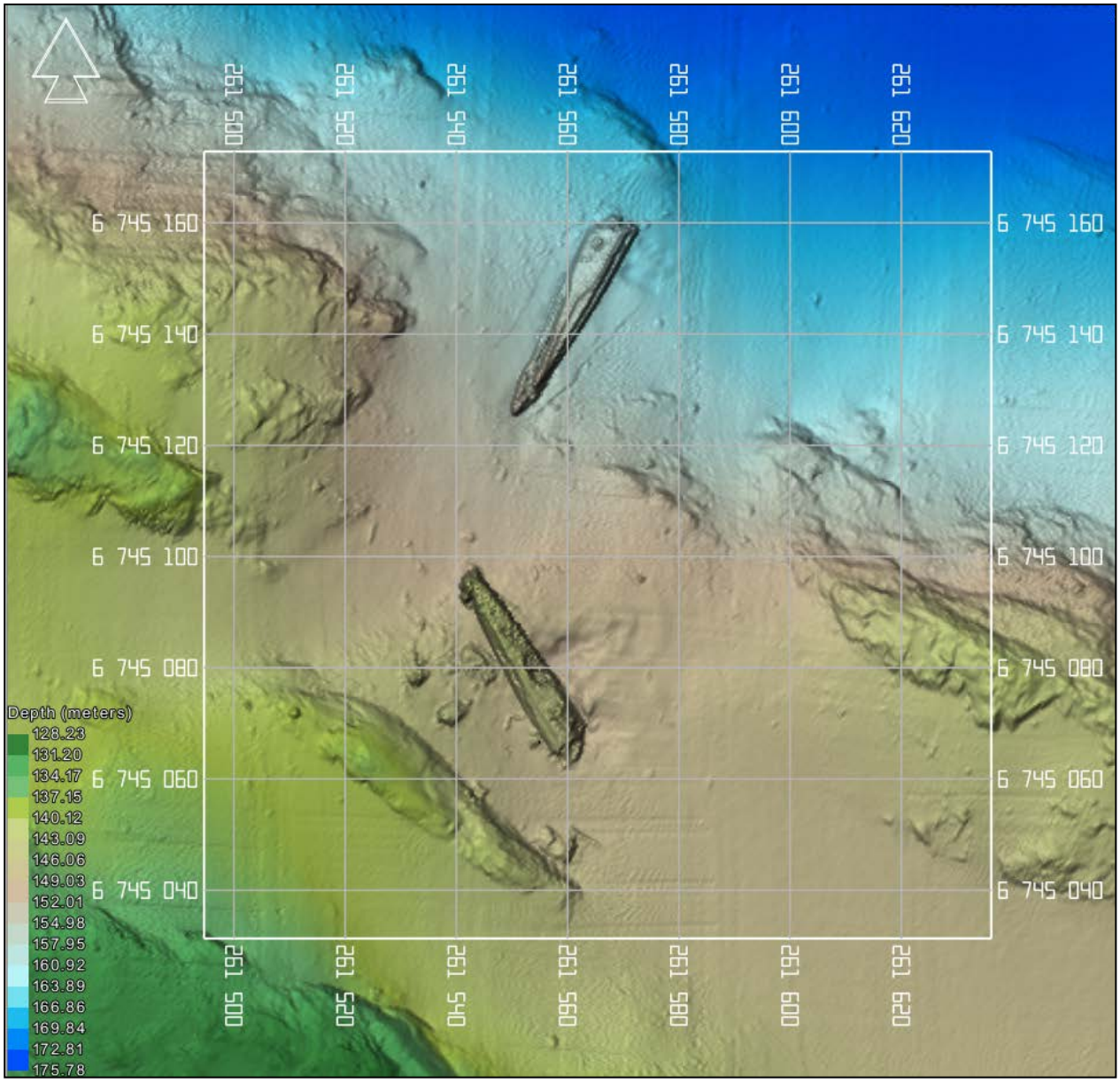



**Figure 1.2 U-864 wreck and orientation on sea bed (From Phase 3A Survey, 2013)**

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.

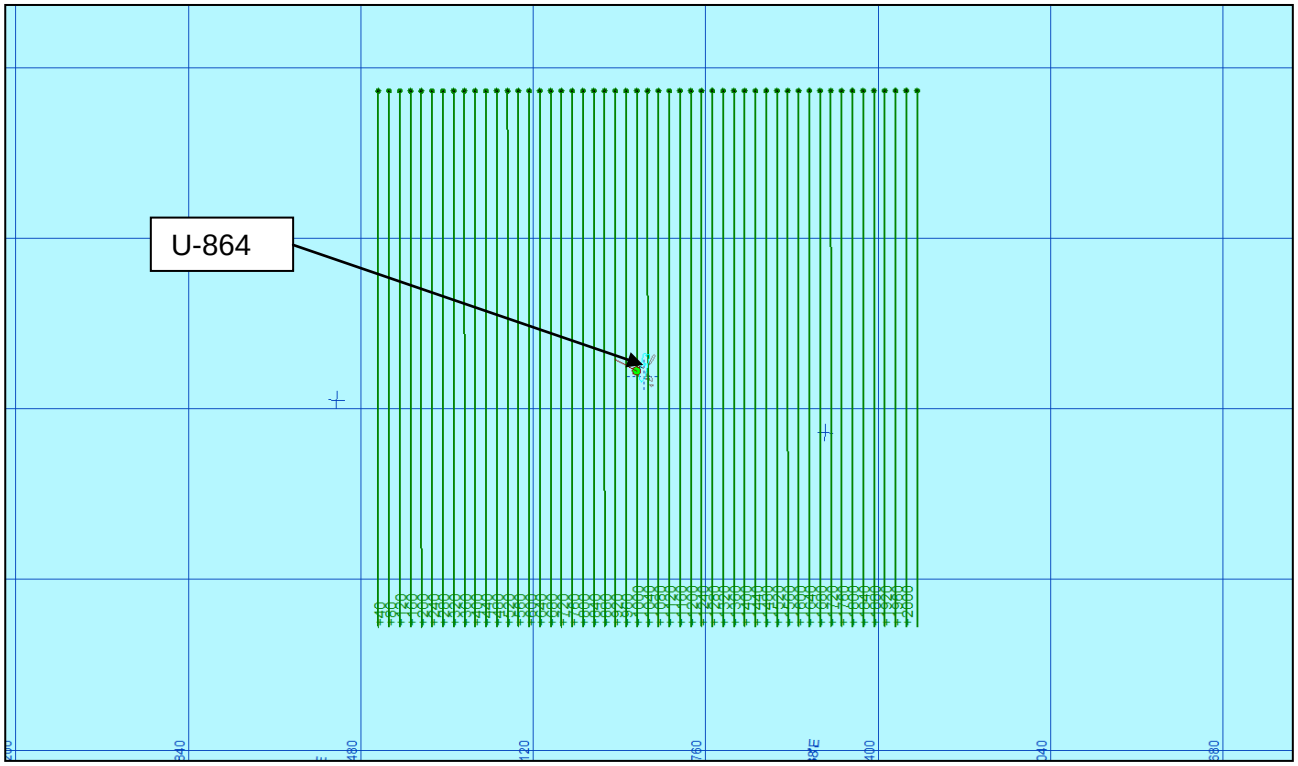



**Figure 2.1 2000m x 2000m line plan used for the MBES survey**

### 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.

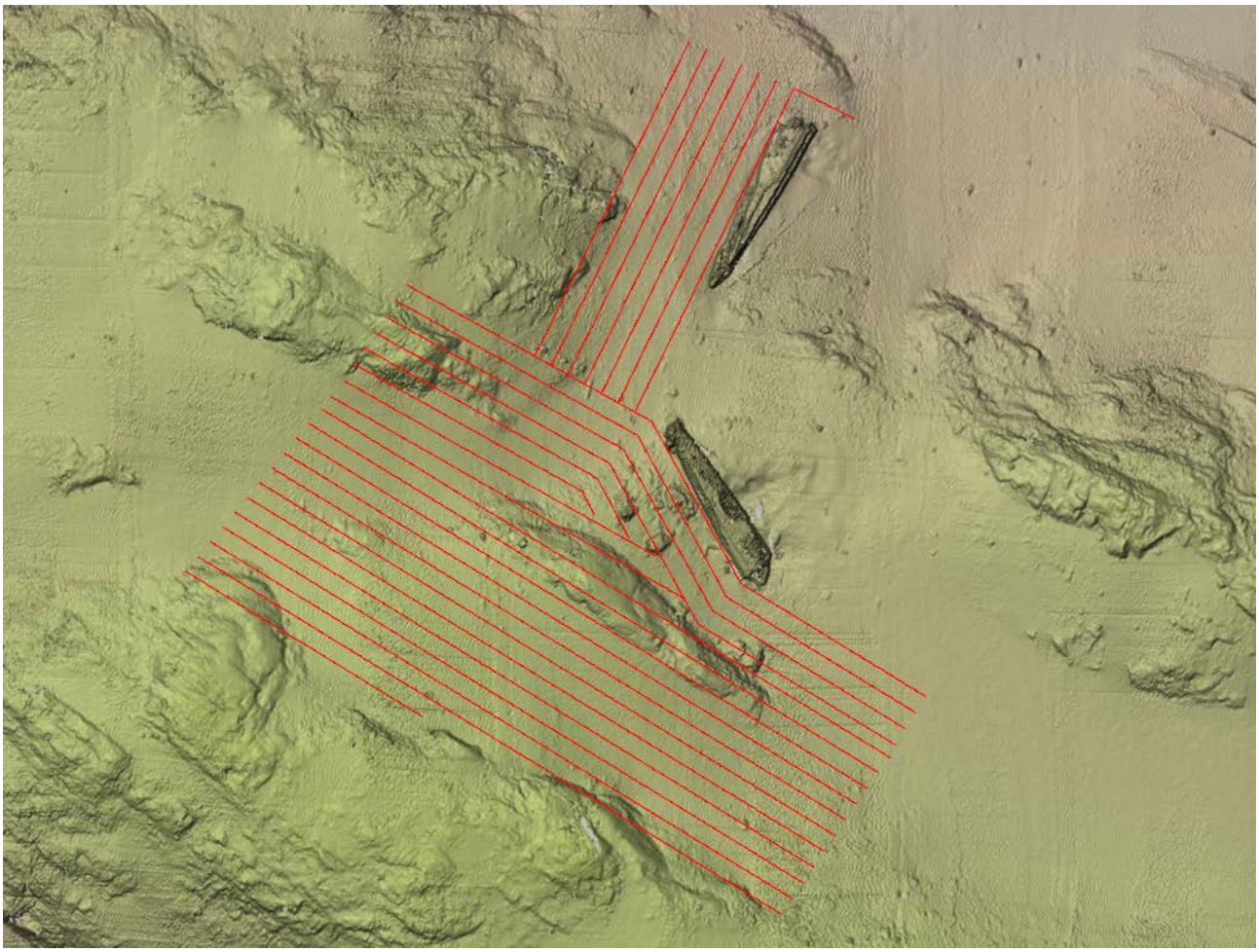


**Figure 2.2 Runlines with DTM**

### 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).

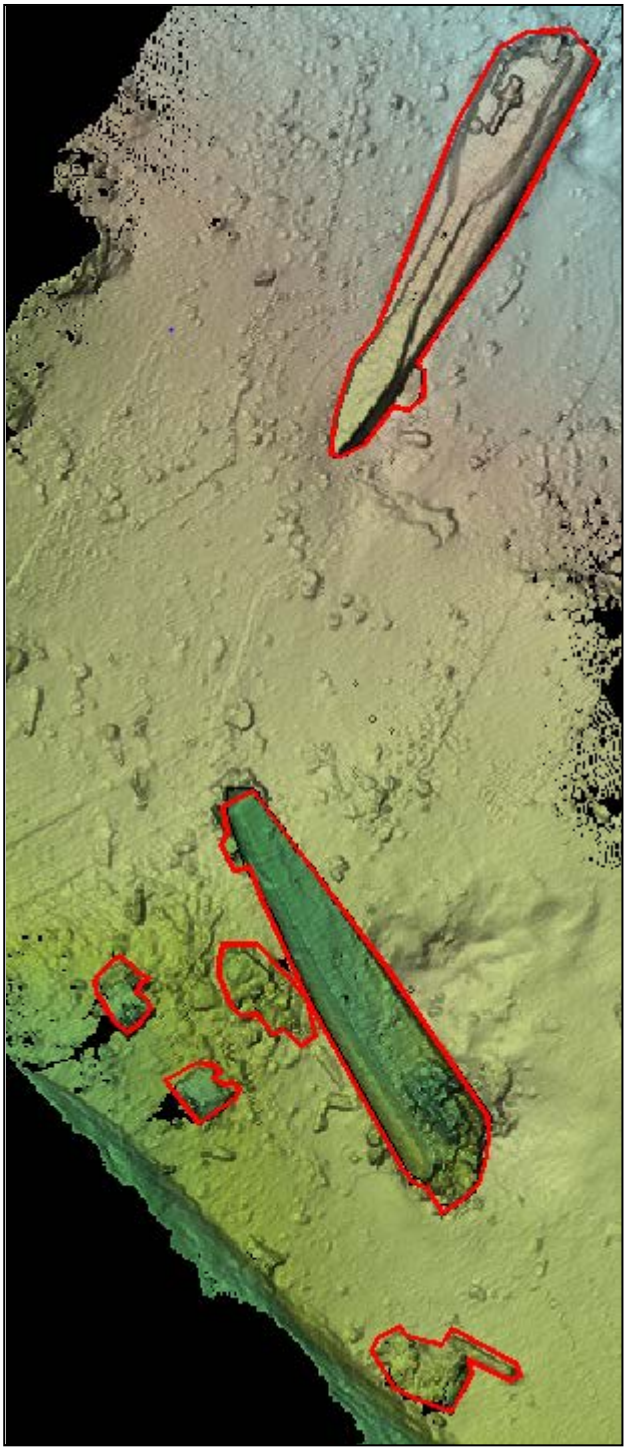


**Figure 2.3 Areas covered in close visual inspection**

### 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.

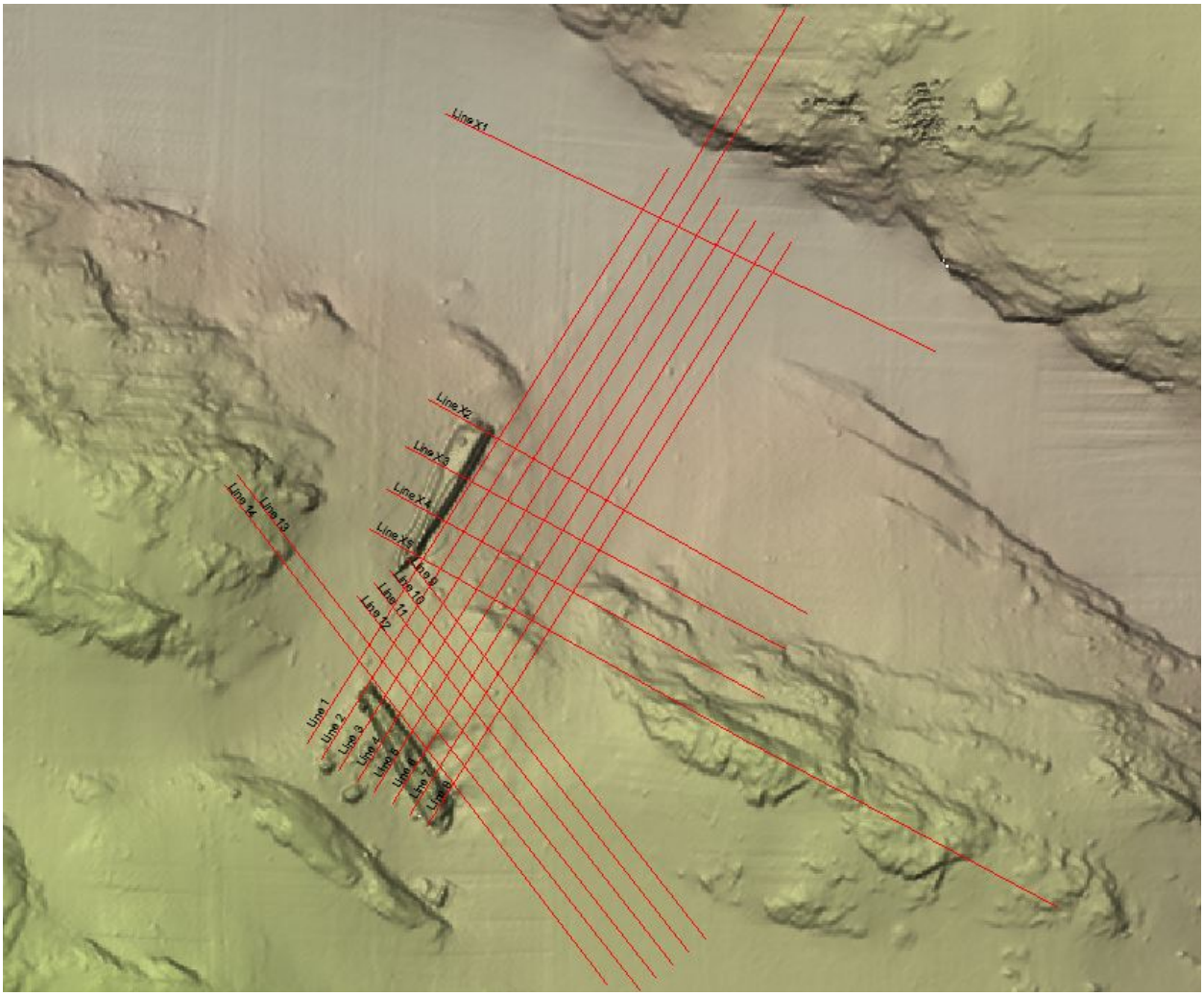



**Figure 2.4 Runlines used for the SBP survey**

### 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.

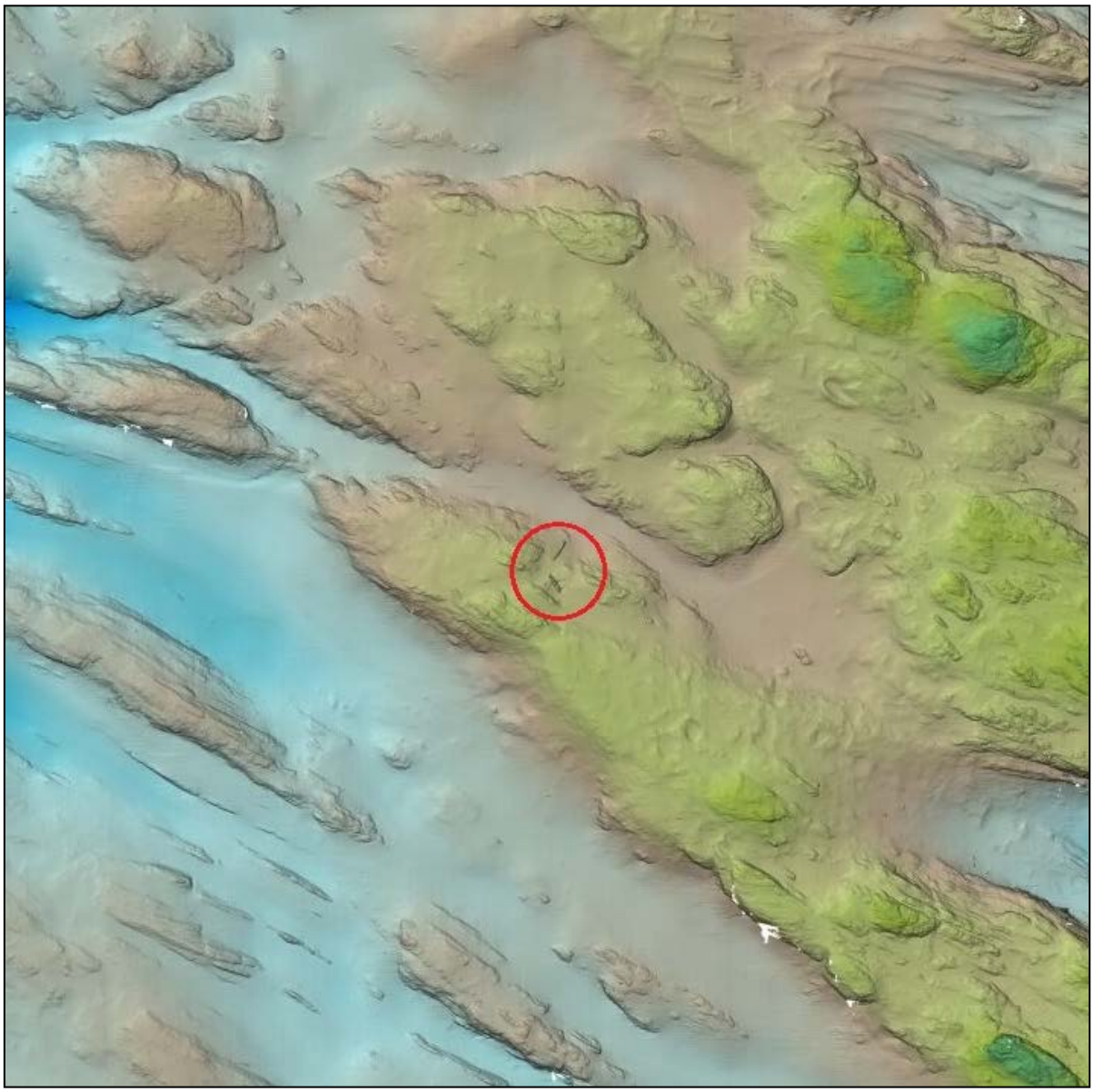


**Figure 3.1 DTM of 2 x 2 km survey data around the U-864 (circled) North up**

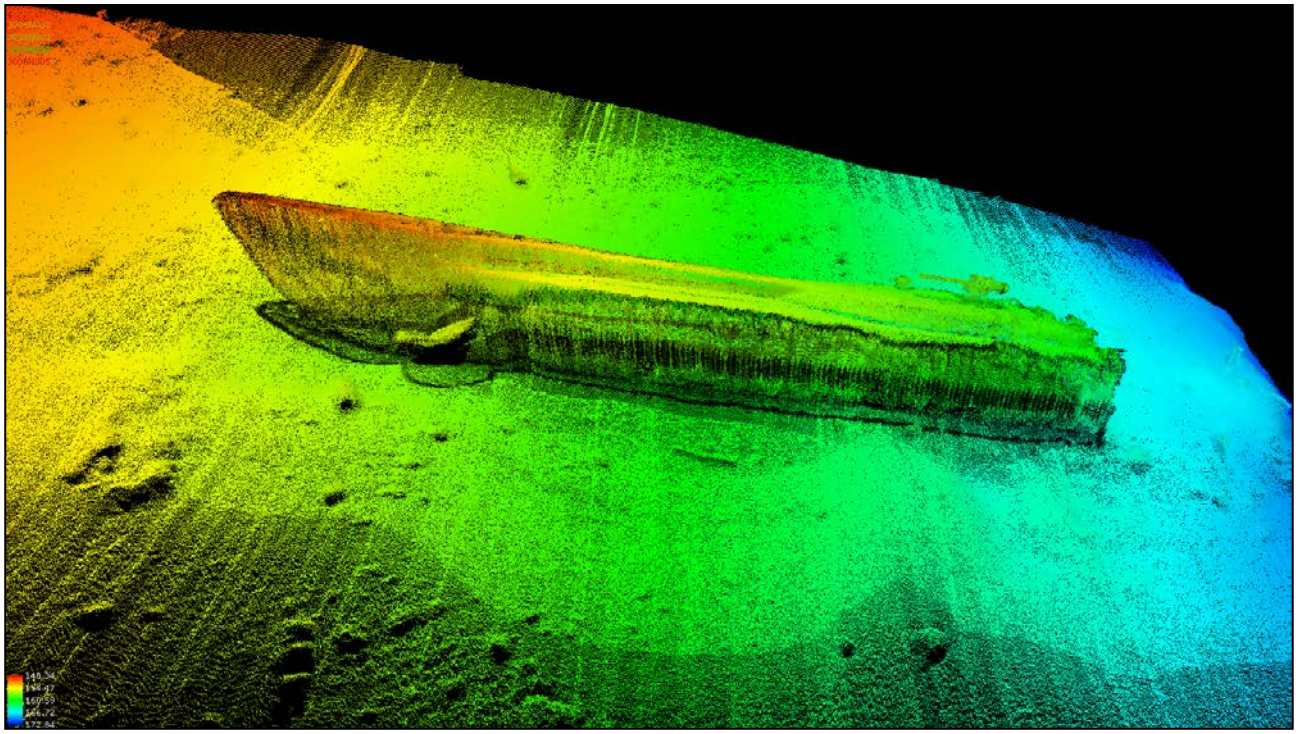


**Figure 3.2** **Example of soundings data from Bow section**

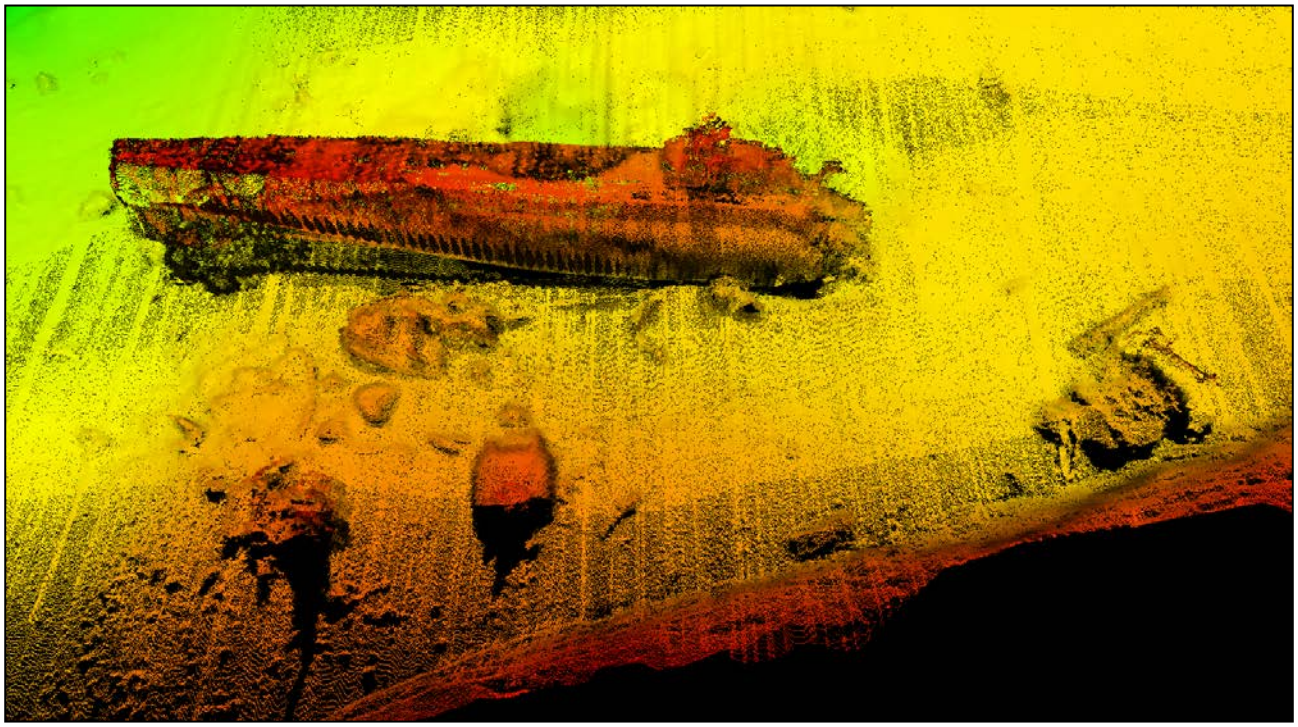


**Figure 3.3** **Example of soundings data from Stern section**

## 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.

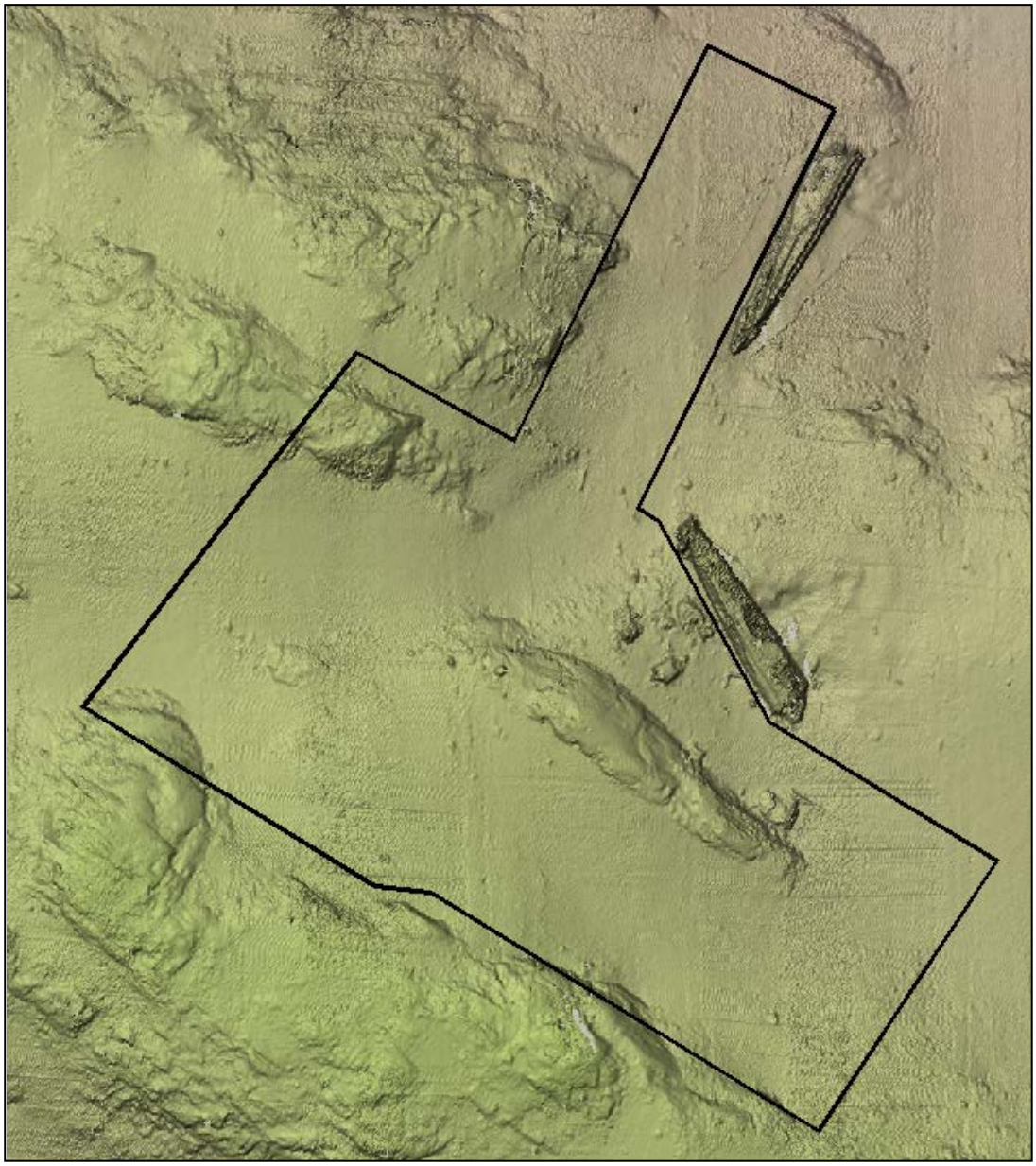


**Figure 3.4 Clear Zone established during High Definition video survey**

## 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

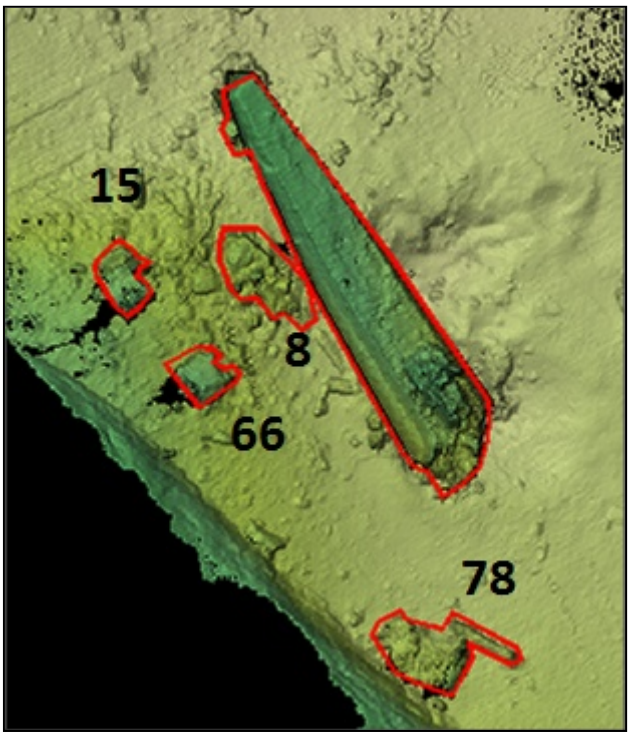



**Figure 3.5 Video Survey targets near the stern section**

### 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).

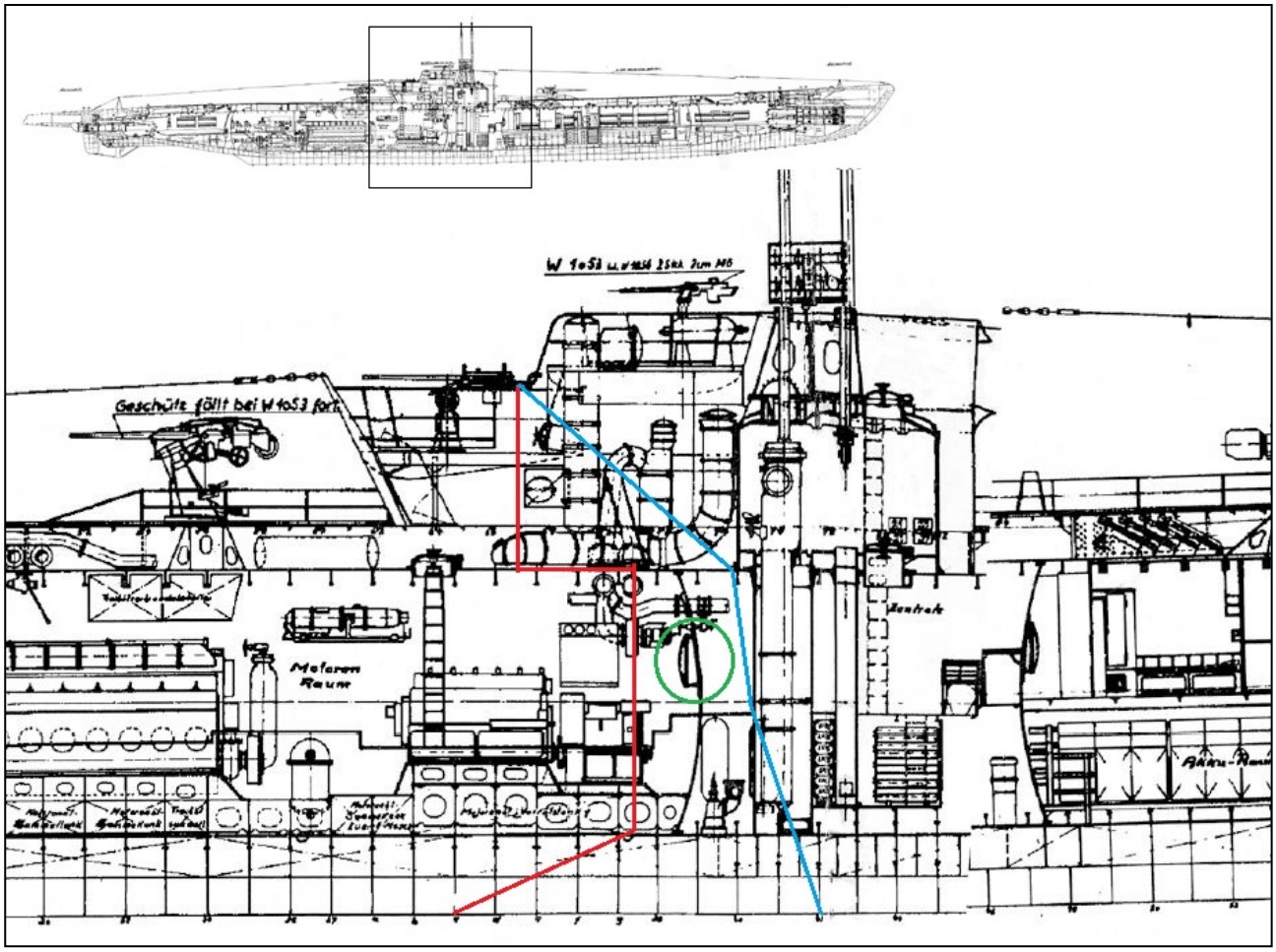



**Figure 3.6** **2006 Estimate of extent of wreckage (red) and revised extent (blue). Identifying hatch circled**




**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.

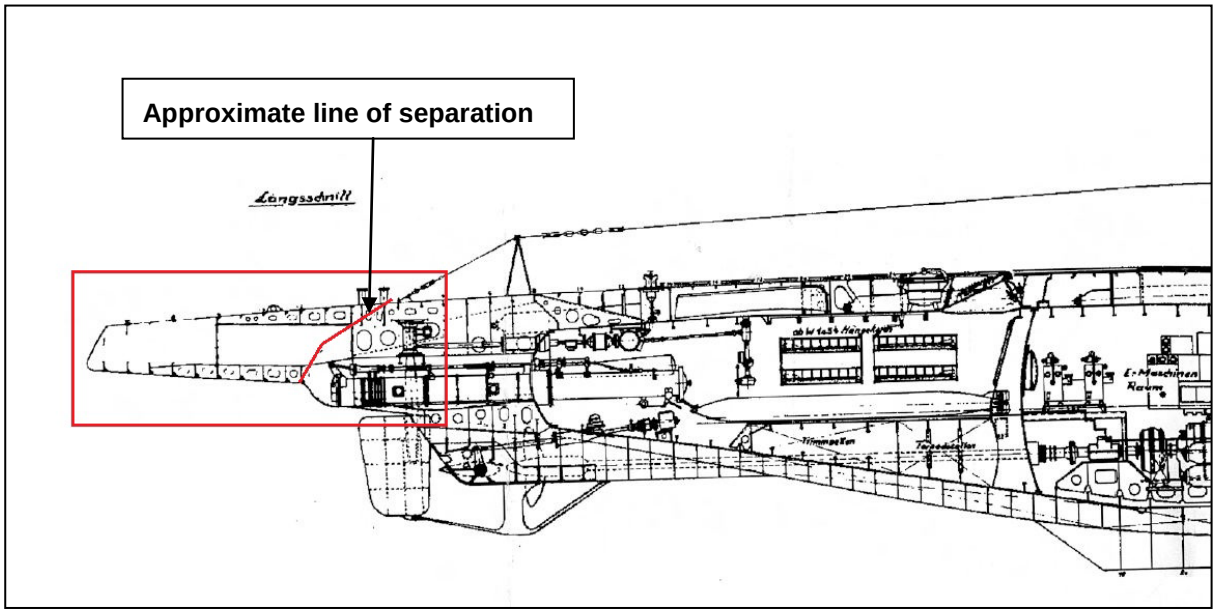



**Figure 3.8 Stern section schematic showing detached area**

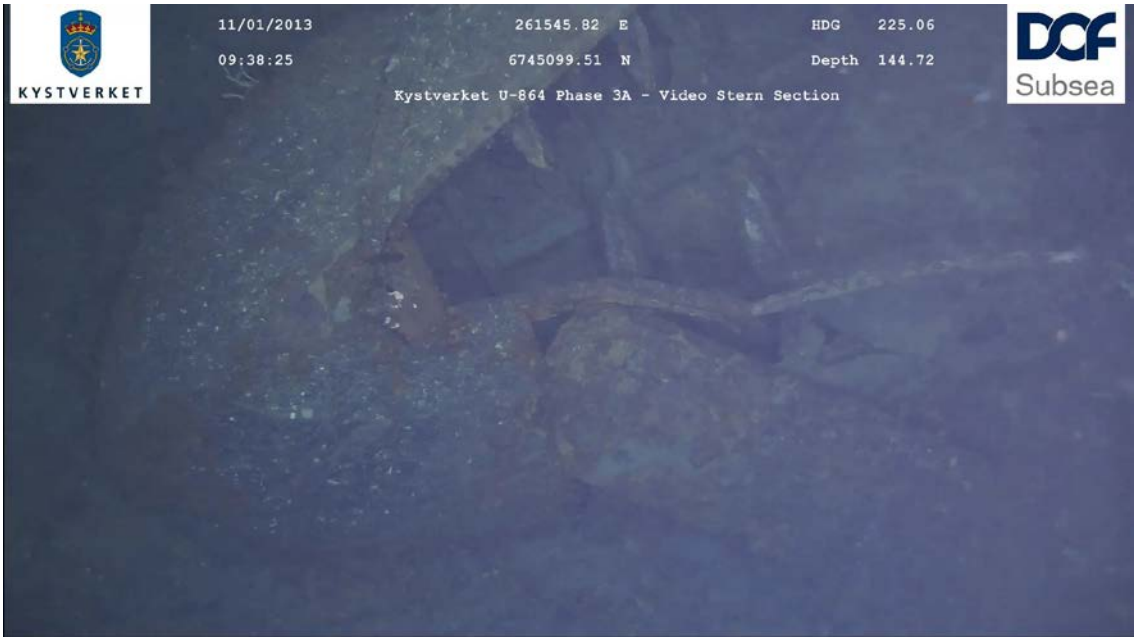



**Figure 3.9** **Detached end section from Aft of stern on seabed**



**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**

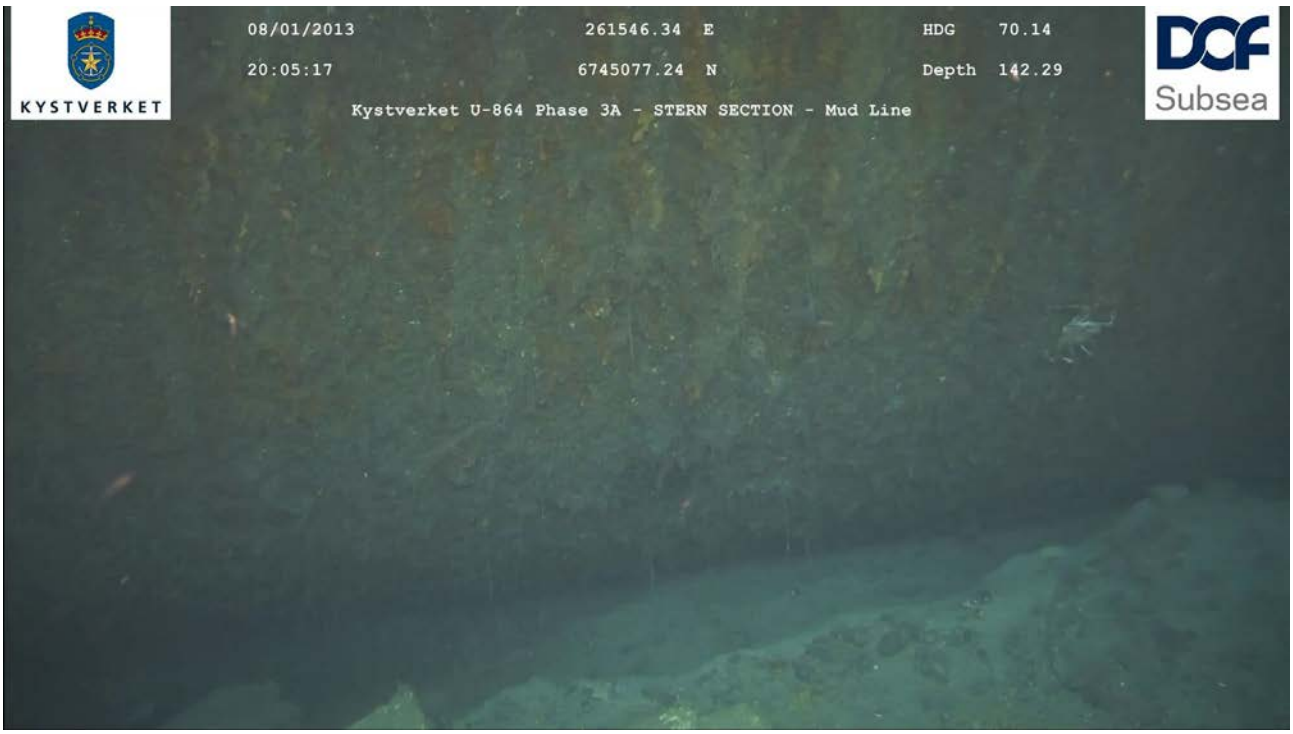



**Figure 3.14 The exposed keel (approx. 2.0m) at starboard rear end of the Stern Section**

### 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).

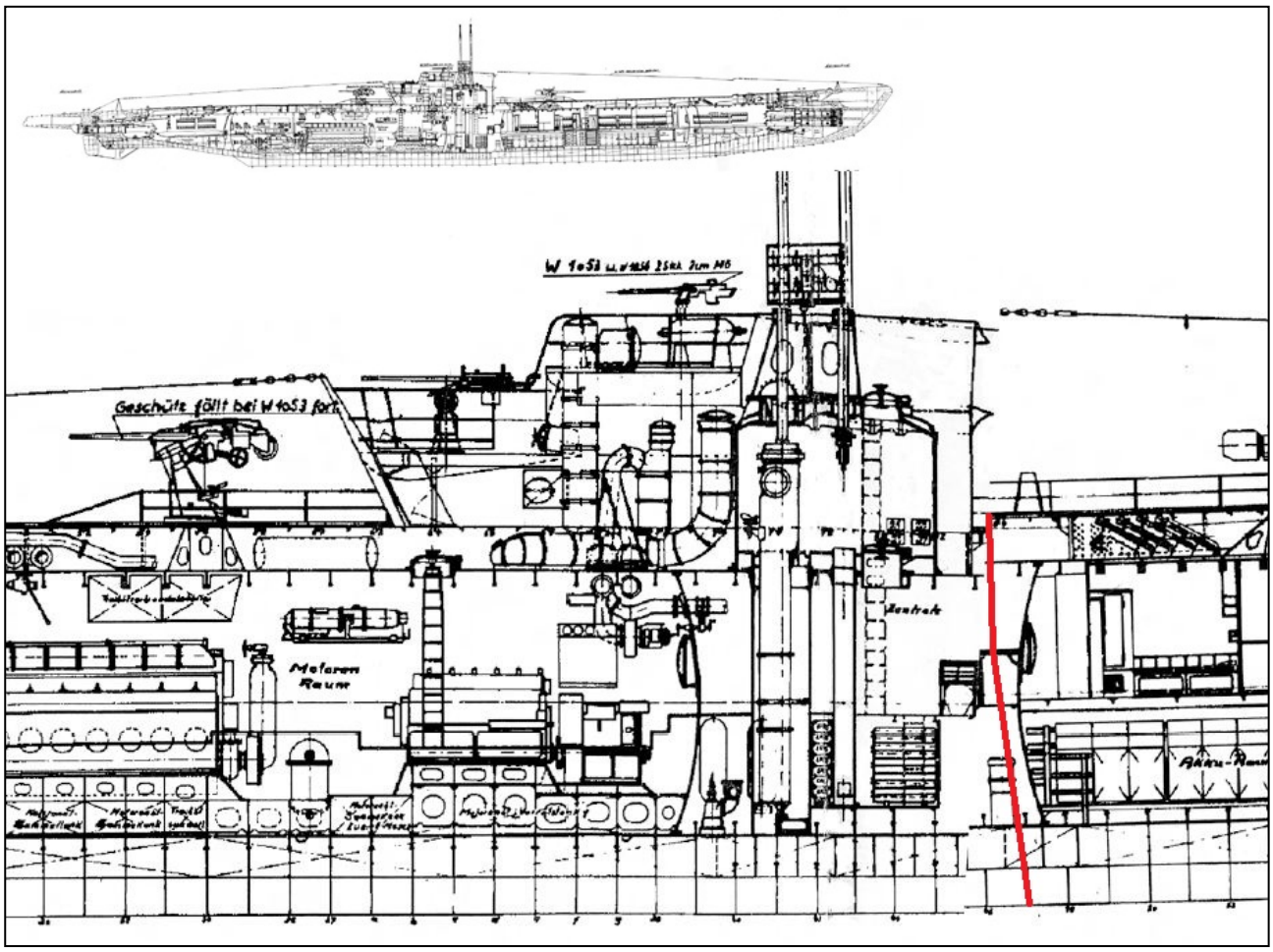



**Figure 3.15 Approximate break point of the bow wreckage (red)**

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**

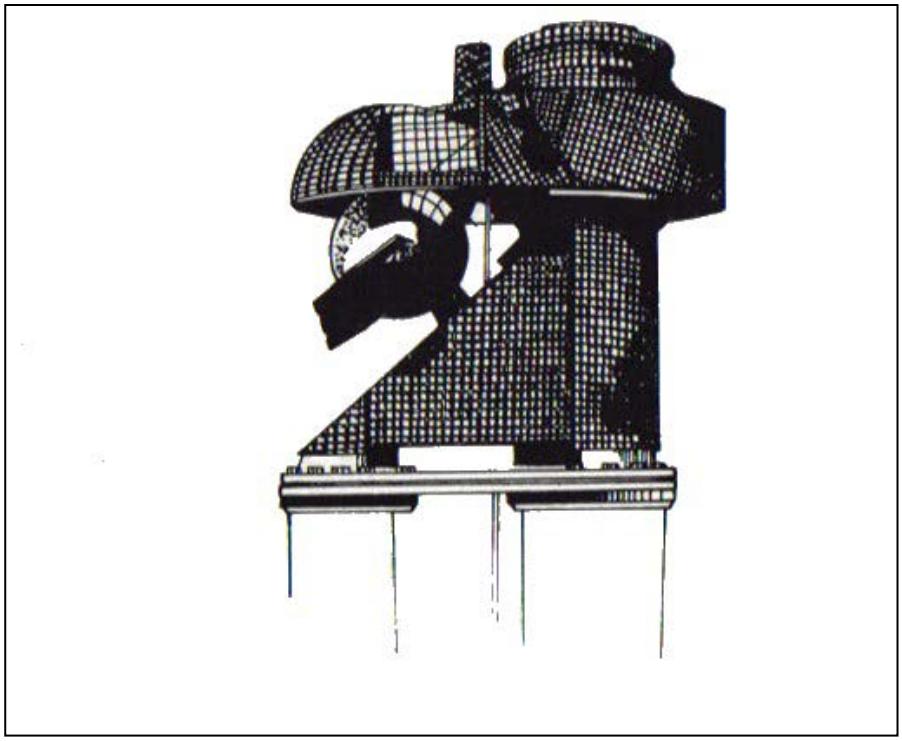


**Figure 3.19 Image of snorkel head from WWII**

### 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).

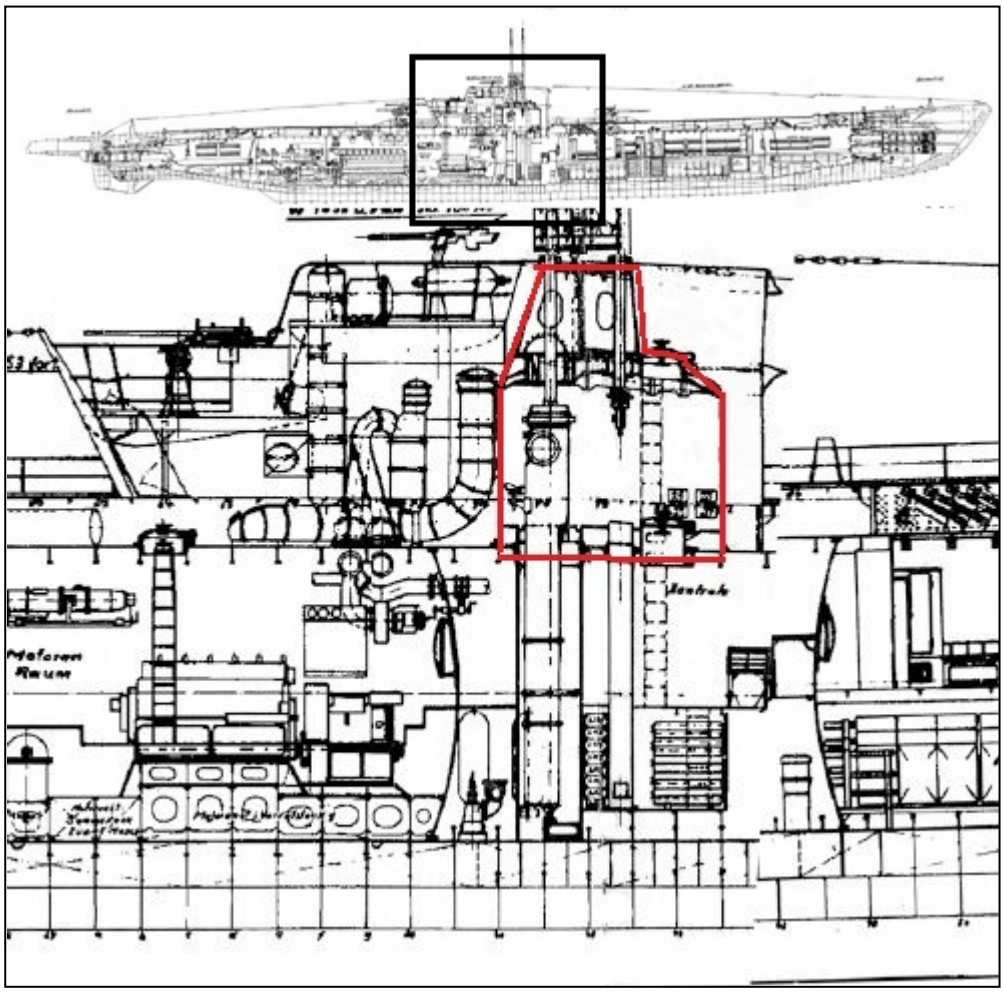


**Figure 3.20 Conning tower and control room schematic. Target 66 Highlighted red**

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**

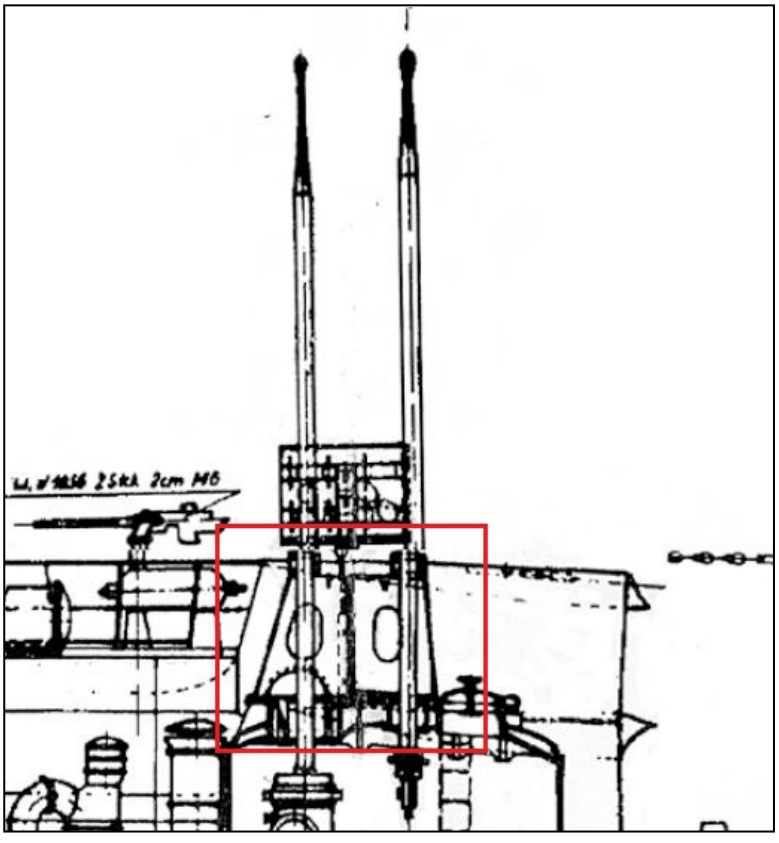


**Figure 3.24 U boat schematic showing periscope support structure (highlighted)**

### 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**

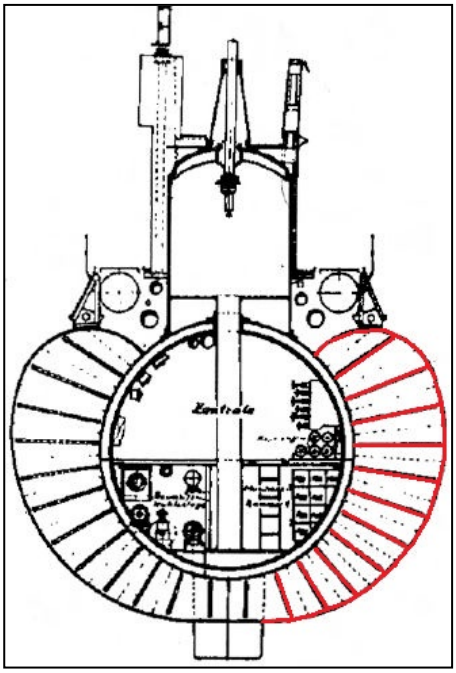


**Figure 3.26 Cross section of U boat schematic showing saddle tanks in the area of the control room (Saddle tank highlighted)**

### 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).

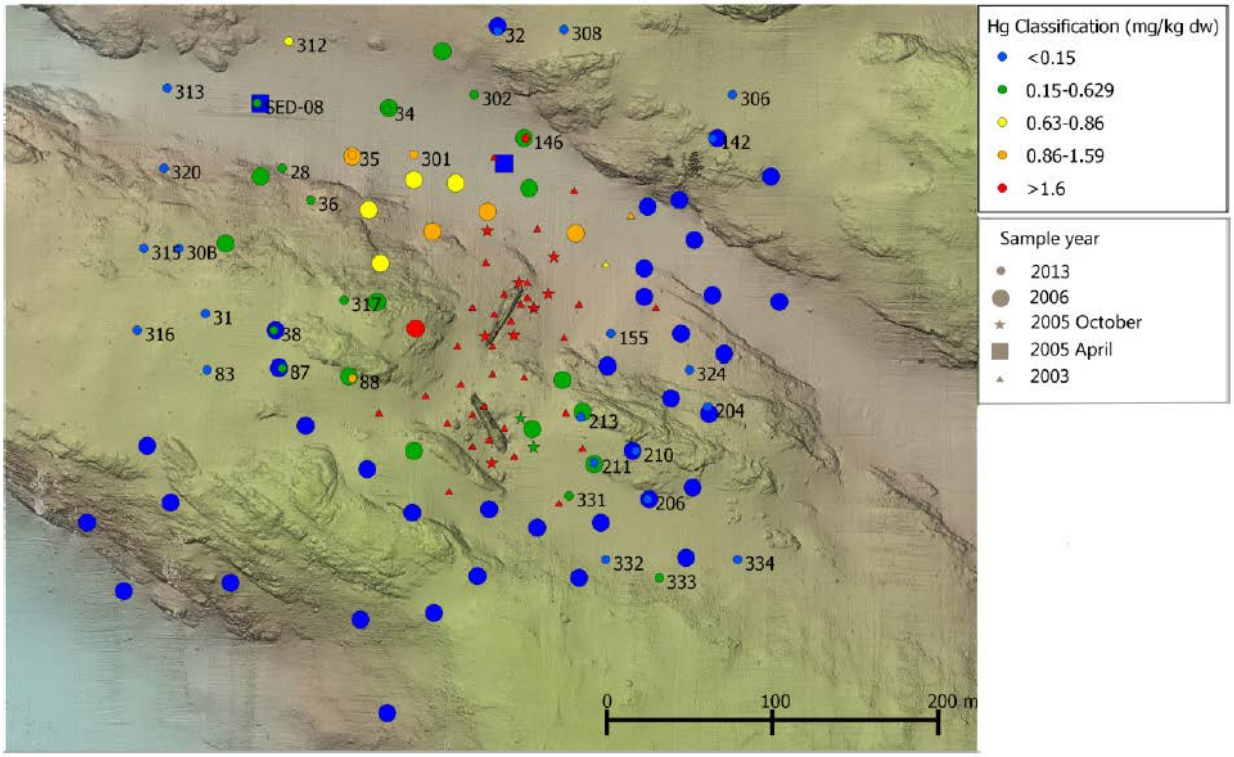



**Figure 3.29 From NIVA report (ref /4/); Mercury content results for all years**

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.

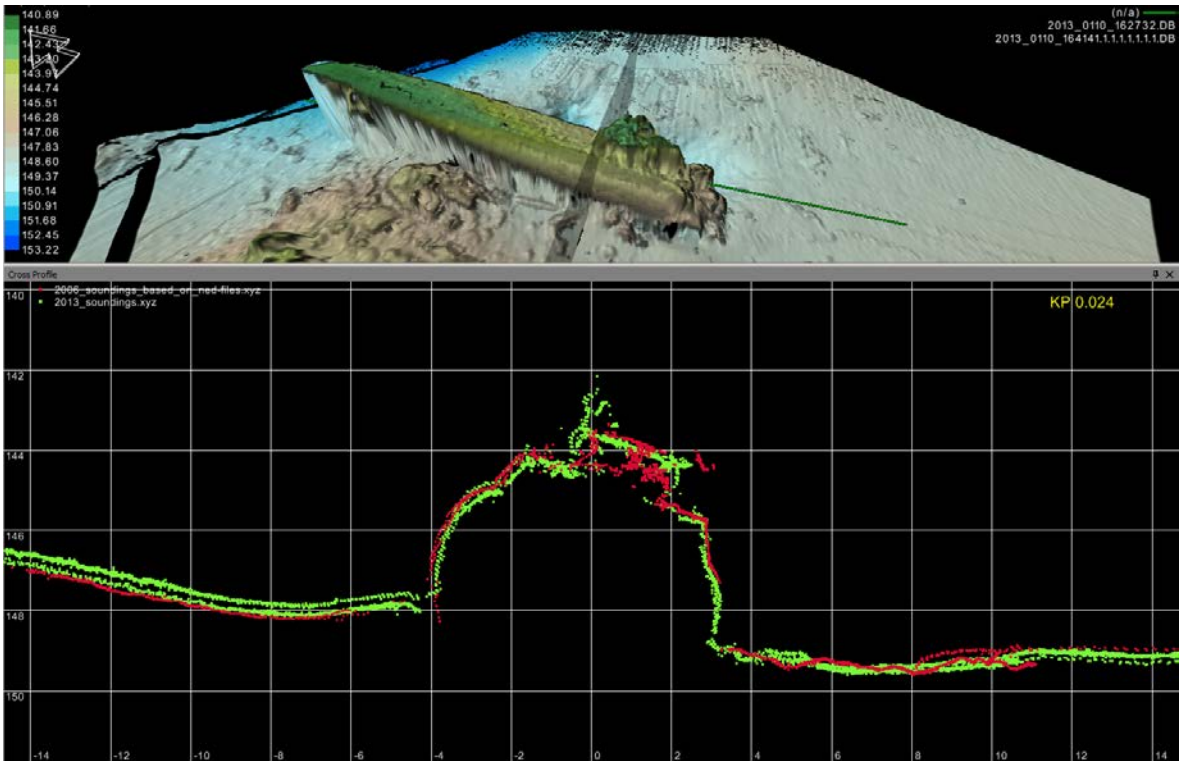



**Figure 3.30** **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

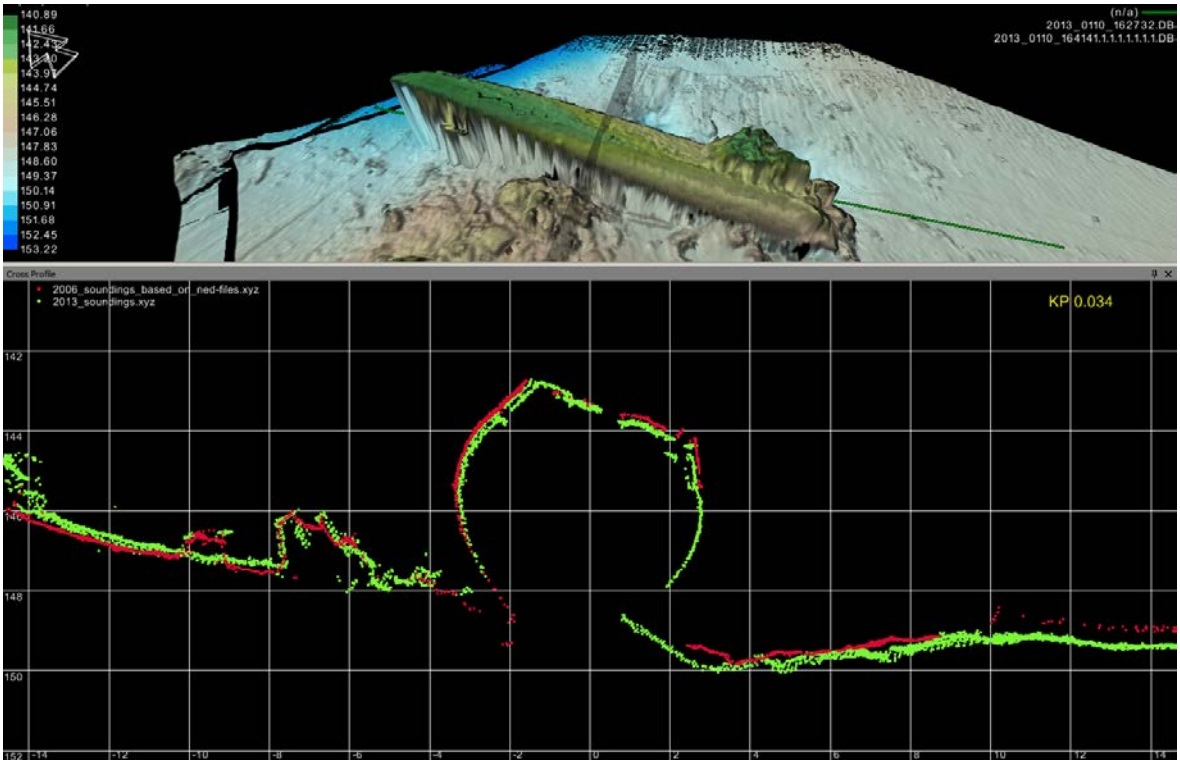



**Figure 3.31** **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

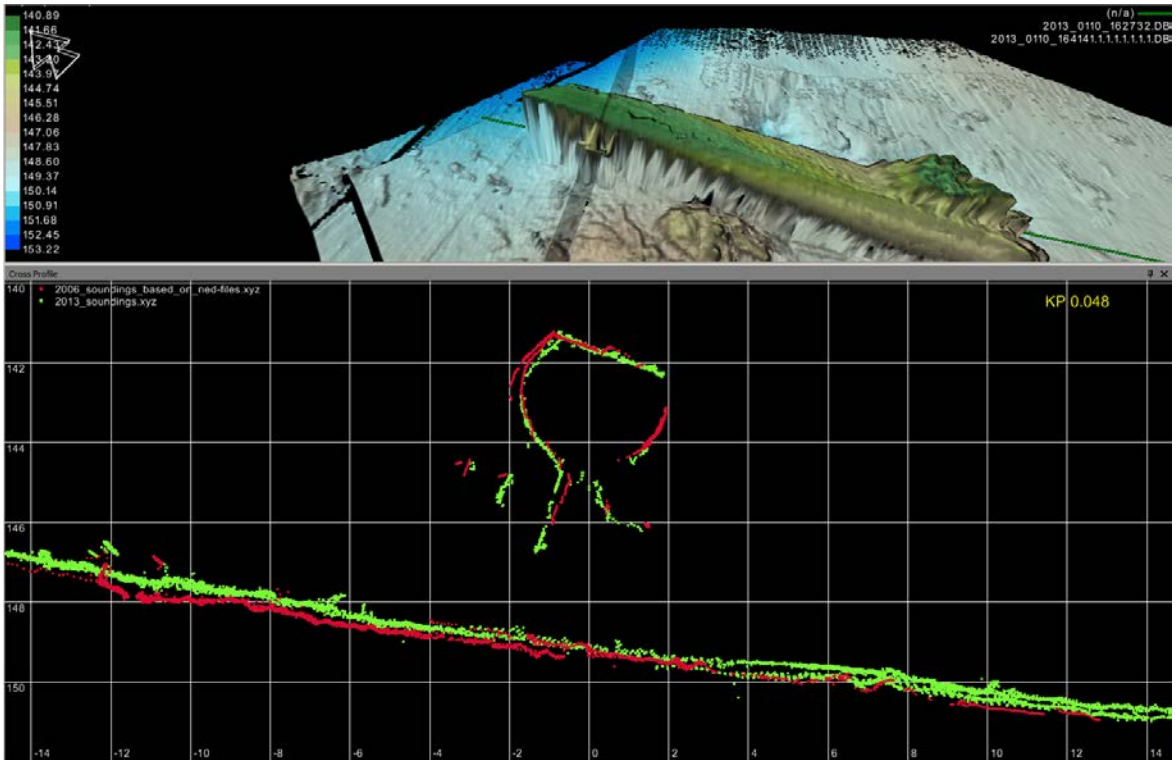



**Figure 3.32** **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

## 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.

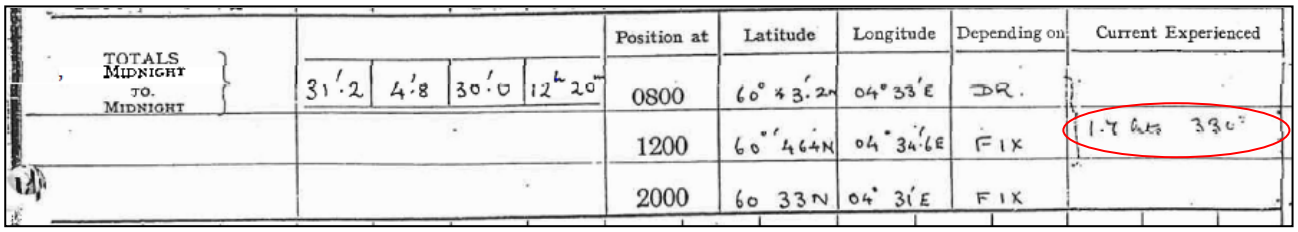
The historical sinking positions given in HMS Venturer's log (see Figure 4.2) were converted from the original Bessel NGO (New Norwegian) spheroid into the project WGS84 and plotted on the DTM (Table 4.1). These were then examined in detail for signs of additional wreckage. Large scale plots of these 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 | 0800 | 60° 43'.2N | 04° 33'E | DR. | |
| | | | | 1200 | 60° 44N | 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**

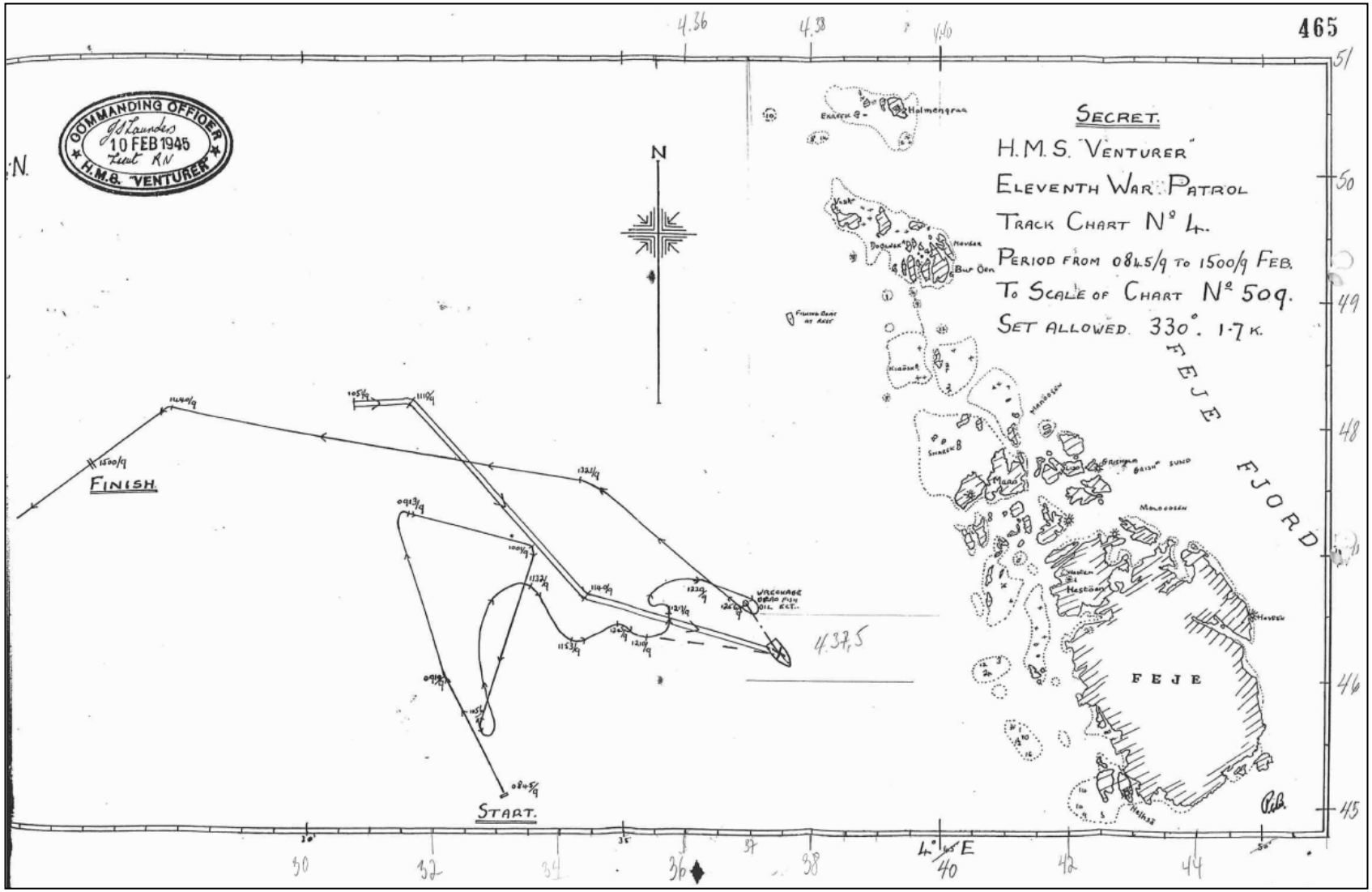



**Figure 4.2** **Image of chart from HMS Venturer's log with positions taken from chart**

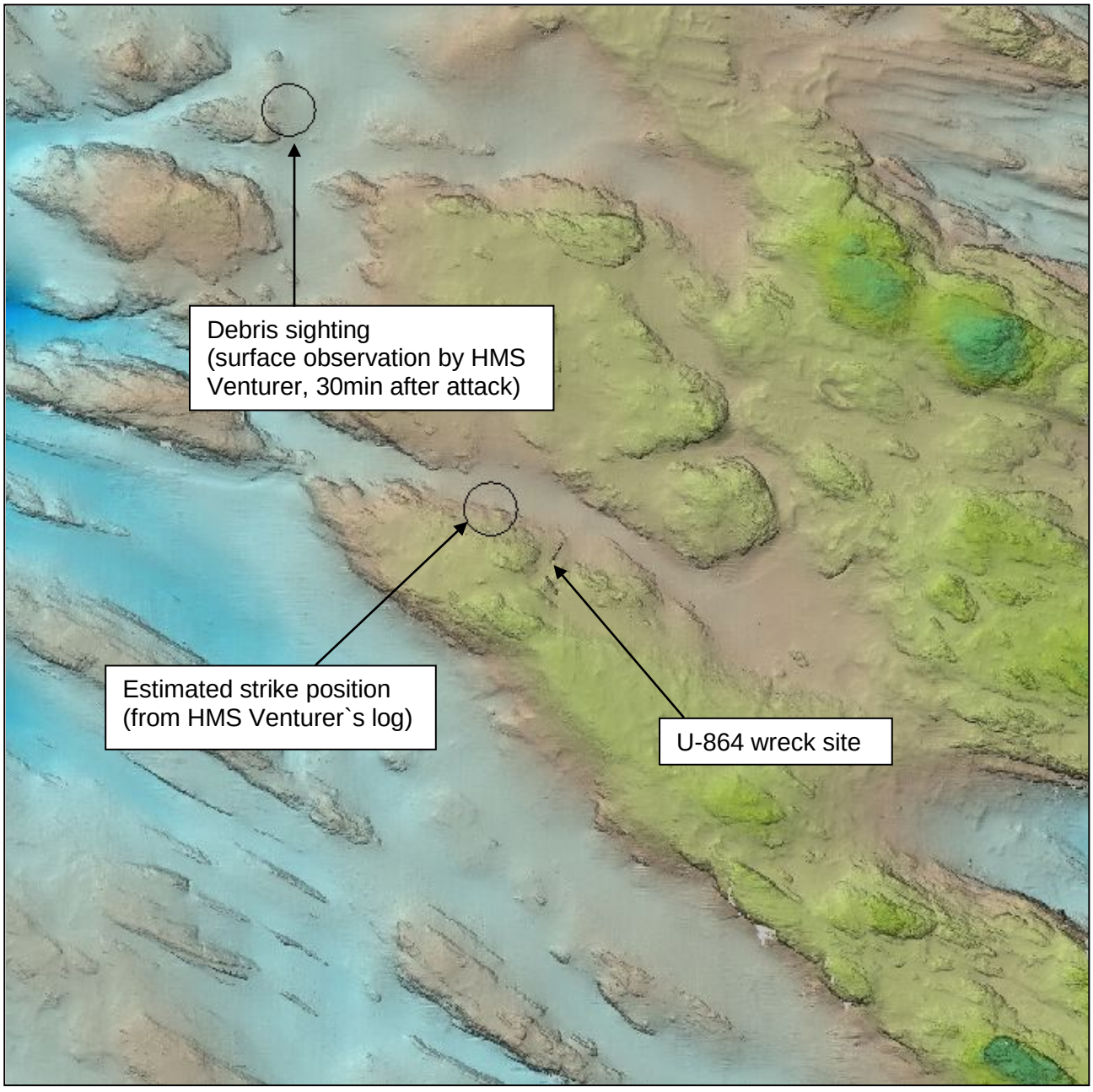



**Figure 4.3** **Complete DTM from the 2013 survey, positions from HMS Venturer's log ringed**

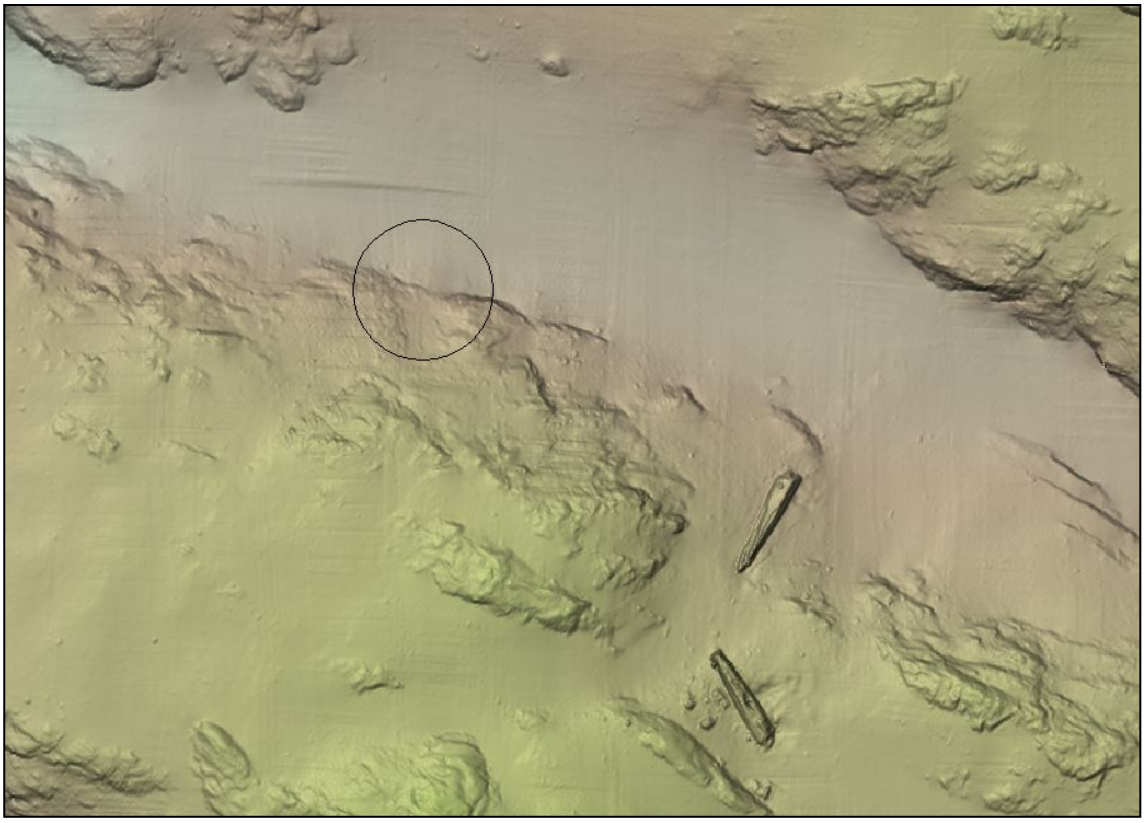


**Figure 4.4** **Historical sinking position taken from HMS Venturer Log circled (25m radius). Actual wreck location can be seen to the SE**

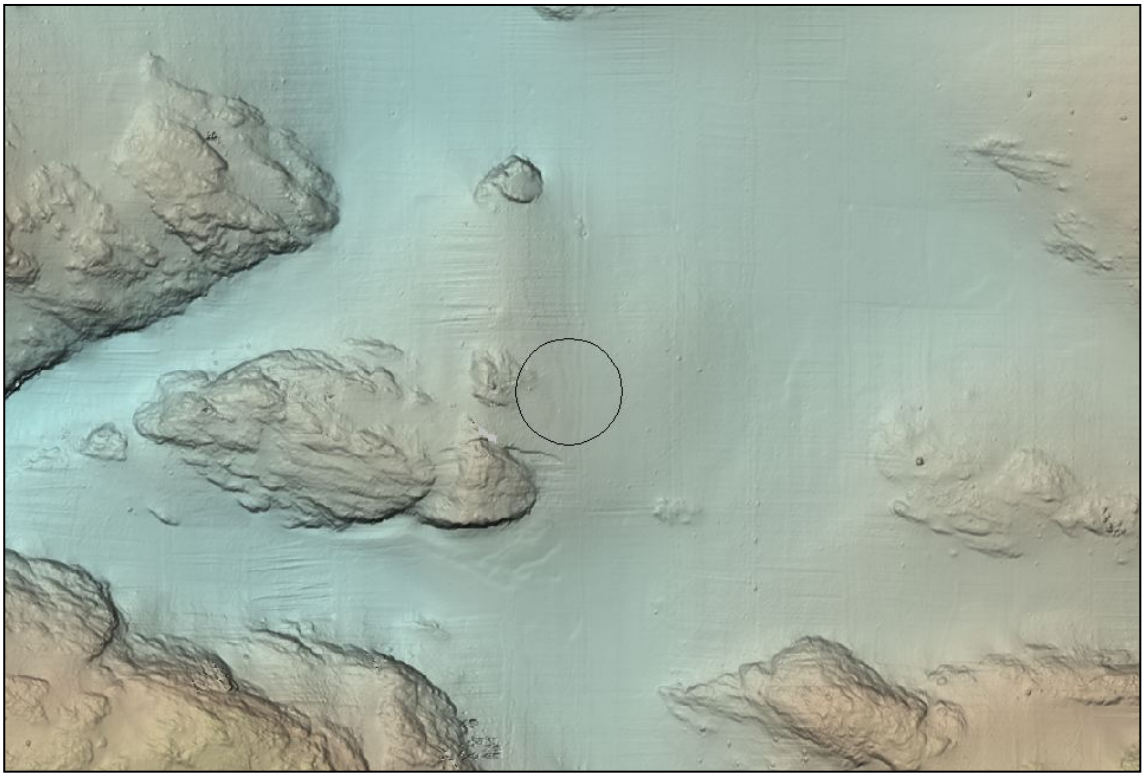


**Figure 4.5** **Oil slick and floating debris position taken from HMS Venturer Log circled (25m radius)**

## 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

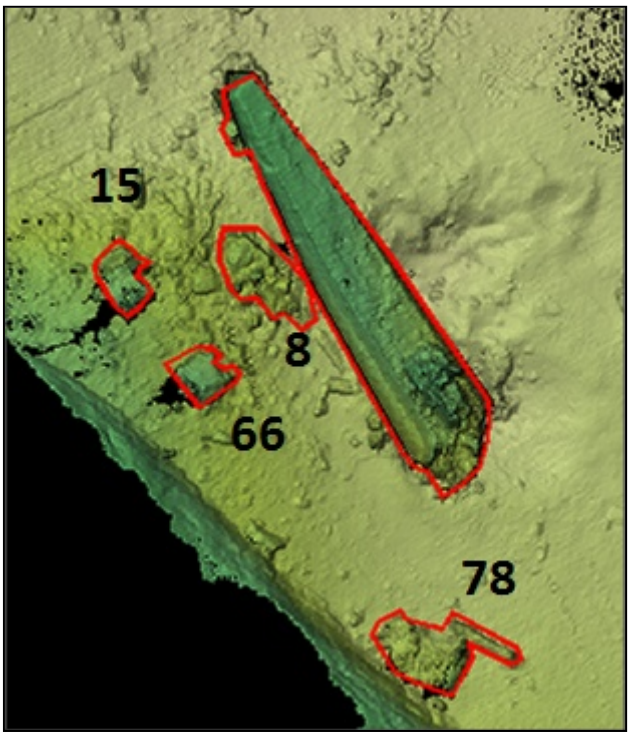



**Figure 4.6 Video Survey targets near the stern section**

### 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.

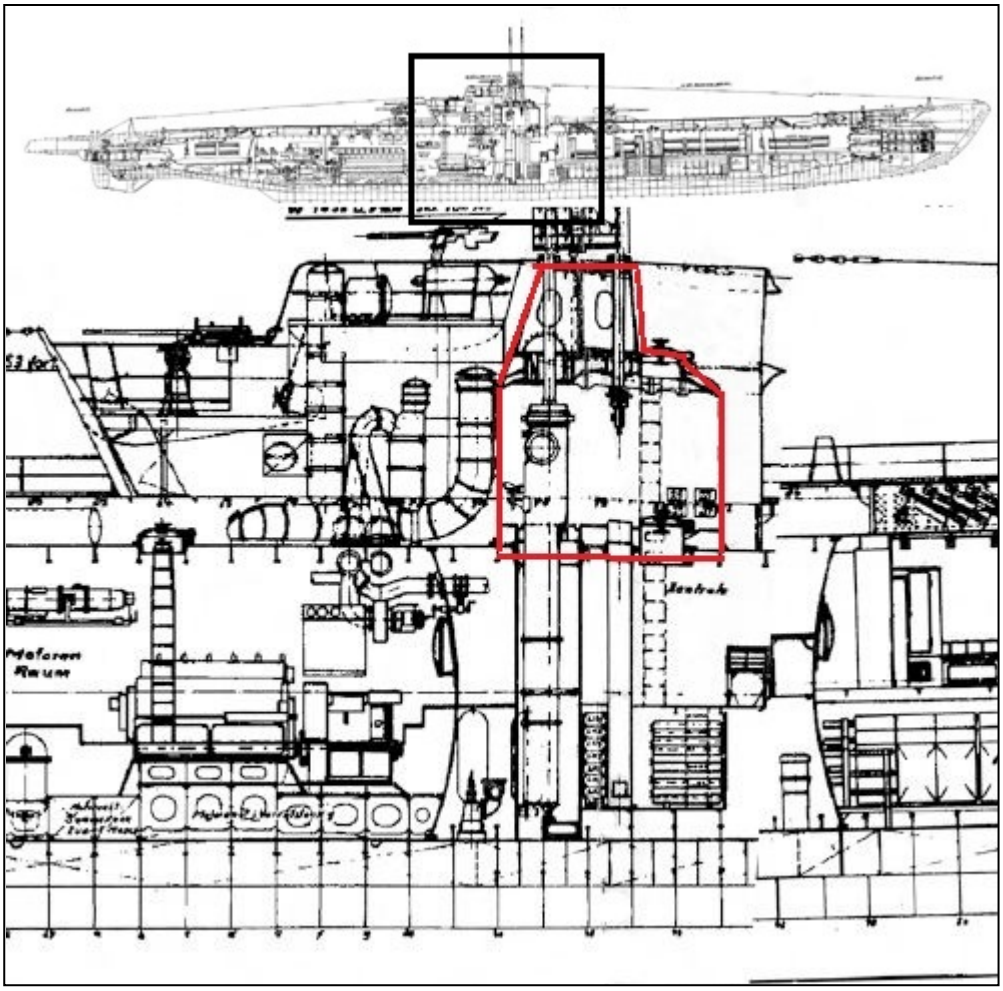


**Figure 4.8 Conning tower and control room schematic. Target 66 Highlighted red**

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.

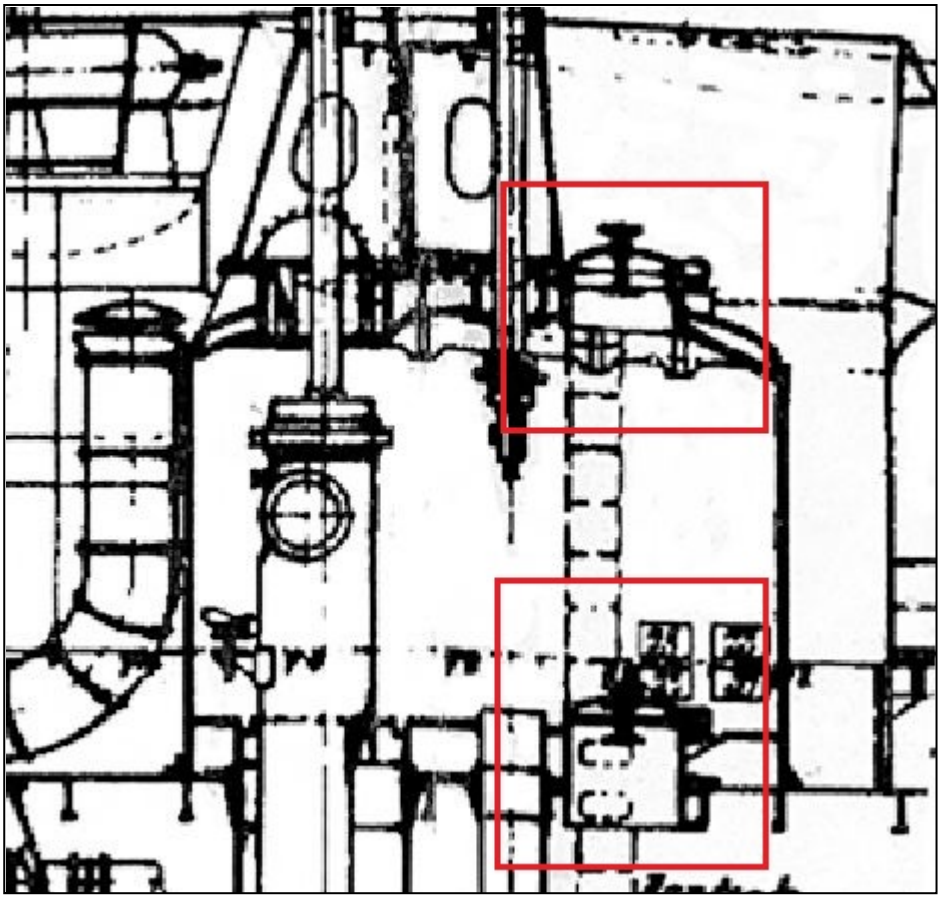


**Figure 4.9** **U Boat Schematic showing Conning Tower Access Hatches (highlighted)**

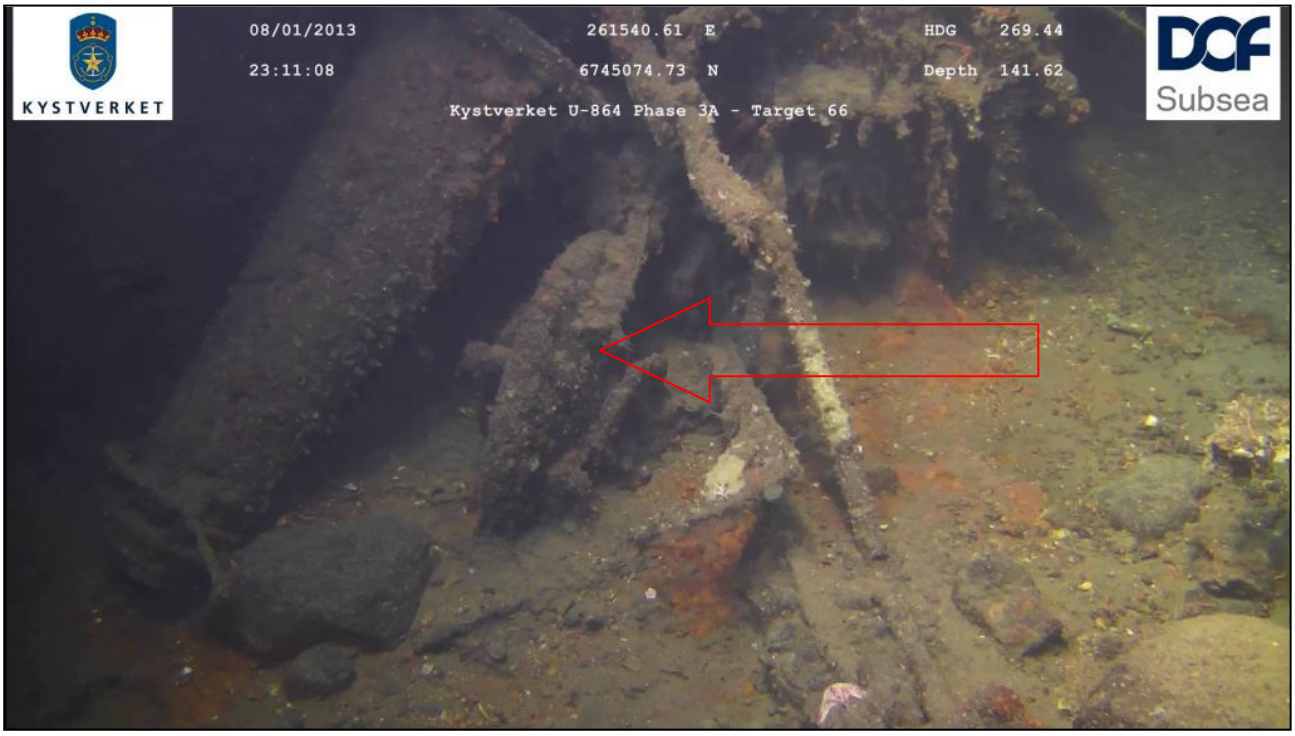



**Figure 4.10** **Upper Conning Tower hatch**




**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).

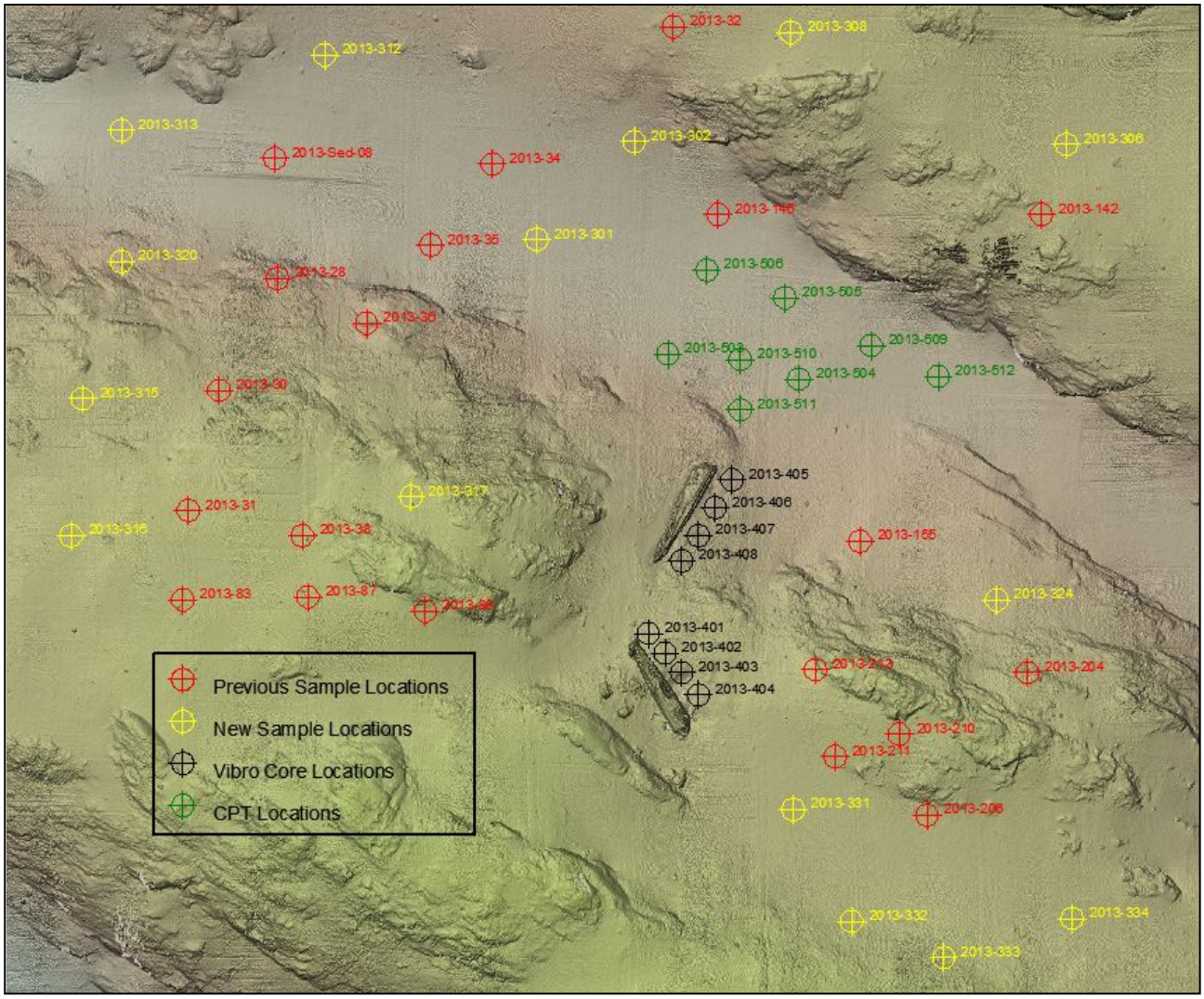



**Figure 4.13 Geotechnical Sampling Locations (Not all completed)**

### 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/).

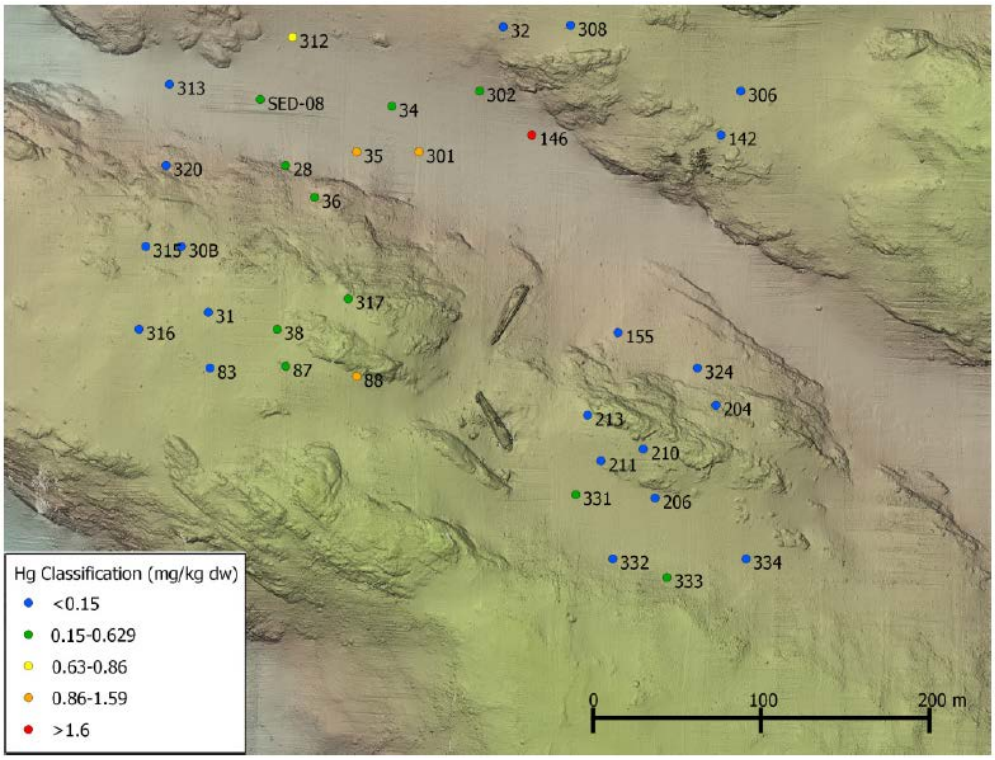



**Figure 4.14 From NIVA report (ref /4/); mercury content in surface sediment (0-2cm) 2013**

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/).

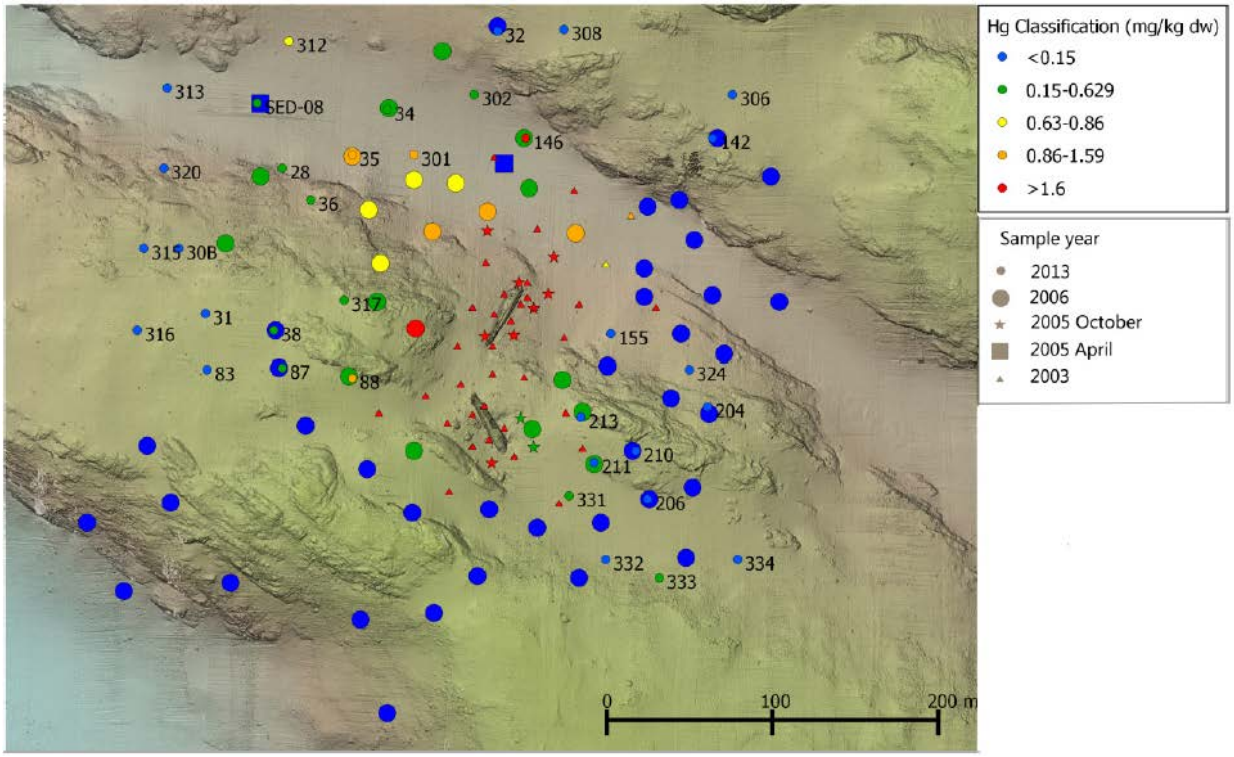



**Figure 4.15 From NIVA report (ref /4/); Mercury content results for all years**

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/).

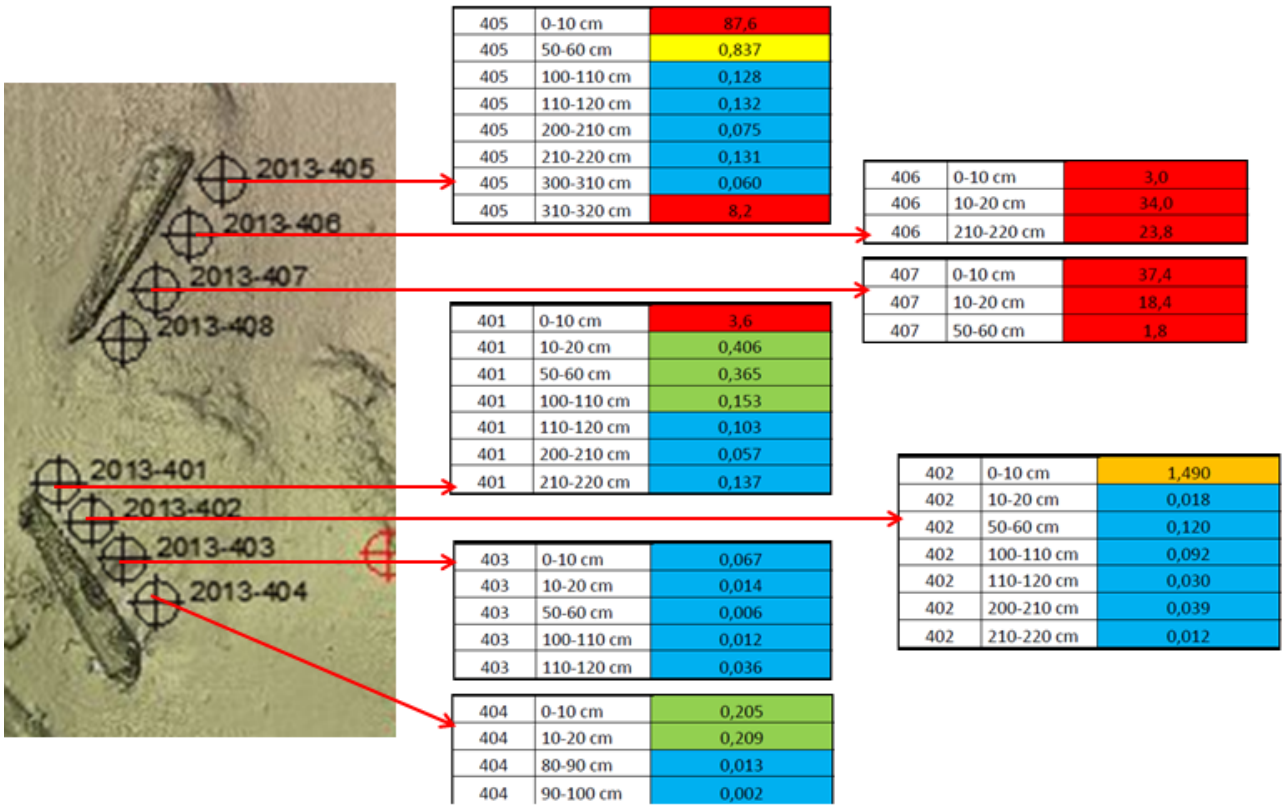



**Figure 4.16 Mercury analyses in vibrocores close to wreck**

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.

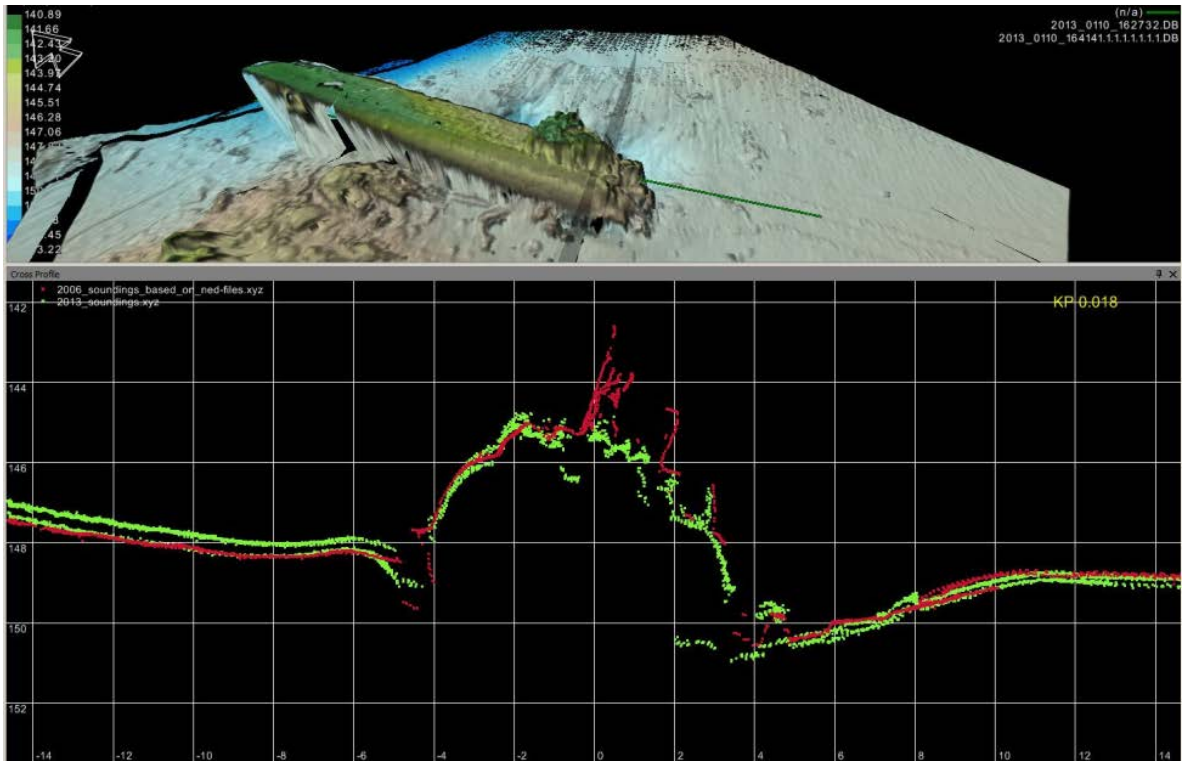



**Figure 4.18** **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

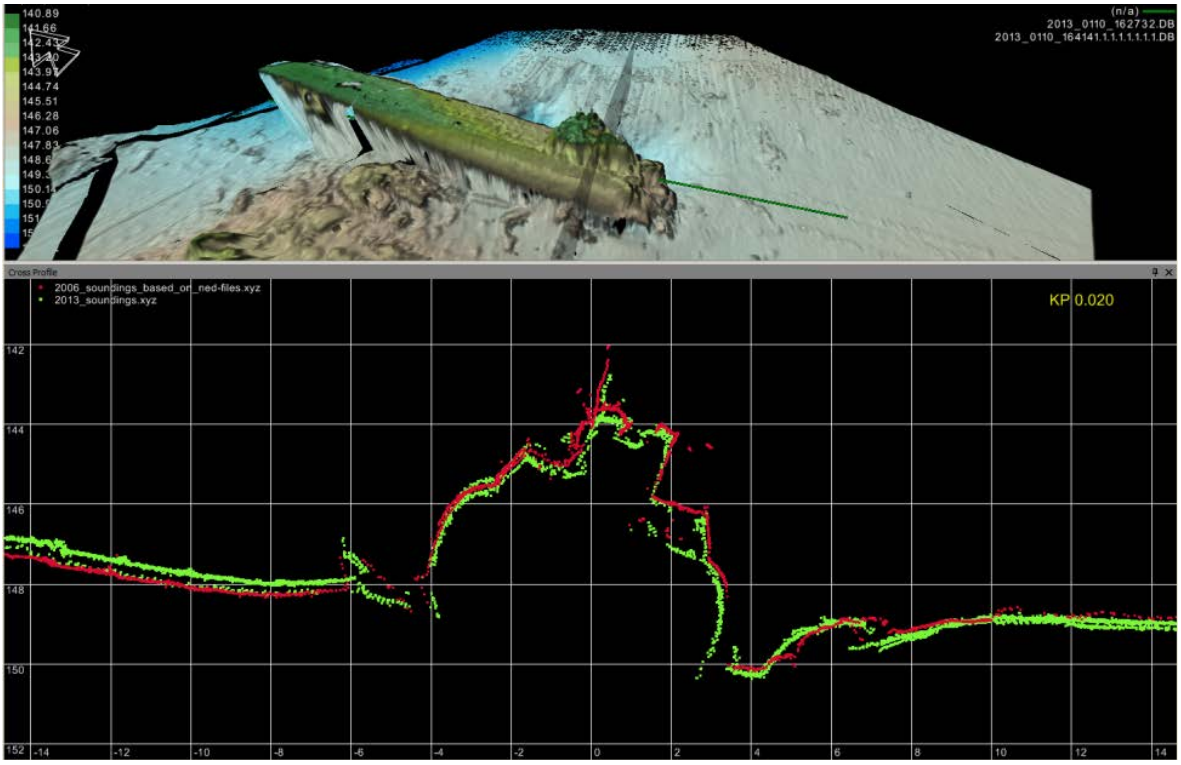



**Figure 4.19** **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

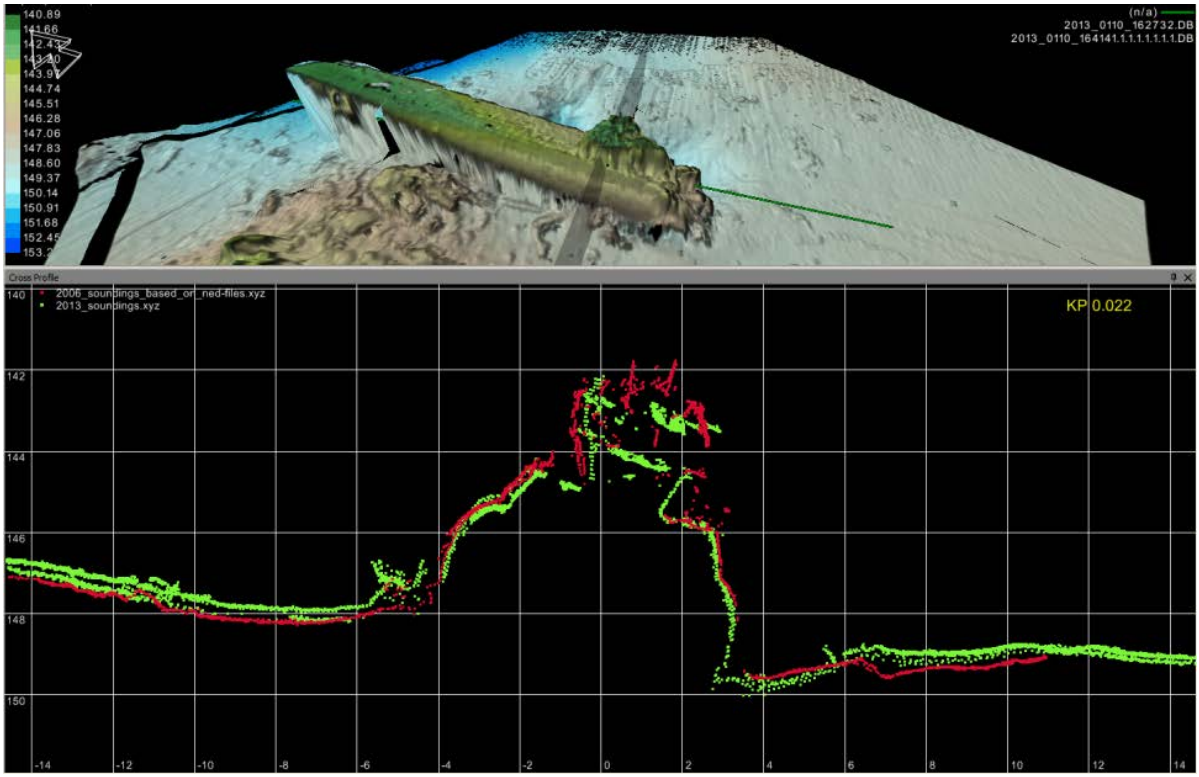



**Figure 4.20** **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

.

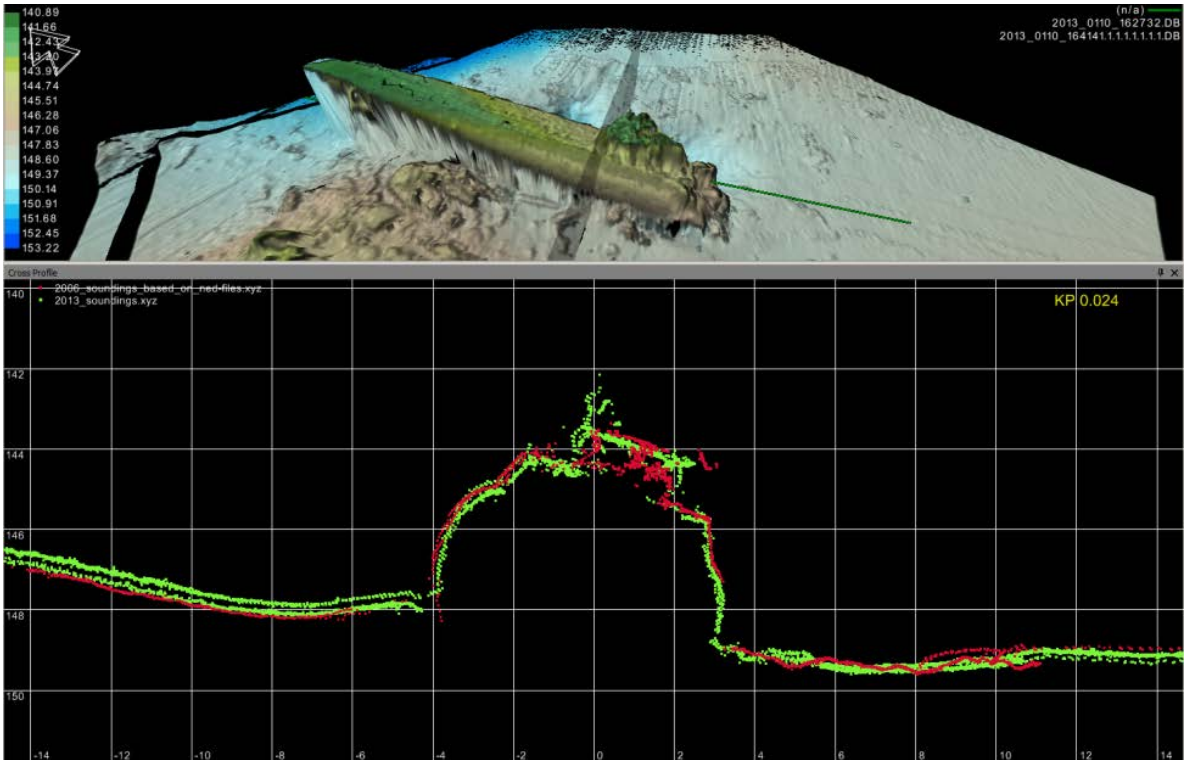



**Figure 4.21** **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

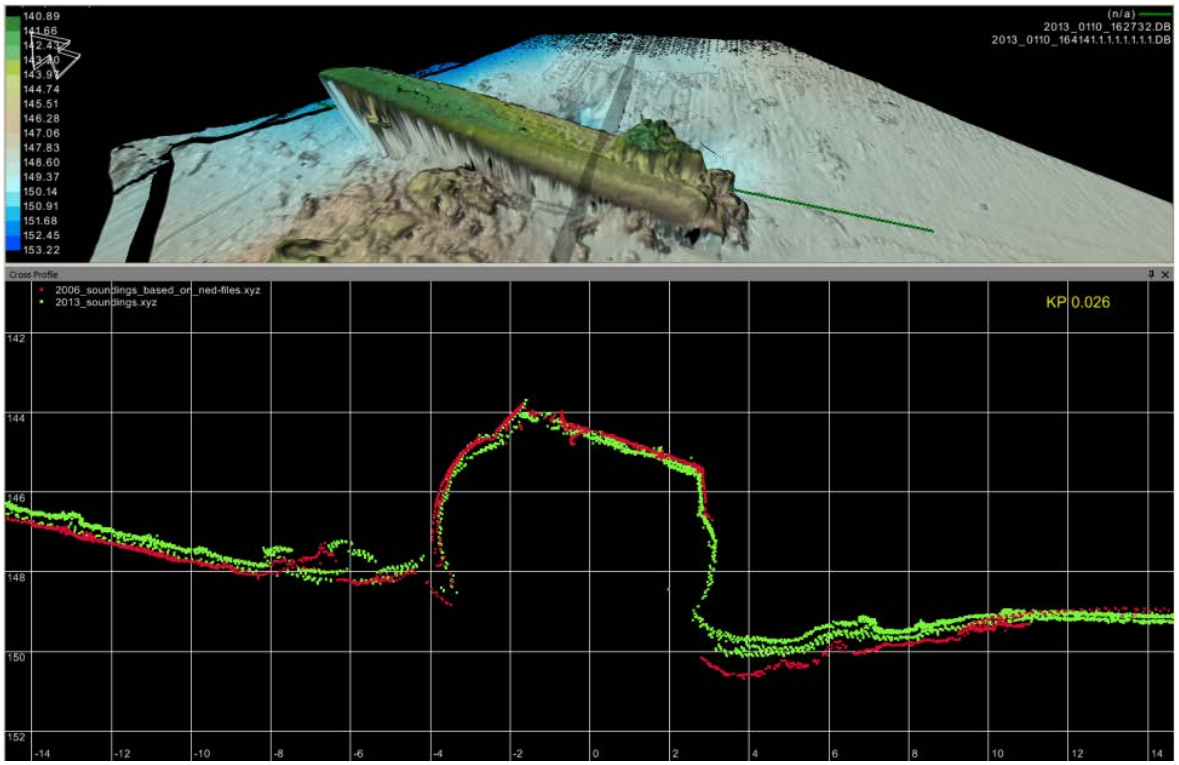



**Figure 4.22** **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

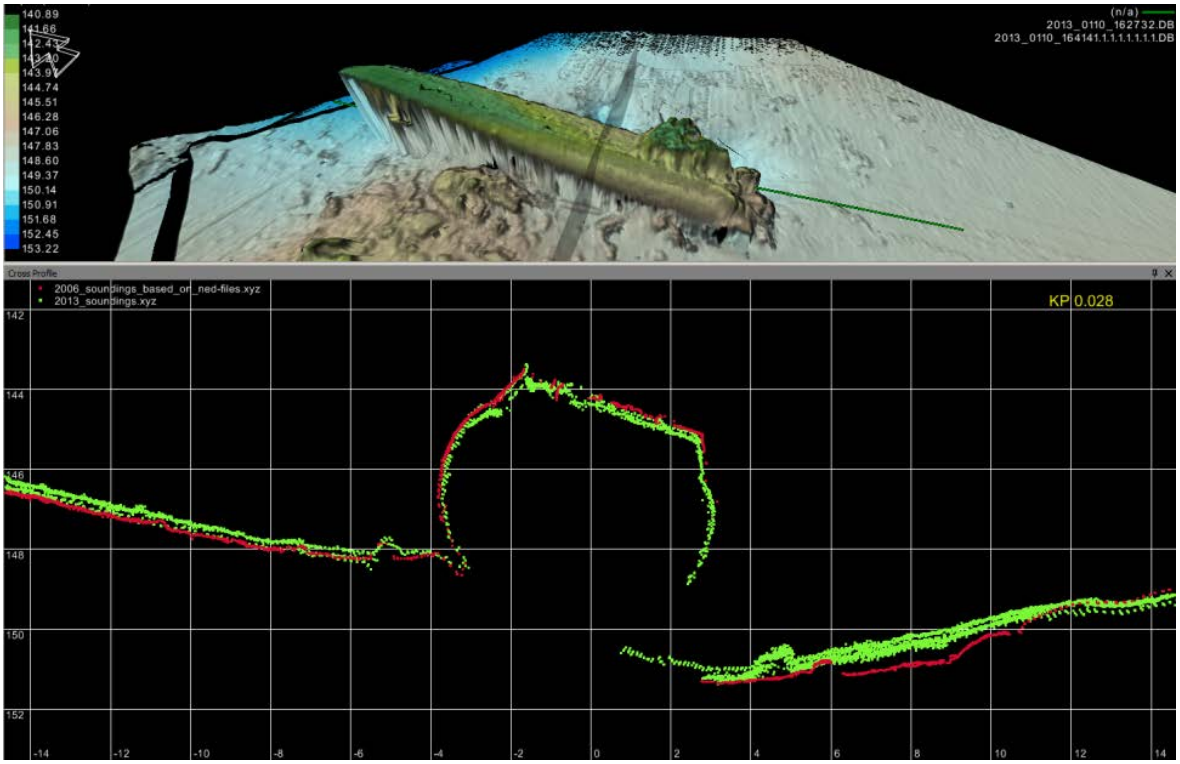



**Figure 4.23** **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

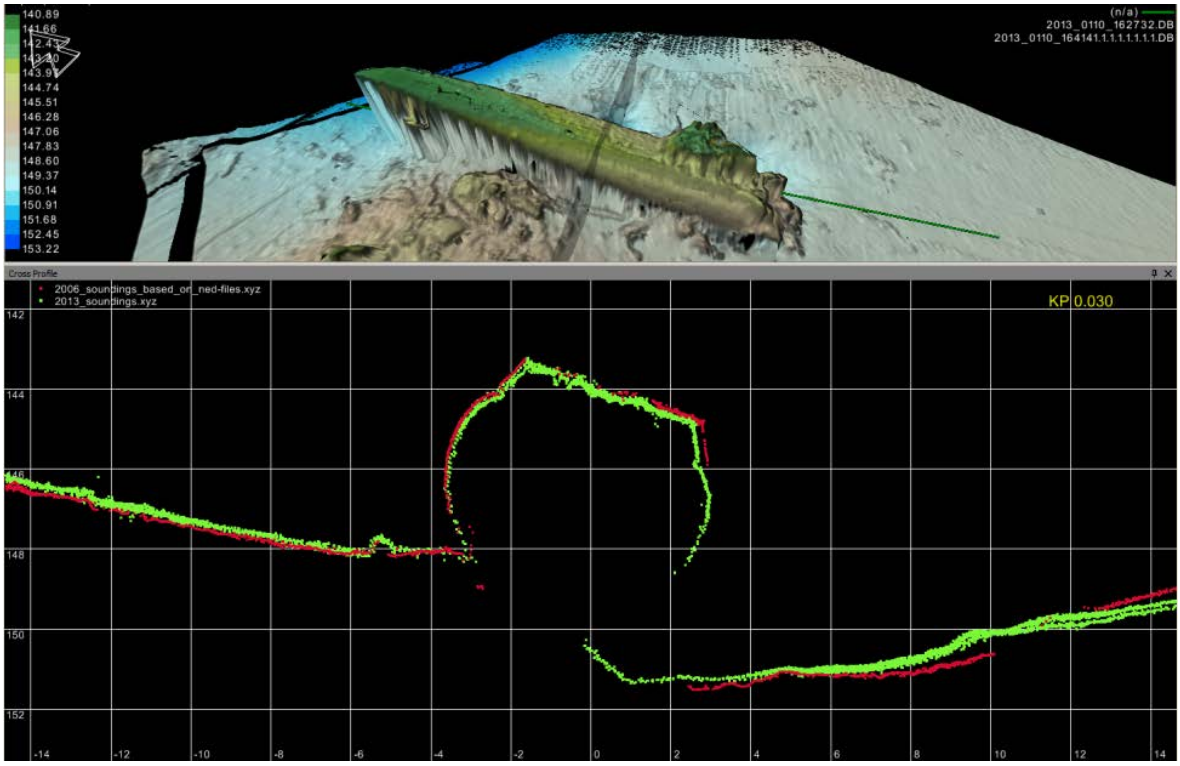



**Figure 4.24** **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

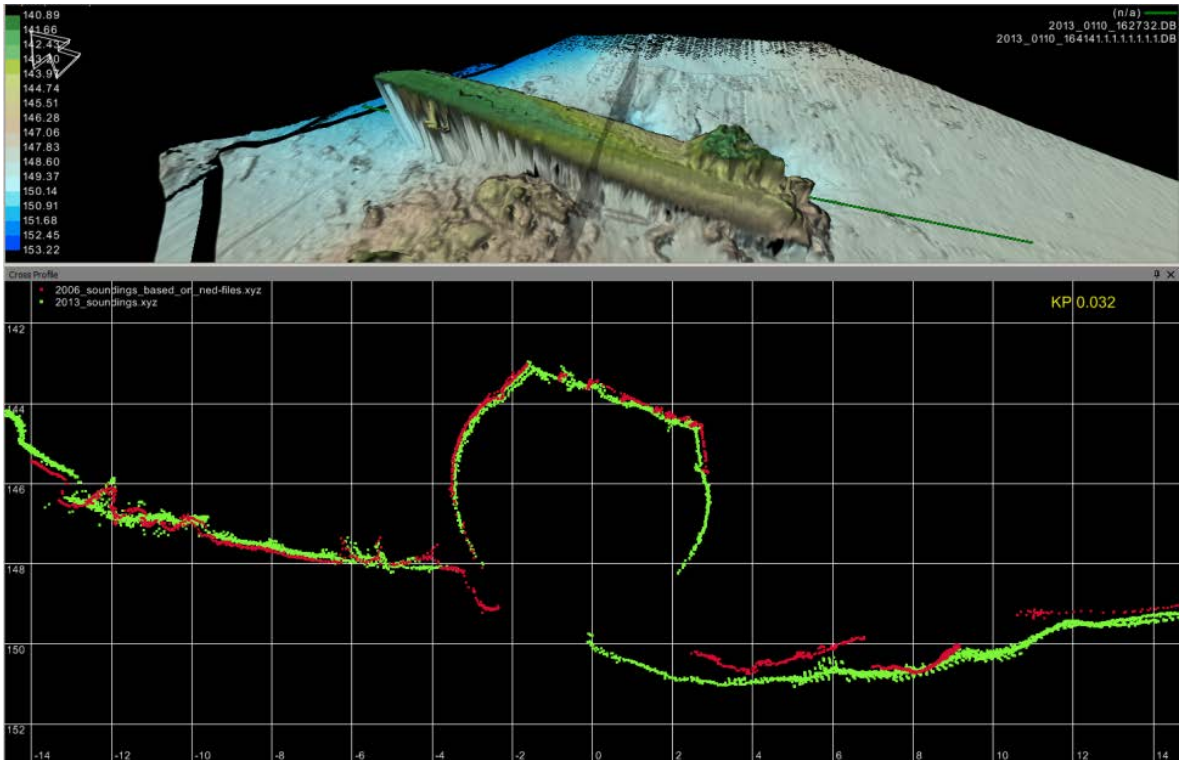



**Figure 4.25** **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

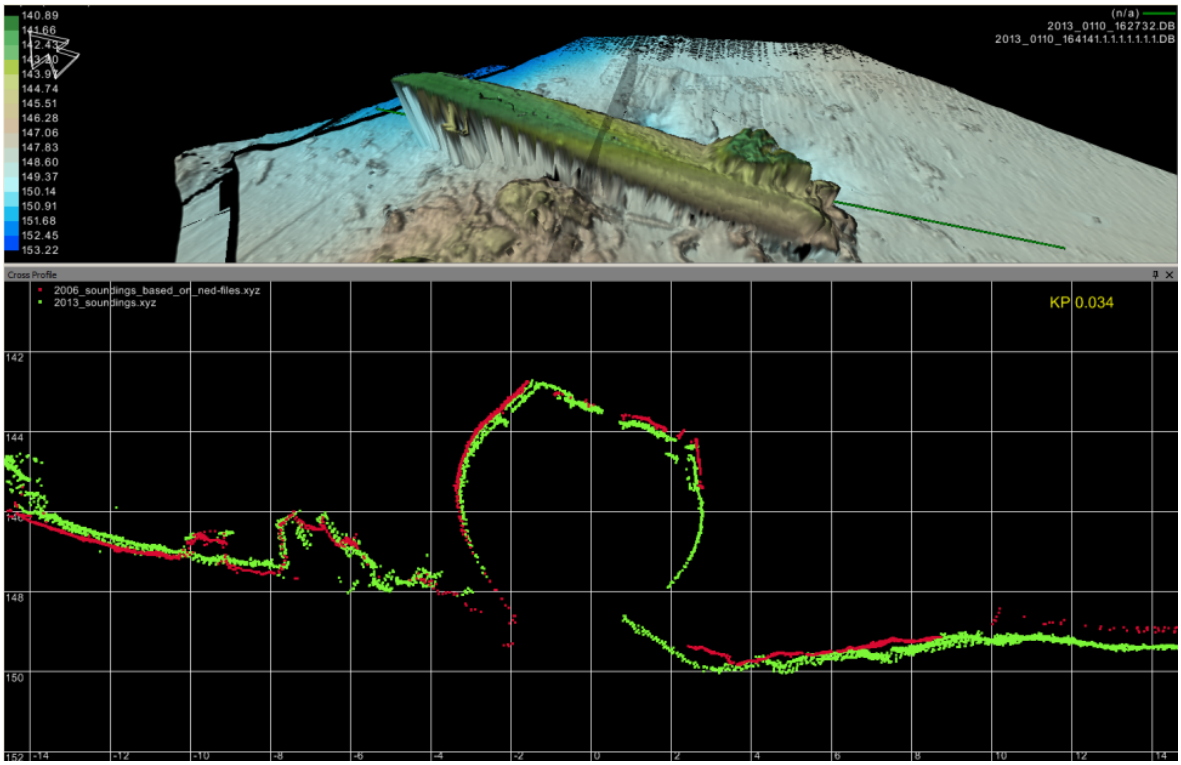



**Figure 4.26** **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

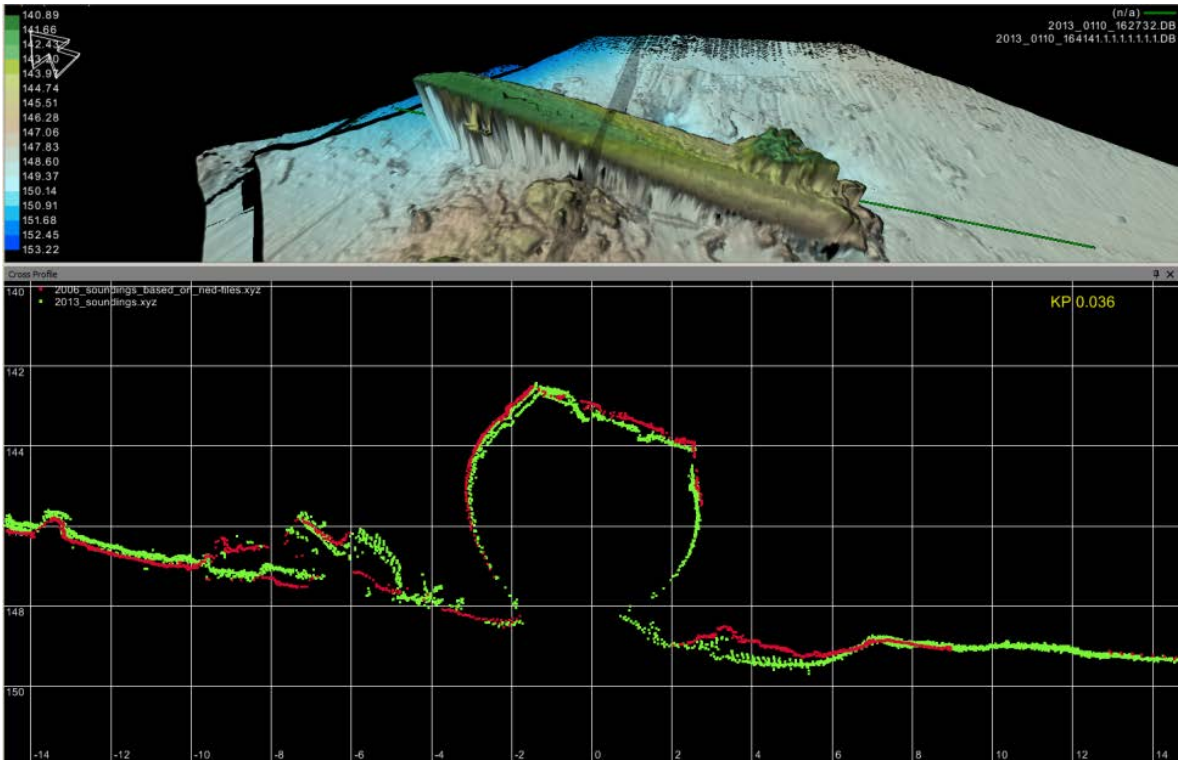



**Figure 4.27** **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

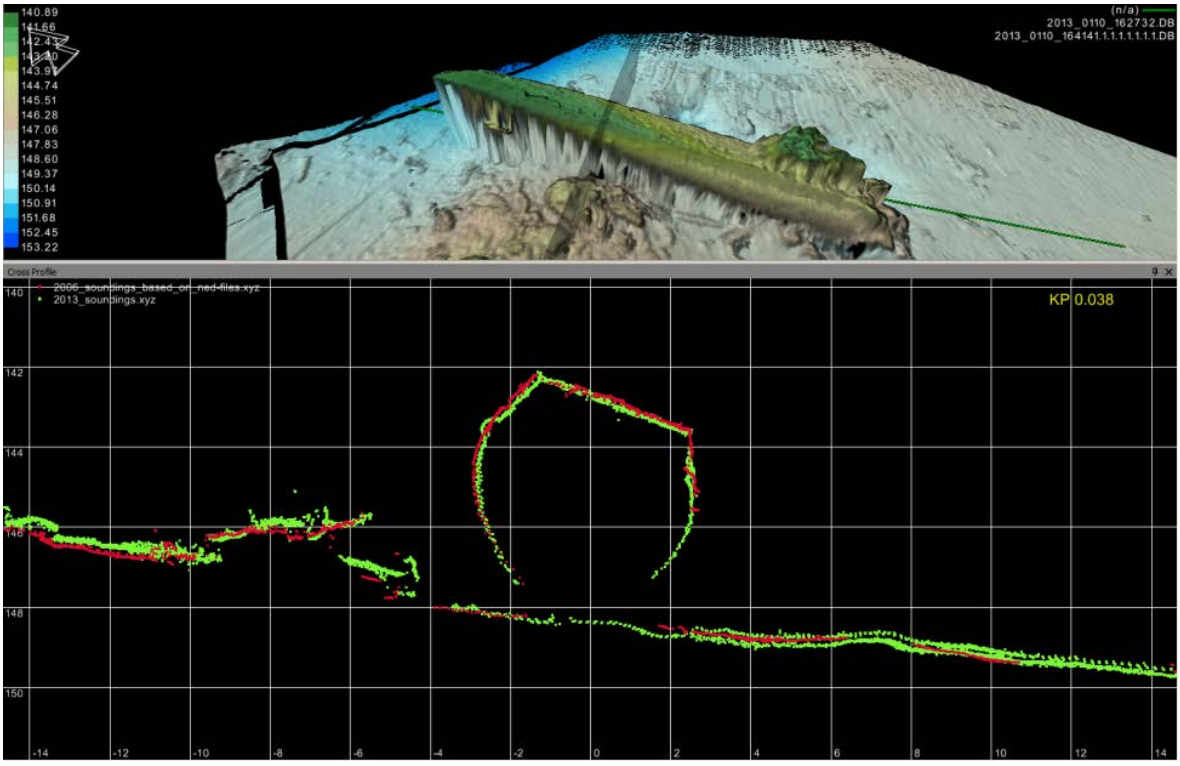



**Figure 4.28** **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

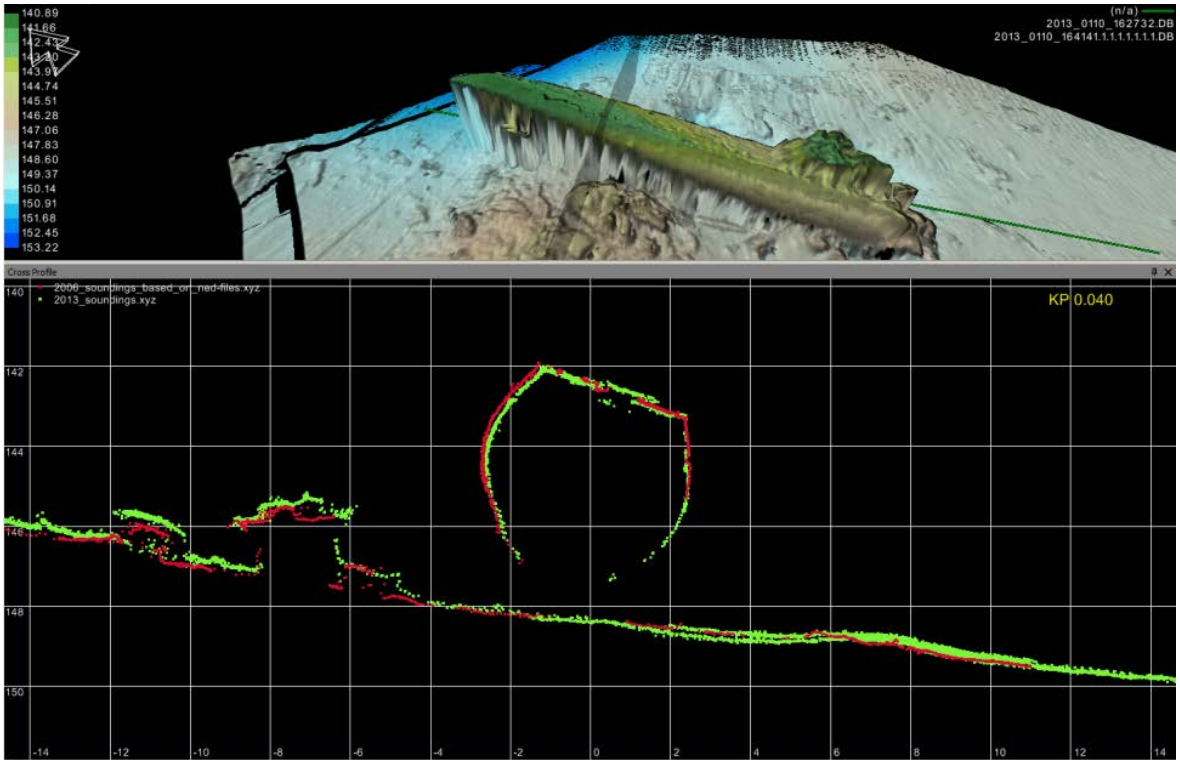



**Figure 4.29** **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

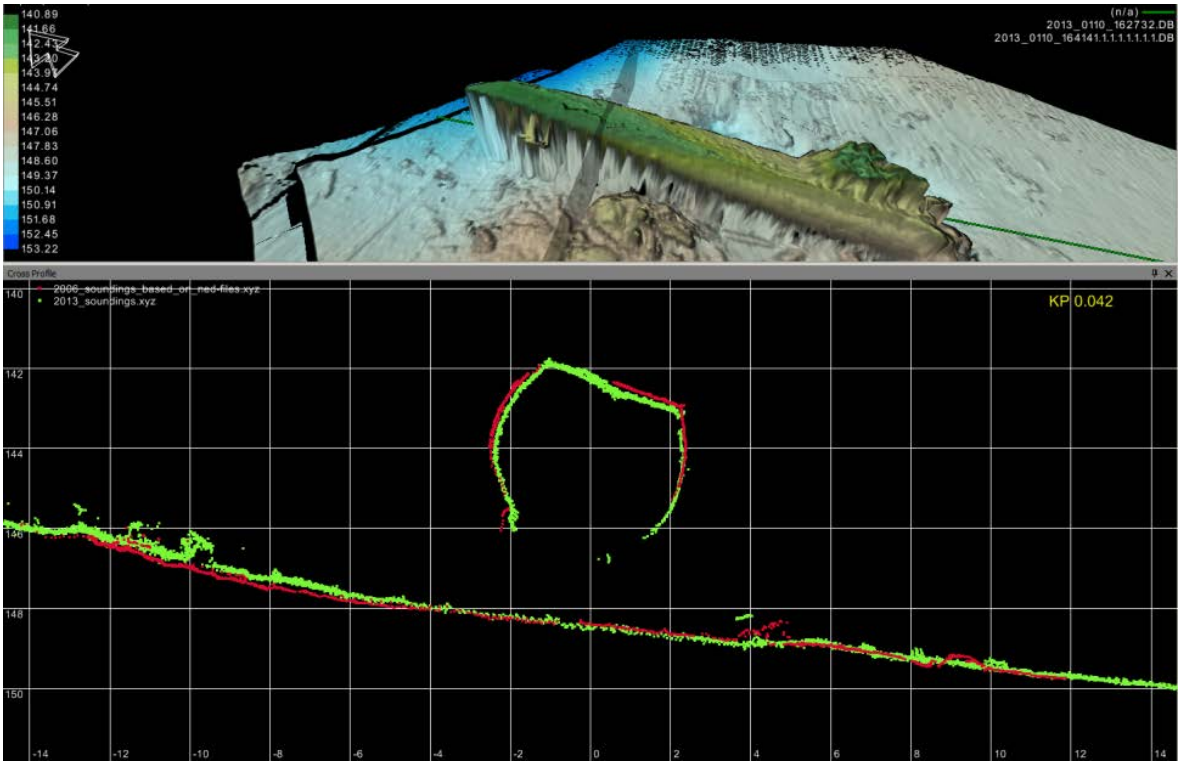



**Figure 4.30** **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

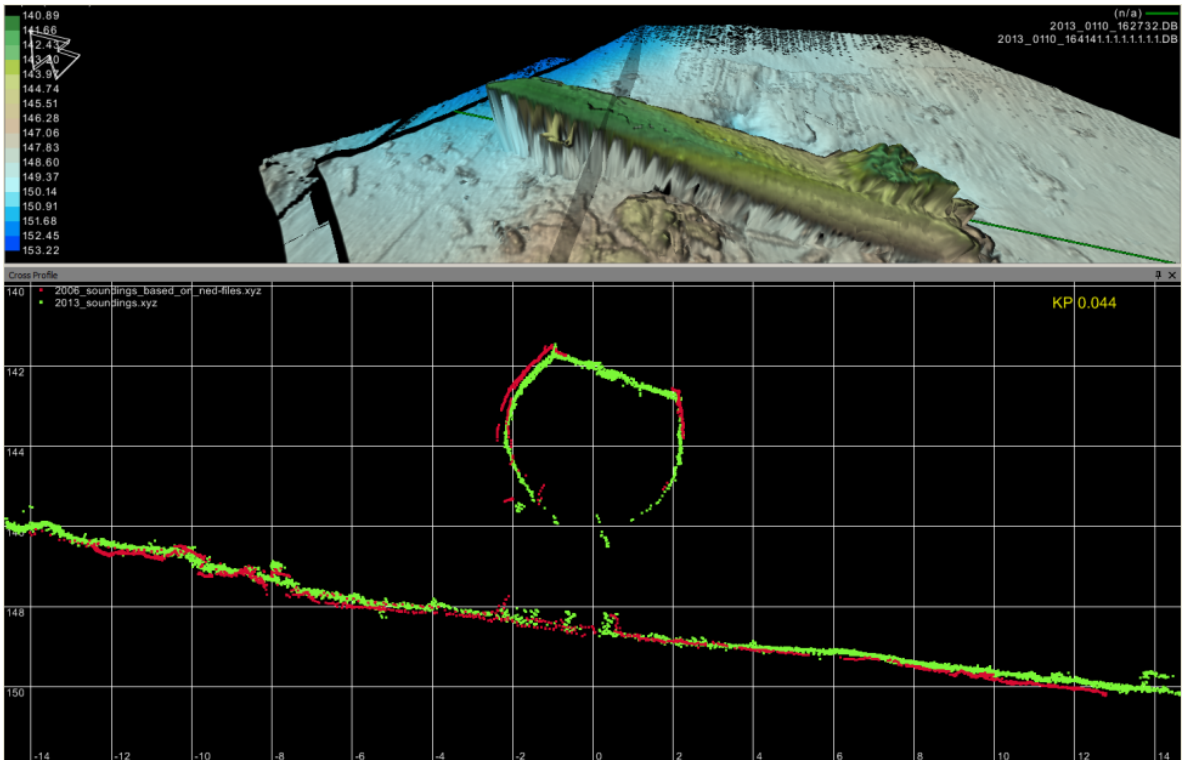



**Figure 4.31** **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

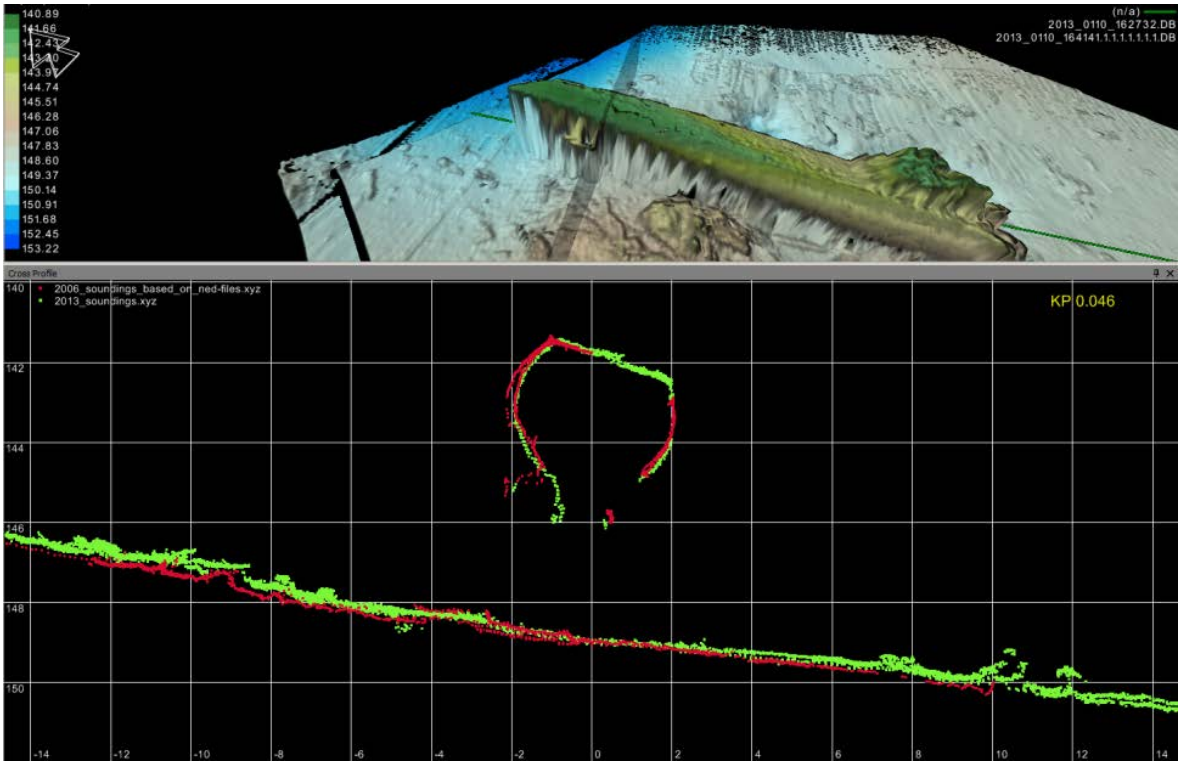



**Figure 4.32** **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

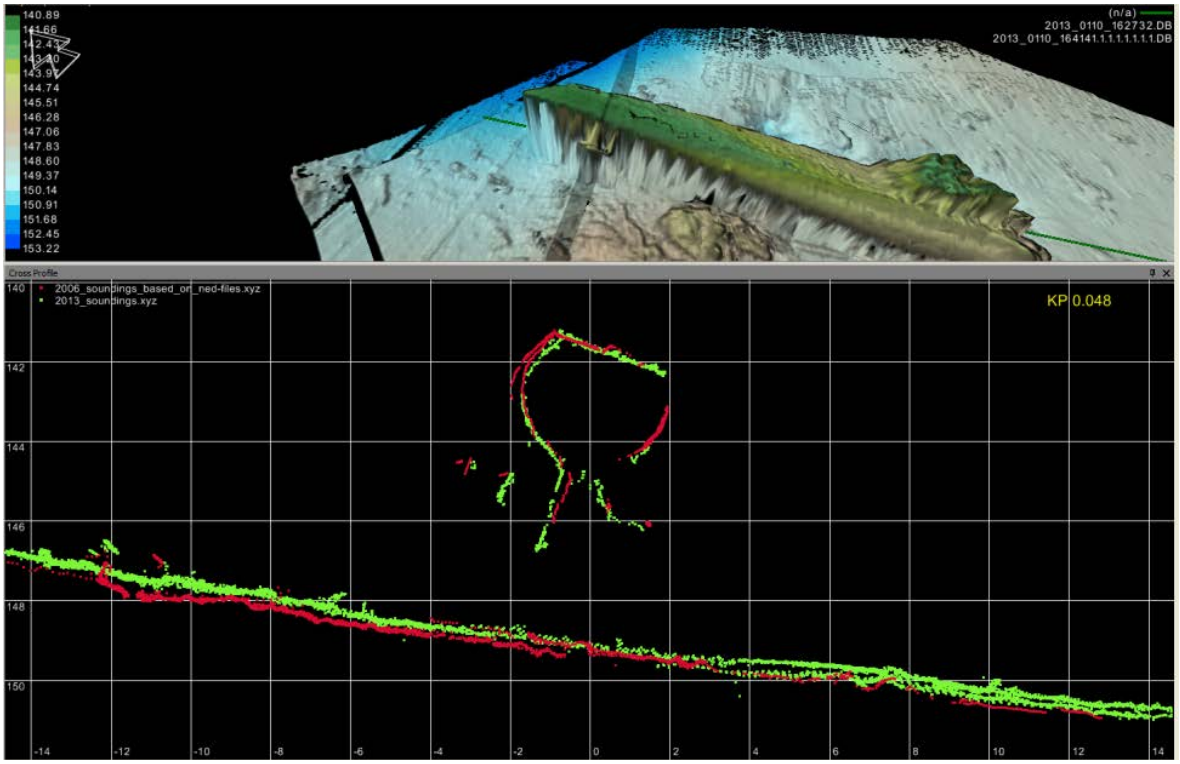



**Figure 4.33** **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

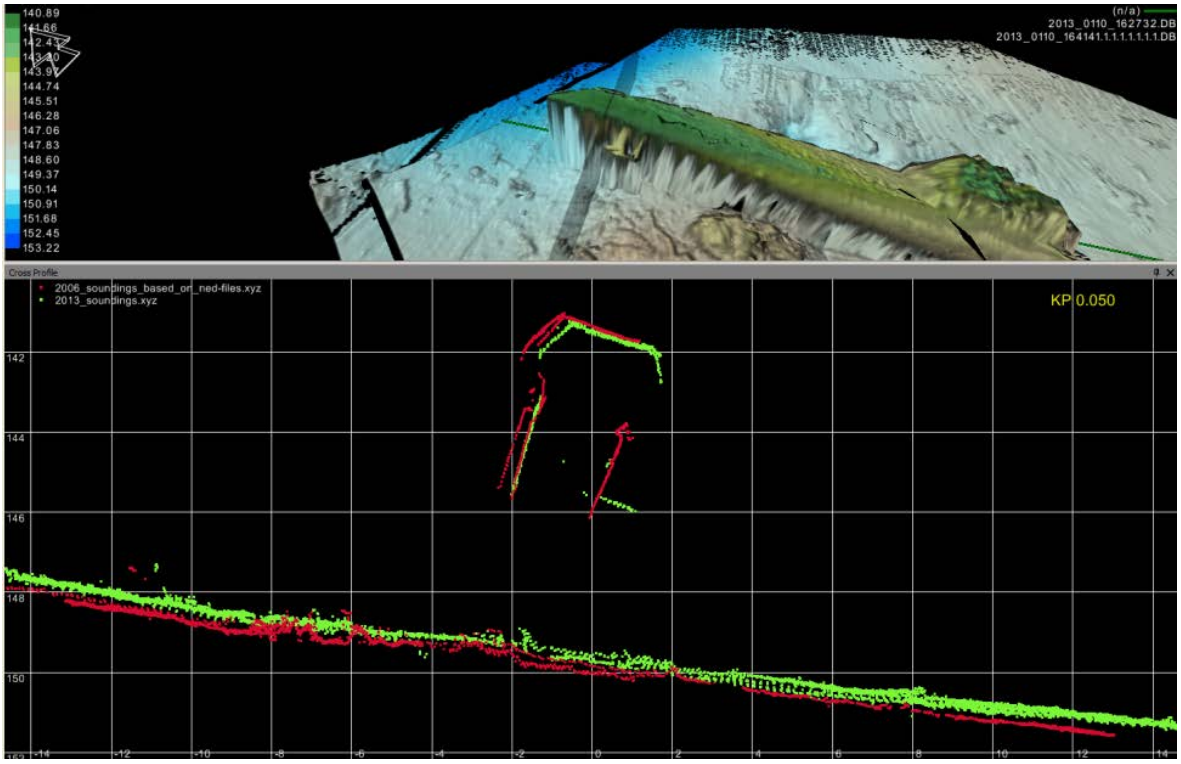



**Figure 4.34** **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location**

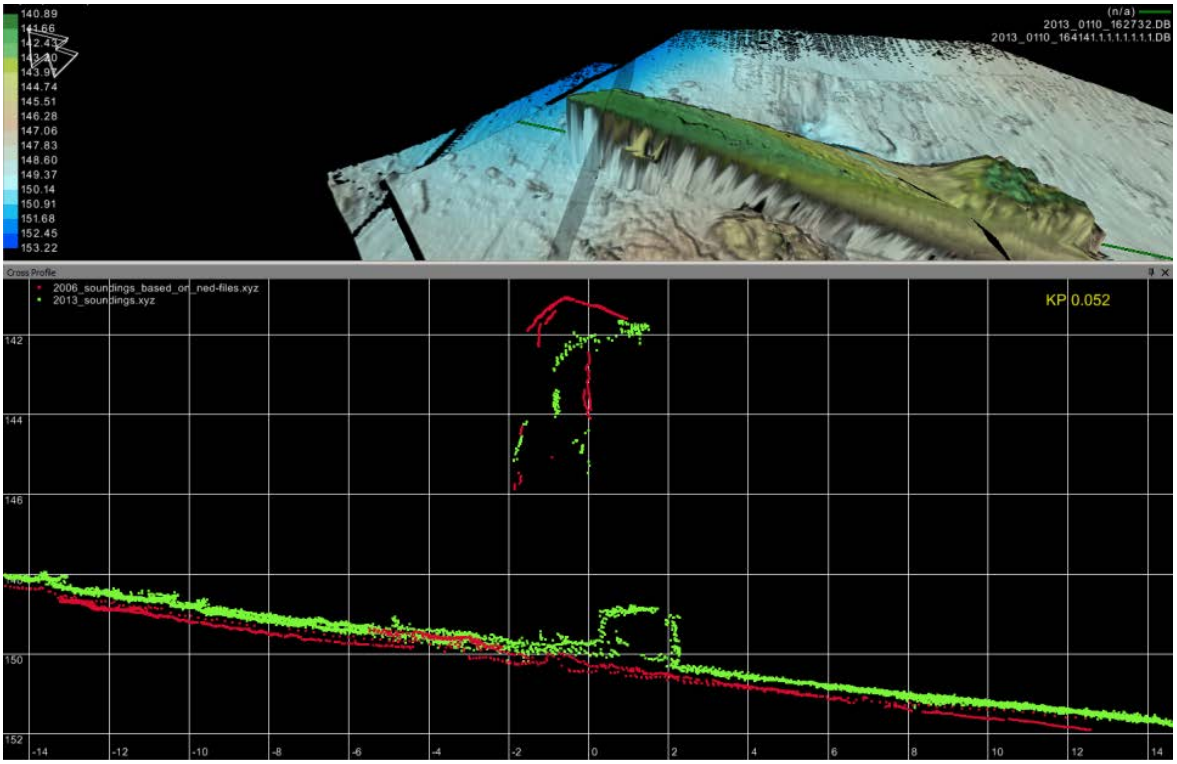



**Figure 4.35** **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location. The fallen stern section can be seen centre of the profile**

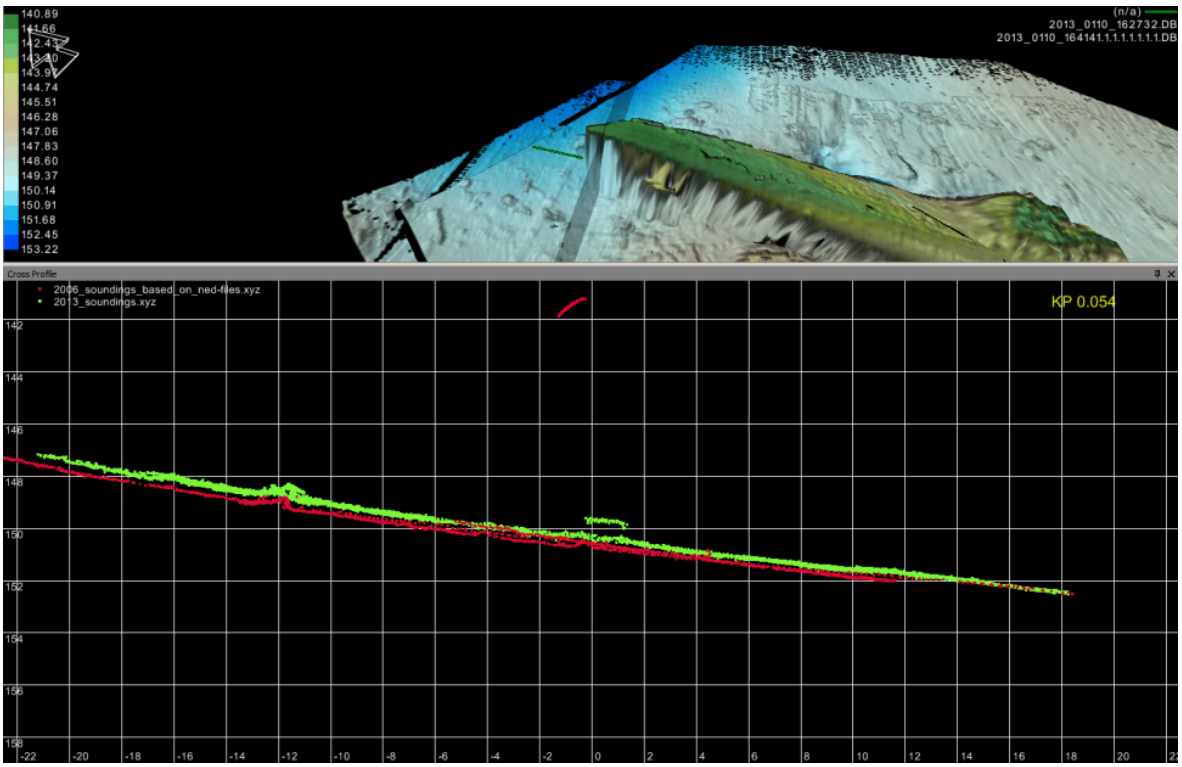



**Figure 4.36** **Comparison of 2006 (red) and 2013 (green). Shaded area in top image shows cross section location. The fallen stern section can be seen centre of the profile**

## 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.

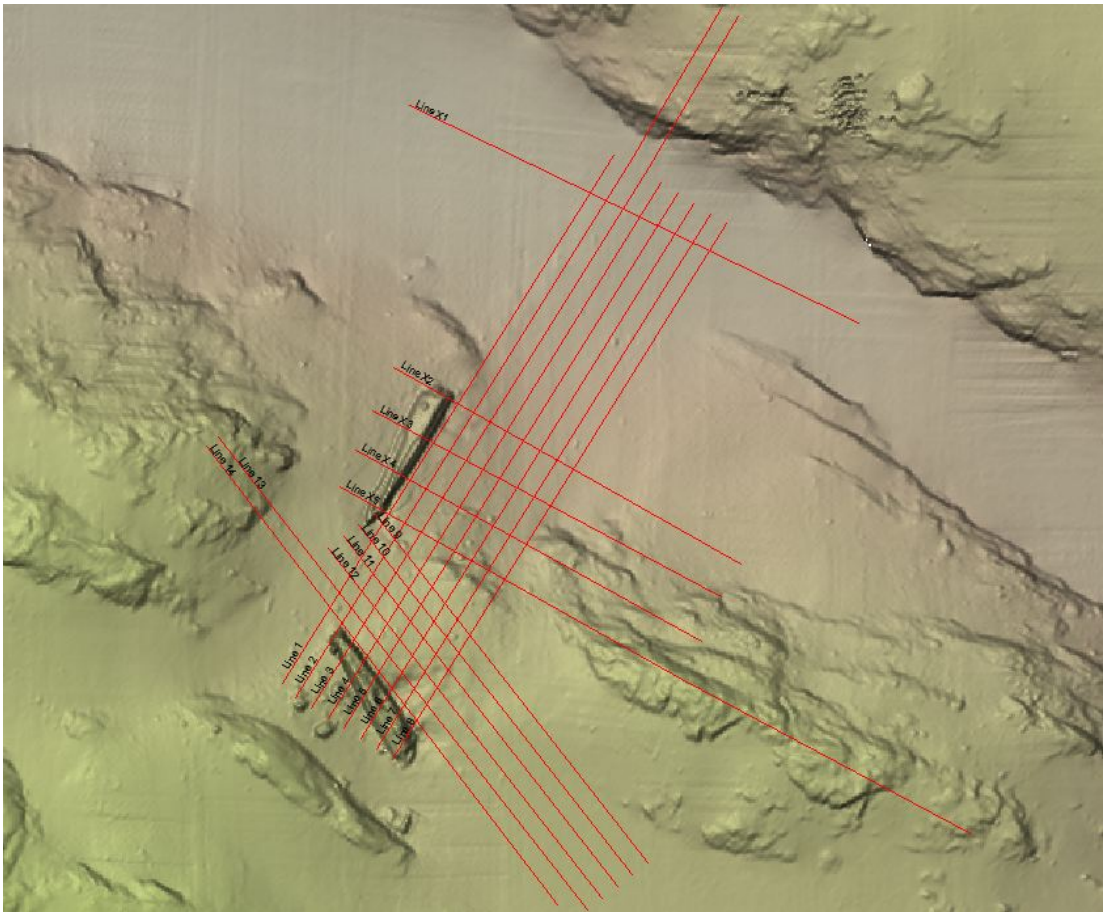



**Figure 4.37**

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/).

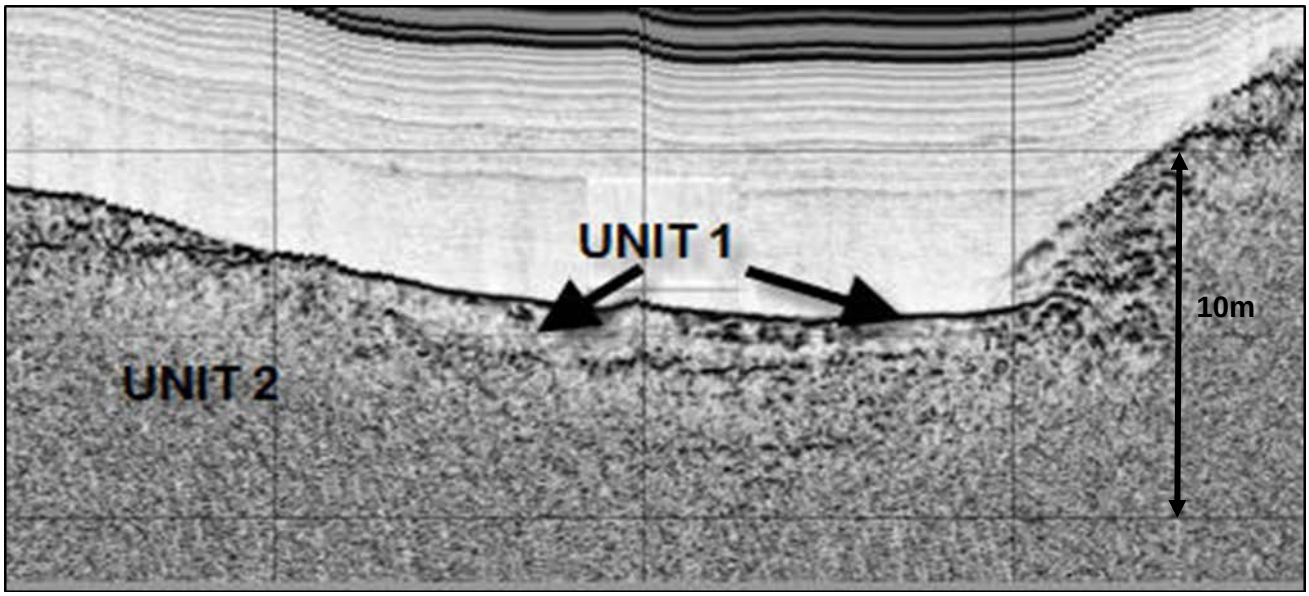



**Figure 4.38 SBP data example from Line 8, showing Unit 1 & 2**

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.

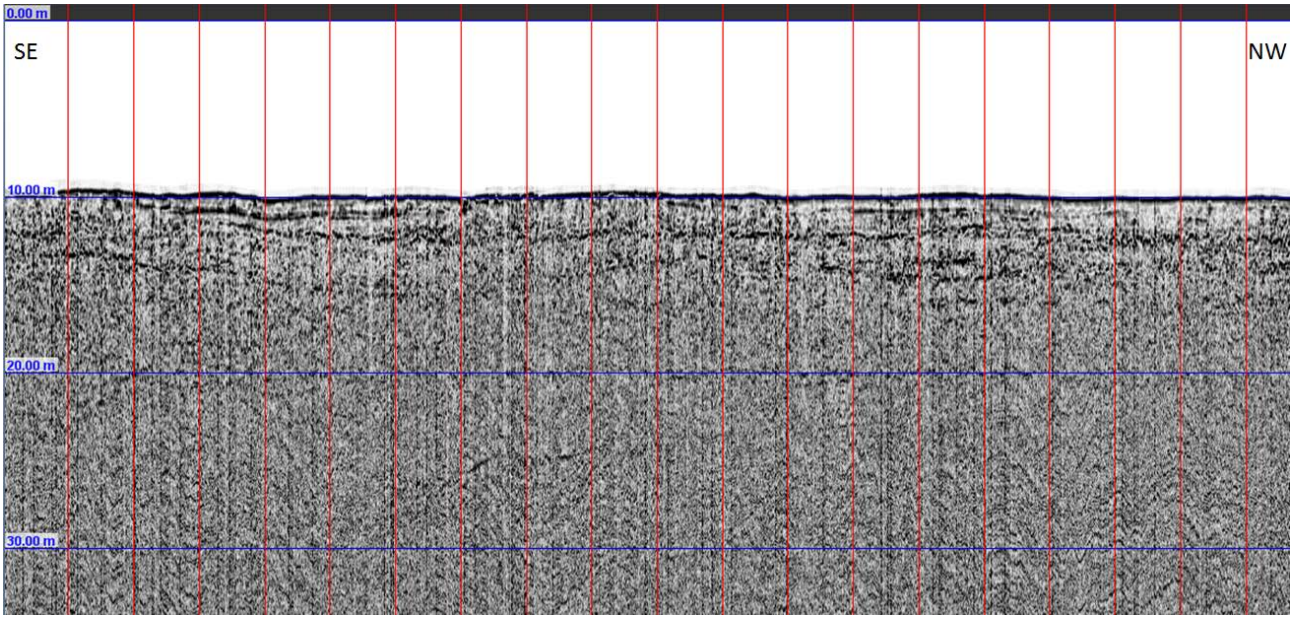



**Figure 4.39 SBP line X1, vertical and horizontal scale lines 10m**

## 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).

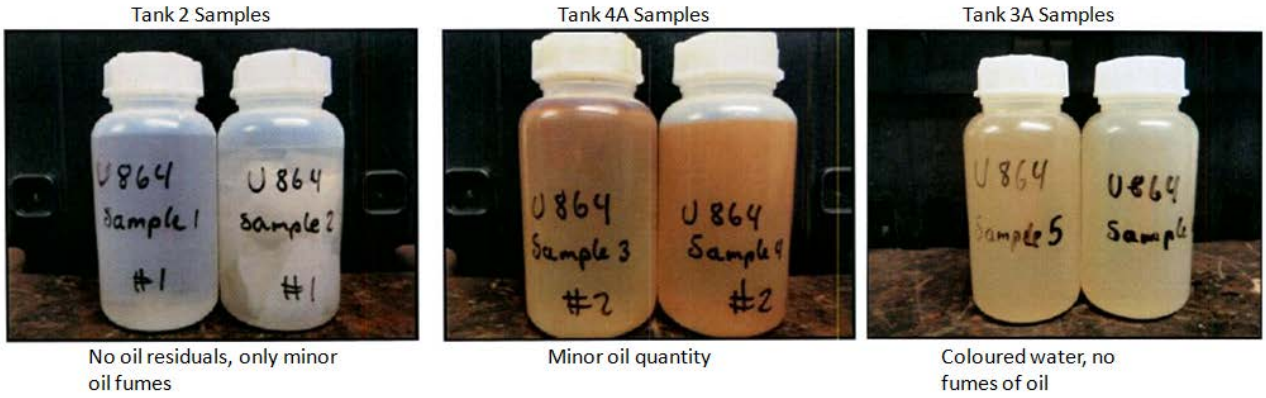



**Figure 4.40 Oil recovery samples (ref /5/)**

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 cassing 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 cassing section |

| ID1<br>Project name | ID2<br>P-line | ID3<br>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<br>Project name | ID2<br>P-line | ID3<br>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<br>Project name | ID2<br>P-line | ID3<br>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<br>Project name | ID2<br>P-line | ID3<br>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<br>Project name | ID2<br>P-line | ID3<br>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<br>Project name | ID2<br>P-line | ID3<br>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<br>Project name | ID2<br>P-line | ID3<br>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<br>Project name | ID2<br>P-line | ID3<br>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<br>Project name | ID2<br>P-line | ID3<br>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.

DOF subsea
delivering solutions at any depth

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.

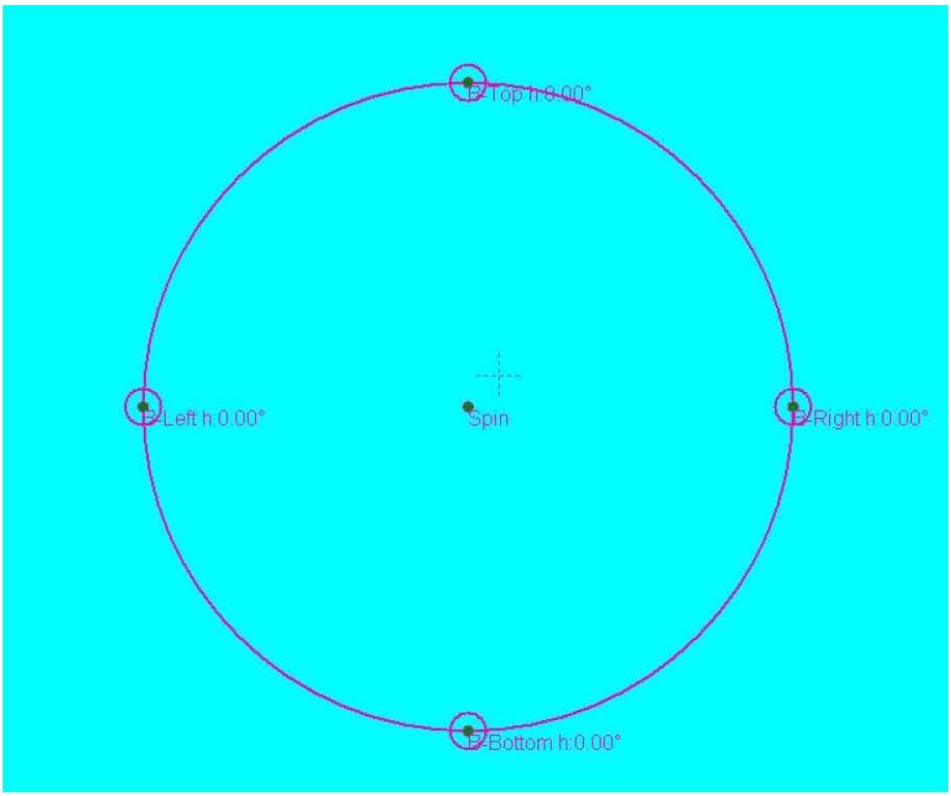



**Figure 1** **Prelim HiPAP boxin at Bunnpunkt (Heading can change to suit weather)**

## 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

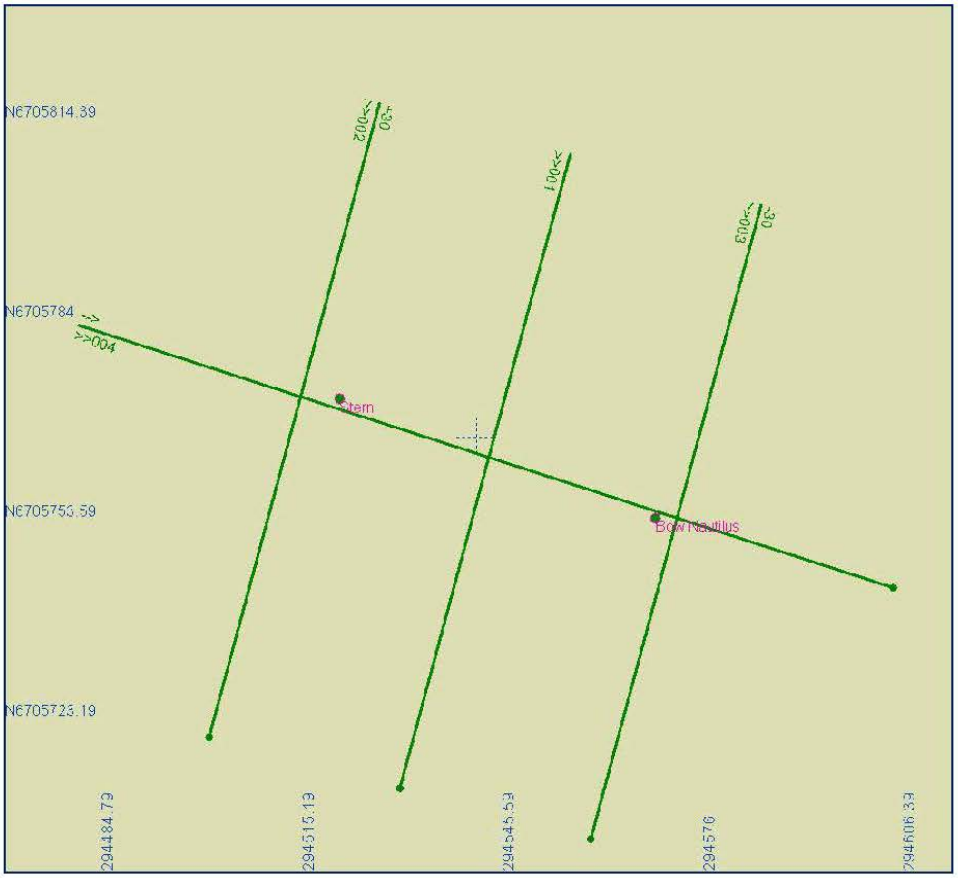
### Gereral Preparations:

| # | 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.

## 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 |

## 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:**

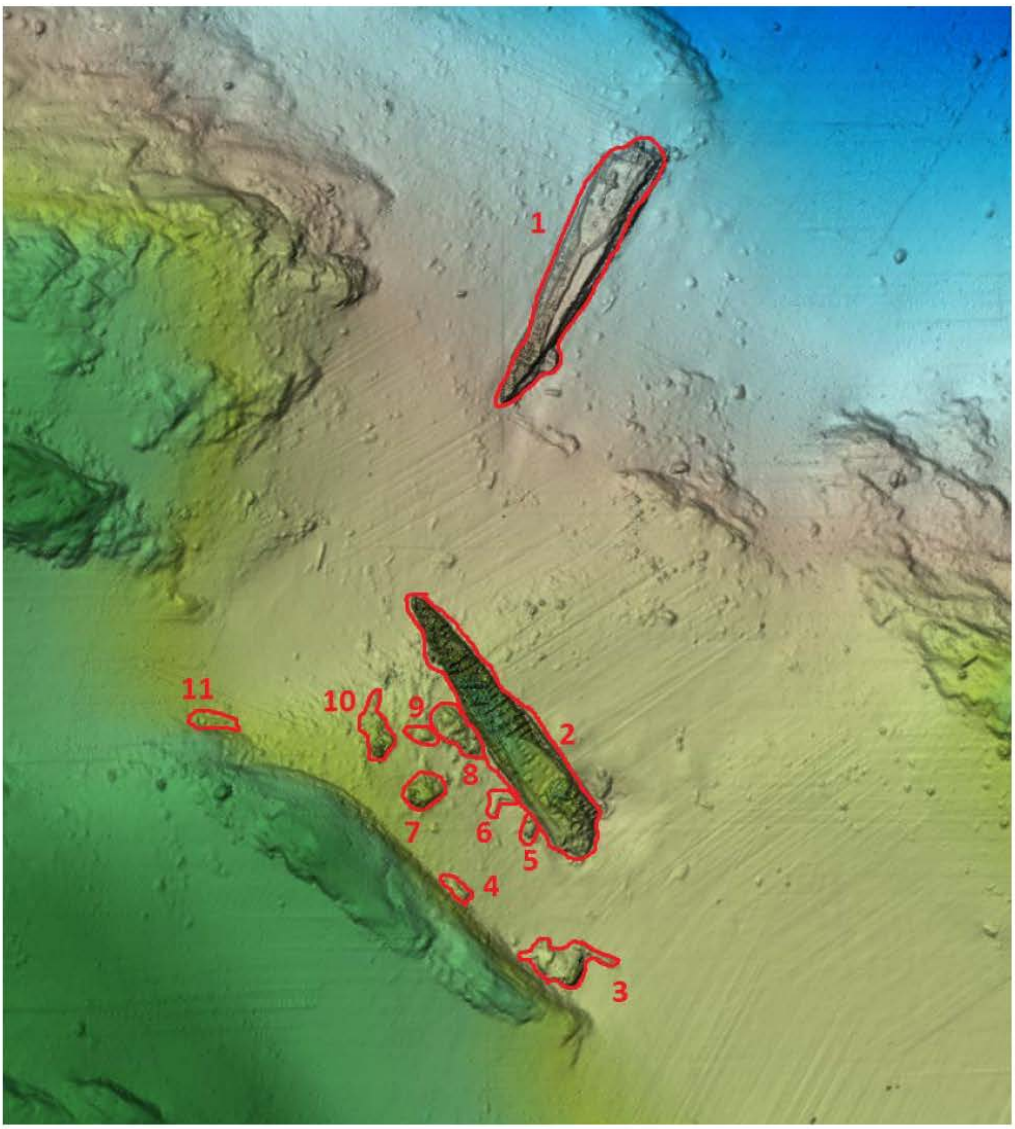
| # | Description | Responsible |
|---|---|---|
| 1. | Prior to all activities, a full QC check of the online systems will be completed and documented | |
| 2. | Prepare XLX27 and conduct pre dive checks | Surv/ROV |
| 3. | CTD to be updated in APOS | Surv |
| 4. | Balance lighting, set up cameras and 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.

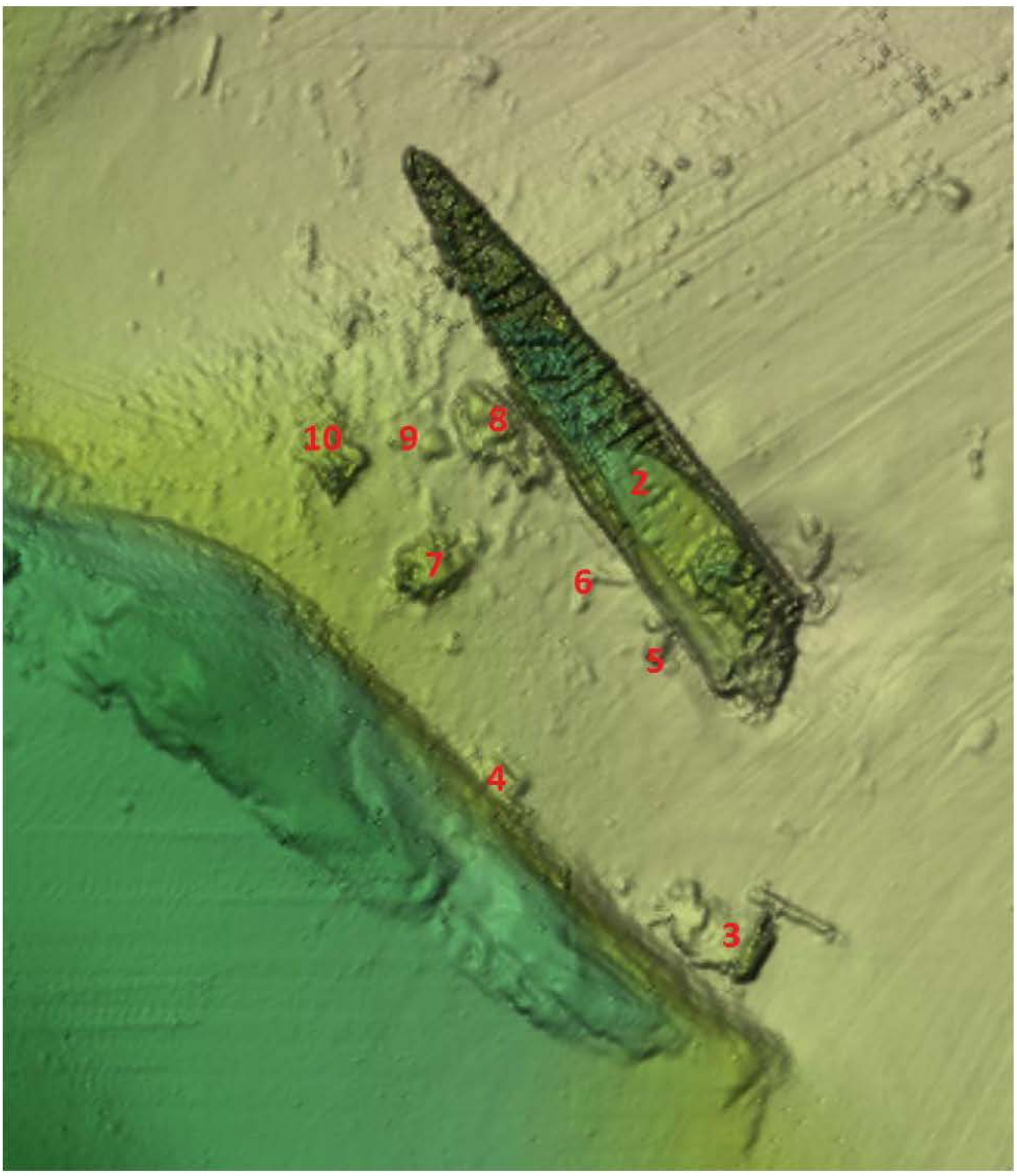
**Any sighting, or possible sighting, of human remains, live ammunition, mercury containers or leaking oil should immediately be notified to the VR. Do not assume they have seen it!**

**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:<br>Outside the pressure hull: 12 stored underneath the casing.<br>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**<br>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.<br>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.<br>**Capping**<br>The possibility of a detonation during capping, without a greater external influence, is assessed only to be theoretically possible.<br>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:<br>Outside the pressure hull: 32 by the 105 mm cannon.<br>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.<br>**Salvage**<br>Should be kept wet until they are removed from the wreck, and kept wet until moved to the deposit site.<br>It is assessed that the risk concerning 37 mm ammunition is insignificant when salvaging.<br>**Capping**<br>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**<br>Should be kept wet until they are removed from the wreck, and kept wet until moved to the deposit site.<br>It is assessed that the risk concerning 20 mm ammunition is insignificant when salvaging.<br>**Capping**<br>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**<br>Demolition charges are safe to handle when salvaging or capping.<br>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**<br>Small arms ammunition safe to handle when salvaging or capping.<br>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.<br>**Salvage**<br>If salvaged, avoid drying. The longer the submarine is stored in a dry environment, the more sensitive the grenade will be.<br>It is assessed that the risk concerning stick grenades are insignificant when salvaging.<br>**Capping**<br>It is assessed that the risk concerning stick grenades are insignificant when capping. |

## 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) |

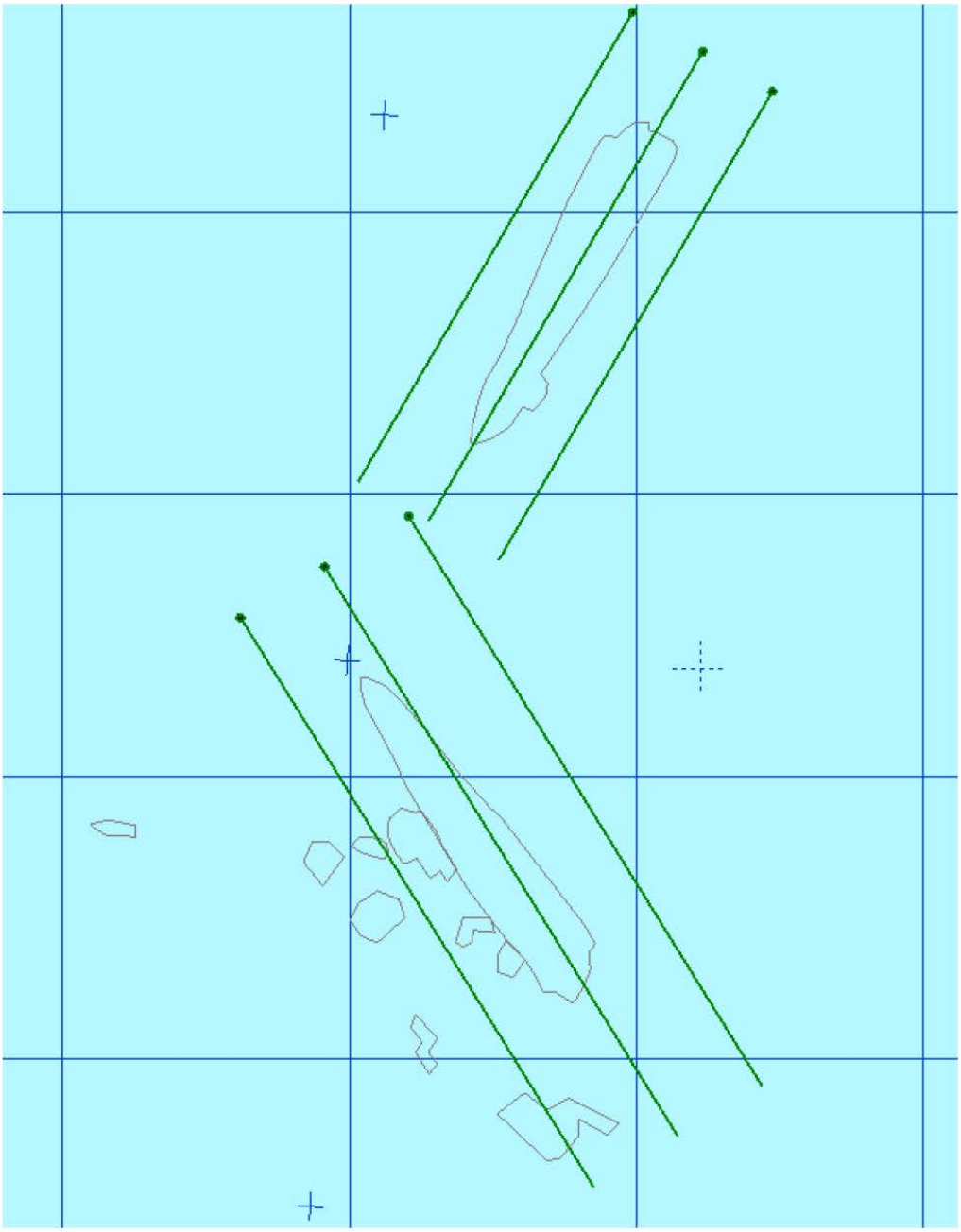
**Consider reducing power over the wreck to prevent ringing**

**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 |



## 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 |

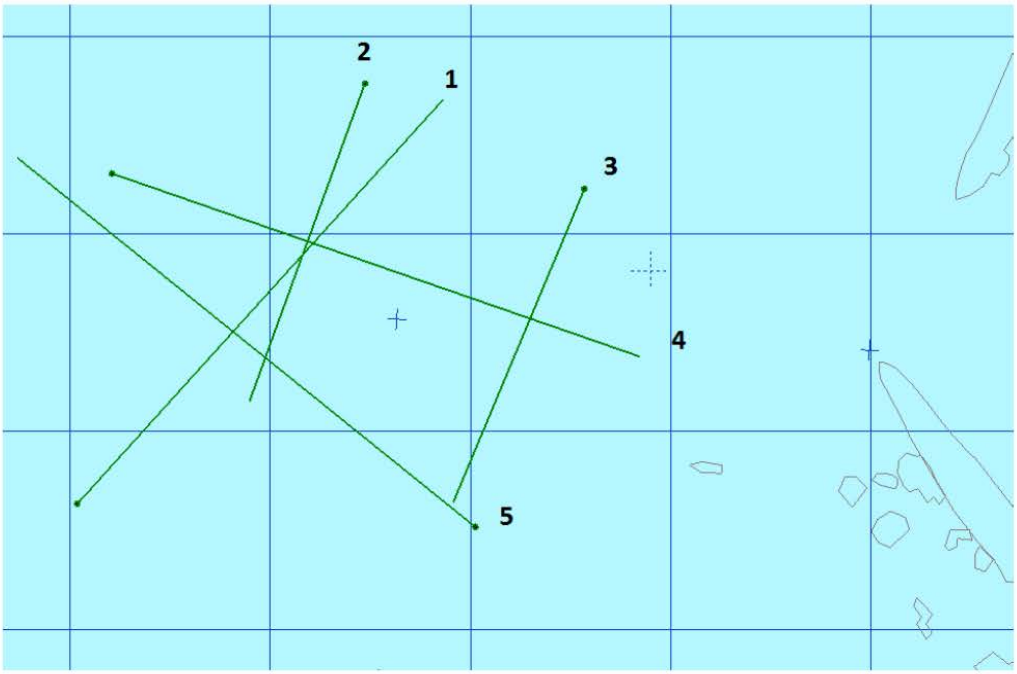
**Gereral Preparations:**

| # | 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 |

| | | |
|---|---|---|
| 7. | **Line 1** | S – N 1.5kt (faster if possible) |
| 8. | **Line 2** | N – S 0.7kt |



## 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"

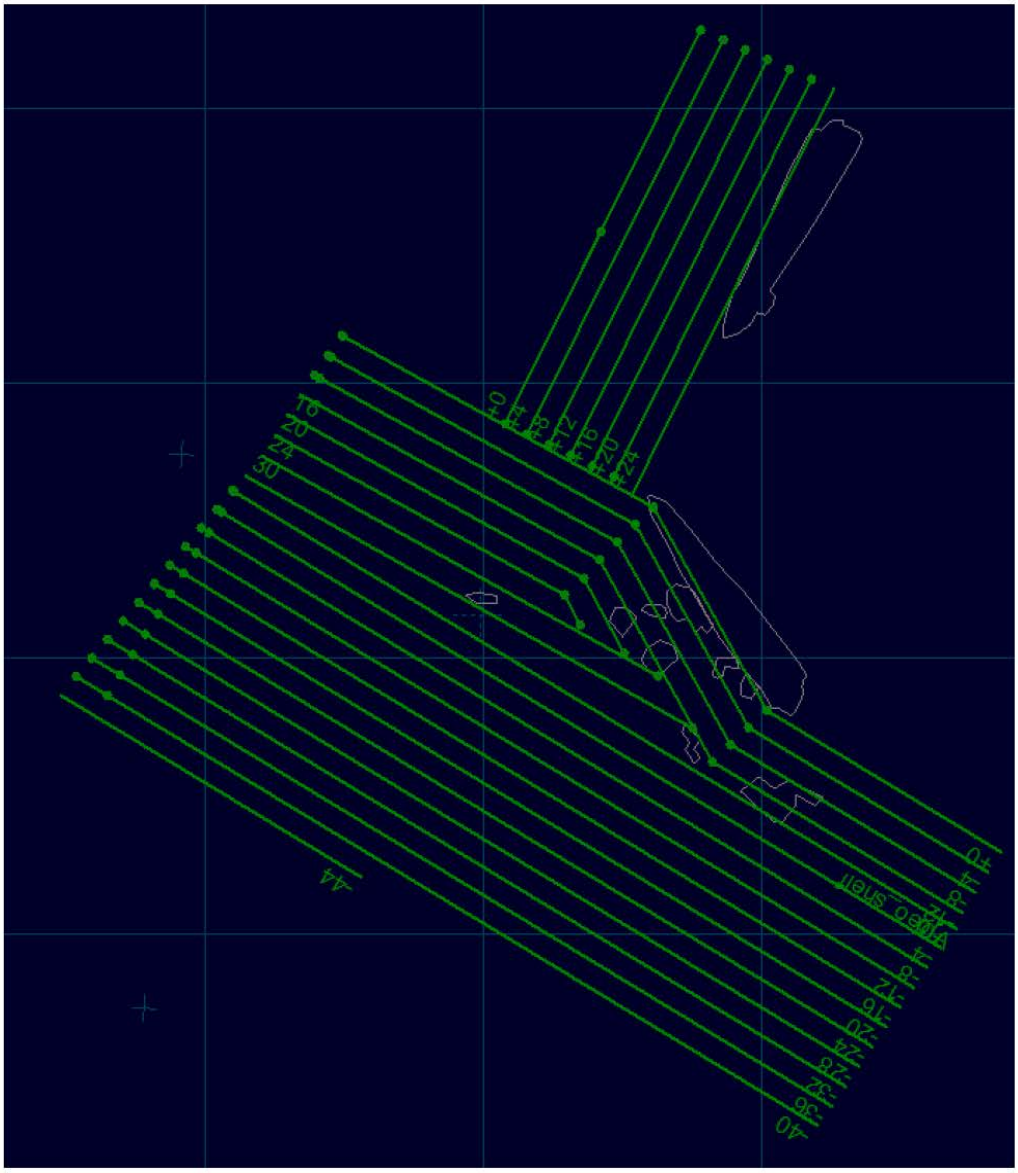
**Gereral Preparations:**

| # | 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.**



## 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:<br>P:\SSKO_Active\SSKO_600225\SSKO_SUR\SSKO_SUR_Online<br>**Priority 1a_Re_Evaluated Areas**<br>**Priority 1b_New_Areas**<br>**Priority 2 Wreck Gravity Core Samples**<br>**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.**

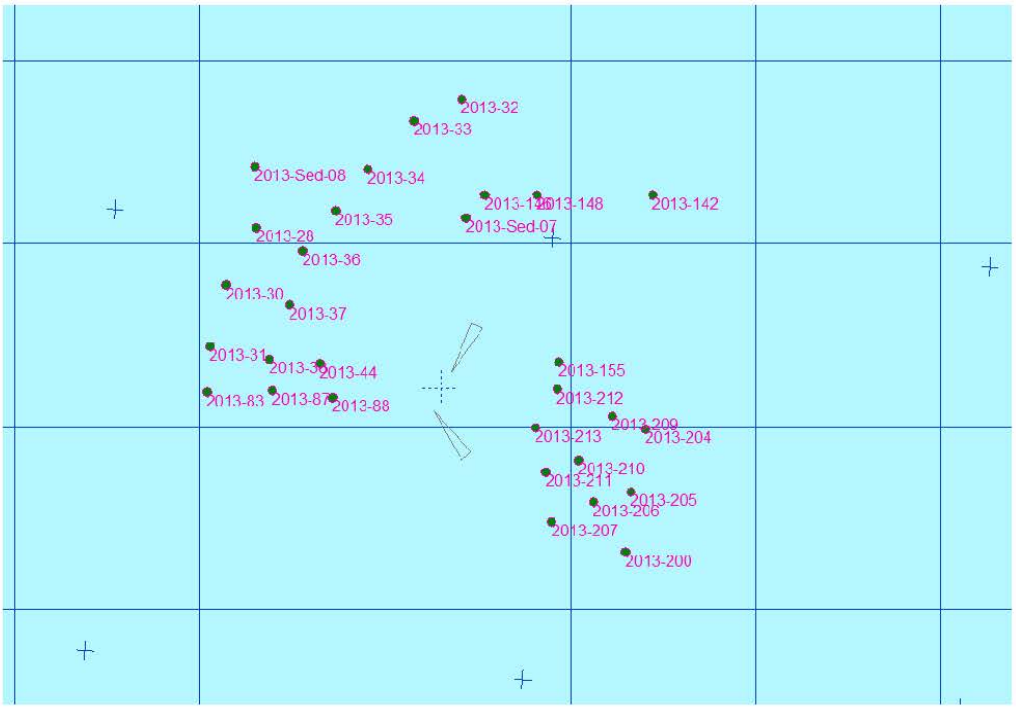
**ROV Soils Sampling**

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

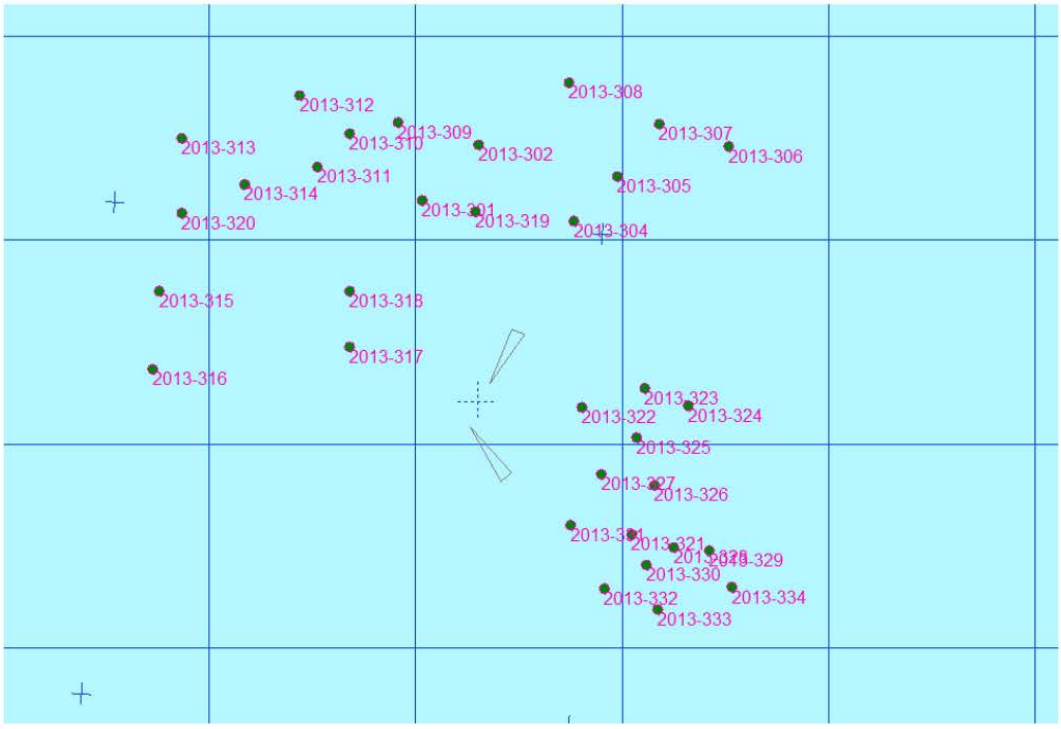



New locations

| 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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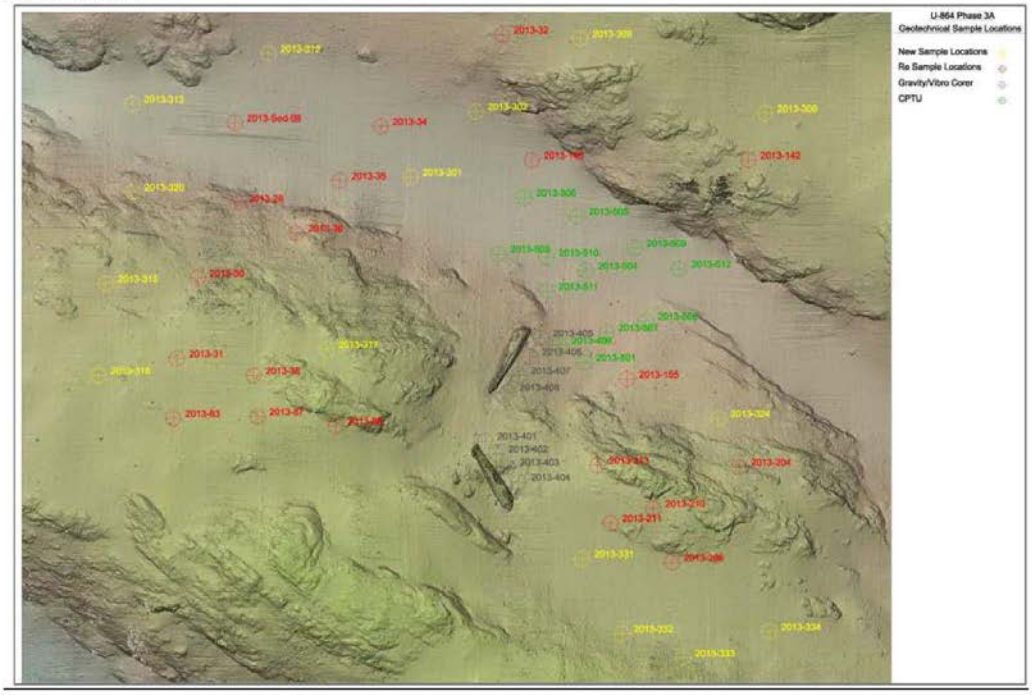
Page 6 of 6

**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**

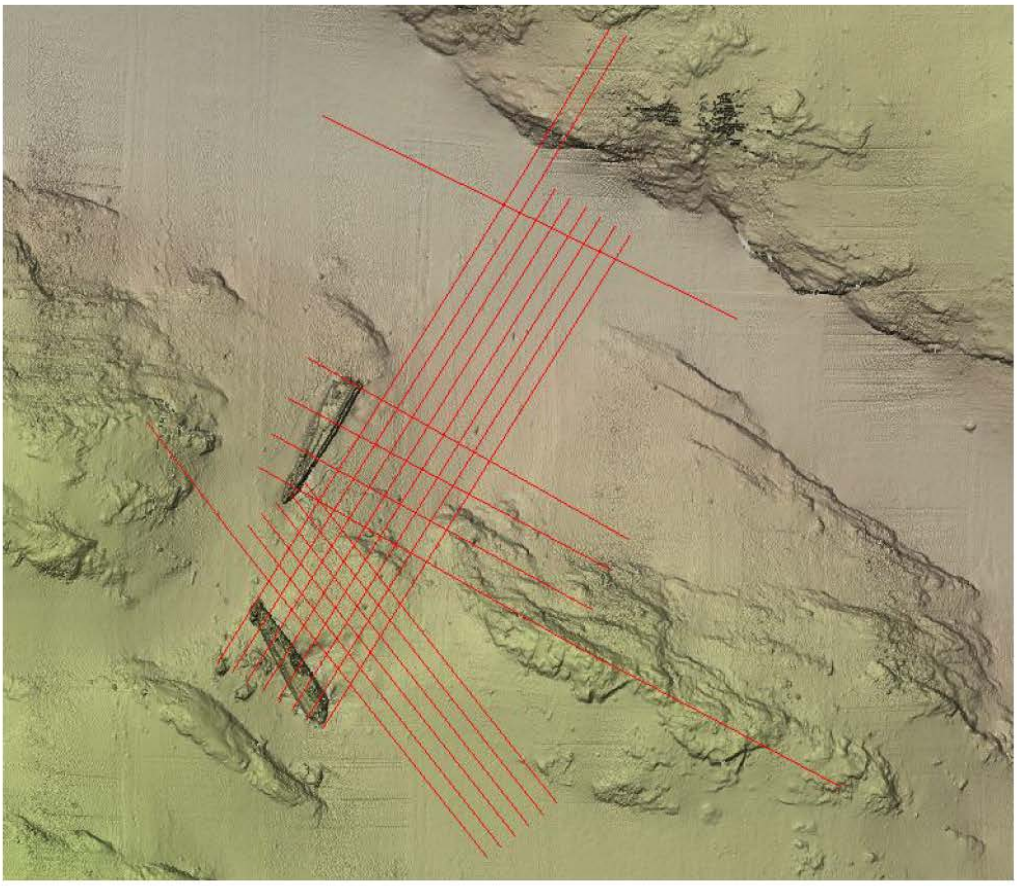
| | | |
|---|---|---|
| Required Logging | : | NP, NS (30min files), HAIN, **CODA** |
| Runline | : | **SBP lines.rlx** in P:\SSKO_Active\SSKO_600225\SSKO_SUR\SSKO_SUR_Online\Runlines |
| Displaylines | : | 864 Outline 2000.DWG |
| Waypoints | : | None |
| SBP Settings | : | To be optimised by Geo's |
| Altitude | : | 10m |
| Speed | : | 0.8- 1.5kt (Achieve high quality data) |

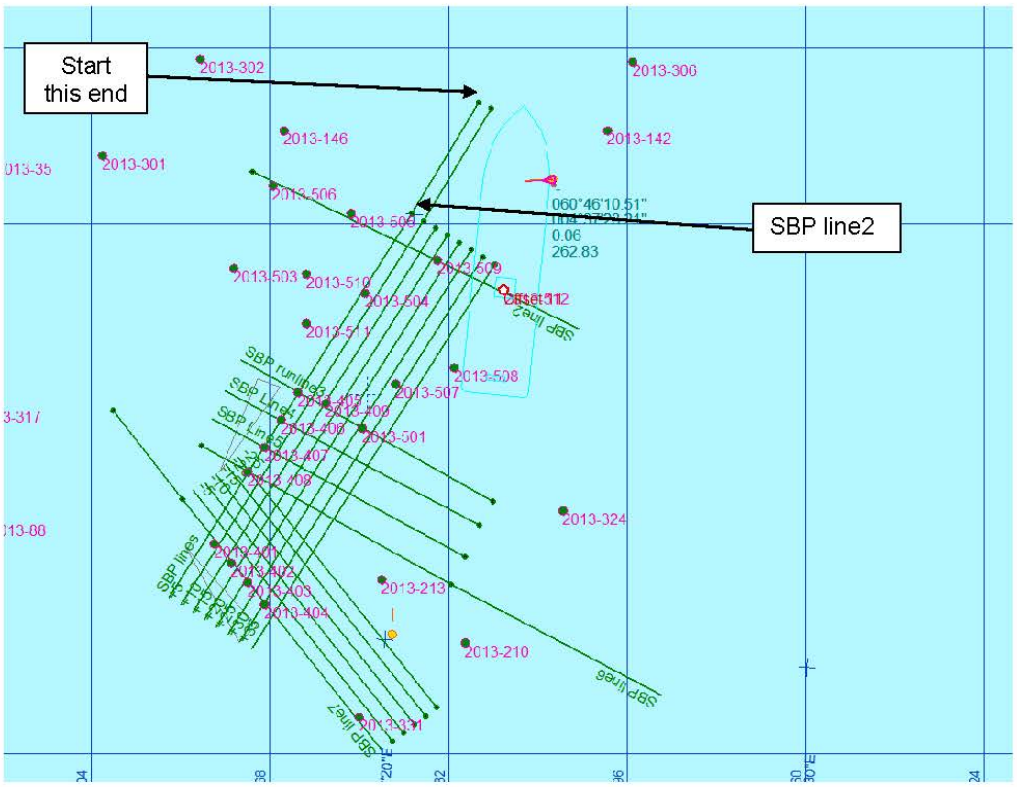
**Gereral Preparations:**

| # | 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 |




Start this end
SBP line2
2013-302
2013-306
2013-146
2013-142
2013-301
2013-506
2013-505
2013-503
2013-510
2013-509
2013-504
2013-511
2013-508
2013-507
2013-405
2013-406
2013-400
2013-501
2013-407
2013-408
2013-324
2013-401
2013-402
2013-403
2013-404
2013-213
2013-210
2013-331
060°46'10.51"
0.06
262.83
SBP lines

## 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.

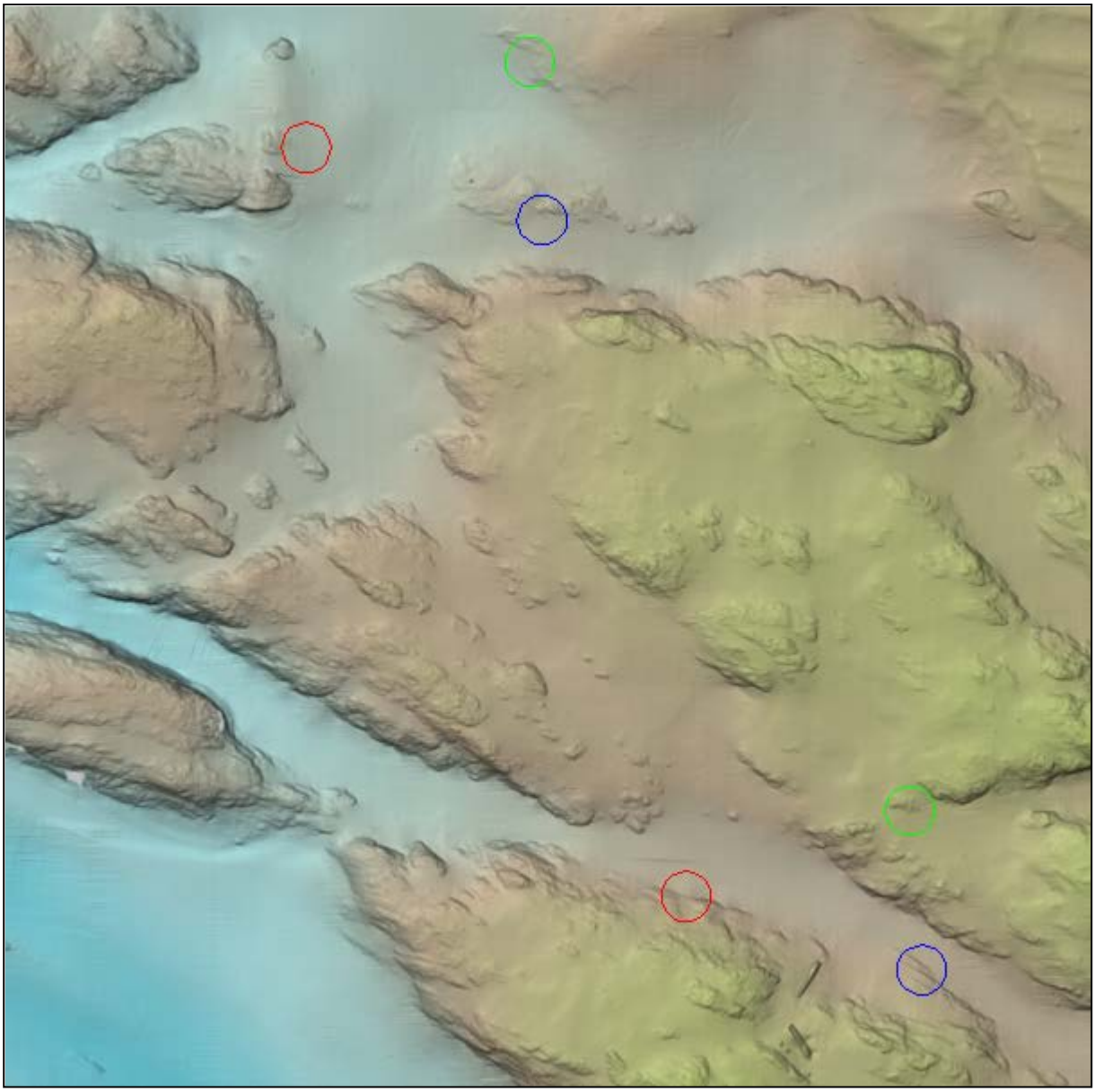
The datum used will vary from area to area (sometimes within the same country) and depends on the use for which the navigation system or chart is designed.

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

DCF subsea
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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 |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| 02 | 10.01.2013 | Issued for Client Comments | MRO | AJO | HKB |
| 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 | | 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
Easting 296627.869
Northing 6700367.853
Scale Factor 0.999600

R.O. : D4
Grid Brg to RO. : 223.8504
Convergence 0
Vessel Heading 0

Target offset
X: 0
Y: 0

ANTENNA : HP
SPHEROID : WGS84
PROJECTION : UTM32N
C.M. : 9°

CLIENT : Kystverket
VESSEL: Skandi Skolten
LOCATION: Dokken
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.

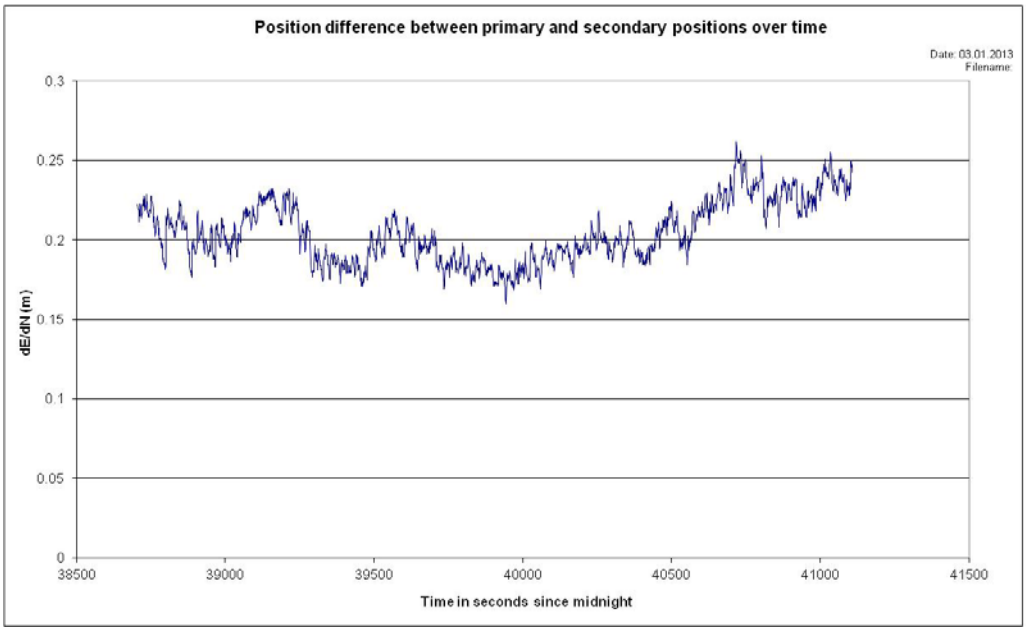



Figure 7-1 Position difference between HP and XP systems, 3rd January 2013

## 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

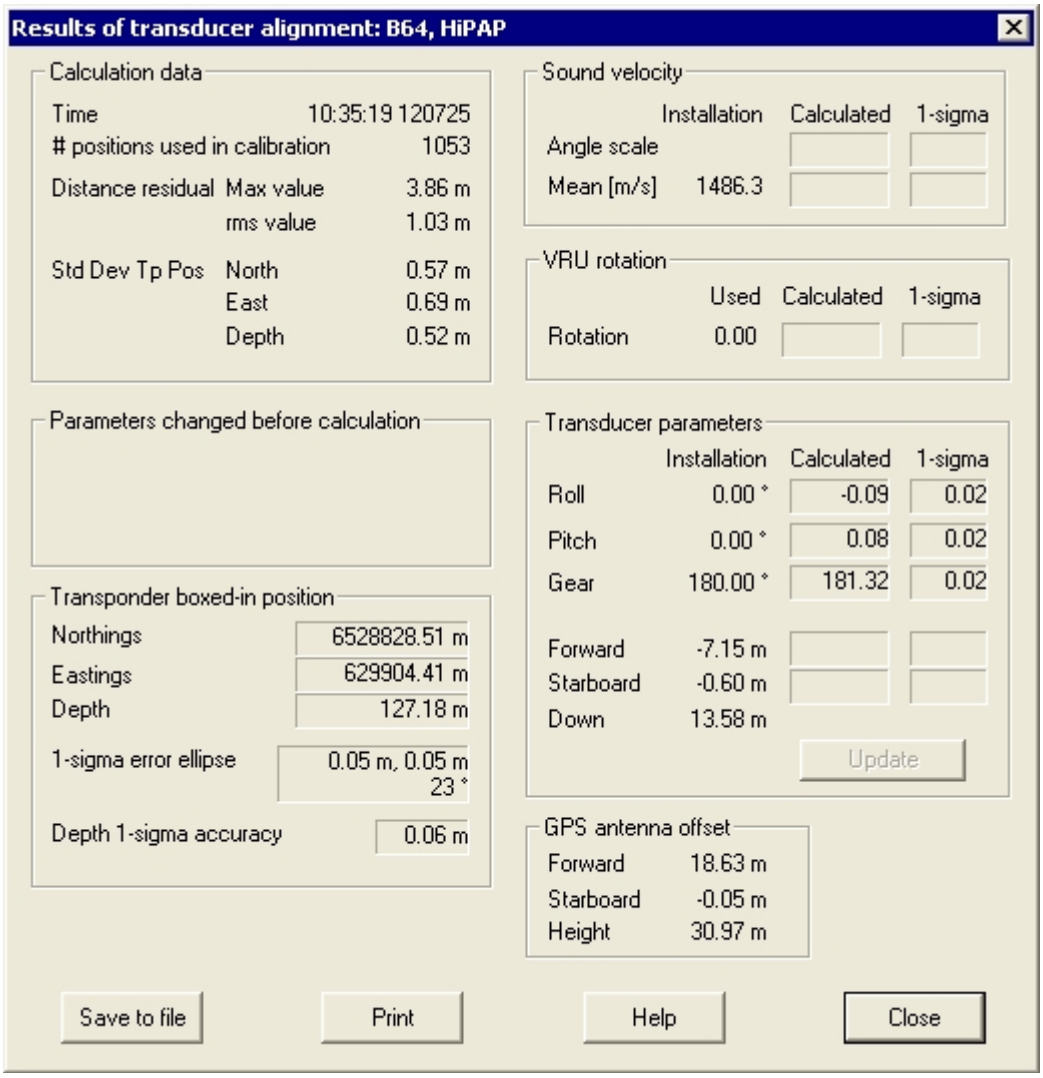



Figure 7-2 HiPAP Calibration results: 23rd July 2012 (existing settings)

### 7.4.3 HiPAP Verification Observations

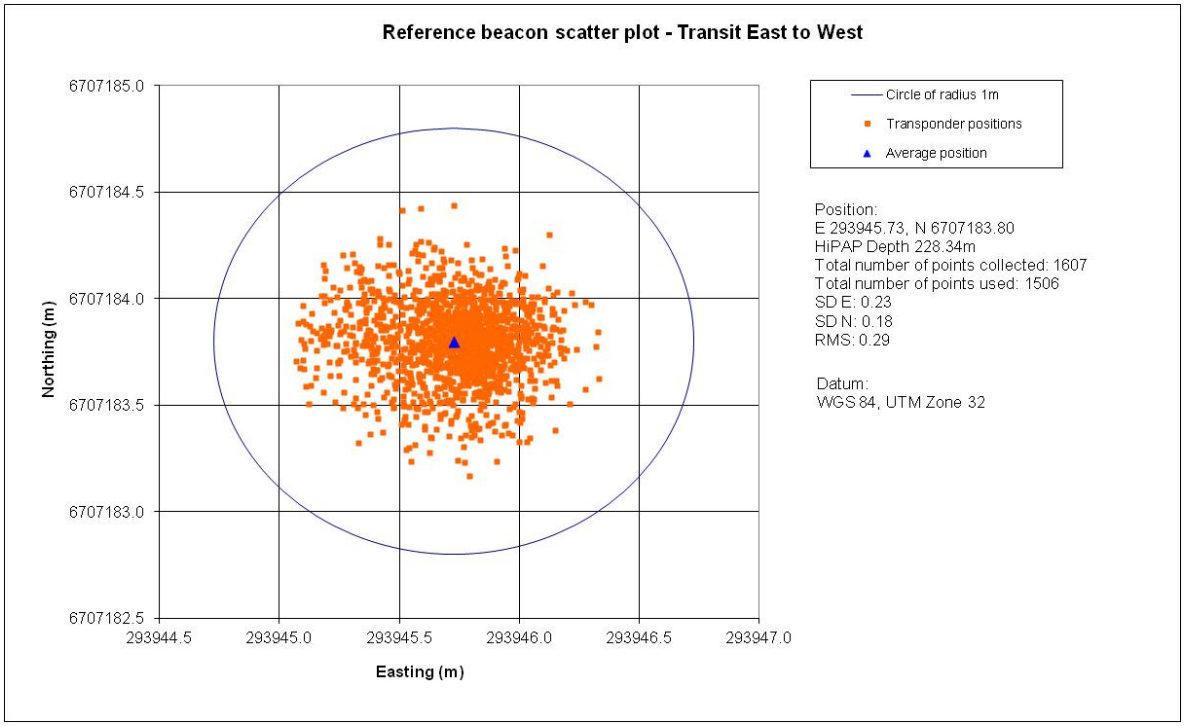



Figure 7-3 HiPAP - Position plot, lateral verification East to West, 4th January 2013

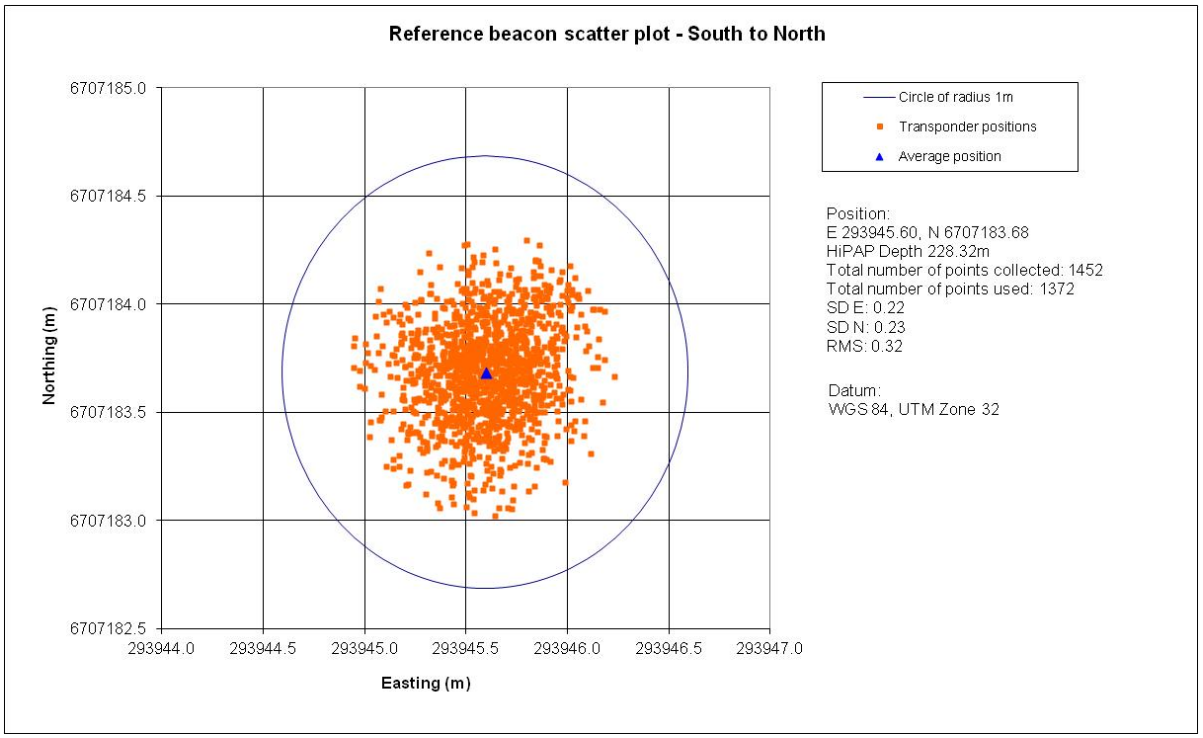



Figure 7-4 HiPAP - Position plot, forward verification South to North, 4th January 2013

### 7.4.4 Sound Velocity Profiles

The speed of sound profile used during the HiPAP calibration is shown below in Figure 7.19

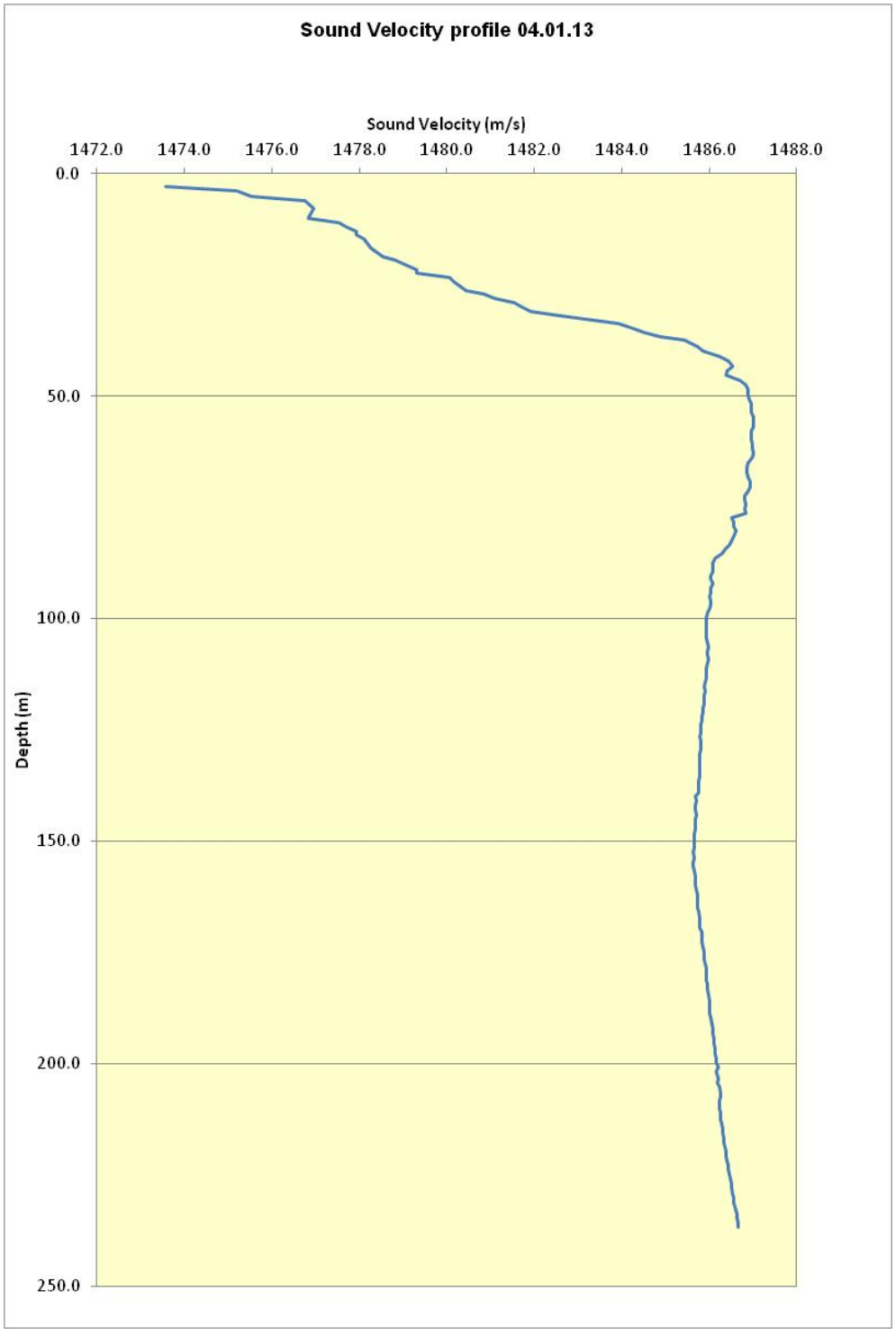



Figure 7-5 Speed of sound profile measured before HiPAP verification 4th January 2013

## 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) |

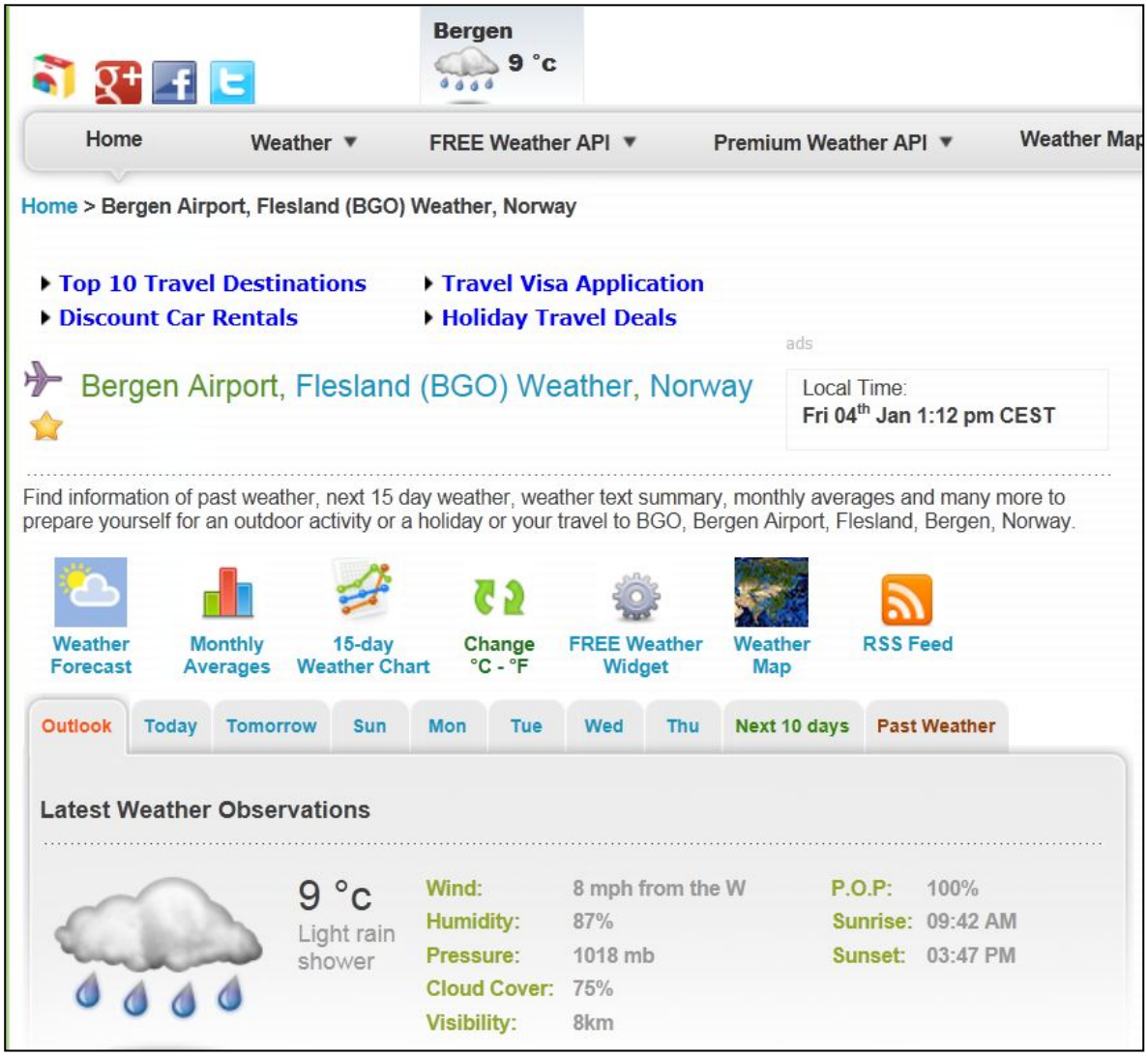



Figure 7-6 Image from World Weather website for Bergen airport.

# 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.

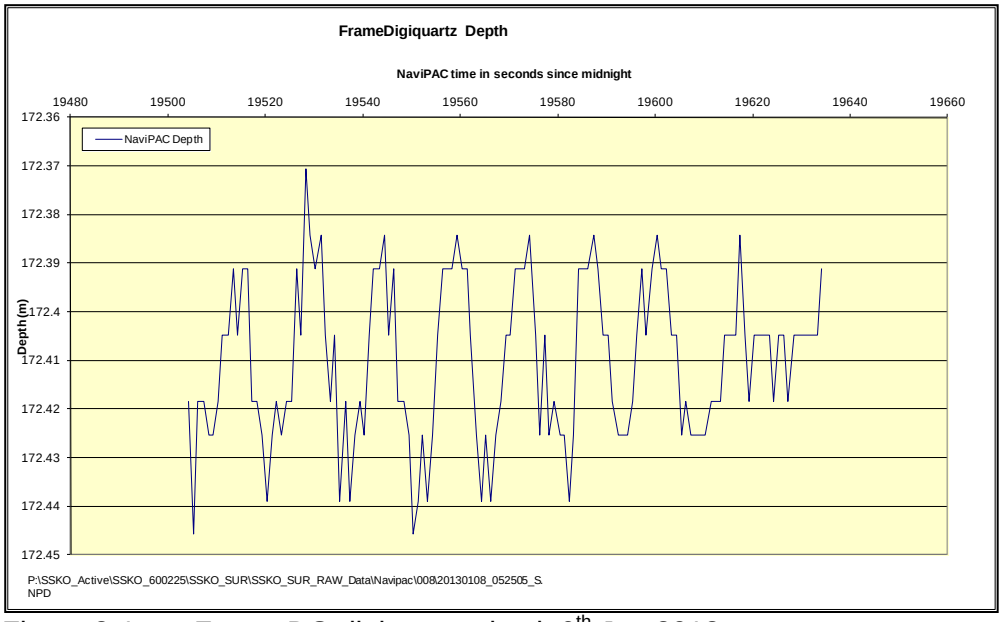



Figure 8-1 Frame DQ digiquartz check 6th Jan 2013

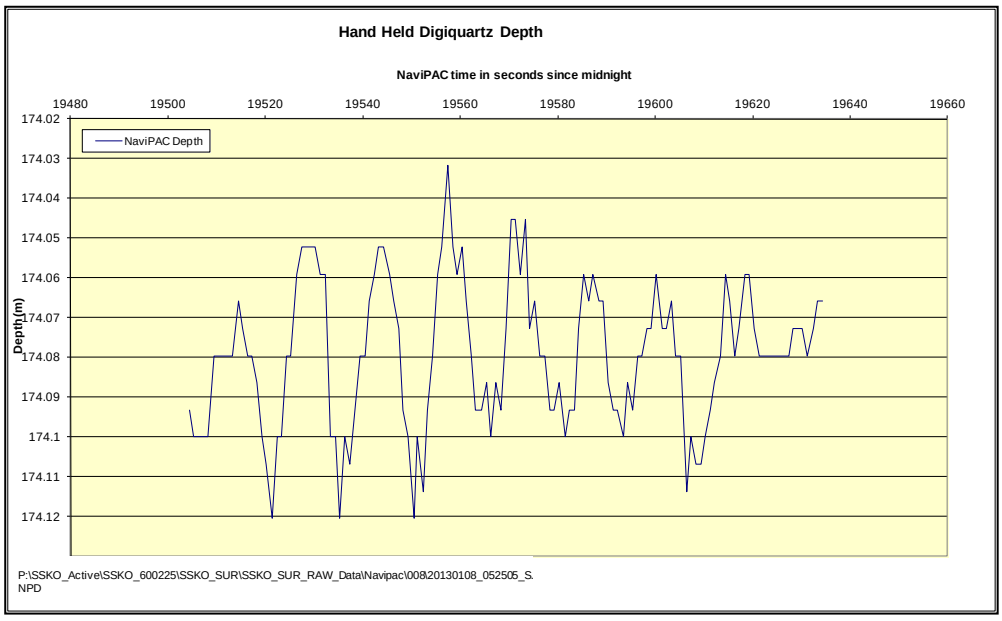



Figure 8-2 Hand Held DQ digiquartz check 6th Jan 2013

## 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.

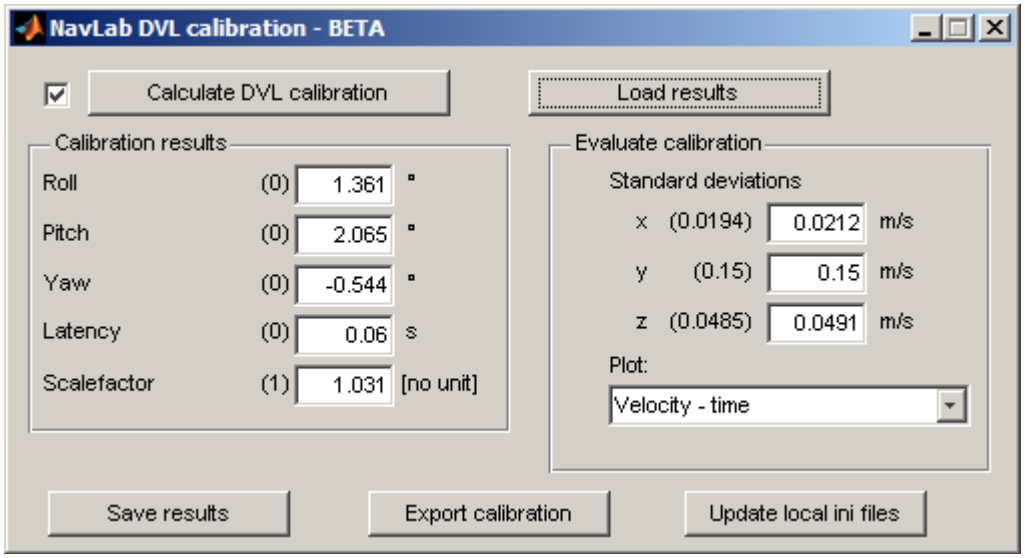



Figure 8-3 DVL calibration results from Navlab DVL Calibration

## 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.

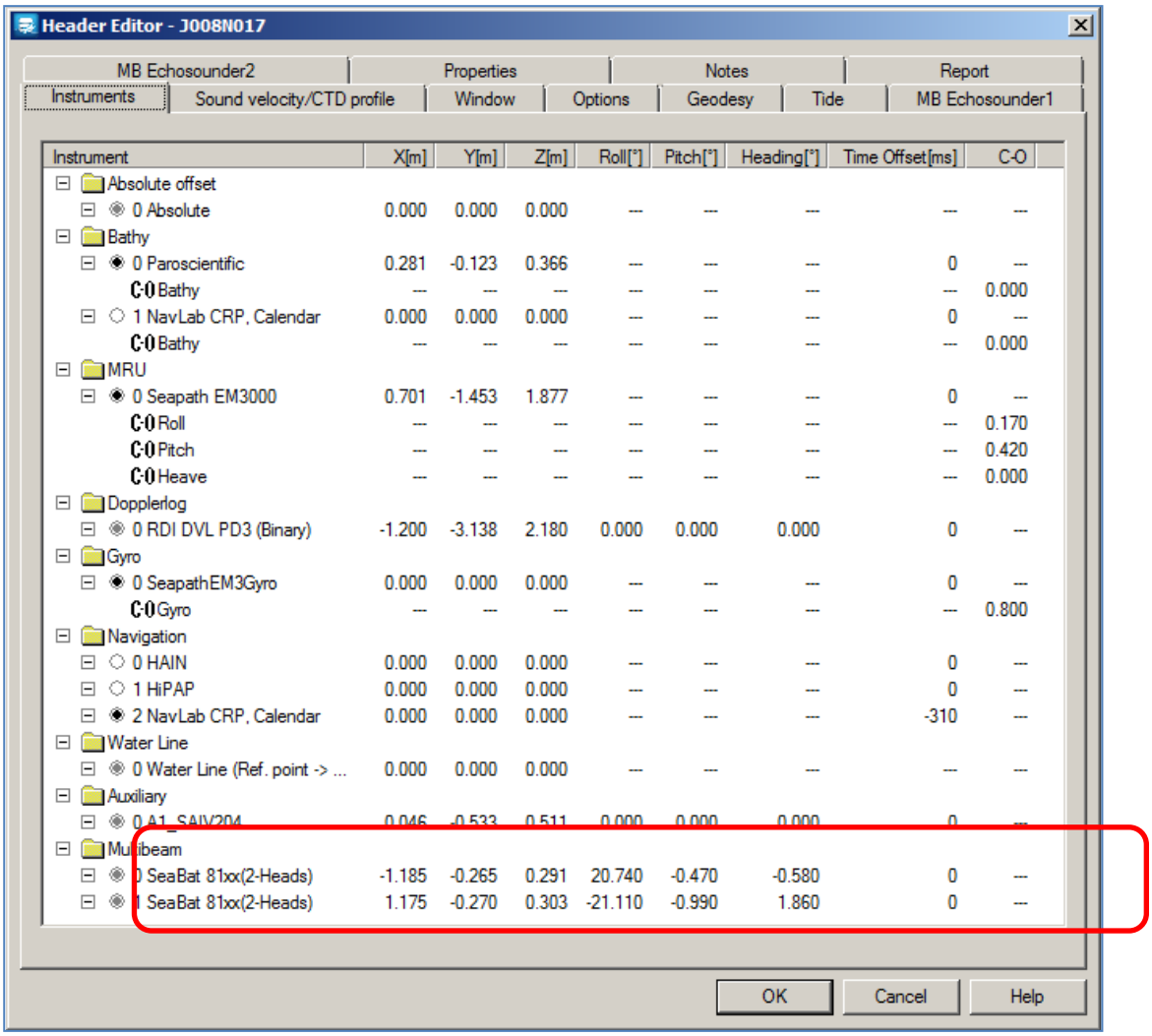
```
#
# Arms.ini, defines the lever arms for the sensors.
# --------  The lever arm is the vector from the ROV / Vessel reference point to the sensor.
#           x is Forward, y is starboard and z is down.
#           x=-0.47 means that the sensor is aft of the reference point.
#
[IMU]
x=-1.453    # 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

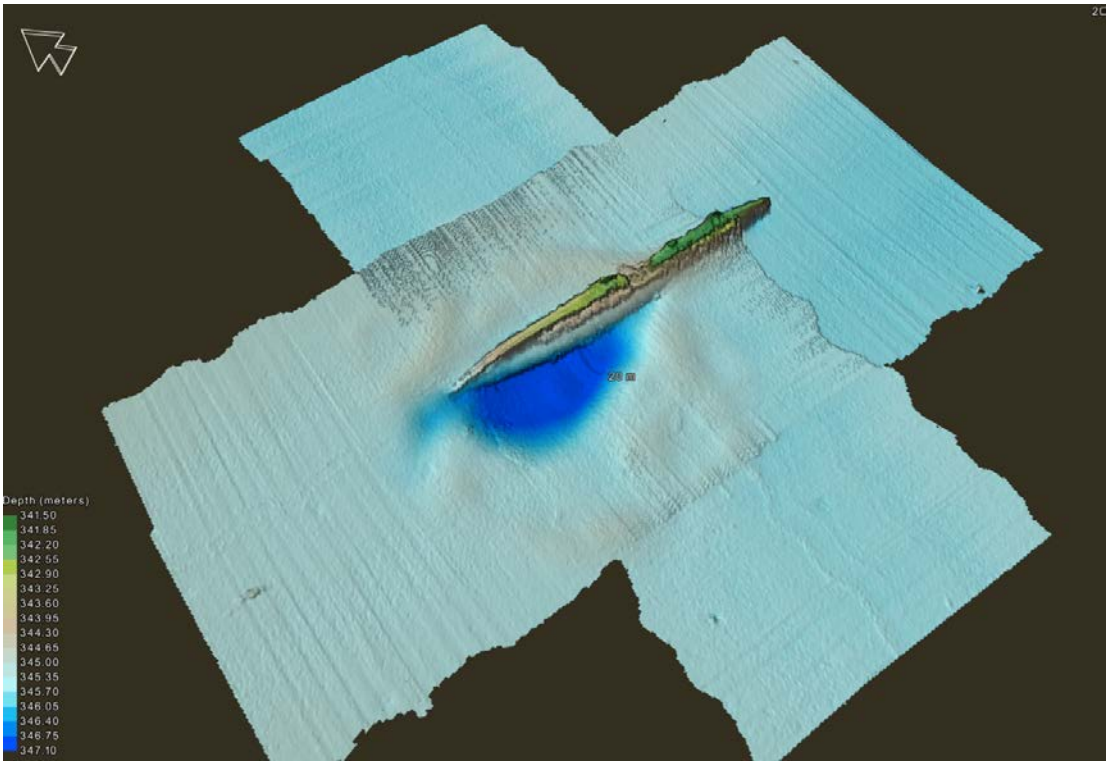



Figure 8-6 DTM before calibration

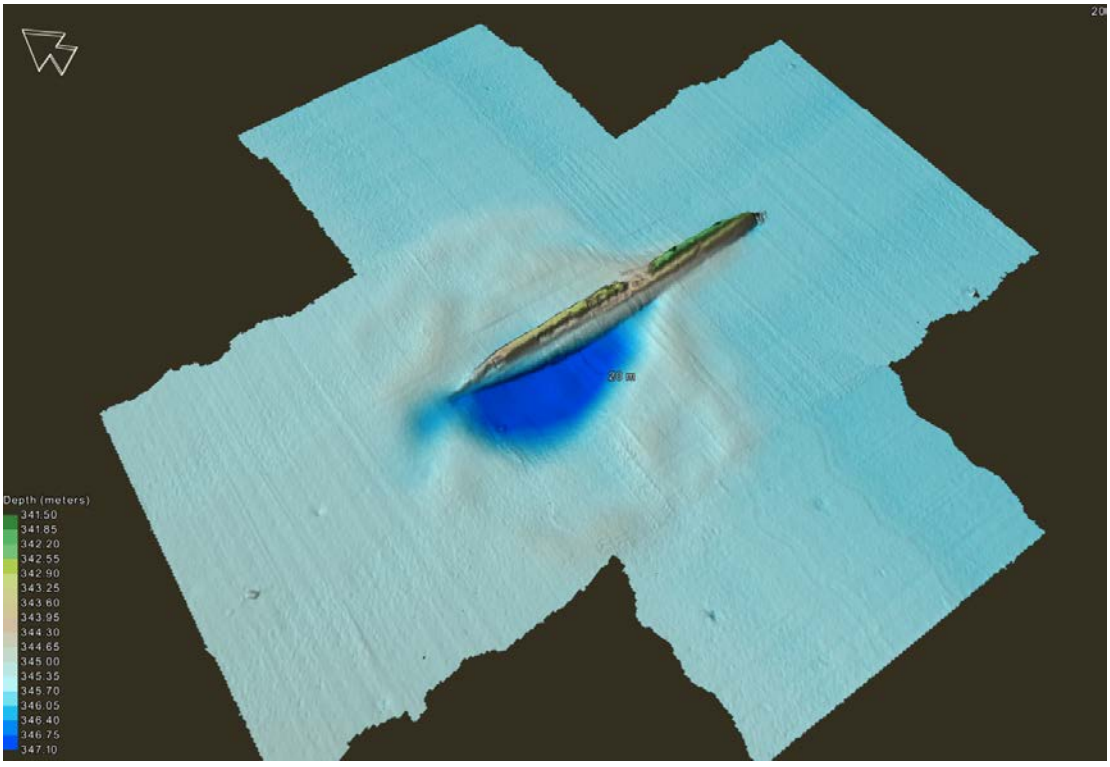



Figure 8-7 DTM after calibration

# 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 | | 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 Scientfic Model OTM S-112 S/N 1377-09JUL96 Accuracy +/- 2/1000 deg.C
Conductivity** Falmouth Scientfic 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: | N 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: | N.M 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.**

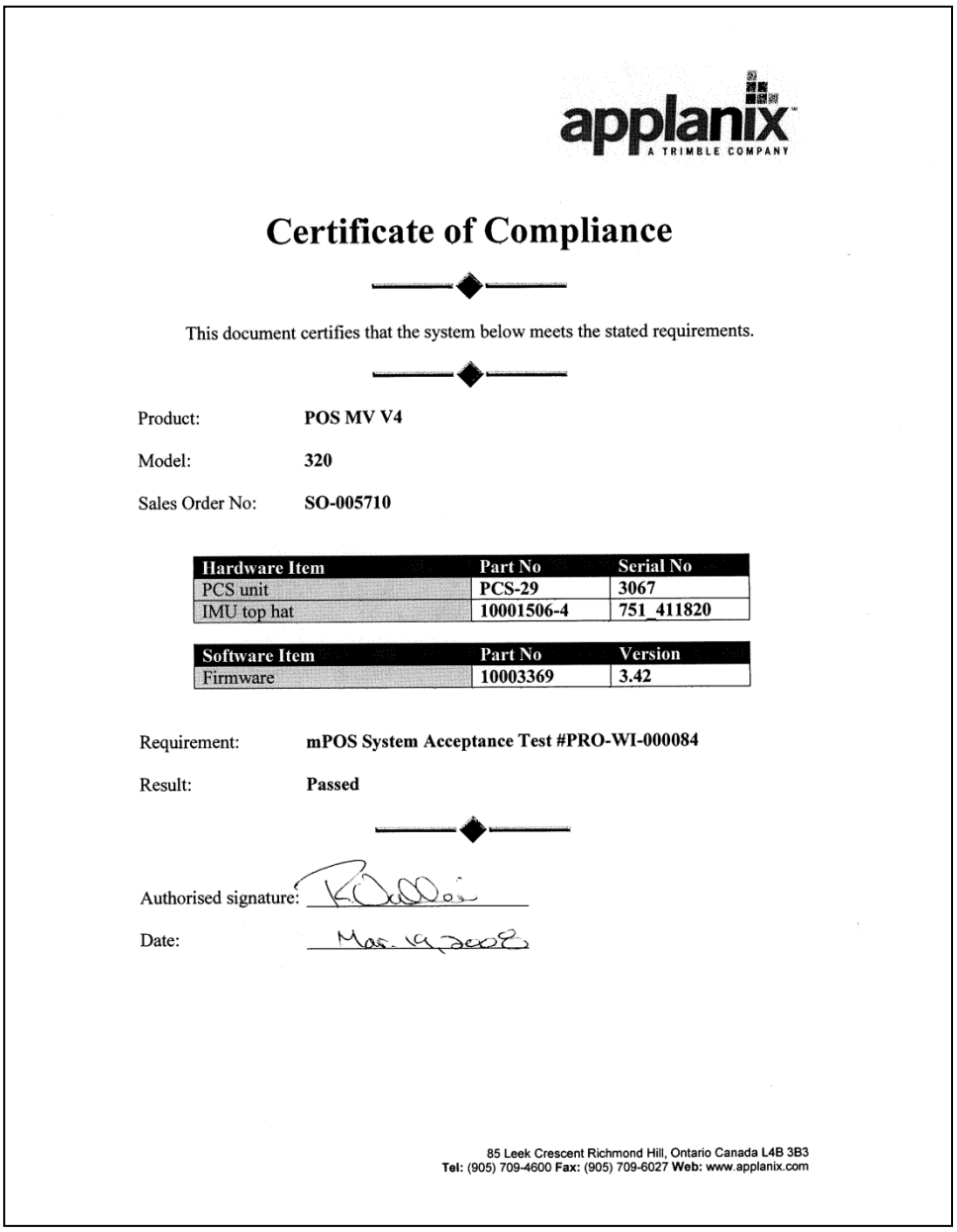
**Valeport Limited**, St. Peter's Quay, Totnes, Devon, TQ9 5EW. U.K.
Tel: +44 (0)1803 869292 Fax: +44 (0)1803 869293
E-mail: sales:valeport.co.uk Web: www.valeport.co.uk

## 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:

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

| Revision DSN | Revision Company | Date | Reason for Issue | Originator | Checked | Approved |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| 02i | - | 25.03.13 | Issued for Construction | TOIs | ÅR | AMS |
| 01 | - | | Issued for Internal Document Control | TOIs | | |

| | Organisation Unit | Person | Title | Signature | Date |
|---|---|---|---|---|---|
| Originator | DOF Subsea Norway AS | Trond Olsen | Offshore Manager | | 25.03.2013 |
| Checked | DOF Subsea Norway AS | Åse Røssland | Proj. Doc. Controller | | 25.03.2013 |
| Approved | DOF Subsea Norway AS | Agnete Marie Strømme | Ass. Project Manager | | 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: | 02i |
|---|---|---|---|
| *DOF Subsea Norway AS Document Number:* 600225-SSKO-O15-0001 | | | |

| *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

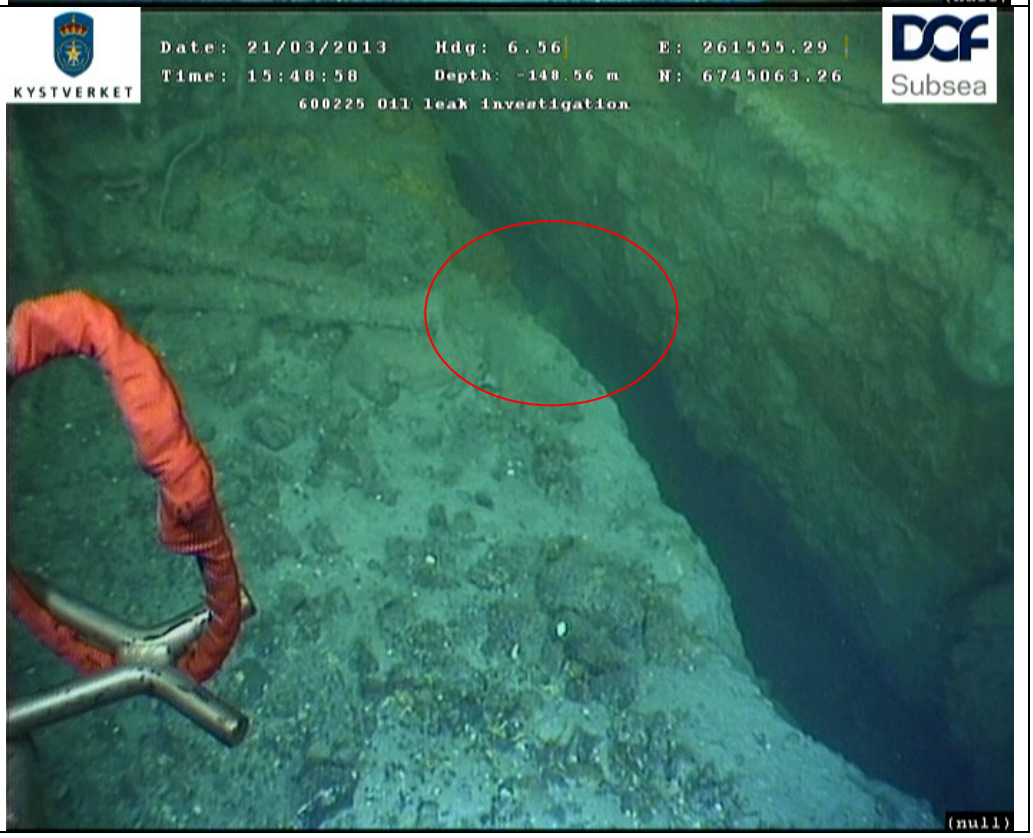
Oil leak was found to come from where we did the first cut to release air at aft section #1. Oil was also spotted coming out from several cracks in the outer fuel tanks.
Leak rate was measured and recorded on DVR over a period of 60 minutes. Approximately 3 dl of oil was captured during this period.

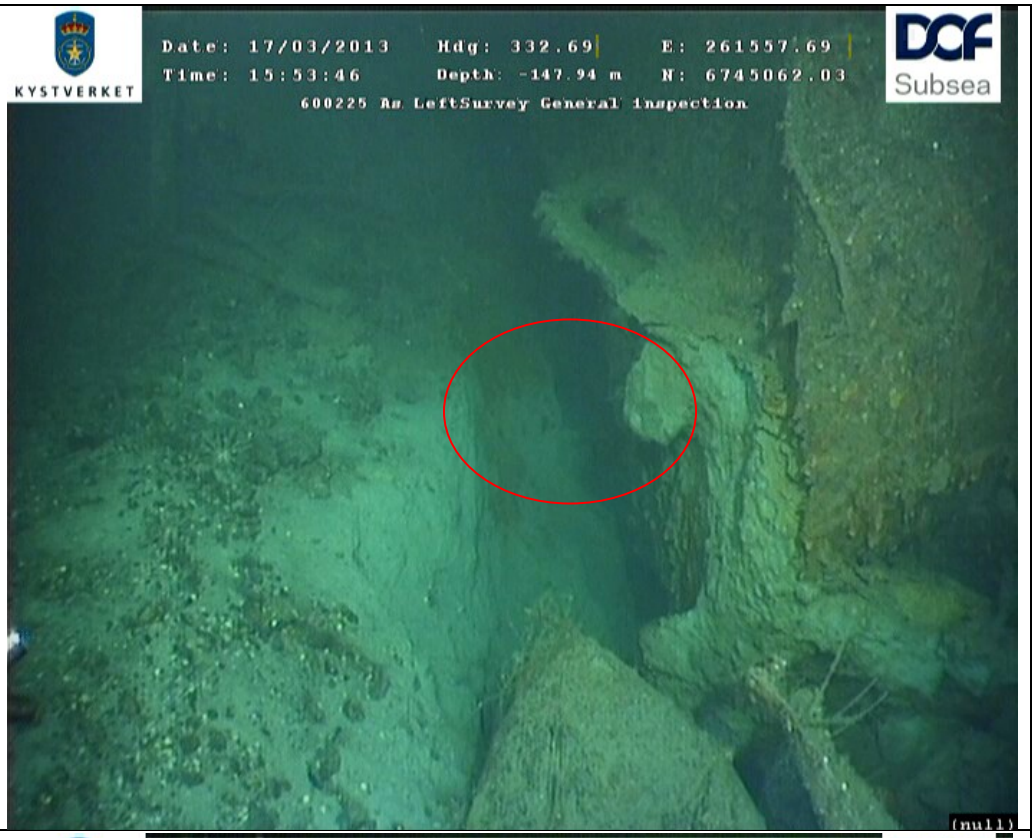
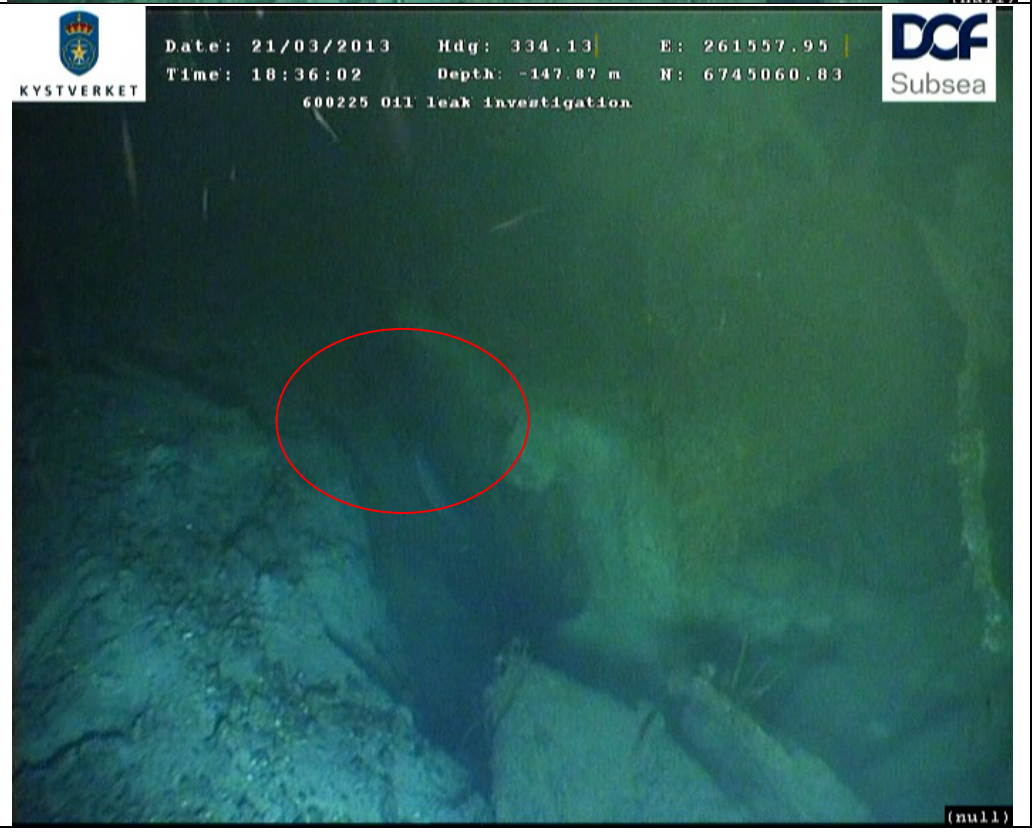
To identify if U-864 has moved since “As-Left”, a 1,5m aluminium measurement stick was used.

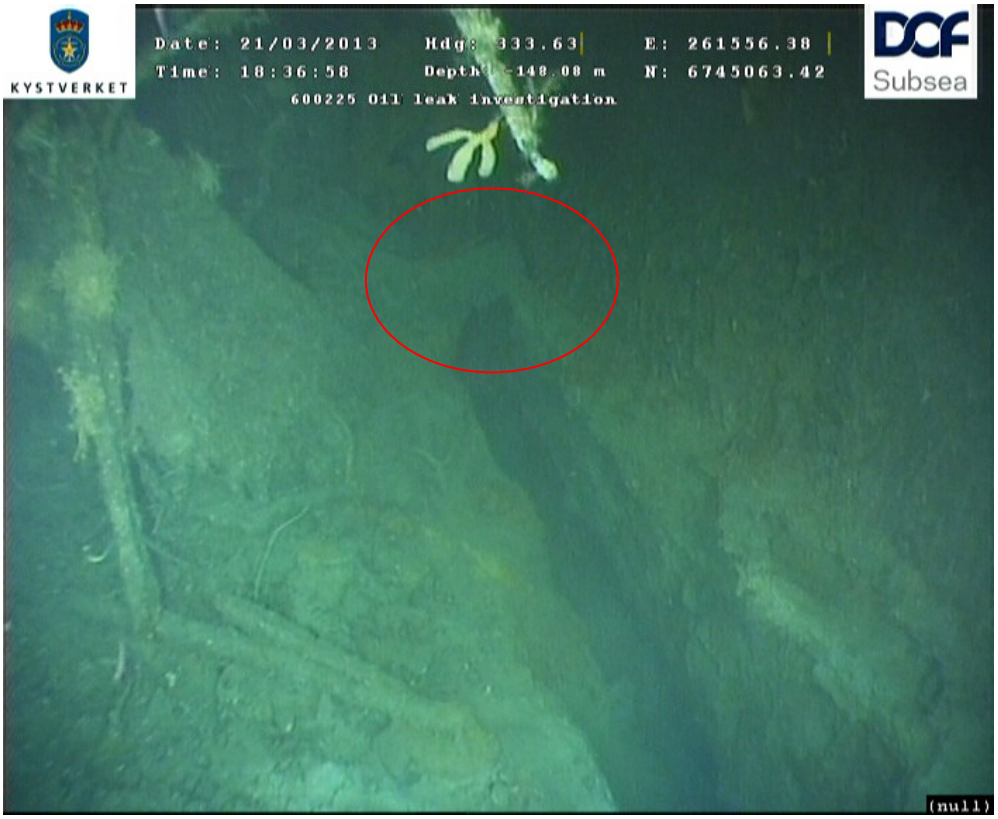
Measurement was only taken at one location due to limited access along mud line. Gap was at the selected spot measured to approximately 1,1 metre.

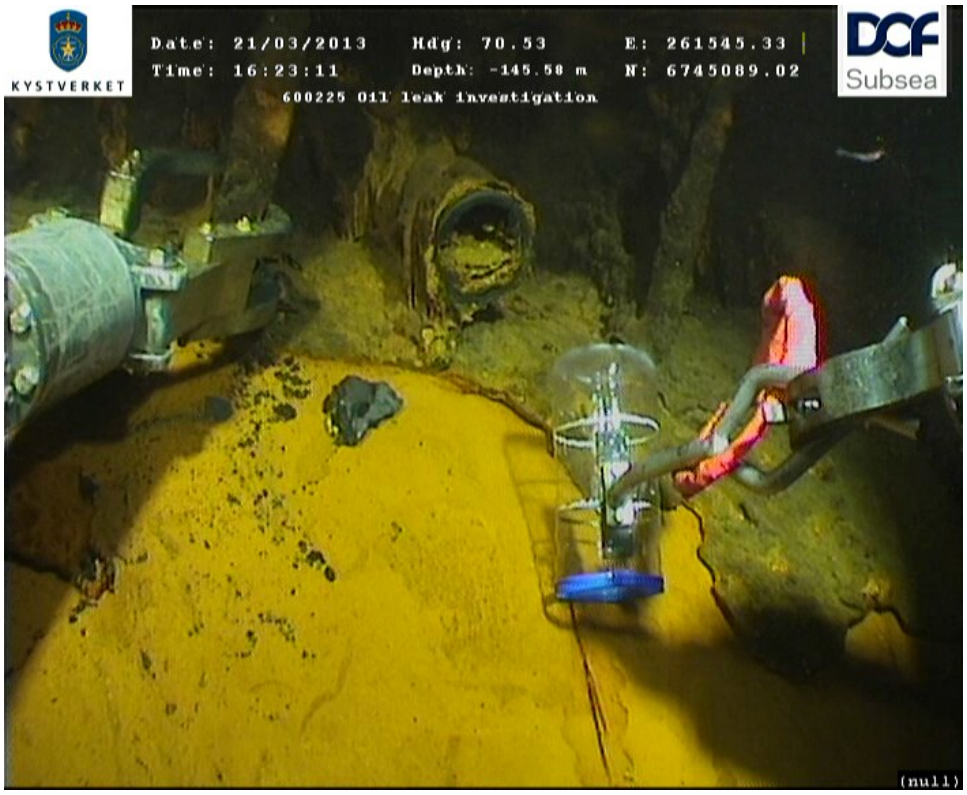
## 3 SCREEN GRABS

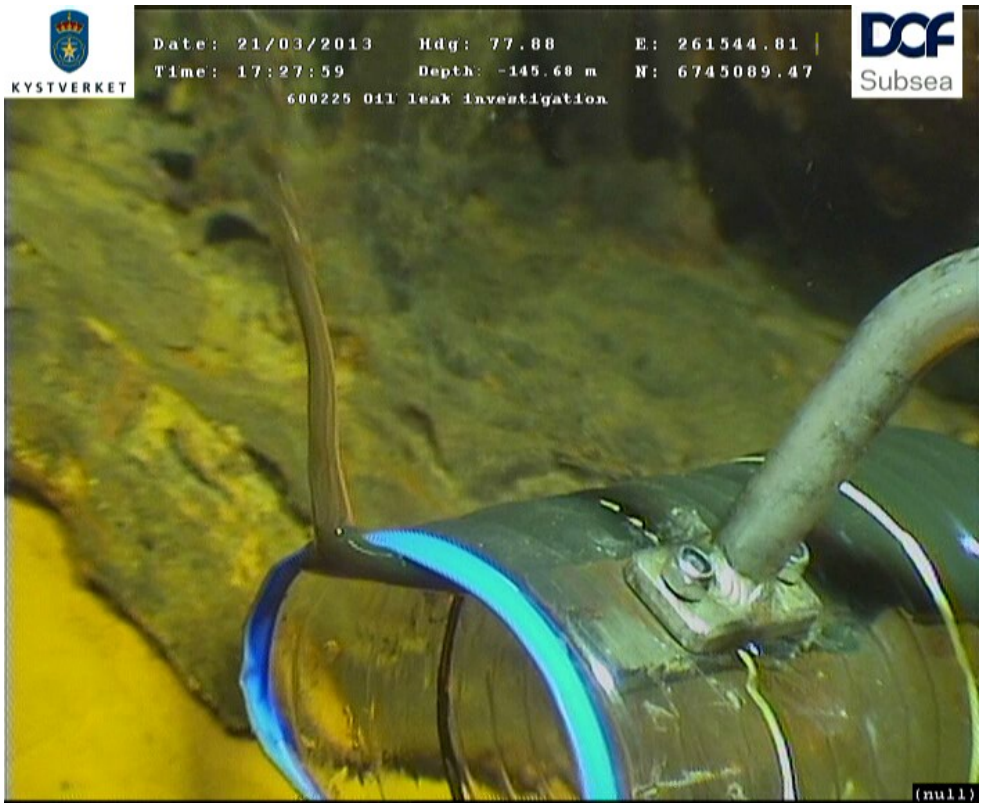
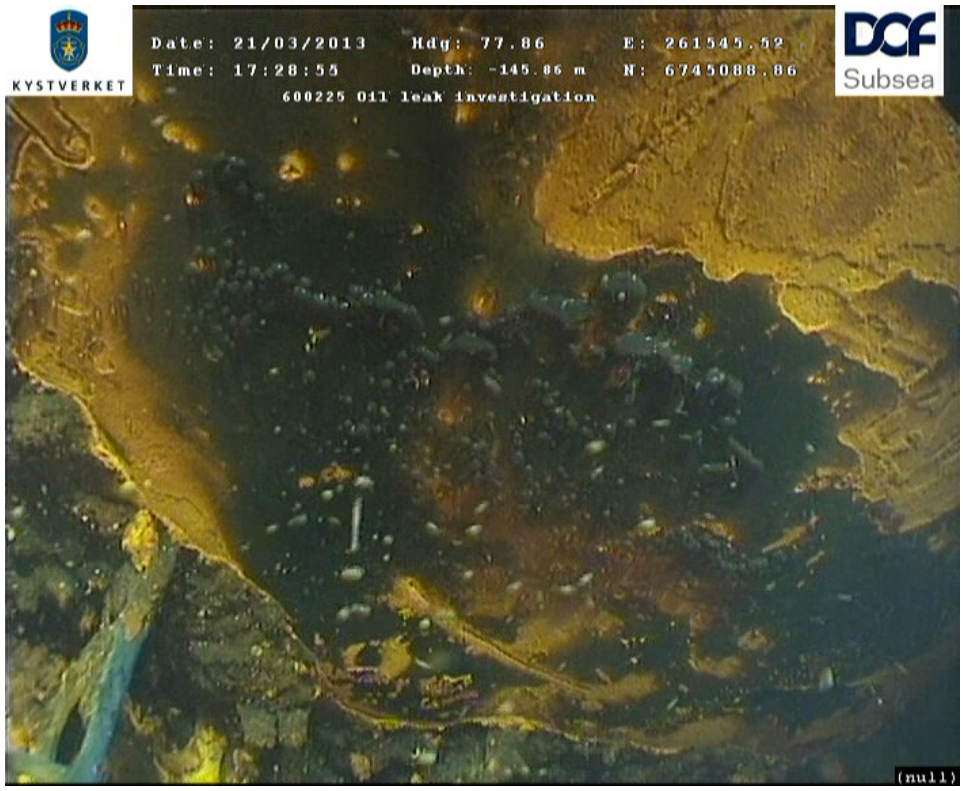
1. Debris resting towards U-864. 17.03.2013
2. Debris resting towards U-864. 21.03.2013
3. Mud gap. 17.03.2013
4. Mud gap. 21.03.2013
5. Debris resting towards U-864. 17.03.2013
6. Debris resting towards U-864. 21.03.2013
7. Start of Oil Leak Rate test. Yellow rings on each 0,5 litre.
8. End of Oil Leak 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

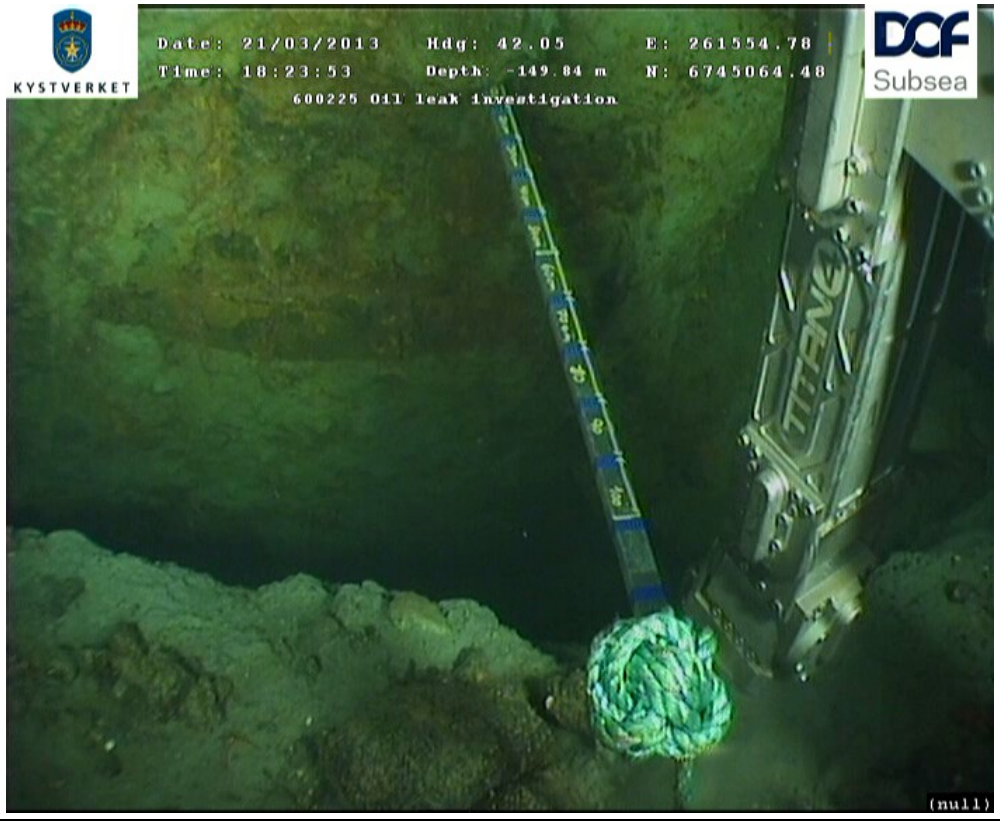
| | |
|---|---|
| **1** |  KYSTVERKET<br>Date: 17/03/2013 Hdg: 6.77 E: 261554.65<br>Time: 15:04:36 Depth: -147.55 m N: 6745062.37<br>600225 Au LeftSurvey Stbd - Mud Line<br>DOF Subsea<br>(null) |
| **2** |  KYSTVERKET<br>Date: 21/03/2013 Hdg: 6.56 E: 261555.29<br>Time: 15:48:58 Depth: -148.56 m N: 6745063.26<br>600225 Oil leak investigation<br>DOF Subsea<br>(null) |

| | |
|---|---|
| **3** |  KYSTVERKET<br>Date: 17/03/2013 Hdg: 332.69 E: 261557.69<br>Time: 15:53:46 Depth: -147.94 m N: 6745062.03<br>600225 Ra LeftSurvey General inspection<br>DOF Subsea<br>(null) |
| **4** |  KYSTVERKET<br>Date: 21/03/2013 Hdg: 334.13 E: 261557.95<br>Time: 18:36:02 Depth: -147.87 m N: 6745060.83<br>600225 Oil leak investigation<br>DOF Subsea<br>(null) |

| | |
|---|---|
| **5** |  KYSTVERKET<br>Date: 17/03/2013 Hdg: 326.73 E: 261557.20<br>Time: 15:54:19 Depth: -146.99 m N: 6745062.11<br>600225  Av LeftSurvey General inspection<br>DOF Subsea<br>(null) |
| **6** |  KYSTVERKET<br>Date: 21/03/2013 Hdg: 333.63 E: 261556.38<br>Time: 18:36:58 Depth: -148.08 m N: 6745063.42<br>600225 Oil leak investigation<br>DOF Subsea<br>(null) |

| | |
|---|---|
| **7** |  KYSTVERKET<br>Date: 21/03/2013 Hdg: 70.53 E: 261545.33<br>Time: 16:23:11 Depth: -145.58 m N: 6745089.02<br>600225 Oil leak investigation<br>DOF Subsea<br>(null) |
| **8** |  KYSTVERKET<br>Date: 21/03/2013 Hdg: 77.90 E: 261544.98<br>Time: 17:24:13 Depth: -145.91 m N: 6745089.48<br>600225 Oil leak investigation<br>DOF Subsea<br>(null) |

| | |
|---|---|
| **9** |  KYSTVERKET<br>Date: 21/03/2013 Hdg: 77.88 E: 261544.81<br>Time: 17:27:59 Depth: -145.68 m N: 6745089.47<br>600225 Oil leak investigation<br>DOF Subsea<br>(null) |
| **10** |  KYSTVERKET<br>Date: 21/03/2013 Hdg: 77.86 E: 261545.52<br>Time: 17:28:55 Depth: -145.86 m N: 6745088.86<br>600225 Oil leak investigation<br>DOF Subsea<br>(null) |

| | |
|---|---|
| **11** |  KYSTVERKET<br>Date: 21/03/2013 Hdg: 42.07 E: 261555.25<br>Time: 18:23:16 Depth: -149.85 m N: 6745064.19<br>600225 Oil leak investigation<br>DOF Subsea<br>(null) |
| **12** |  KYSTVERKET<br>Date: 21/03/2013 Hdg: 42.05 E: 261554.78<br>Time: 18:23:53 Depth: -149.84 m N: 6745064.48<br>600225 Oil leak investigation<br>DOF Subsea<br>(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.

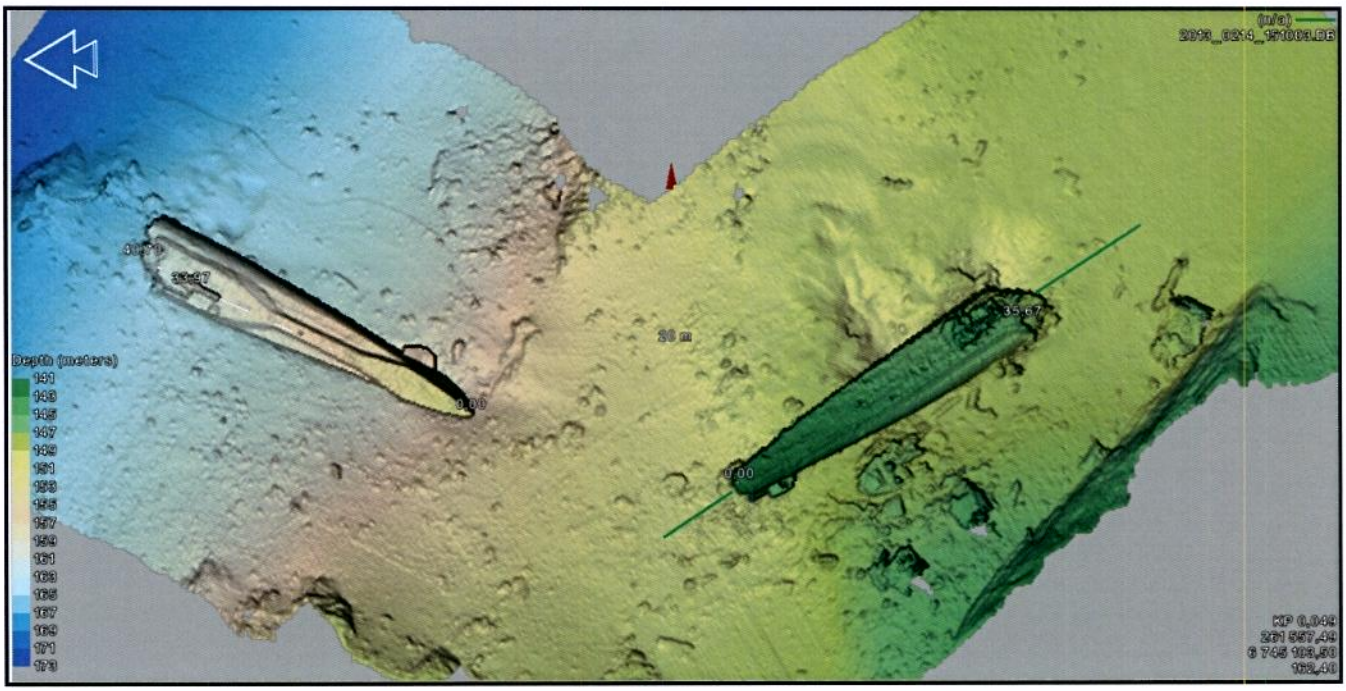
# Oil recovery for the ship wreck of U-864

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.

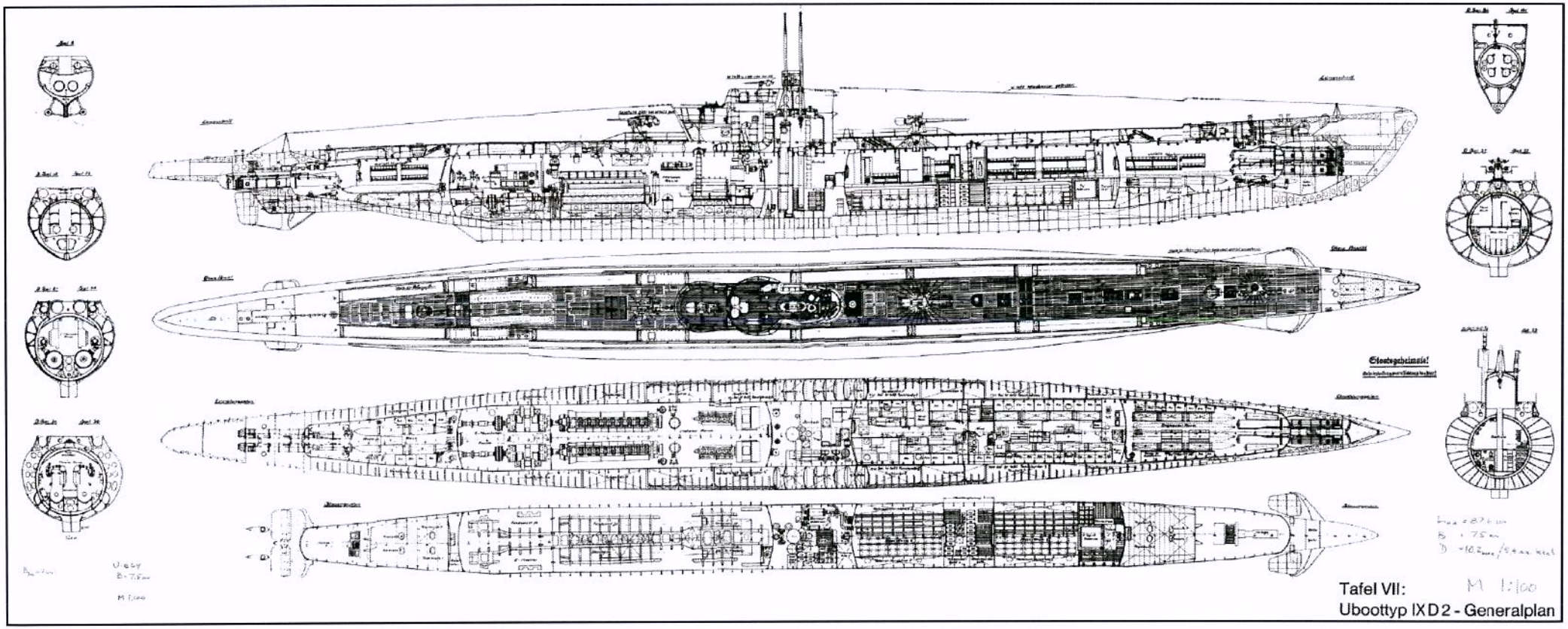



**Figure 1 - General arrangement U-864**

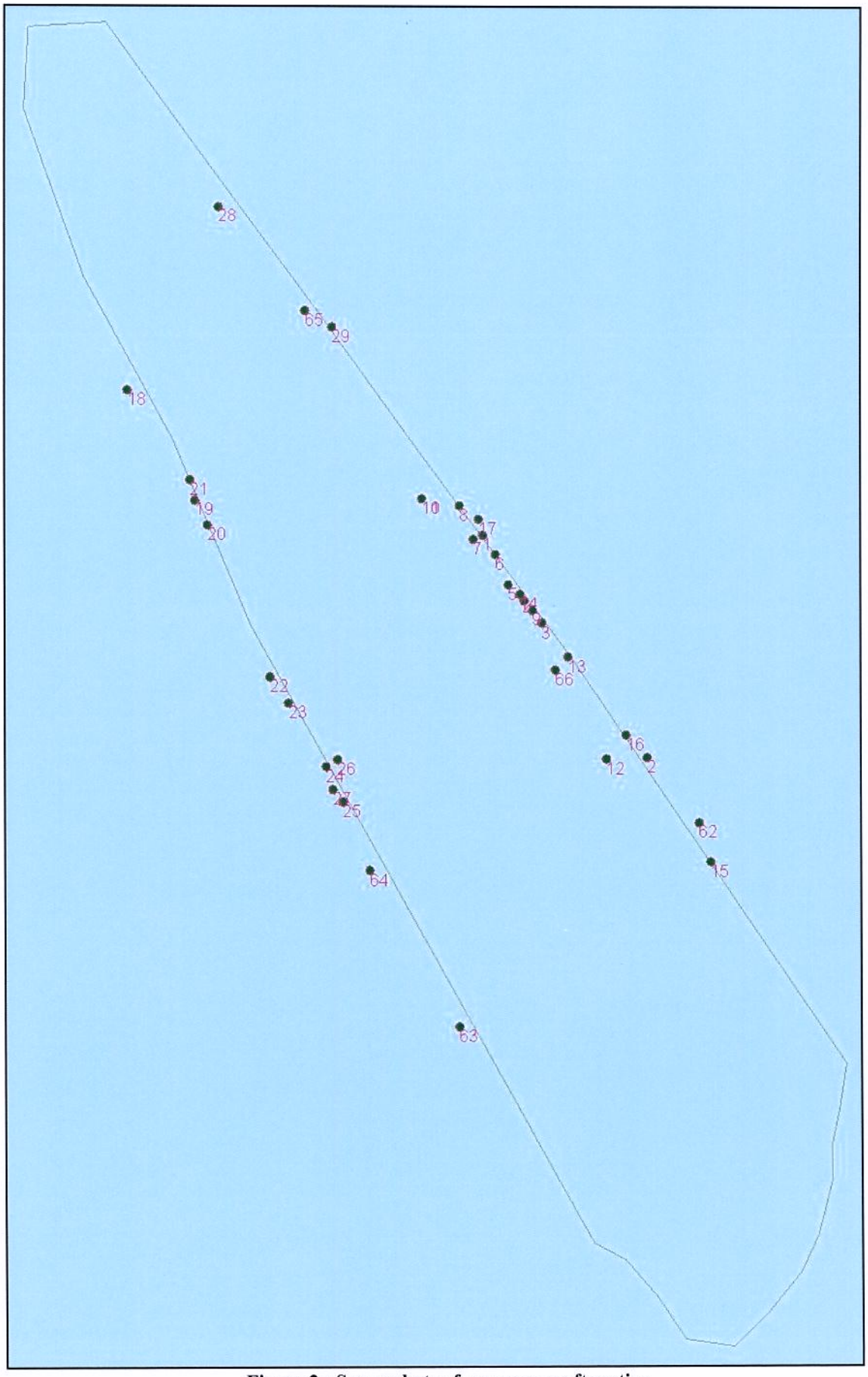



**Figure 2 - Screenshot reference map aft section**

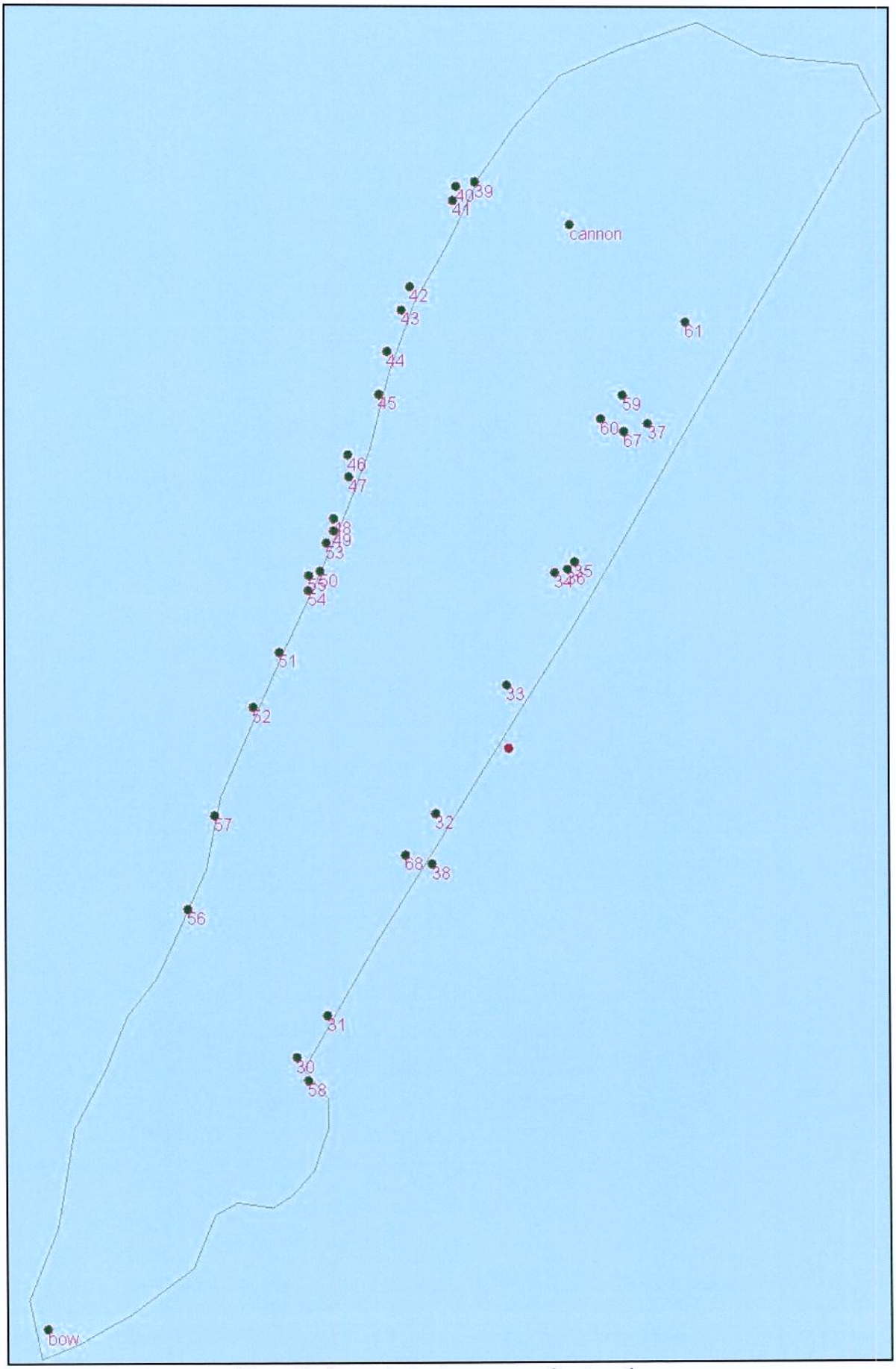



**Figure 3 - Screenshot reference map front section**

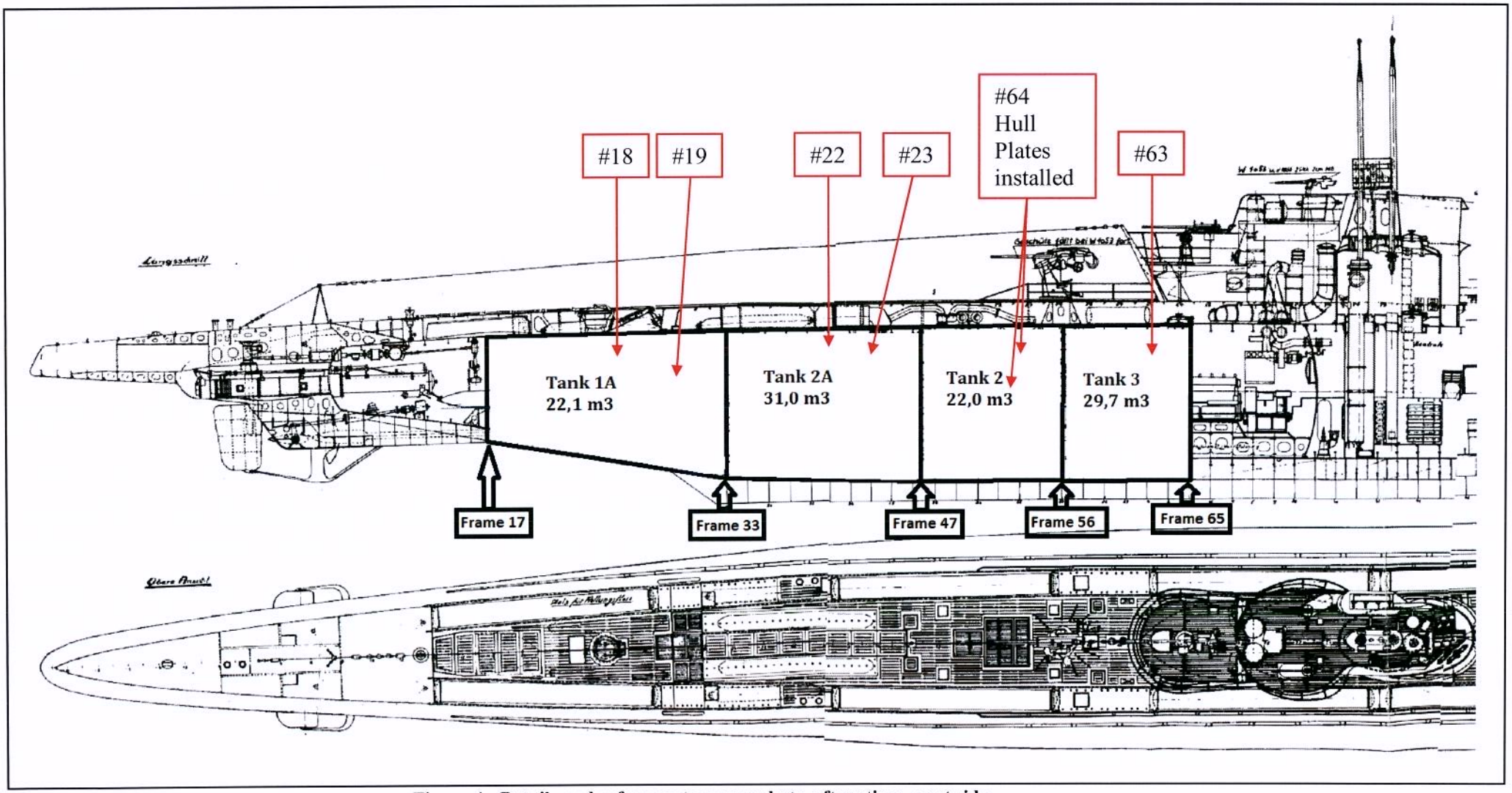



**Figure 4 - Details and reference to screen shots, aft section - port side**

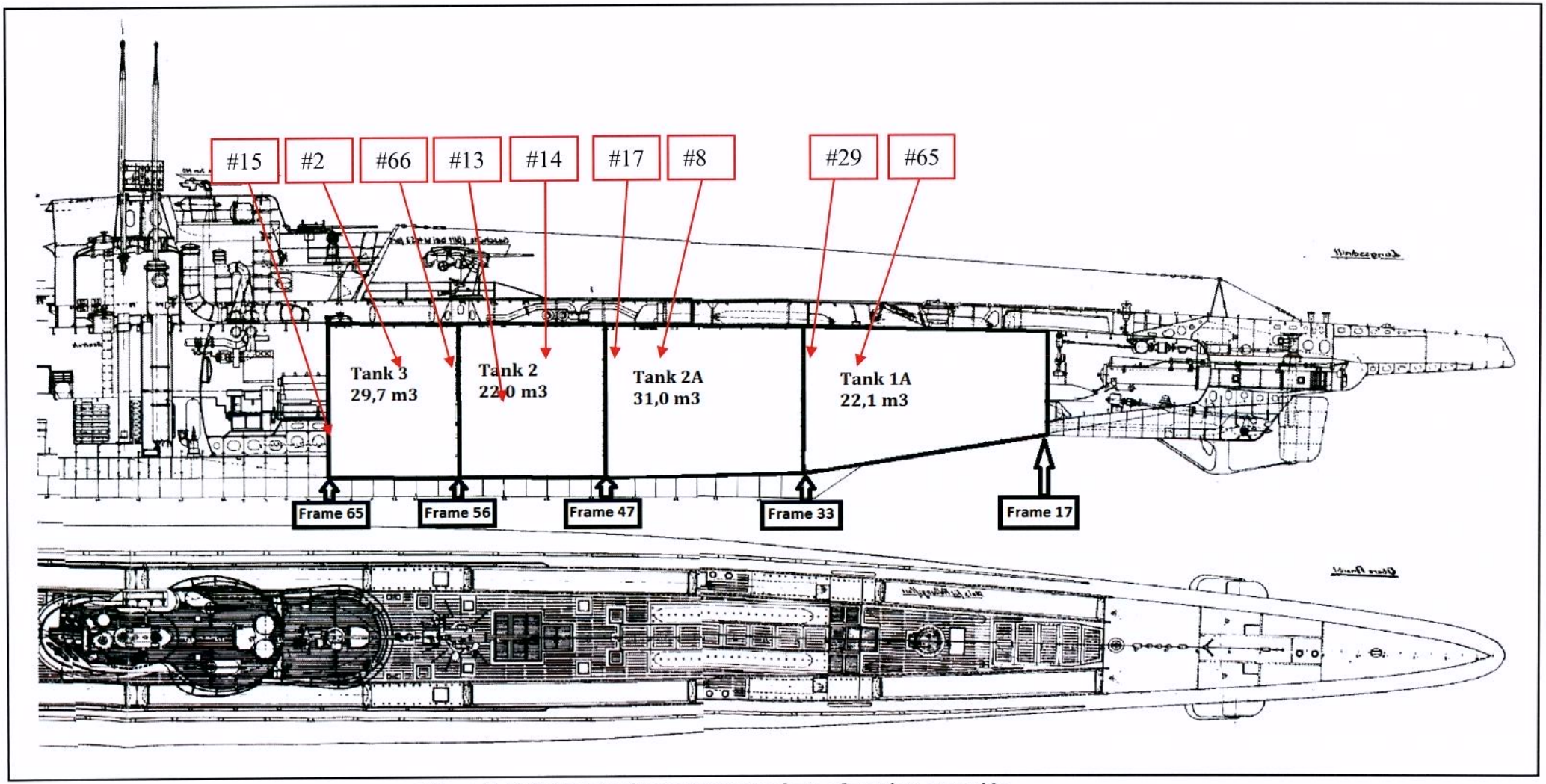



**Figure 5 - Details and reference to screen shots, aft section - port side**

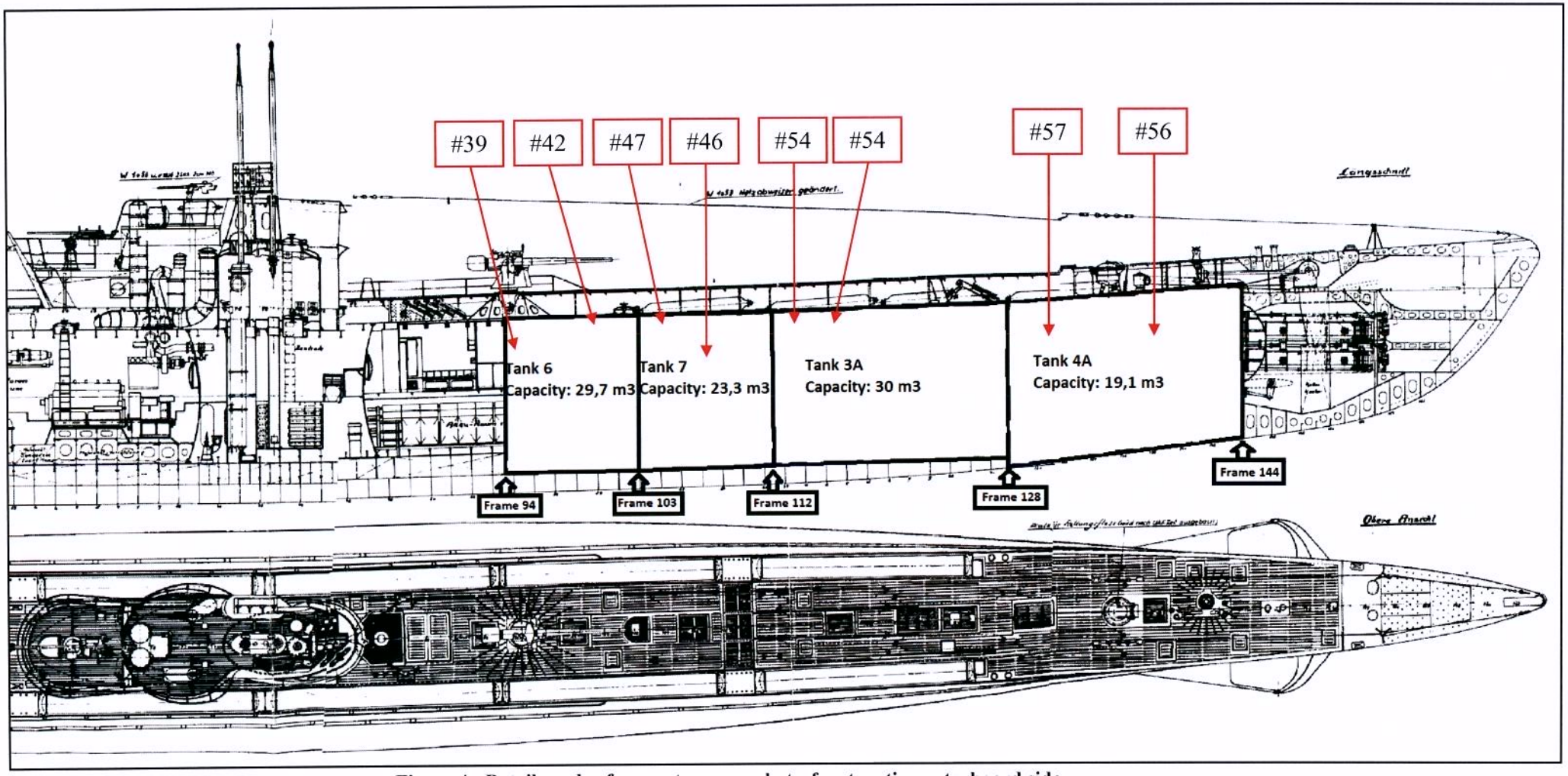



**Figure 4 - Details and reference to screen shots, front section - starboard side**

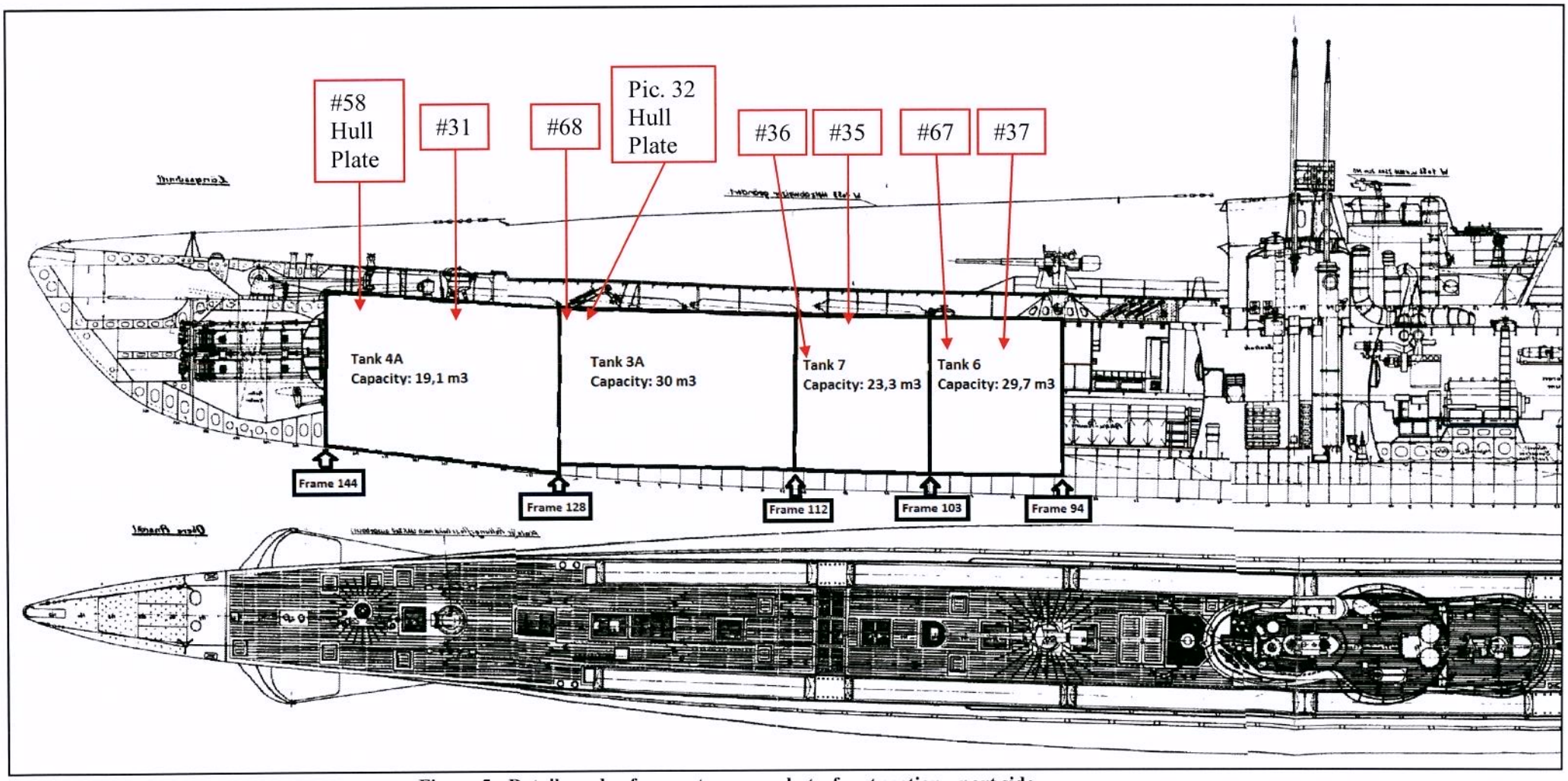



**Figure 5 - Details and reference to screen shots, front section - port side**

FRAMO



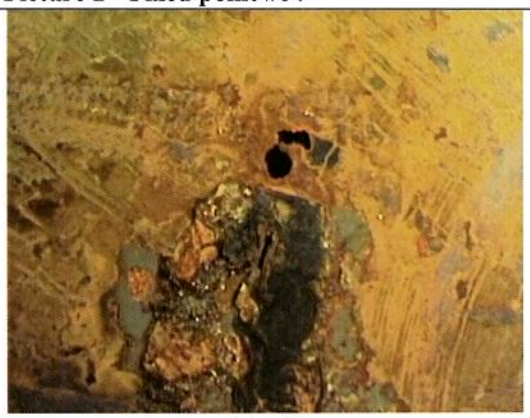
Picture 1 - Fixed point #63



Picture 2 - Fixed point #64



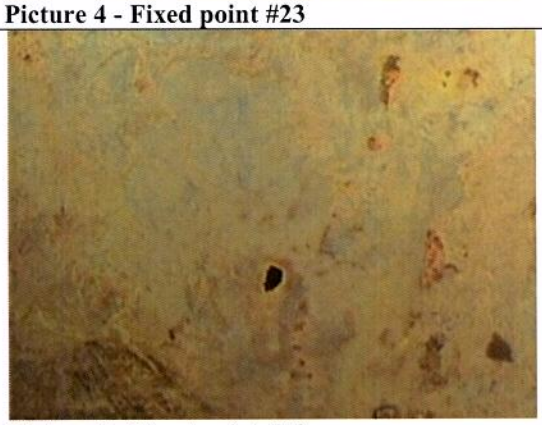
Picture 3 - Fixed point #22



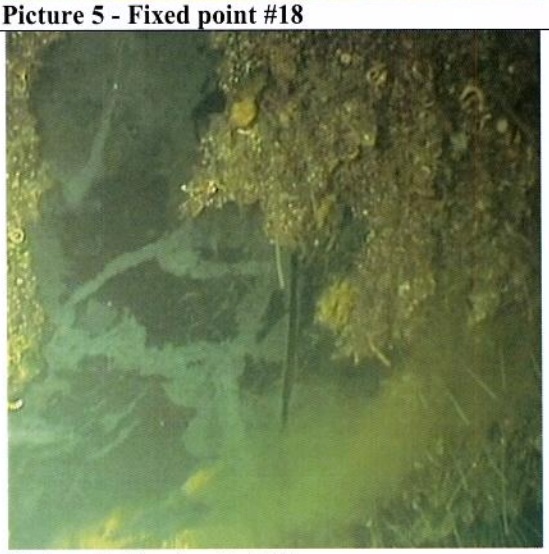
Picture 4 - Fixed point #23



Picture 5 - Fixed point #18



Picture 6 - Fixed point #19



Picture 7 -Fixed point #29



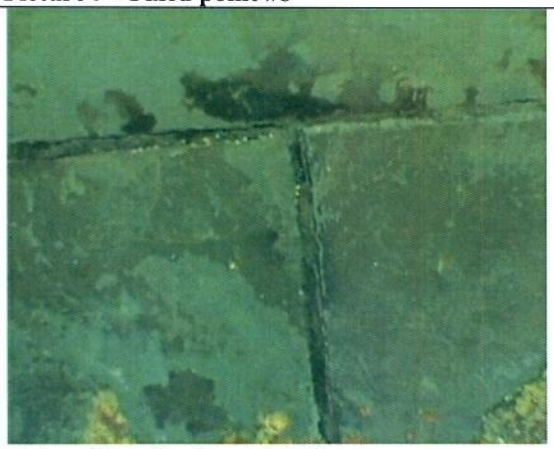
Picture 8 - Fixed point #65



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



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



Picture 25 - Fixed point #58 , Hull Plate



Picture 26 - Fixed point #31



Picture 27 - Fixed point #68



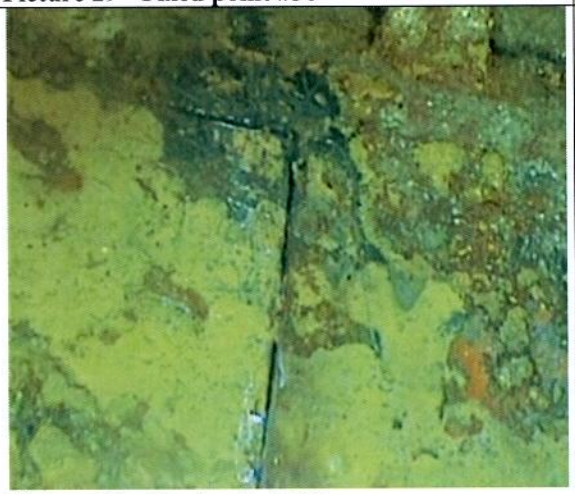
Picture 28 - Fixed point #35



Picture 29 - Fixed point #36



Picture 30 - Fixed point #37



Picture 31 - Fixed point #67




Picture 32 - Hull plate for tank 3A

## 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.

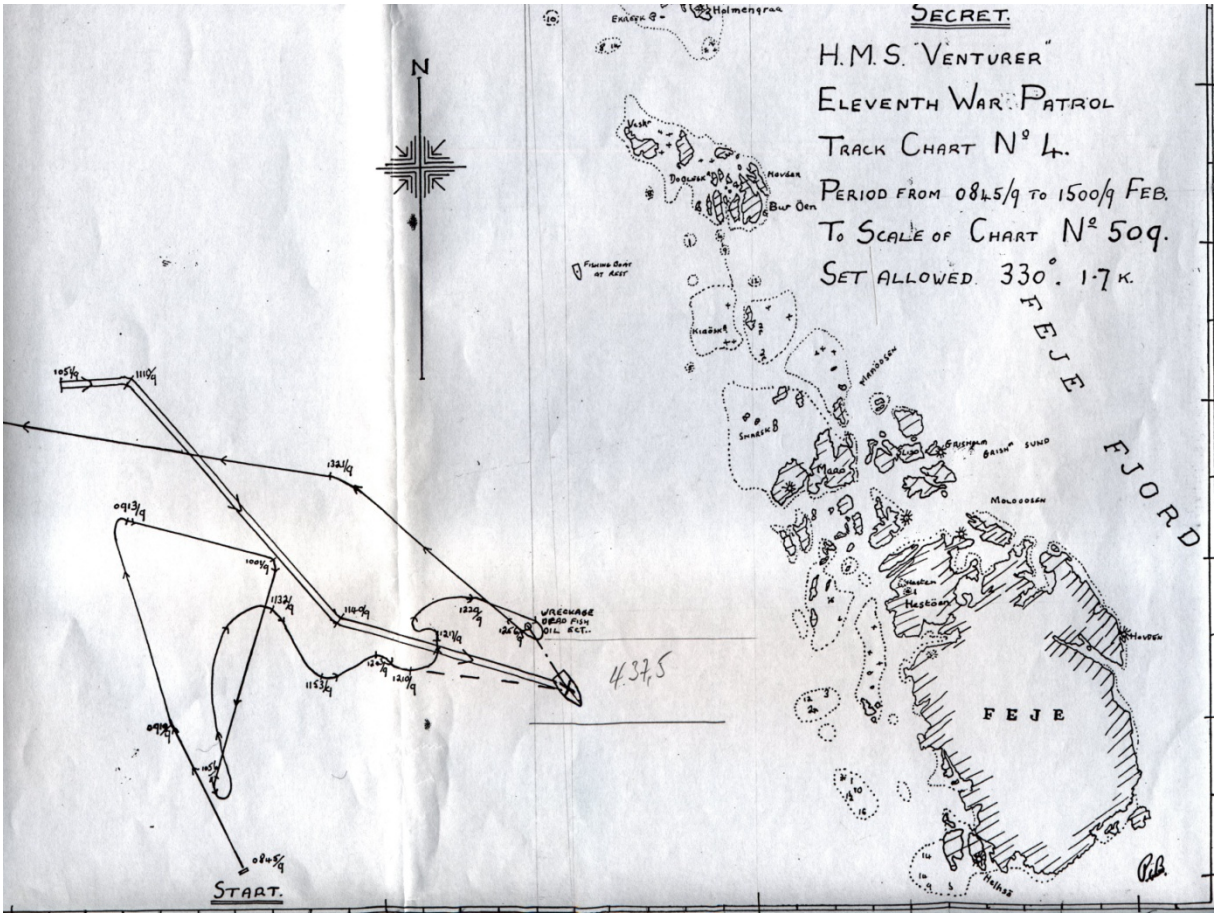



**Figure 1** **Image of chart from HMS Venturer's log with positions taken chart**

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.

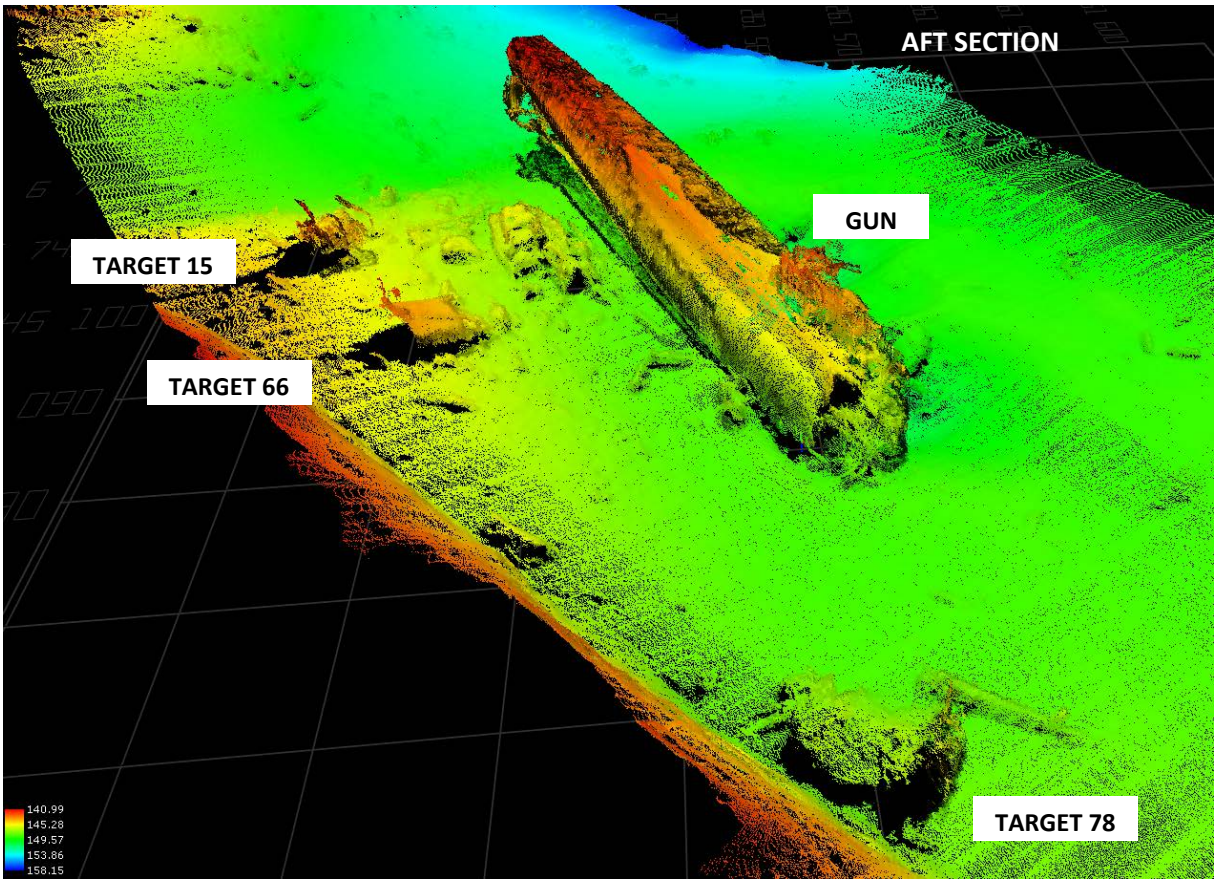



**Figure 2** **The Aft section of U 864 with target 15, 66 and 88**

## 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.

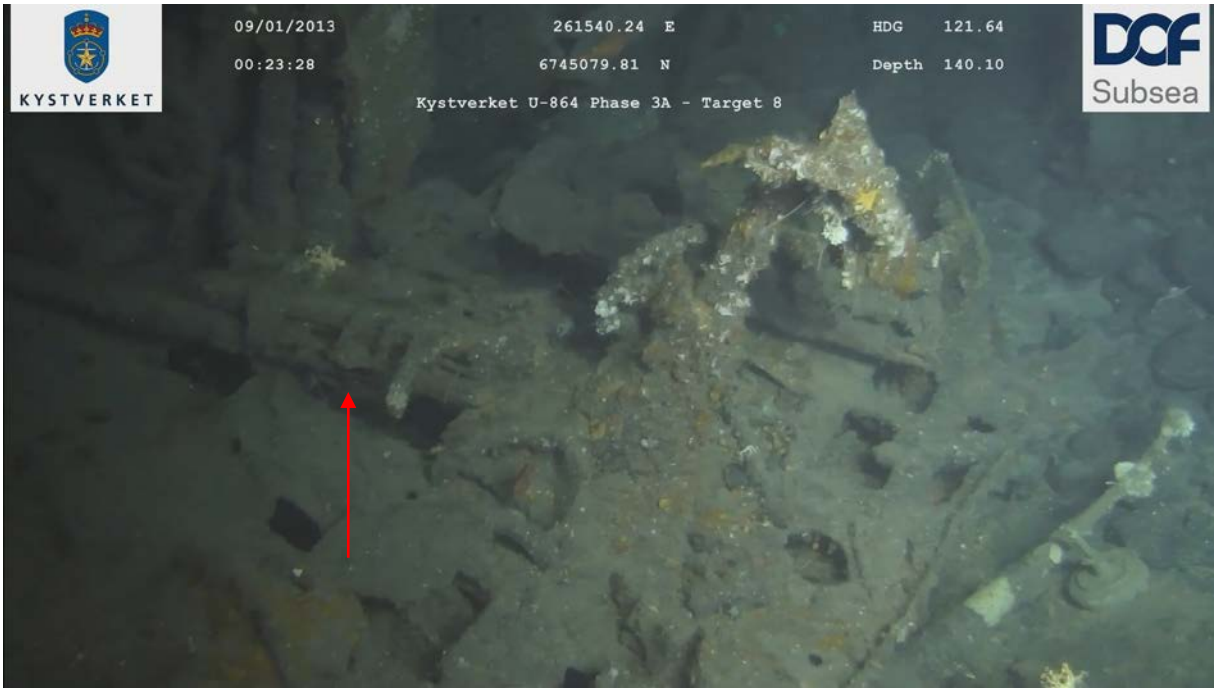



**Figure 4** **One of the two Single barreled guns (red arrow), from the conning tower**

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.

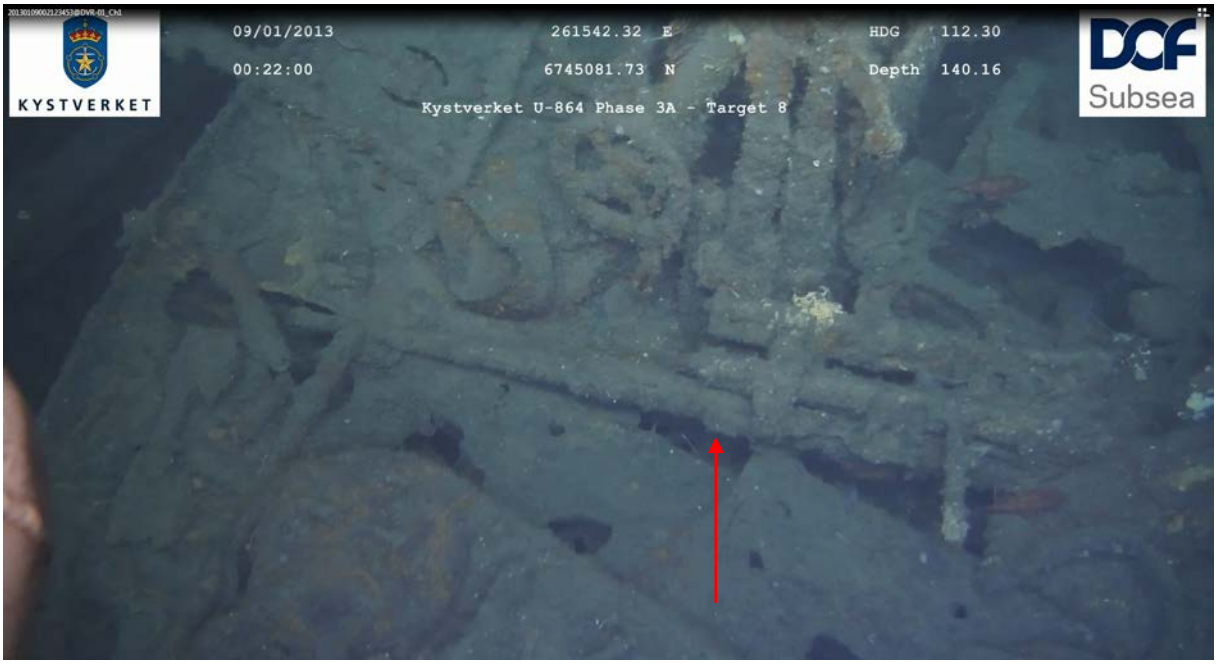



**Figure 5** **One of the two Single barreled guns (red arrow), from the conning tower**

## 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)**

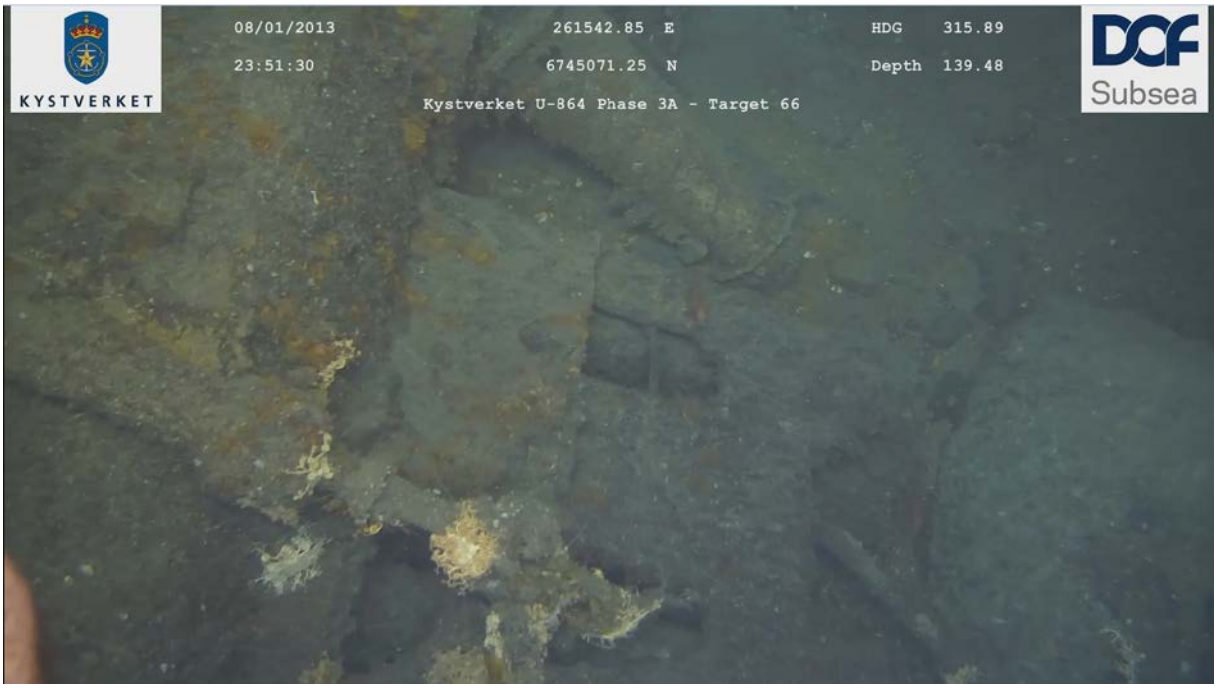



**Figure 8** **Top of the periscope on the top of the conning tower**

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.

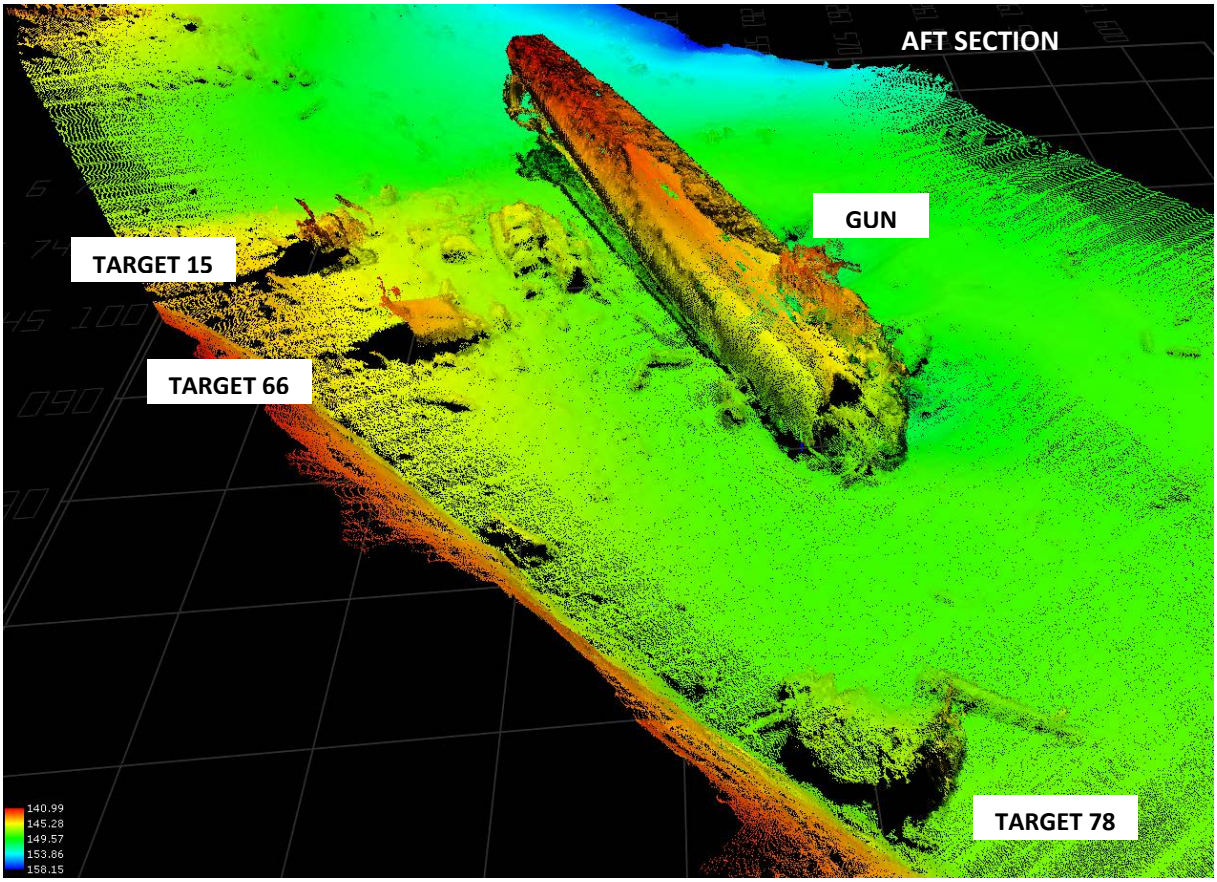



**Figure 11** **The Aft section of U 864 with target 15, 66 and 88**

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 |
| 3. Kvikksølv | 3. Mercury |
| 4. Sediment | 4. Sediment |



*Sigurd Øxnevad*
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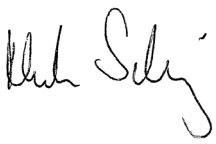

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# Investigation of mercury during a survey near submarine U-864 outside Fedje in 2013

# 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

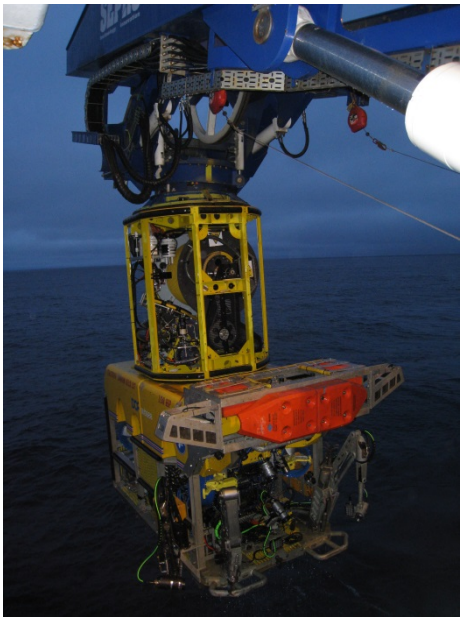
In January 2013 a final data collecting campaign was performed in order to obtain additional information regarding the two alternatives.

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 |

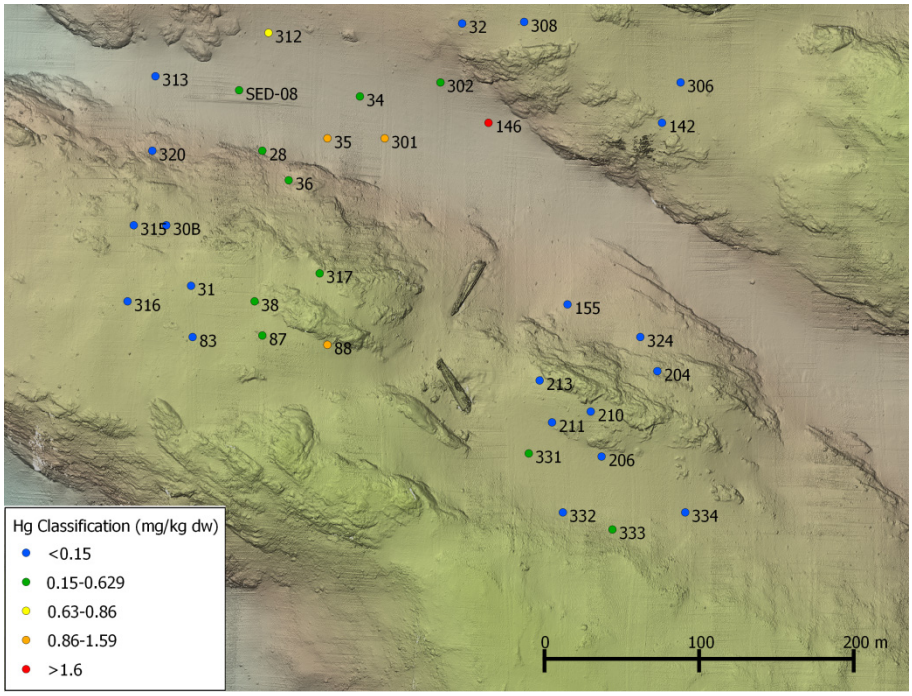



Figure 1. Concentrations of mercury in the surface sediment (0-2 cm) near the wreck of U-864 outside Fedje. The samples were taken in January 2013. The results are classified according to the classification system of the Norwegian Climate and Pollution Agency (Bakke et al. 2007).

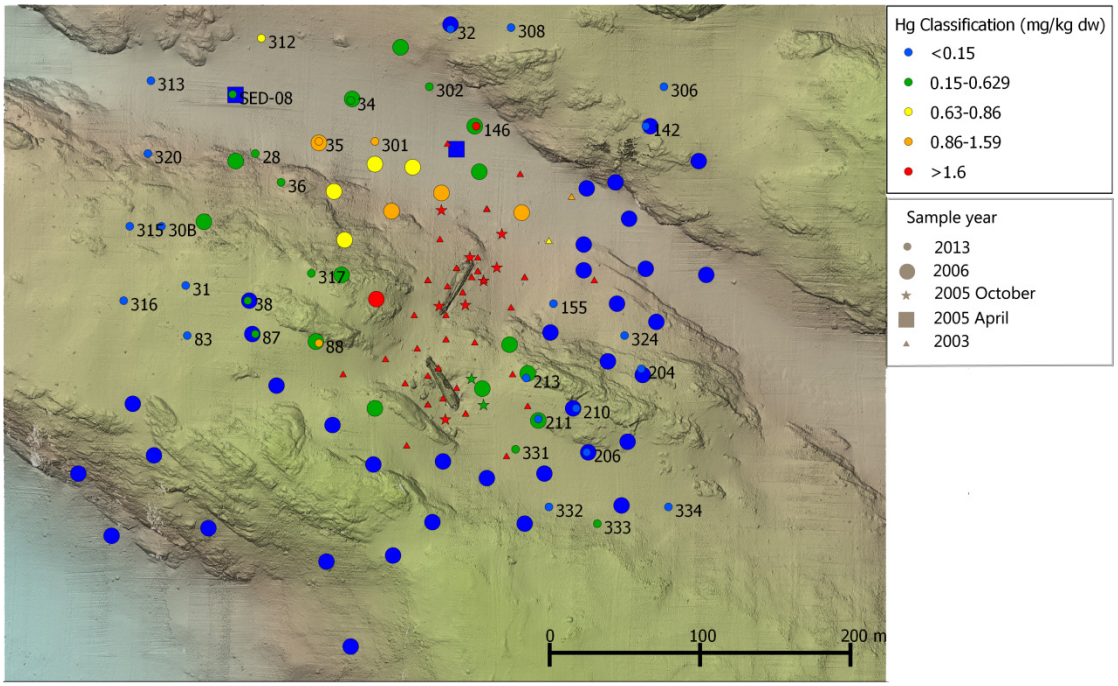



Figure 2. Concentrations of mercury in the sediment around U-864 outside Fedje. Results for all years are presented on the map. The results are classified according to the classification system of the Norwegian Climate and Pollution Agency (Bakke et al.2007). Because of the revision of the classification 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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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. 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.

## Innholdsliste


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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:

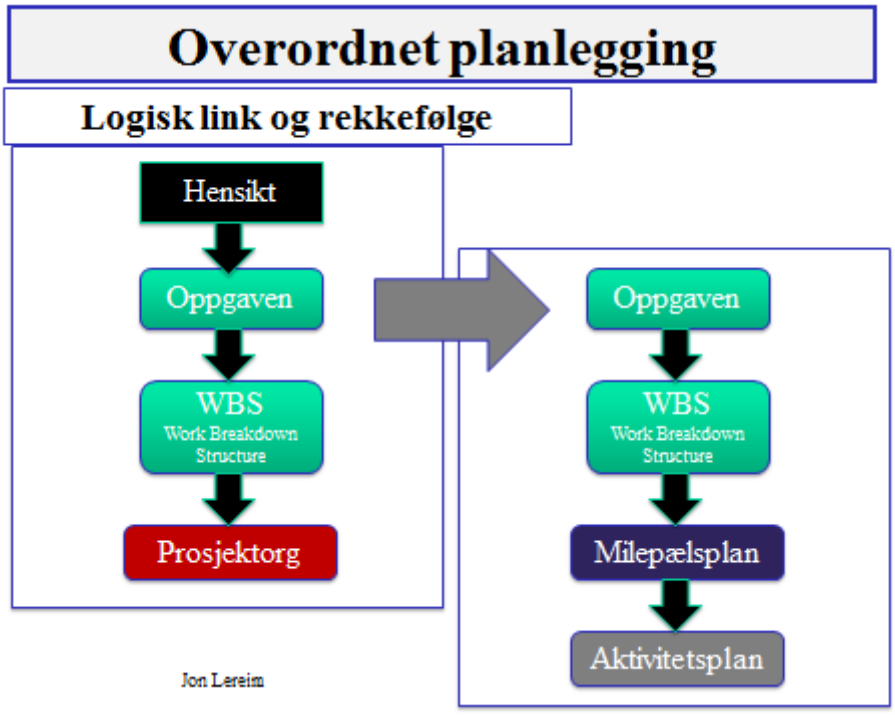
- Prosjektorganiseringen skal understøtte hensikt og oppgave
- Prosjektorganisasjonen må være dynamisk og kunne endres underveis i prosjektet, avhengig av situasjon og behov
- Roller må være tydelig beskrevet, oppfattet og etterlevd
- Unngå «10 %»- deltakere i kjerneteamet til prosjektet
- Sikre kontinuitet 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).

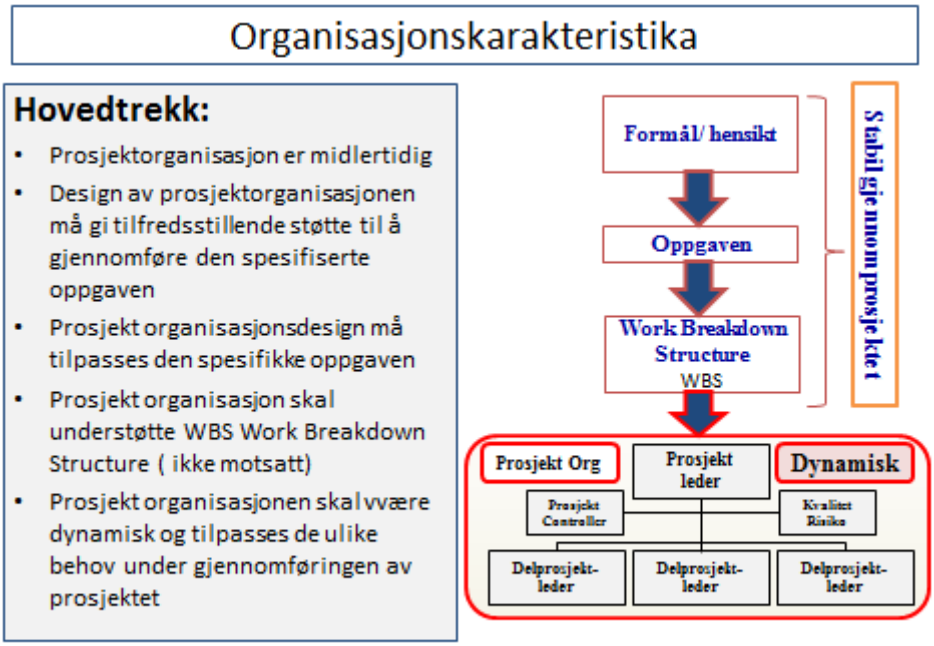
Oppgavebeskrivelsen er grunnlaget for oppdeling av denne i hensiktsmessige deler/delobjekter. Det fremgår av nedbrytningsstrukturen, NBS. (WBS Work Breakdown Structure) Dernest følger design av prosjektorganiseringen, som skal tilpasses til enhver tid hva som er best egnet form i løpet av prosjektgjennomføringen 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

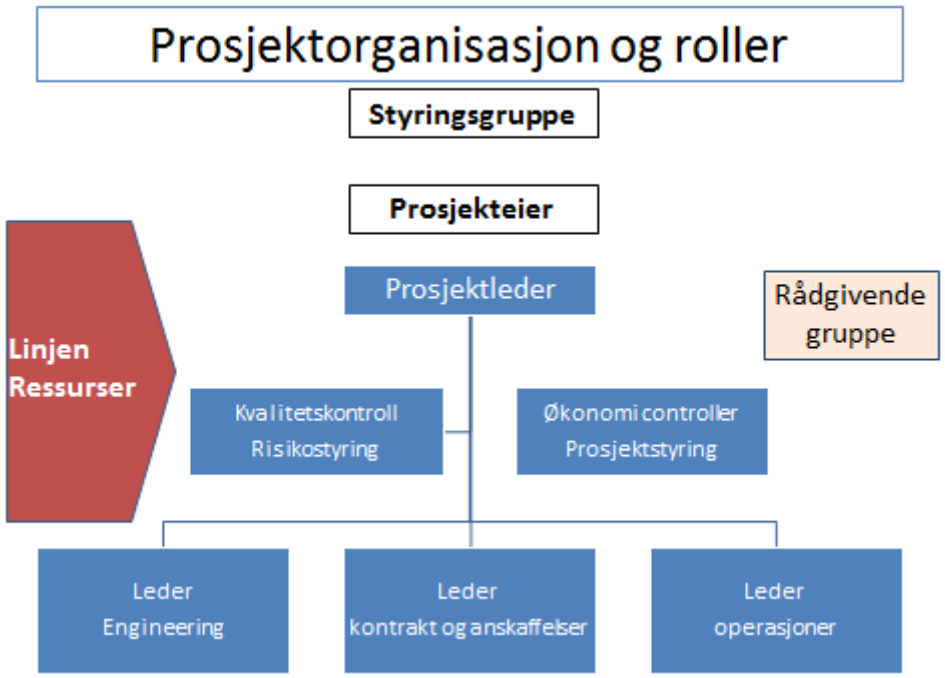
Rådgivende gruppe/referansegruppe

- 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:

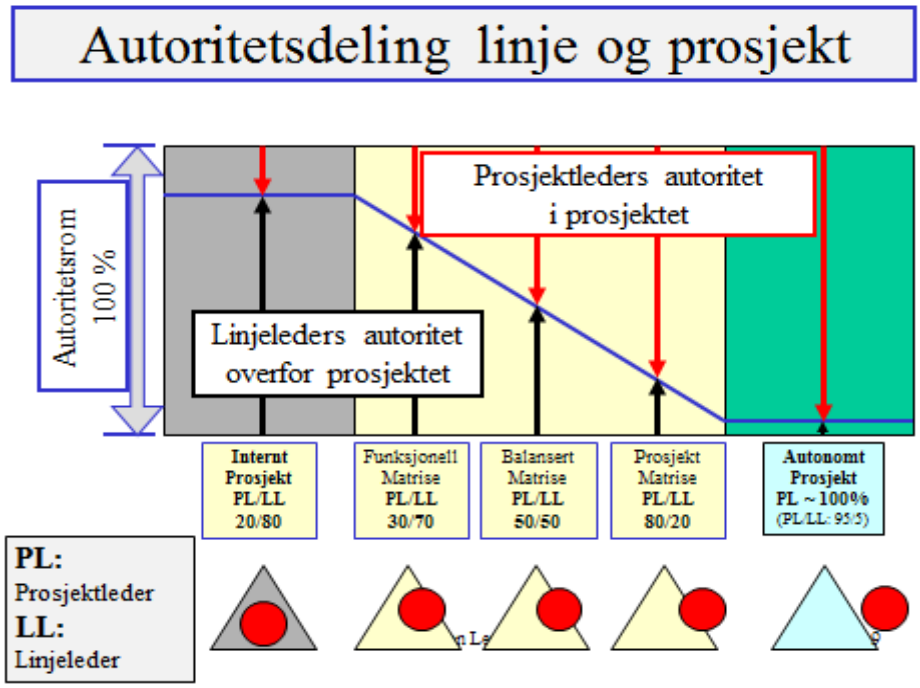
- Det er en delt autoritet mellom linjeleder og prosjektleder, hvem kan bestemme hva
- Prosjektmedarbeidere arbeider med oppgaver både i linjen og i prosjektet
- Prioriteringsrekkefølge mellom linjeoppgaver og oppgaver i prosjektet
- Prosjektmedlemmene utfører for mange oppgaver samtidig

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.

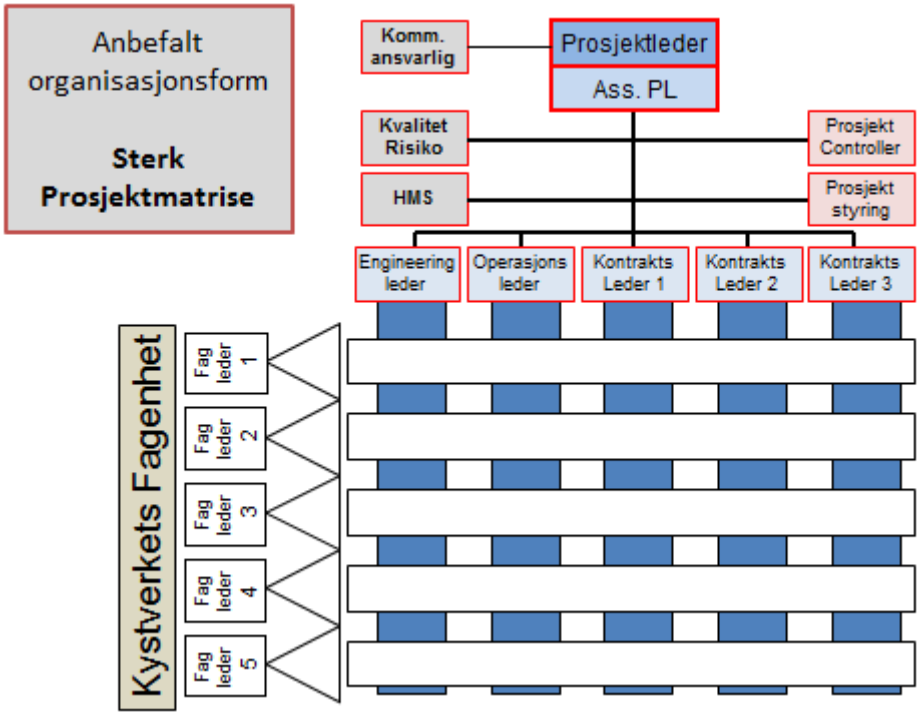
I Dovre/TØI KS2- rapporten kapittel 8 anbefales det at prosjektleder U – 864 rapporterer direkte til kystdirektør som prosjekteier. Prosjekt U – 864 er ved en slik organisering sidestilt Beredskapsavdelingen i den anbefalingen, noe Dovre/TØI tydelig har anbefalt.

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.

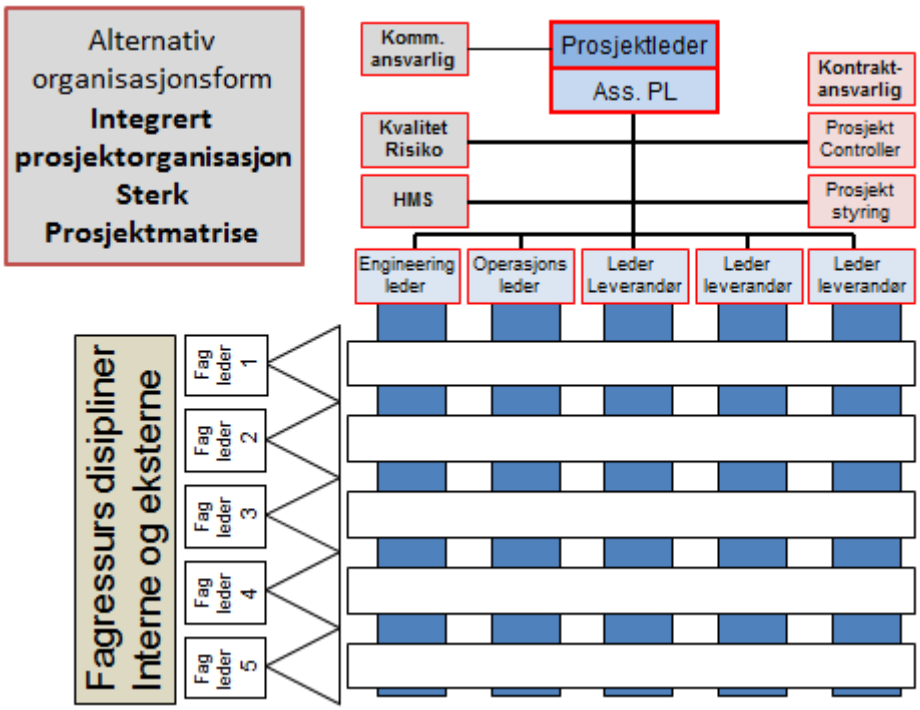
Hovedpunktene er som følger:

- 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

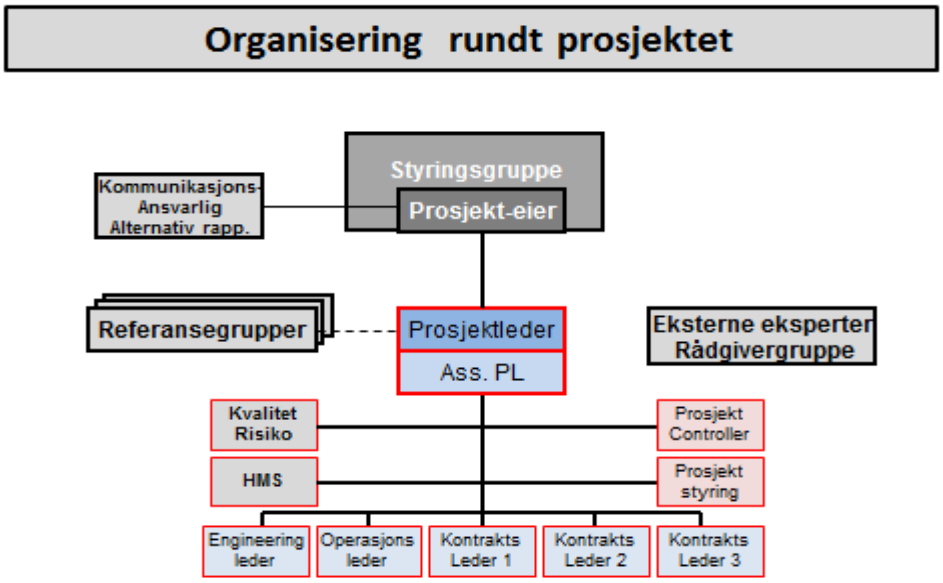
- En styringsgruppe kunne styrke eierstyringen i prosjektet og være en støtte for Kystverket sin eierstyring av prosjektet i å sikre et helhetlig perspektiv. Dette er illustrert i prinsippskissen i figur 7.




*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.

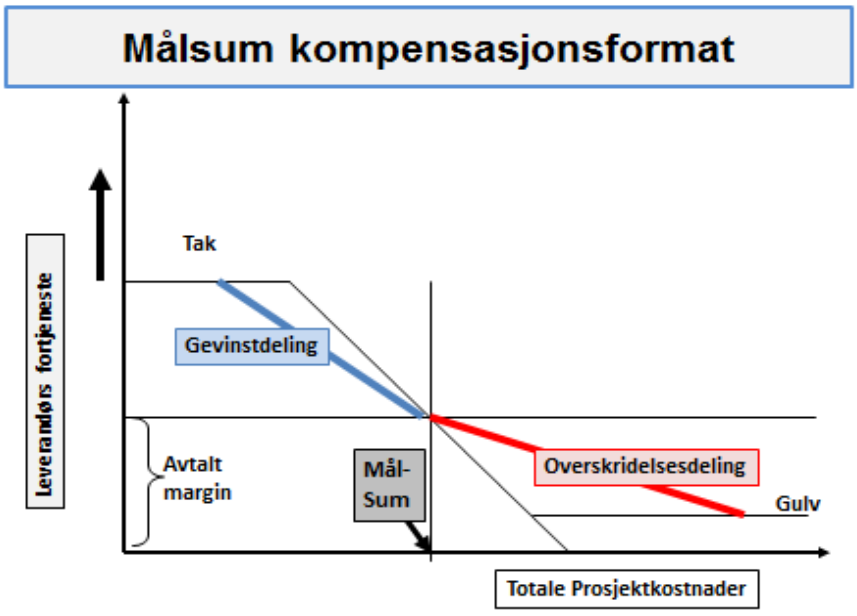
Målsum som kompensasjonsformat synes å gi en bedre balanse og jevnere risikofordeling mellom kunde og leverandør. Det er imidlertid viktig å enes om en målsum som reelt gir omtrent like muligheter for gevinst som overskridelser. Da gir det insentiver til å utføre arbeidet mer effektivt.

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

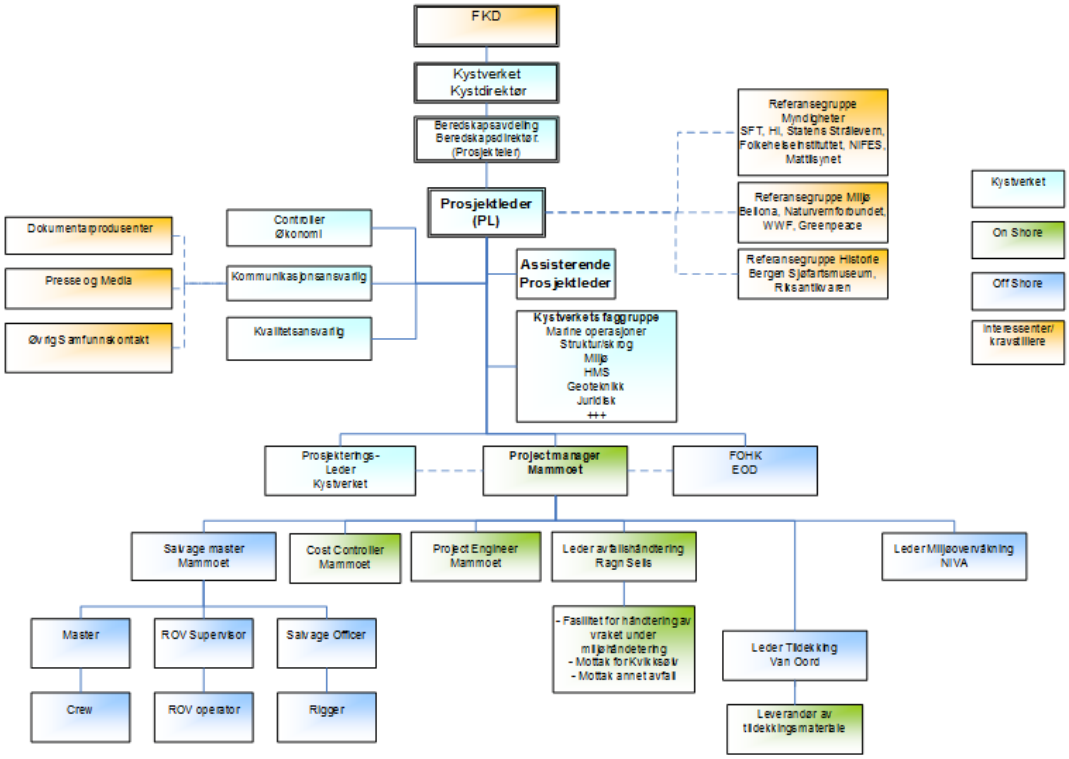
Dokumentasjon fra Kystverket:


- Kystverket: U – 864 Presentasjon (2014)
- Kystverket: Sentralt styringsdokument; Heving av U – 864 (2009)
- KS2 rapport; Heving av U -864, Dovre gruppen & Transportøkonomisk Institutt (2009)
- Kystverket: Konseptvalgutredning for håndtering U – 864, av 04. januar 2011.
- 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
- Kolltveit, B.J., Lereim, J., og Reve, T.: «Prosjekt – strategi, organisering, gjennomføring», Universitetsforlaget

# 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

# INNHOLDSFORTEGNELSE

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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.

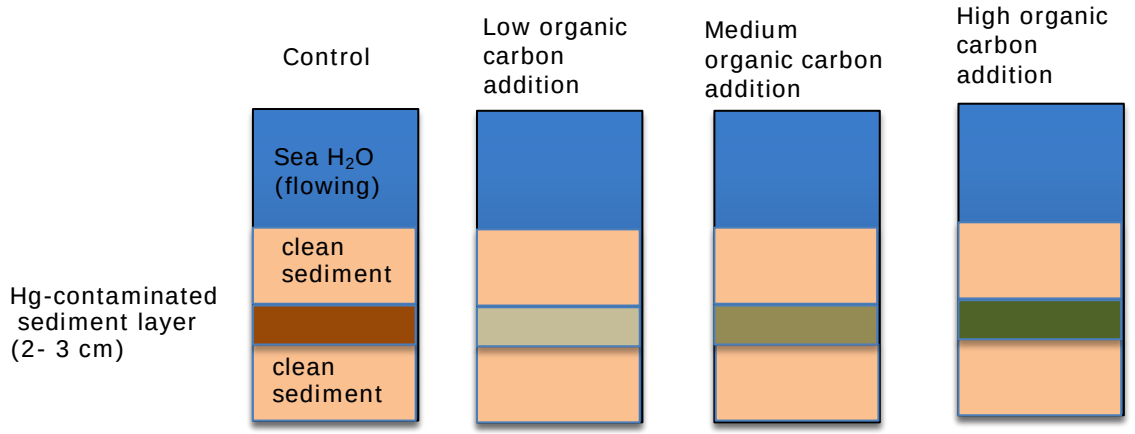


**Figure 1:** Microcosm experimental set up to study the effect of capping and organic matter on Hg speciation in contaminated sediments sampled from the U-864 seabed site near Fedje. The treatments illustrated include; a control with no organic carbon addition; low, medium and a high organic carbon 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 tildekkingslaget. 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 porevannskonsentrasjoner 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.

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.

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 approximately 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.

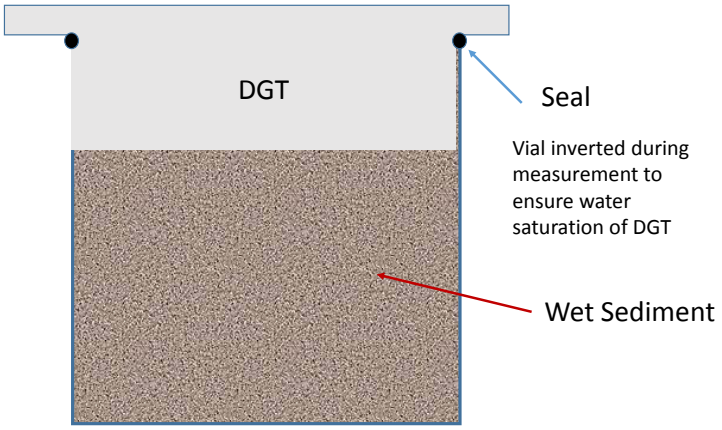


**Figure 1:** Vial with DGT inserted for THg and MeHg in porewater analysis. Approximately 20 mL of wet sediment fills the vial.

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

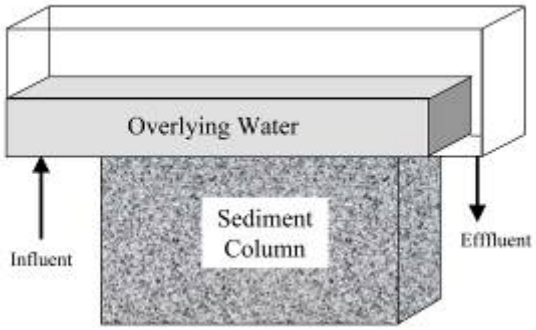


**Figure 2:** Schematic of experimental mesocosms. Approximately 20 cm x 10cm x 5 cm (LxHxW) sediment layer with 3 cm overlying water

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).

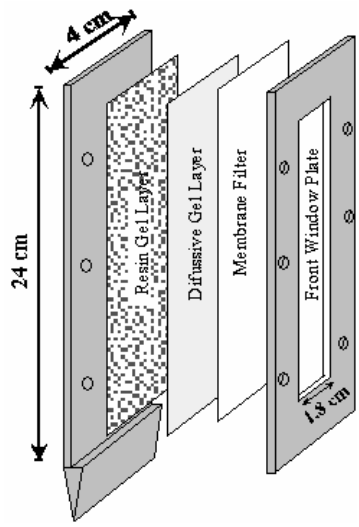


**Figure 3:** DGT profiler. These will be employed in the mesocosms but a smaller cylindrical piston shape will be used in the vials

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.

## References

Brendel, P. J.; Luther, G. W., III. 1995. Development of a gold amalgam voltammetric microelectrode for the determination of dissolved Fe, Mn, $O_2$, and S(-II) in porewaters of marine and freshwater sediments. Environ. Sci. Technol. 29 (3), 751–61.

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Divis, P., Leermakers, M., Docekalova, H., and Gao, Y. 2005. Mercury depth profiles in river and marine sediments measured by the diffusive gradients in thin films technique with two different specific resins Analytical And Bioanalytical Chemistry, 382(7), 1715-1719

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# 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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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 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

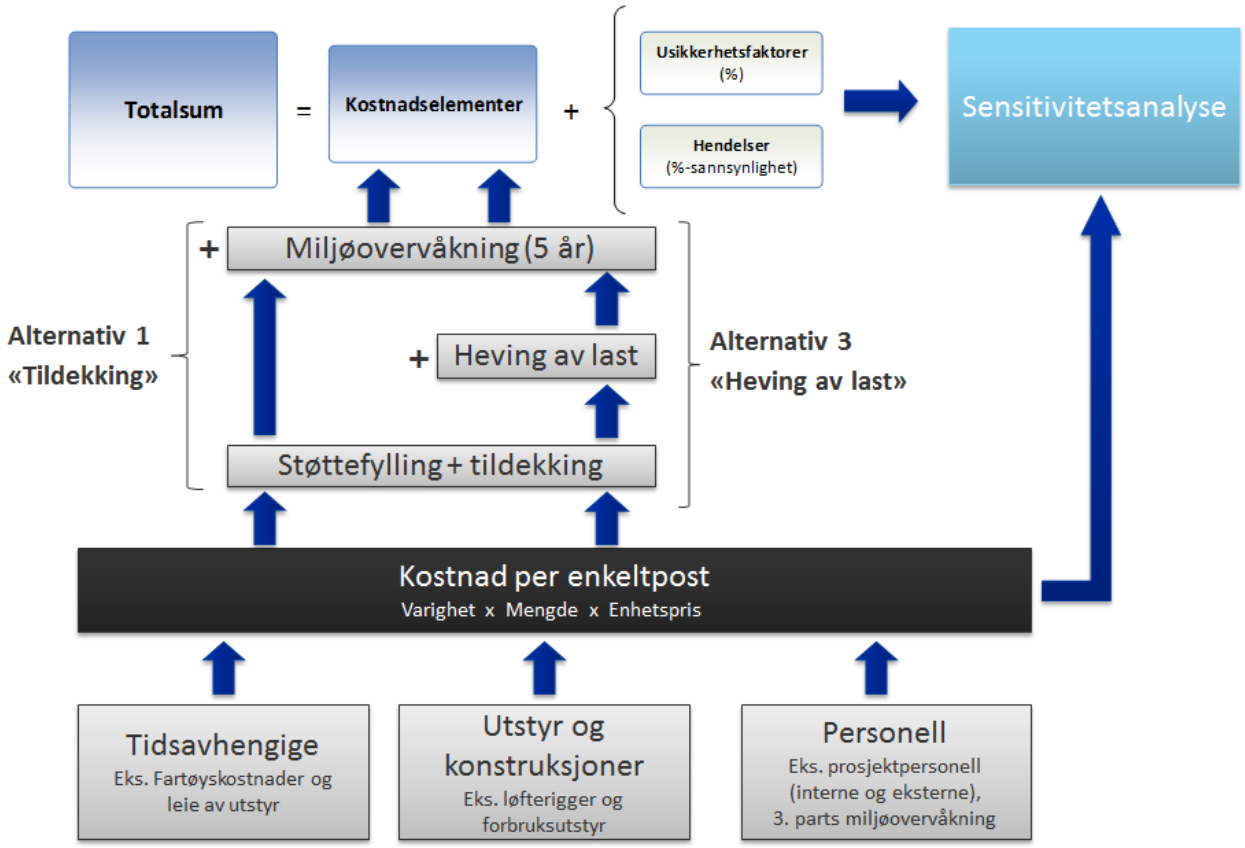
Usikkerhetsanalysen følger standard metode som benyttes i kravene til kvalitetssikring av offentlige investeringsprosjekter utarbeidet av Finansdepartementet. Dette er en anerkjent metode for beregning av usikkerhet i store, komplekse prosjekter. Kystverket har utarbeidet én kostnadsmodell som dekker 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.

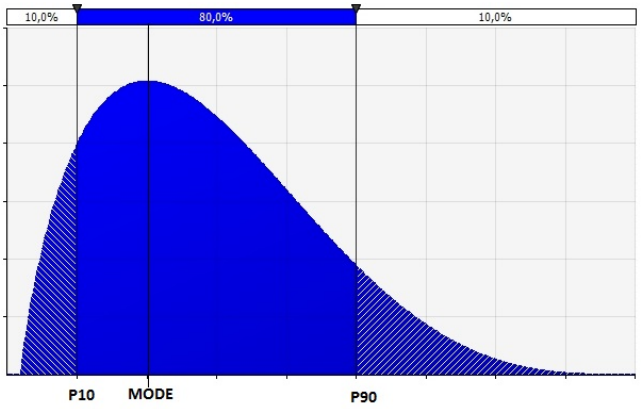



**Figur 1 - Fremstilling av beregningsmodellen for begge alternativer**

# 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

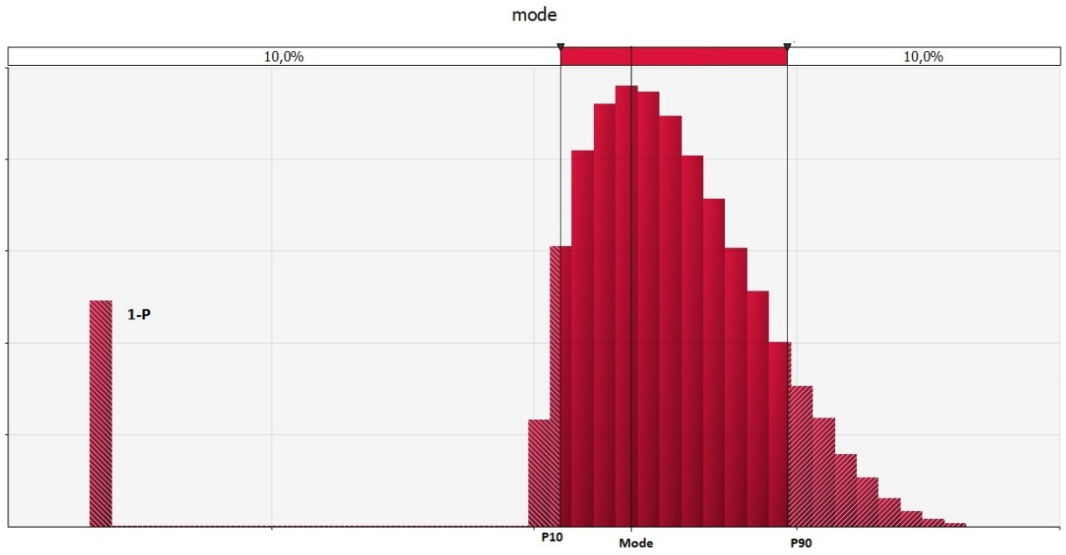
Beregning av en usikkerhetsfaktors påvirkning skjer ved multiplisering av de to fordelingene for kostnadsposten og for usikkerhetsfaktoren. For å isolere faktorens bidrag benyttes kun den prosentvise endringen. Det medfører at dersom faktoren F er oppgitt som en variasjon rundt 0 (for eksempel med trippelanslaget -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.

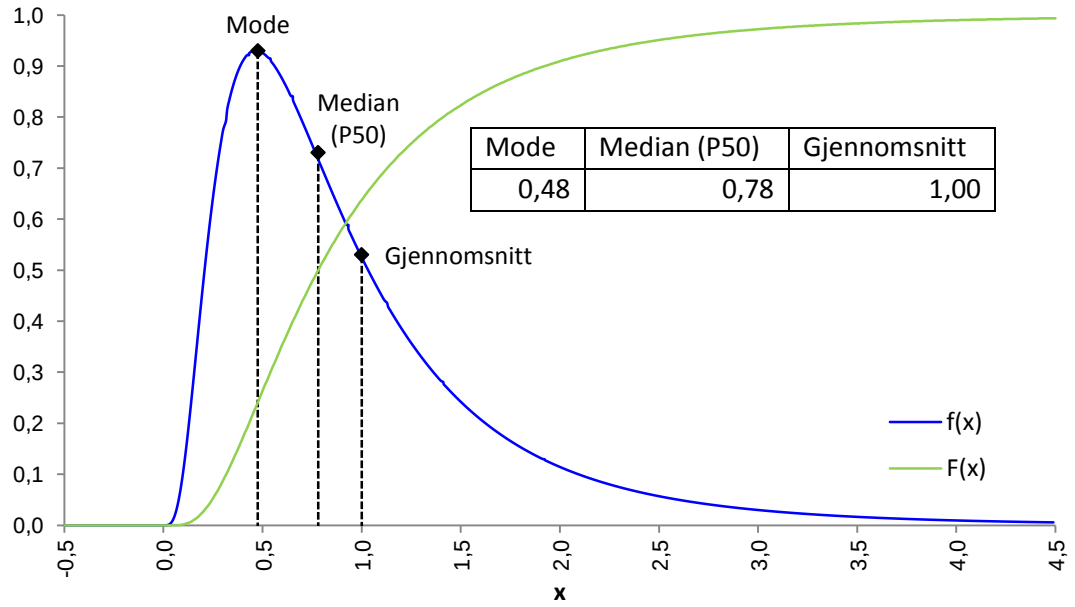
## 5.1 Grunnleggende statistikk

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.**

## 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 V0.11

ENVIRONMENTAL MEASURES FOR THE WRECK OF U-864

# Monitoring

Norwegian Coastal Administration

| | | |
|---|---|---|
| Project name: | Environmental measures for the wreck of U-864 | DNV GL AS |
| Report title: | Monitoring | Project Management & Technical Services Program<br>P.O.Box 300<br>1322 Høvik<br>Norway<br>Tel: +47 67 57 99 00 |

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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.

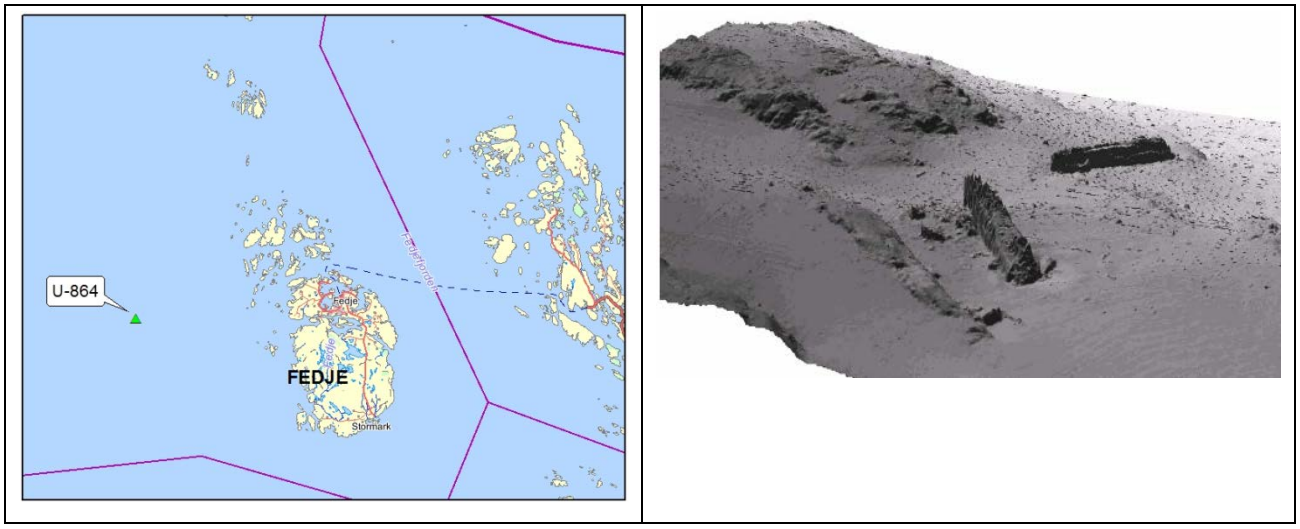


**Figure 2-1 Location (left) and a sonar picture of the wreck of U-864 on seabed (right) (from Geoconsult).**

## 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.

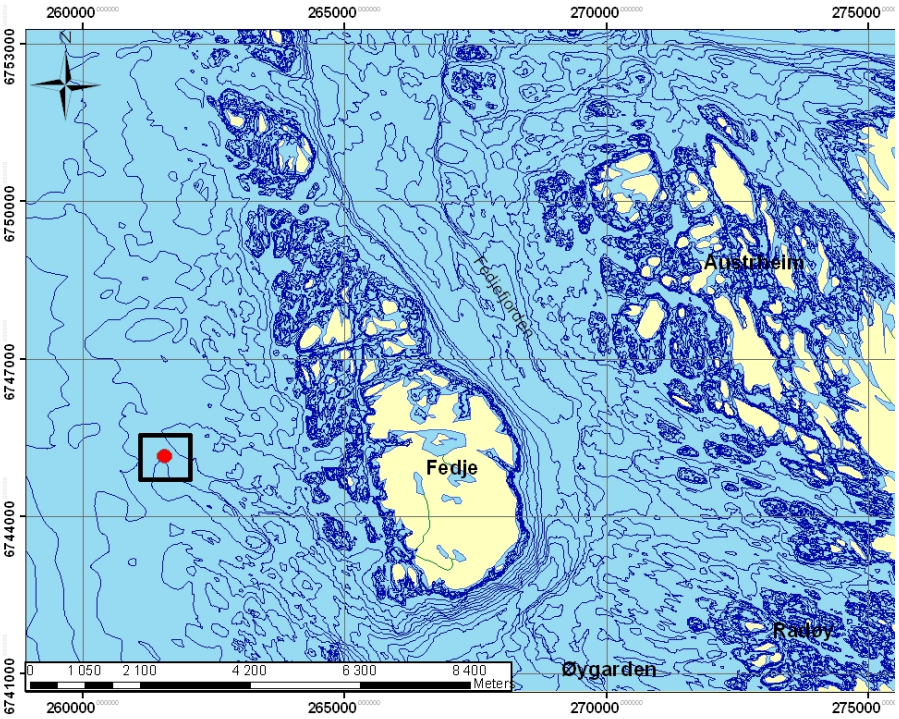


**Figure 3-1 Location of U-864 outside Fedje on the west coast of Norway.**

### 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.

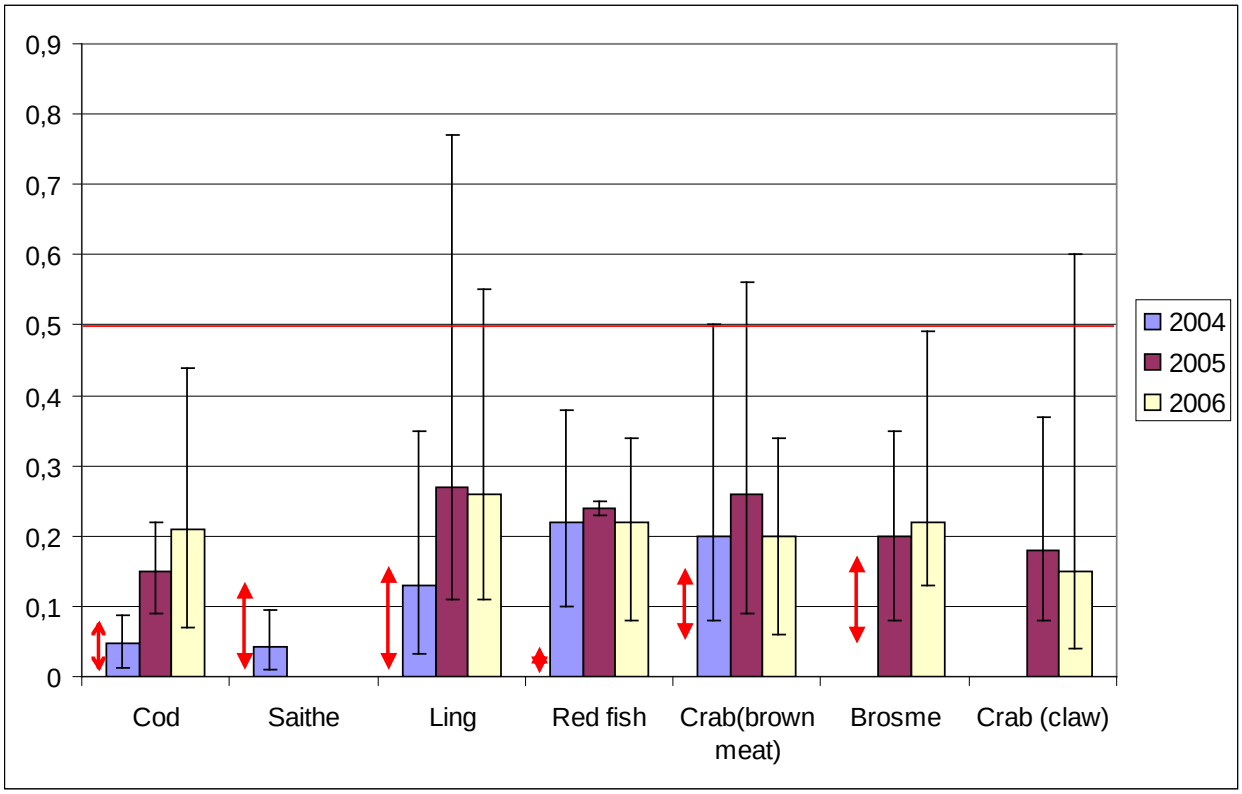


**Figure 3-2 Mercury content in fish and crab (mg/kg wet weight) from the sampling performed in 2004-2006 by NIFES. Red arrows indicate normal values (from Norwegian areas unaffected by pollution), columns average values and black bars maximum and minimum values.**

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.

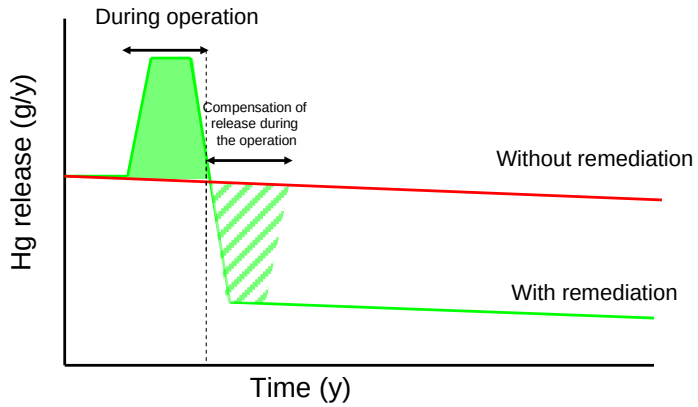


**Figure 4-1 Schematic example of a contaminant budget**

## 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.

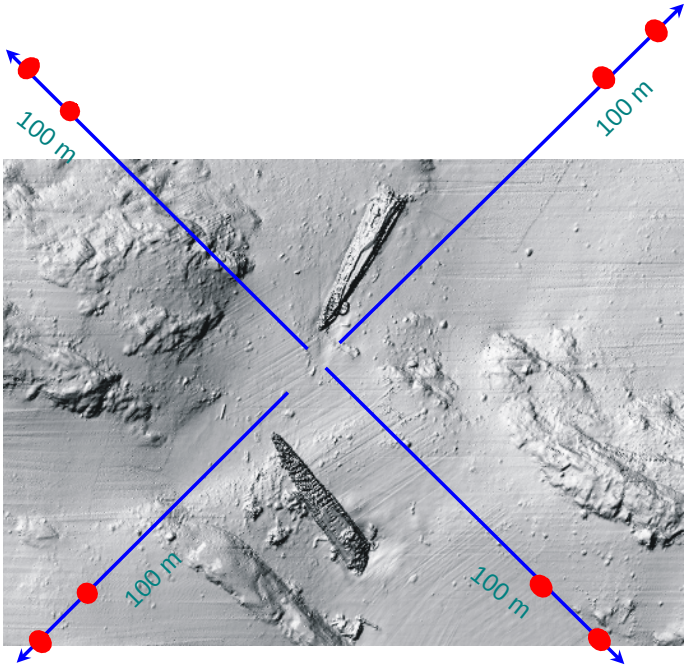


**Figure 4-2 Sampling strategy - water samples (distance given not exact, for illustration purpose only).**

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.

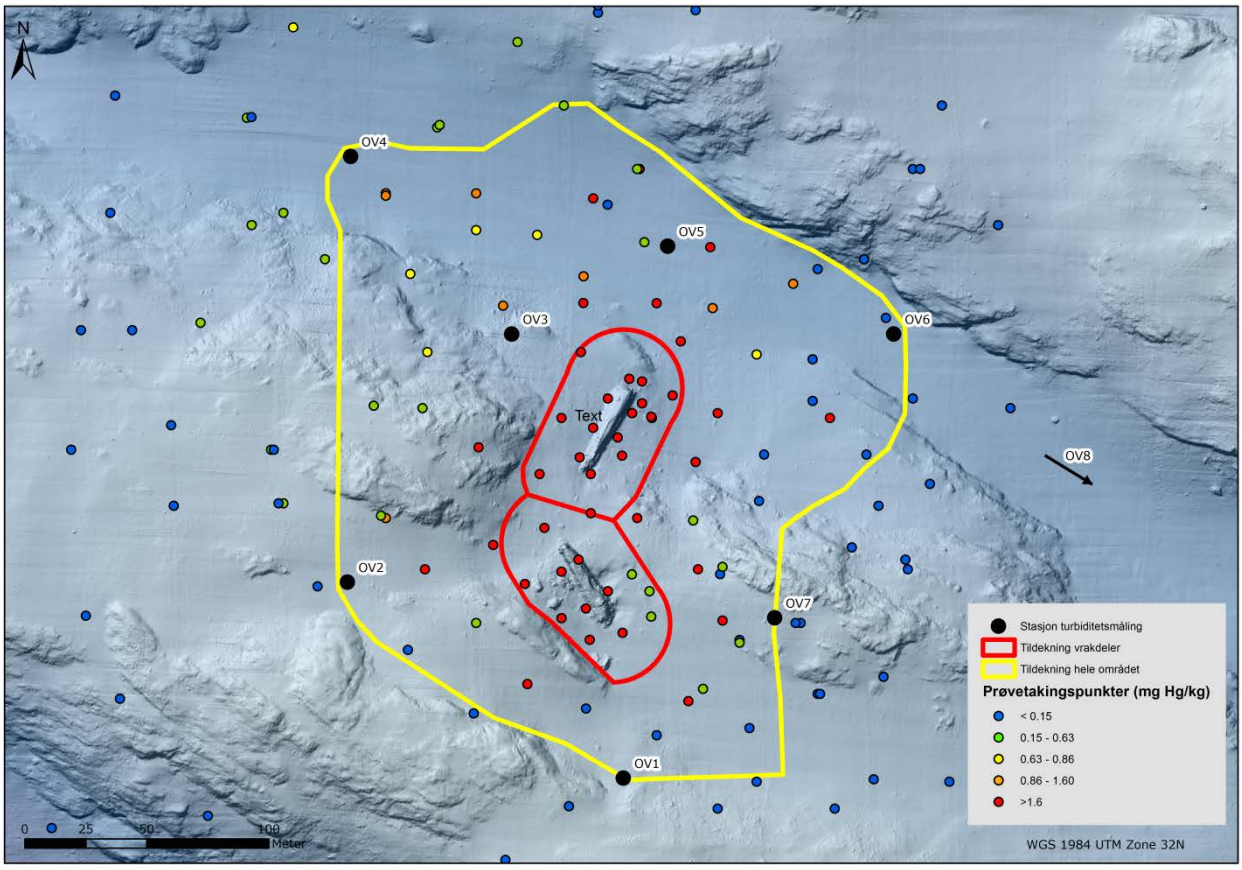


**Figure 4-3 Suggested locations for turbidity measurements.**

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**.

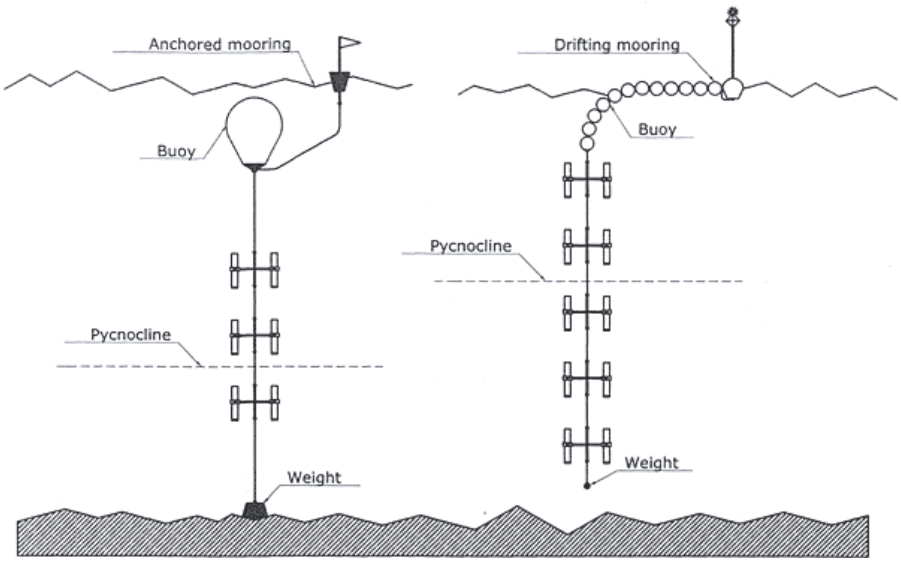


**Figure 4-4 Mooring arrangement (for illustration purposes only)**

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.

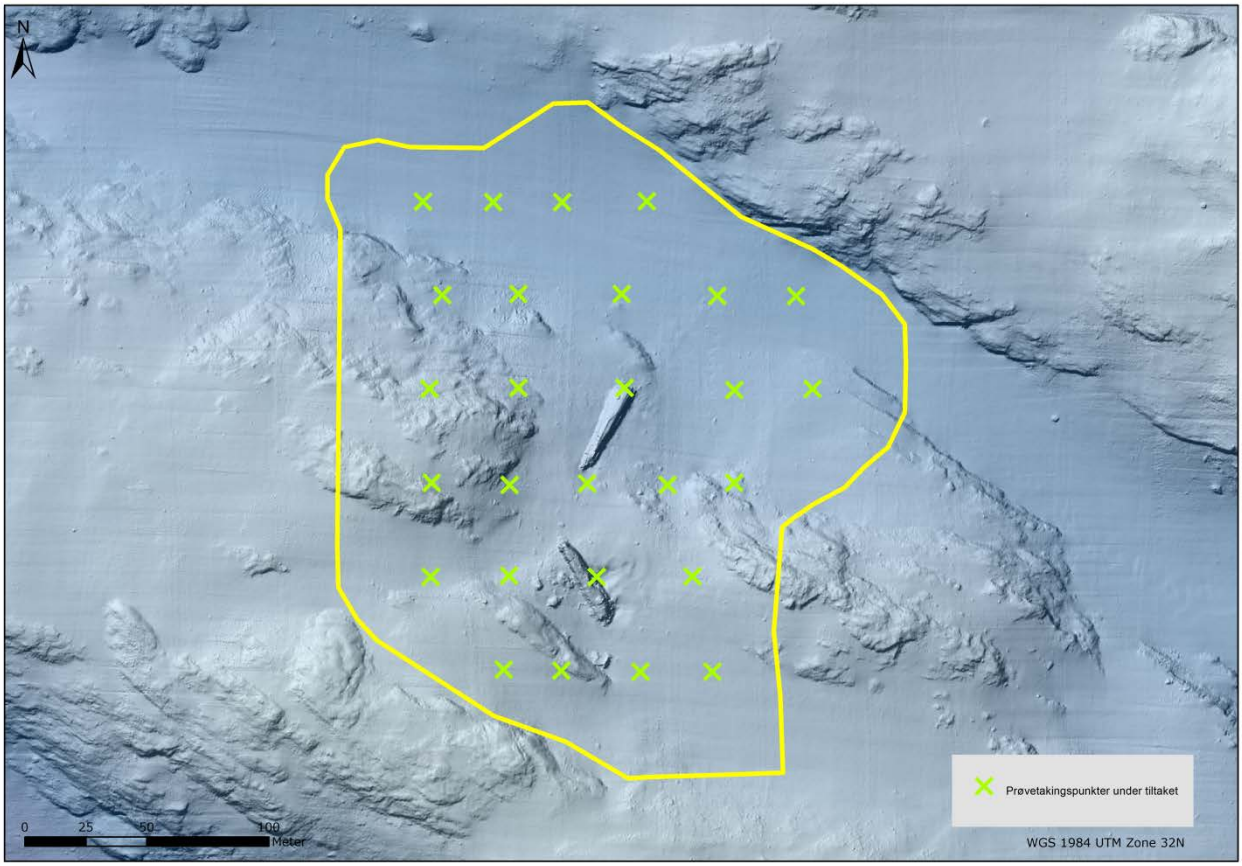


**Figure 4-5 Suggested sampling grid for sediments and pore water. Green crosses indicate location of the sampling stations. Yellow line marks the perimeter of the remediation area. Note that sediment samples will only be taken as part of the final control of the capping layer while pore water will be 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.

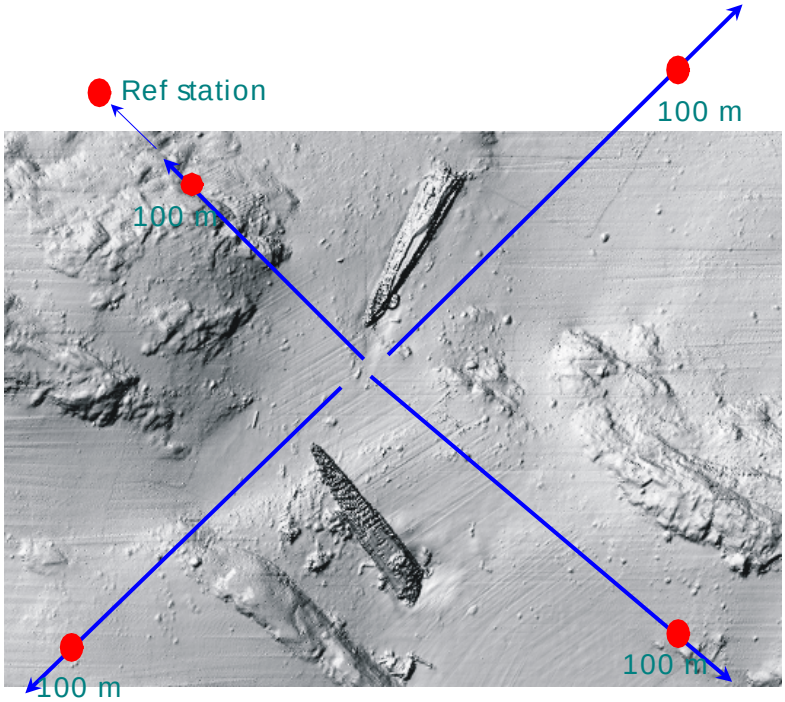


**Figure 4-6 Illustration of suggested sampling stations. Red dots illustrate sampling stations (distance given not exact, for illustration purpose only).**

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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# Keel Inspection U-864 (Phase 3b) (DOF Subsea)

DOF Subsea

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# 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).

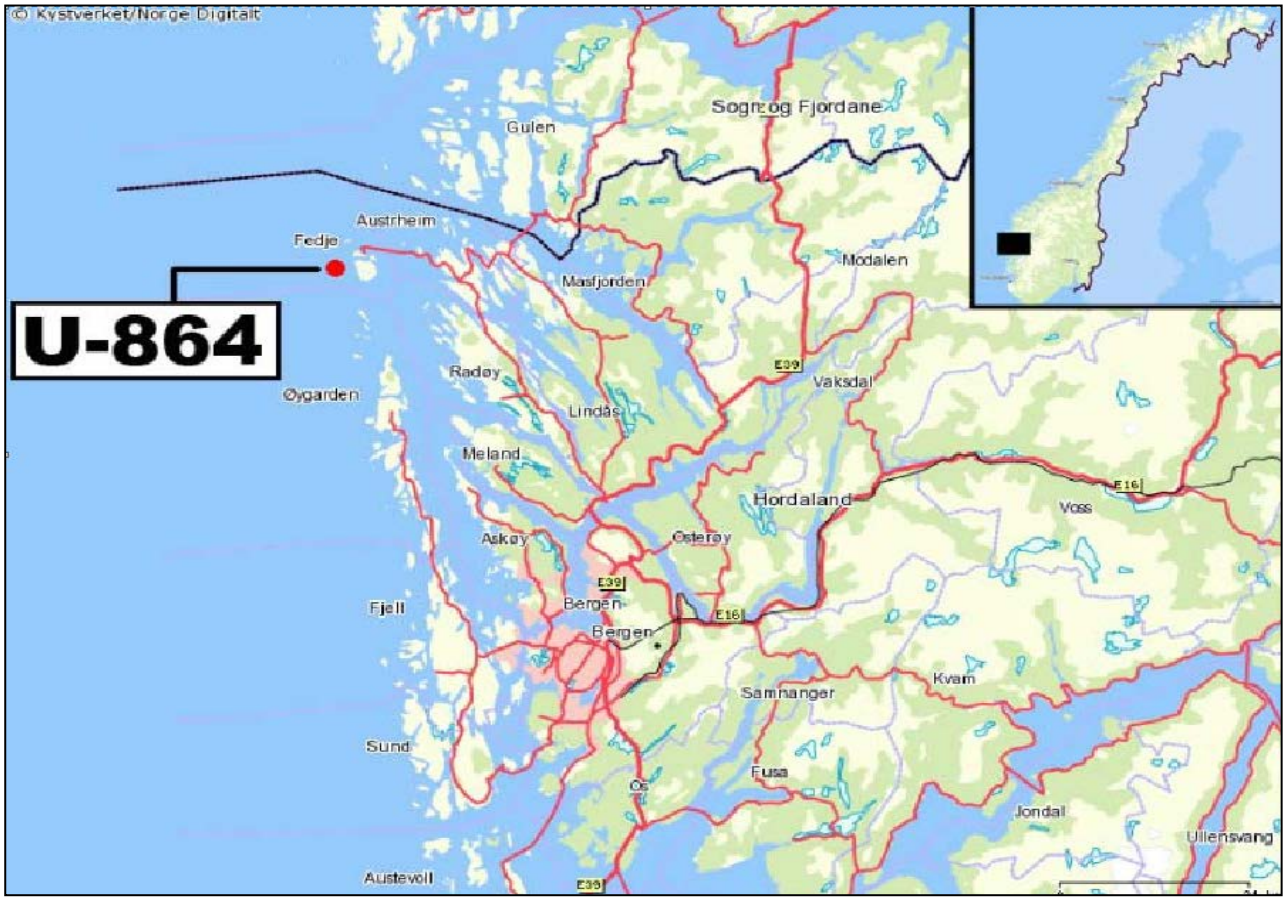



**Figure 1.1 Map of U-864 Location**

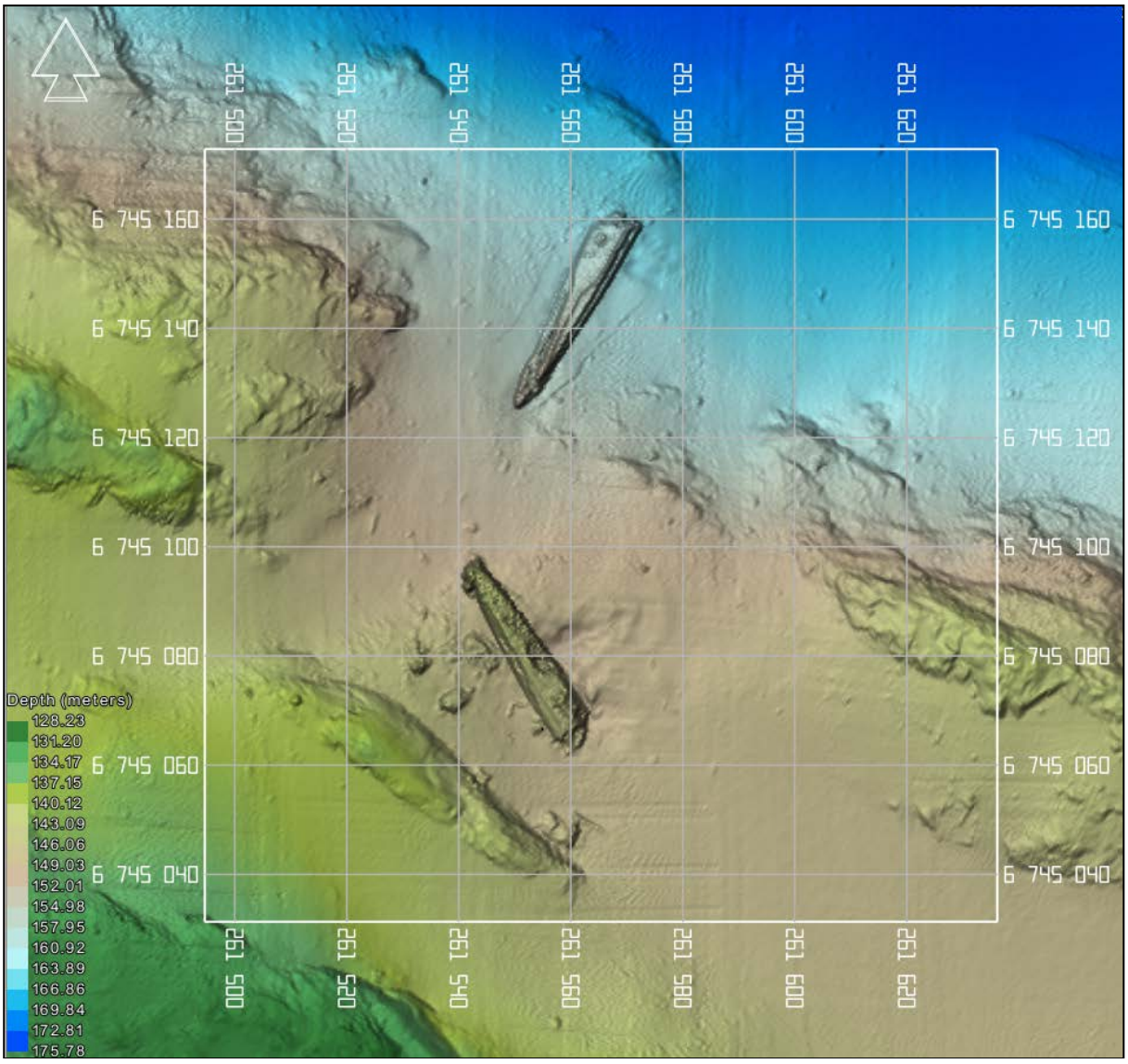



**Figure 1.2 U-864 wreck and orientation on sea bed (From Phase 3A Survey, 2013)**

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.

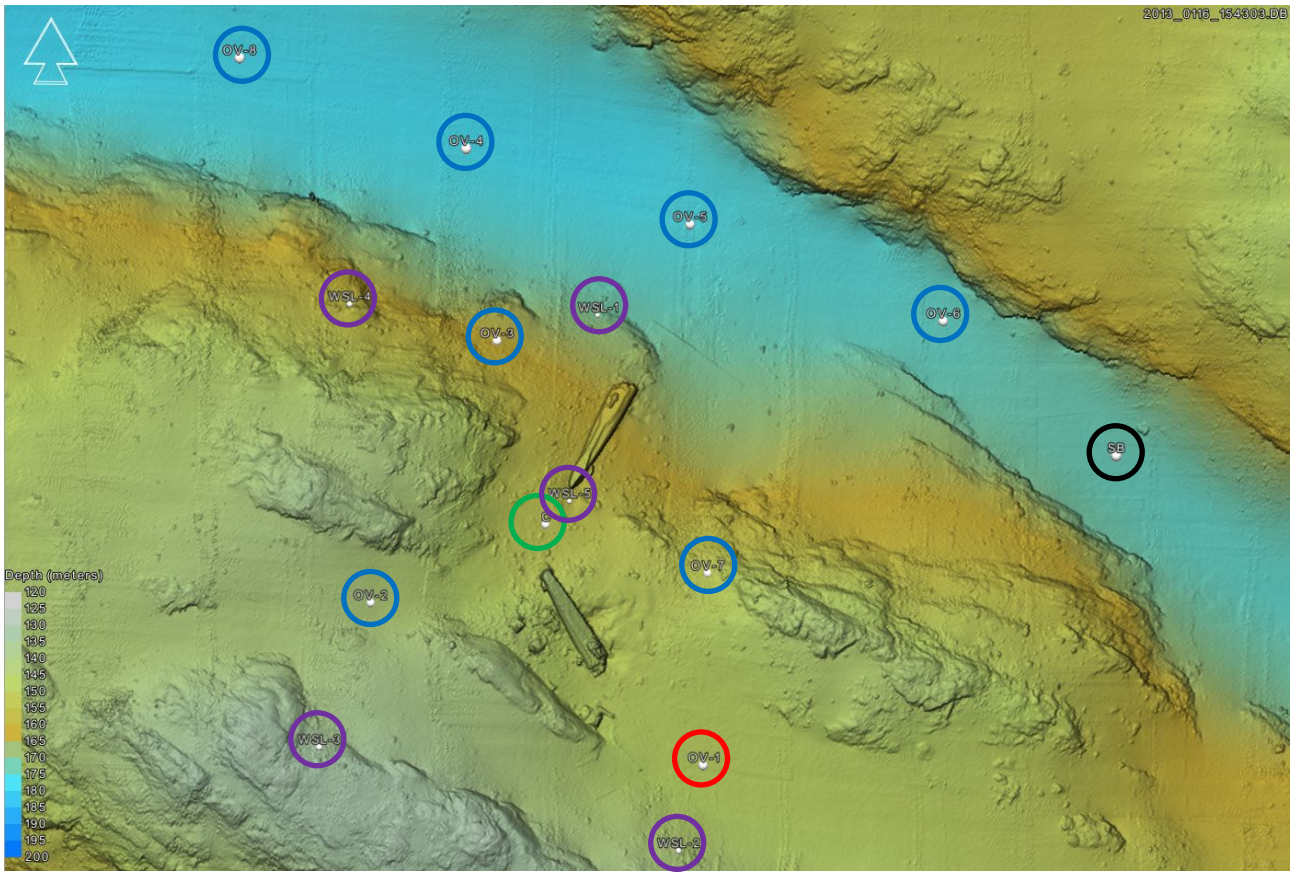



**Figure 2.1 Environmental monitoring stations: Turbidity and sediment traps (OV) Blue, Current meter (C) Green, Surface telemetry buoy (SB) Black and Water sampling location (WSL) Purple. (OV-1 not used Red)**

**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).

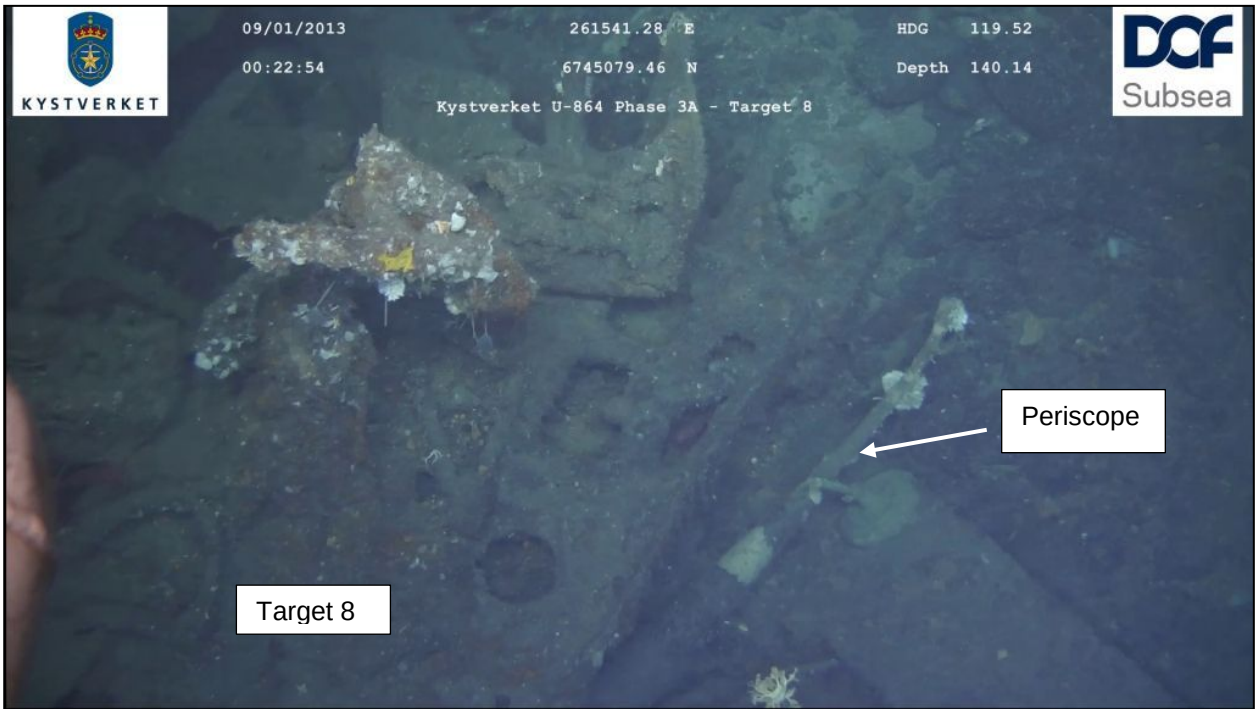



**Figure 2.3 U-864 periscope as located during Phase 3A**

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.

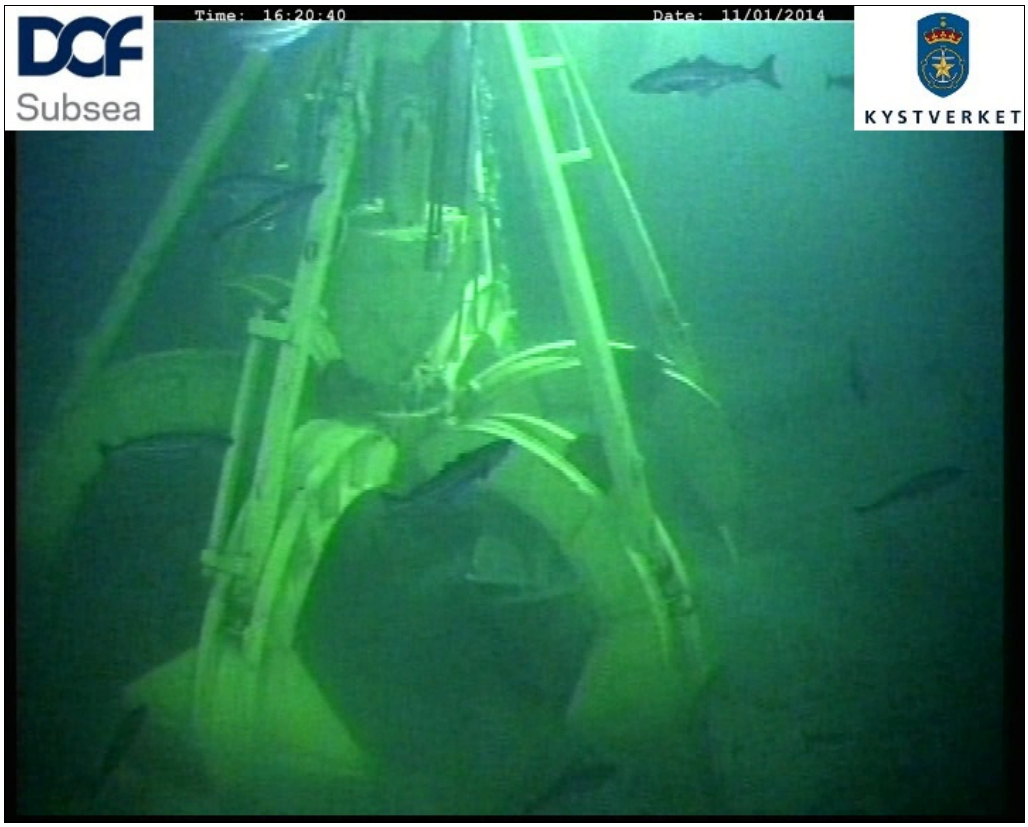



**Figure 2.4 Grab in operation**




**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).

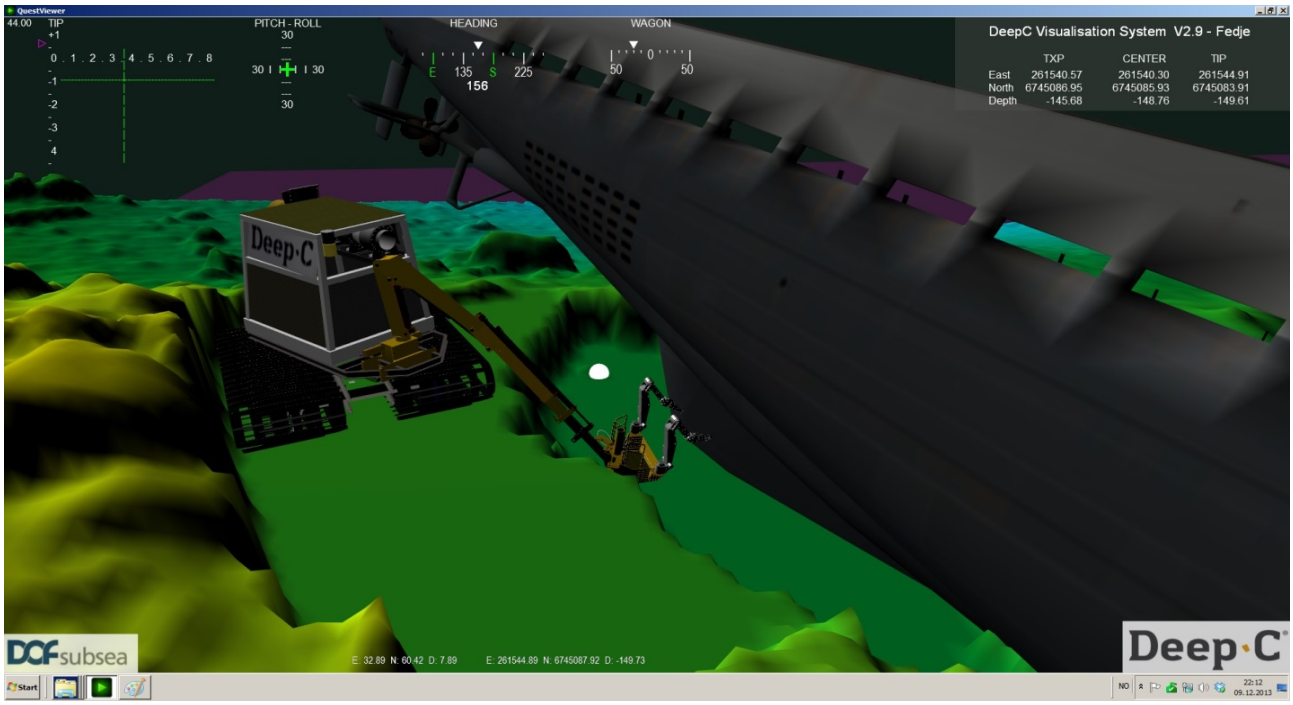



**Figure 2.7 Conceptual imagery of Deep C digger fitted with tooling platform (robotic arms)**

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 |

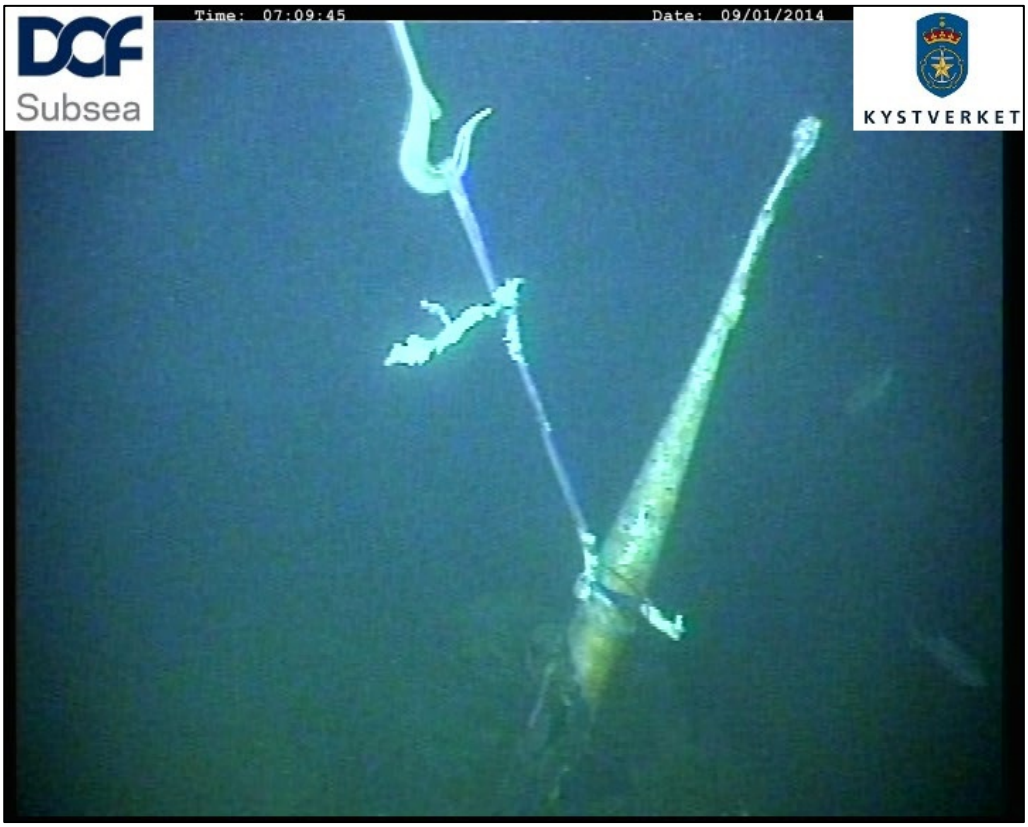



**Figure 3.1 Periscope being pulled clear of Target 8**

## 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.

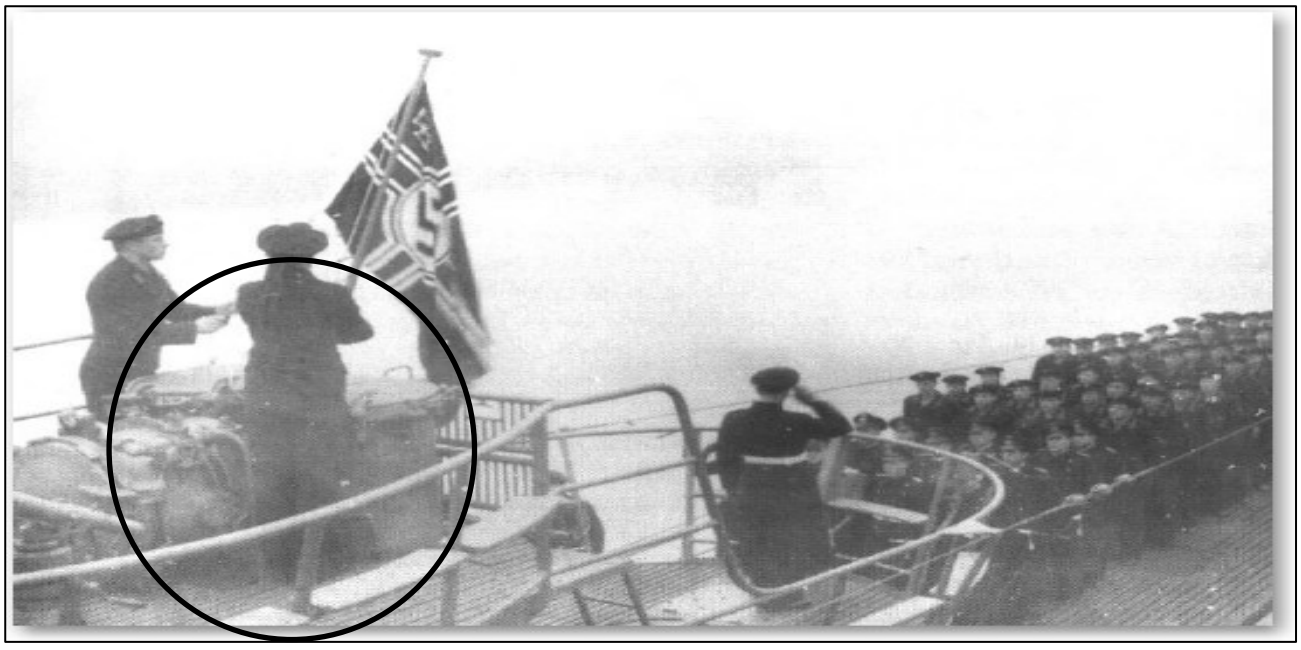


**Figure 3.2 U-864 showing after part of Target 8 (circled)**




**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**

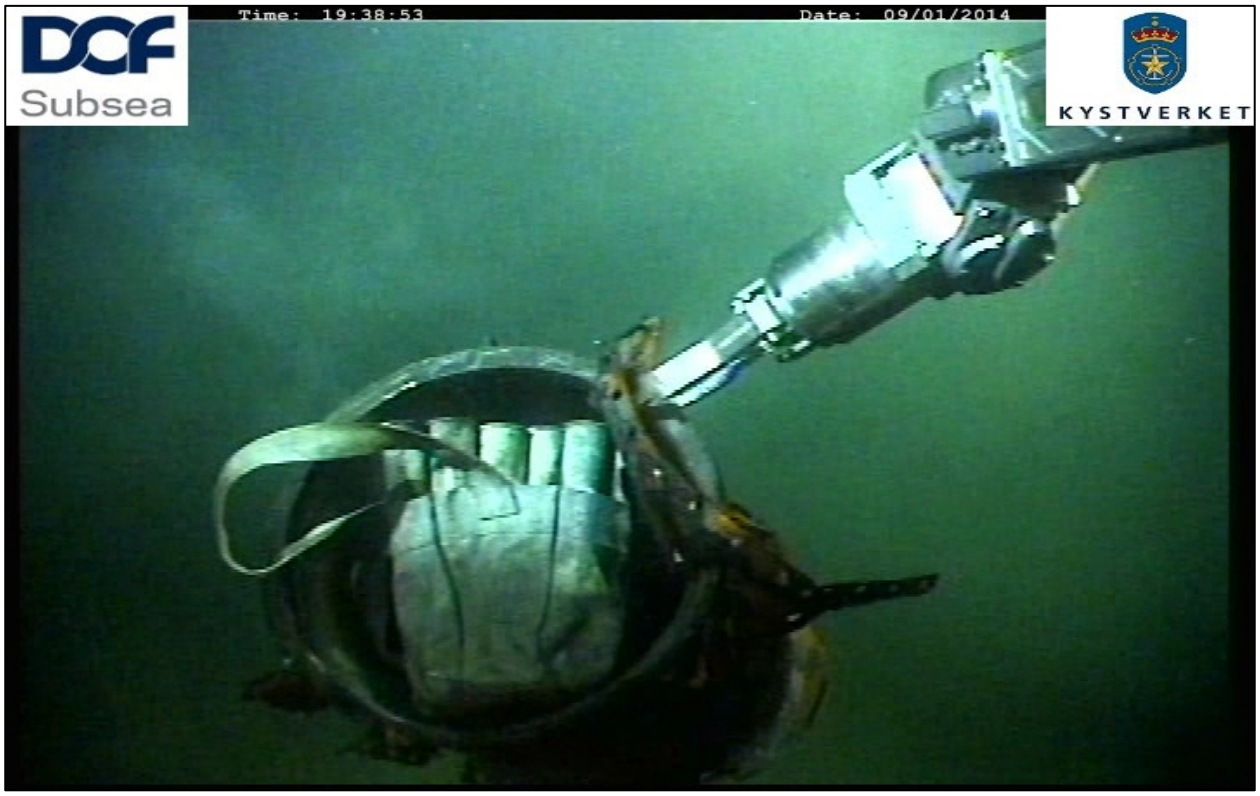



**Figure 3.5 20mm ammunition being transported to the wet store area. Note the excellent condition of the satchel**




**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 |

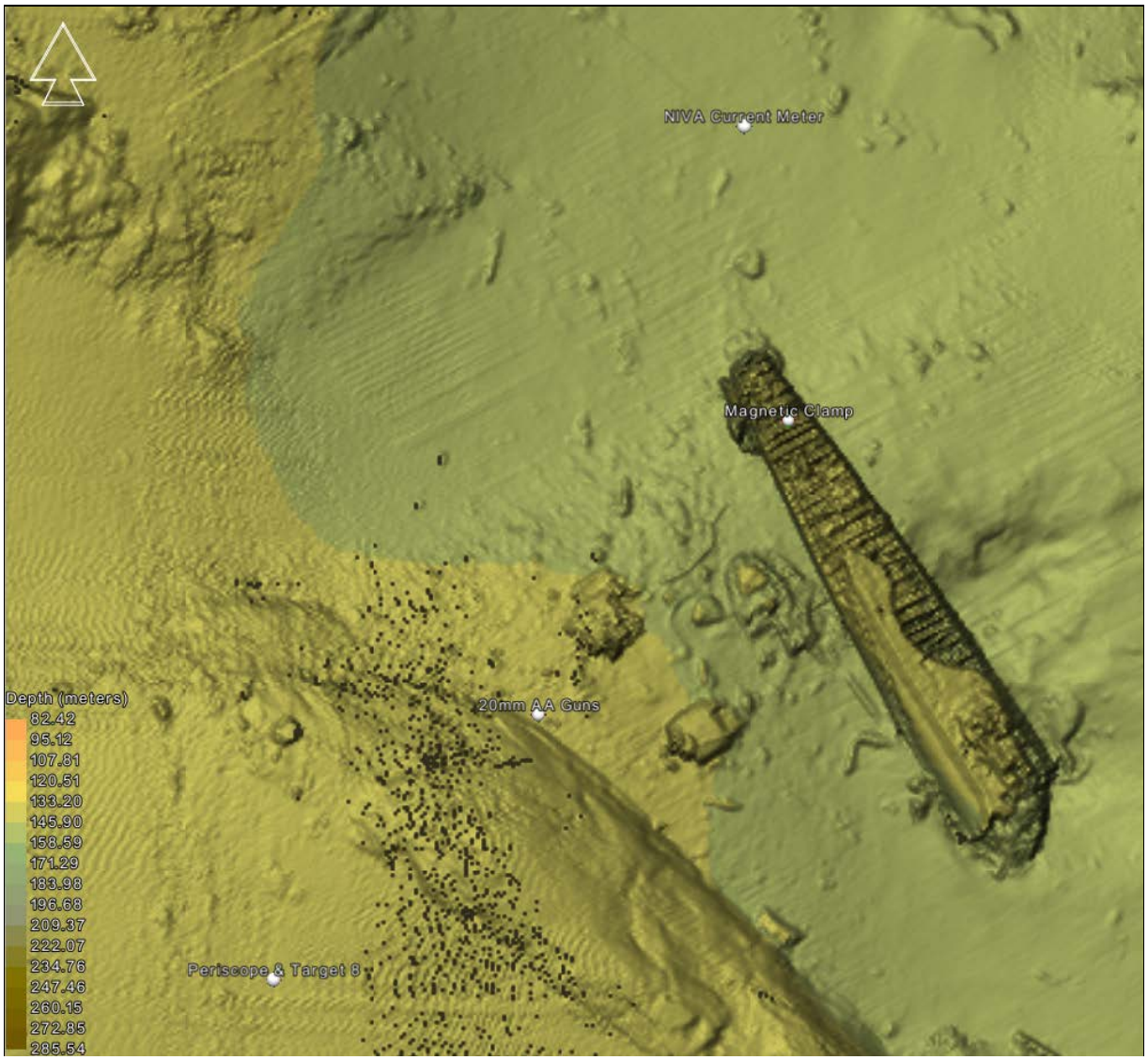



**Figure 3.9 Items on the seabed**

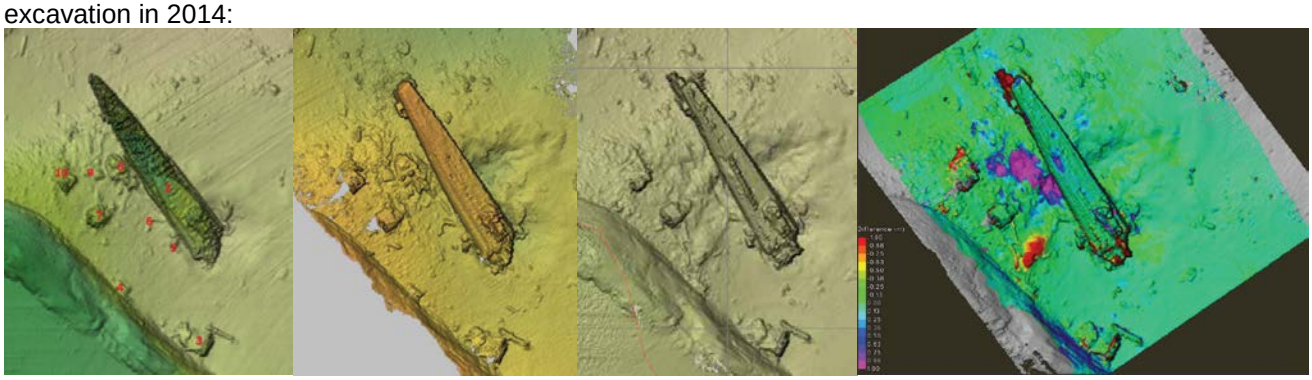
# 4 AS-LEFT MBE SURVEY

## 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: PRESURVEY AND TARGET INVESTIGATION | Revision date: 08.01.2014 | Page: 1 of 3 |
|---|---|---|---|
| | | Doc no.: 600264-GSUN-O03-0001-01 | Rev.: 01i |

| **Task description :** Pre survey, installation of inclinometer and targetinvestigation.<br><br>**Worksite:** M/V Geosund, Fedje<br><br>**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. 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:**<br>**1. Deck Foreman is in charge on deck.**<br>**2. Perform Toolbox talk prior to start of operations.**<br>**3. The sequence in this task plan may change for safety or practical reasons.**<br>**4. Management of change process to be used in the event of procedural changes**<br>**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.**<br>**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.<br><br>**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.<br><br>**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:<br>- 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.<br><br>**NOTE!**<br>**Niva to check for contamination, if any traces of mercury is found Franzefoss will clean according to procedure.** | 2/3 | ROV | |
| 3.8. | | | Crane | |

| DCFsubsea delivering solutions at any depth | Document title: OPERATIONAL TASKPLAN | Revision date: 08.01.2014 | Page: 1 of 4 |
|---|---|---|---|
| | | Doc no. | Rev.: 05i |

**Task description :**
Deploy and position monitoring- and water sampling equipment

**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. 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 | |

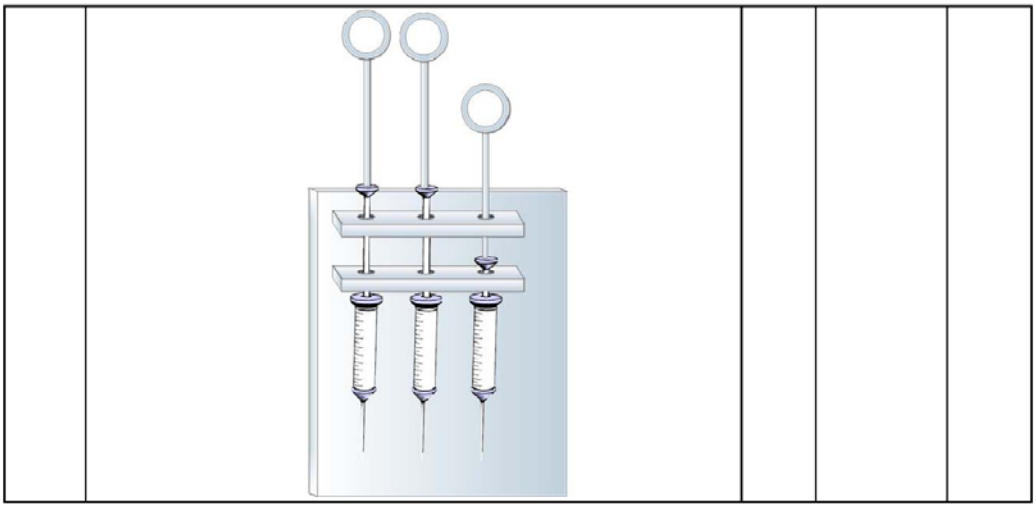
**Distribution:**

| | | | |
|---|---|---|---|
| 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:**<br>**1. Deck Foreman is in charge on deck.**<br>**2. Perform Toolbox talk prior to start of operations.**<br>**3. The sequence in this task plan may change for safety or practical reasons.**<br>**4. Management of change process to be used in the event of procedural changes**<br>**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.**<br>**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.<br><br>**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.<br><br>**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 | |



| 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 :**<br>Wetstoring of periscope<br><br>**Worksite:**<br>M/V Geosund,<br>Fedje<br><br>**Project:**<br>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 | |
| Approver | Brynjar Wiig/Rein Henrik Pelsholen | Sift 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 | 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:**<br>**1. Deck Foreman is in charge on deck.**<br>**2. Perform Toolbox talk prior to start of operations.**<br>**3. The sequence in this task plan may change for safety or practical reasons.**<br>**4. Management of change process to be used in the event of procedural changes**<br>**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.**<br>**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.<br><br>**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.<br><br>**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:<br>- 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.<br>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.<br>(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.<br><br>**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 | |

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|---|---|---|---|---|
| 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.<br><br>**NOTE!**<br>**Niva to check for contamination, if found Franzefoss will clean according to procedure.** | 2/3 | ROV | |
| 6.3. | | | | |
| 6.4. | | | | |
| 6.5. | | | | |
| 6.6. | | | | |

| DOF subsea delivering solutions at any depth | Document title: MOVING TARGET 8 AND DEEP C OPERATIONS | Revision date: 08.01.2014 | Page: 1 of 7 |
|---|---|---|---|
| | | Doc no.: 600264-GSUN-O03-0004-01 | Rev.: 01i |

**Task description :**
Moving of target 8 and Deep C operations.
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**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:**<br>**1. Deck Foreman is in charge on deck.**<br>**2. Perform Toolbox talk prior to start of operations.**<br>**3. The sequence in this task plan may change for safety or practical reasons.**<br>**4. Management of change process to be used in the event of procedural changes**<br>**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.**<br>**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.<br><br>**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 | |

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|---|---|---|---|---|
| 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.<br><br>**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:<br>- 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.<br><br>**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.<br><br>**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 | |

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| | distance, but keep visual contact if possible.<br>  <br>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.<br><br>**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.<br><br>**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 | |

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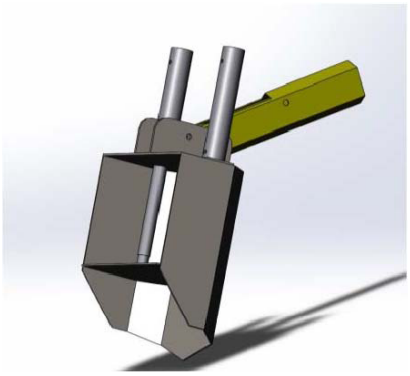
| 4.3. | Attach crane hook to Deep C excavator rigging and remove sea fastening.<br><br>**NOTE! Make sure the umbilical is placed securely inside the chute. Pay out approx. 20 m umbilical prior to launch. Also remove grounding wire from frame.** | 1 | Deck Foreman | |
| 4.4. | Deploy dredger and lower to approx. 10 above seabed. ROV to get visual. Deep C to pay out on umbilical winch.<br><br>**NOTE! Reposition vessel as required.** | 1 | Crane | |
| 4.5. | Lower dredger to dedicated area.<br><br>**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.<br><br>  <br><br>**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 | |

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|---|---|---|---|---|
| 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.<br><br>**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 | |

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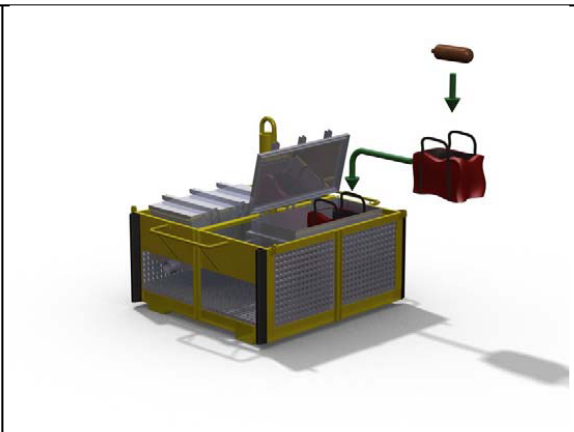
| |  **NOTE! ROV must be positioned close by and handle the canister bags.** | | | |
| 5.9. | ROV to place canister bag in basket. | | ROV | |
| 5.10. | Repeat steps 6.7 – 6.13 of until all canisters are recovered. | | ROV | |
| 5.11. | Deploy crane and lower towards ROV basket. Stop at 10 m above seabed 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<br><br>**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: ENTERING KEEL AND REMOVING HG-CANISTERS | Revision date: 12.01.2014 | Page: 1 of 6 |
|---|---|---|---|
| | | Doc no.: 600264-GSUN-O03-0005-01 | Rev.: 01i |

**Task description :**
Entering keel and removing Hg-canisters

**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:**

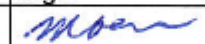
1. Preparatory works
2. Drilling through keel section
3. Inspect
4. Remove Hg-canisters

**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 |  |
| Approver | Brynjar Wig | 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. | 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:**<br>**1. Deck Foreman is in charge on deck.**<br>**2. Perform Toolbox talk prior to start of operations.**<br>**3. The sequence in this task plan may change for safety or practical reasons.**<br>**4. Management of change process to be used in the event of procedural changes**<br>**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.**<br>**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.<br><br>**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.<br><br>**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.<br><br>• 2 x Grinders w/ cutting disk<br>• Spycam | 1 | Deep C | |
| 2.8. | Prepare Crane with transponder. | 1 | Deck Foreman | |
| 2.9. | ROV to carry following equipment:-<br>• Drill rig (long hoses)<br>• 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 | |

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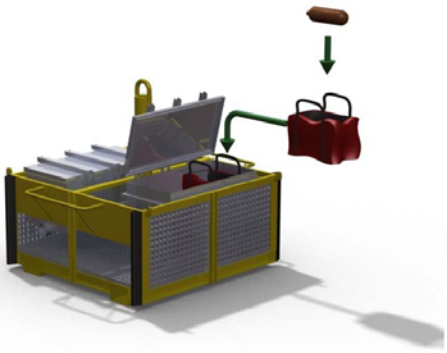
|---|---|---|---|---|
| |  | | | |
| 3.9. | Insert camera into inspection hole, inspect and evaluate further actions. If it's decided to continue cutting off a keel plate section, proceed to next step. | | ROV / Deep C | |
| 3.10. | Commence cutting the keel section plating. Deep C manipulator platform 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.<br><br>**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.<br><br>**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 | |

| DCF subsea delivering solutions at any depth | Document title: SOIL SAMPLING | Revision date: 12.01.2014 | Page: 1 of 3 |
|---|---|---|---|
| | | Doc no.: 600264-GSUN-O03-0006-01 | Rev.: 01i |

| **Task description :** Soil sampling<br>**Worksite:** M/V Geosund, Fedje<br>**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:**<br>**1. Deck Foreman is in charge on deck.**<br>**2. Perform Toolbox talk prior to start of operations.**<br>**3. The sequence in this task plan may change for safety or practical reasons.**<br>**4. Management of change process to be used in the event of procedural changes**<br>**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.**<br>**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.<br><br>**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:<br>• box for Hg canisters<br>• bucket for collecting soil | 1 | Deck Foreman | |
| 2.6. | ROV need to carry following equipment:<br>• 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.<br><br>**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: RECOVERY OF NIVA BUOY | Revision date: 14.01.2014 | Page: 1 of 3 |
|---|---|---|---|
| | | Doc no.: 600246-GSUN-O03-0010-01 | Rev.: 01i |

| **Task description :** Recovery of NIVA buoy<br><br>**Worksite:** M/V Geosund, Fedje<br><br>**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 | |
| Checker | Marius B. Nesse | Project Engineer | |
| Approver | Rein Henrik Pelsholen | 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:**<br>**1. Deck Foreman is in charge on deck.**<br>**2. Perform Toolbox talk prior to start of operations.**<br>**3. The sequence in this task plan may change for safety or practical reasons.**<br>**4. Management of change process to be used in the event of procedural changes**<br>**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.**<br>**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.<br><br>**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.<br><br>**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.<br>**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.<br>**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)

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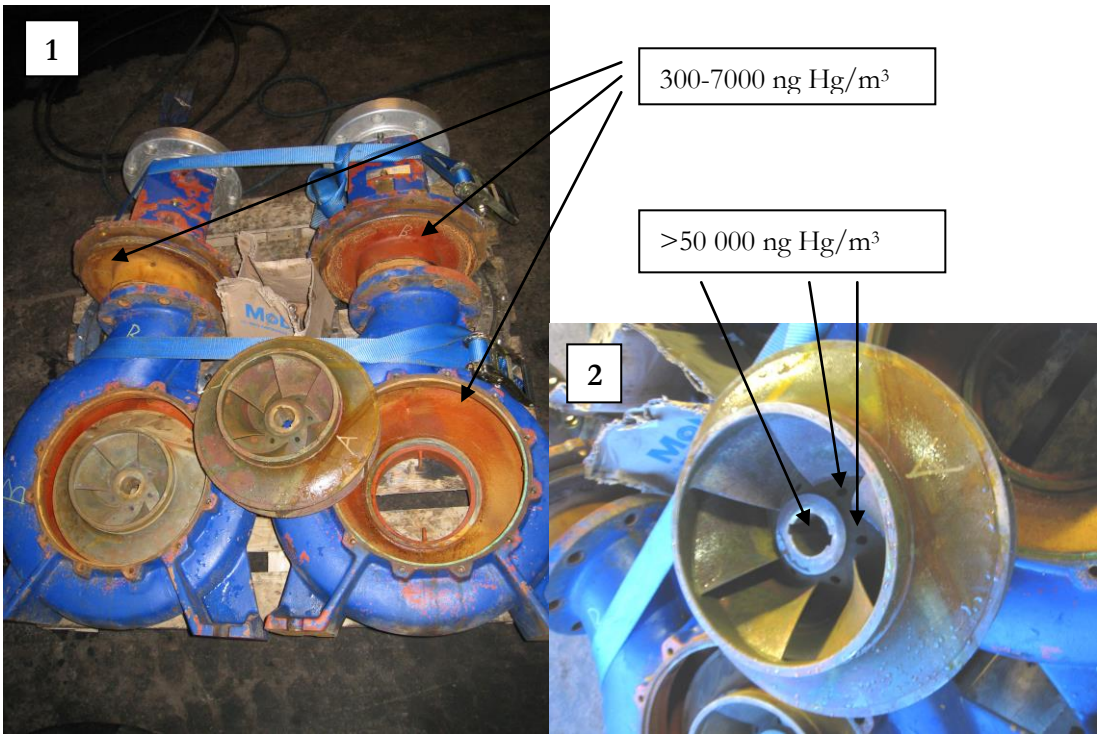
Att: Håvard Berge

| Deres referanse | Deres brev av | Vår referanse | Dato |
|---|---|---|---|
| | | J.nr. 0272/14<br>*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<br>I midten av pumpedel | 300 til 7000<br>>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<br><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.

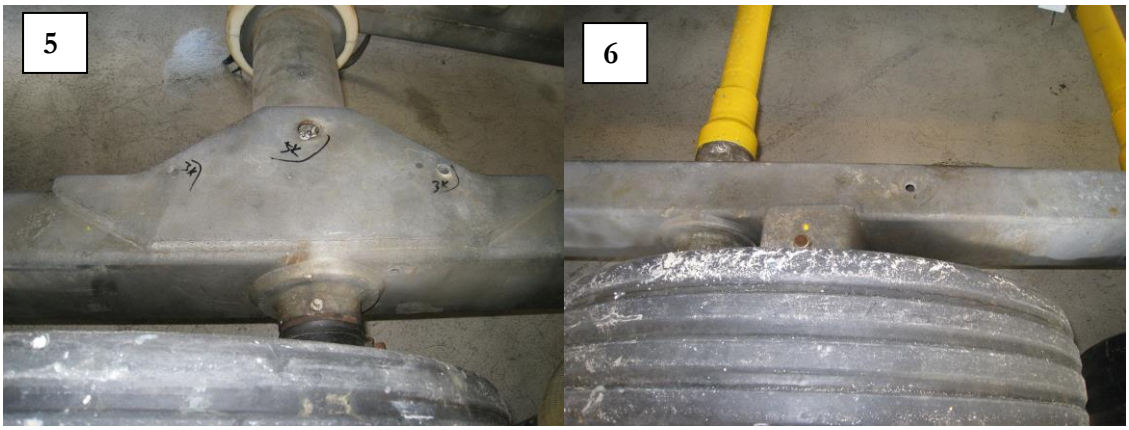
Det ble målt konsentrasjoner av kvikksølv som var på over 50 000 ng/m$^3$ på tre steder i hulrom i rammen (se bilde 3). Målingene på de andre hulrommene i rammen viste at konsentrasjonen var på lavere eller på samme nivå som ved forrige måling.



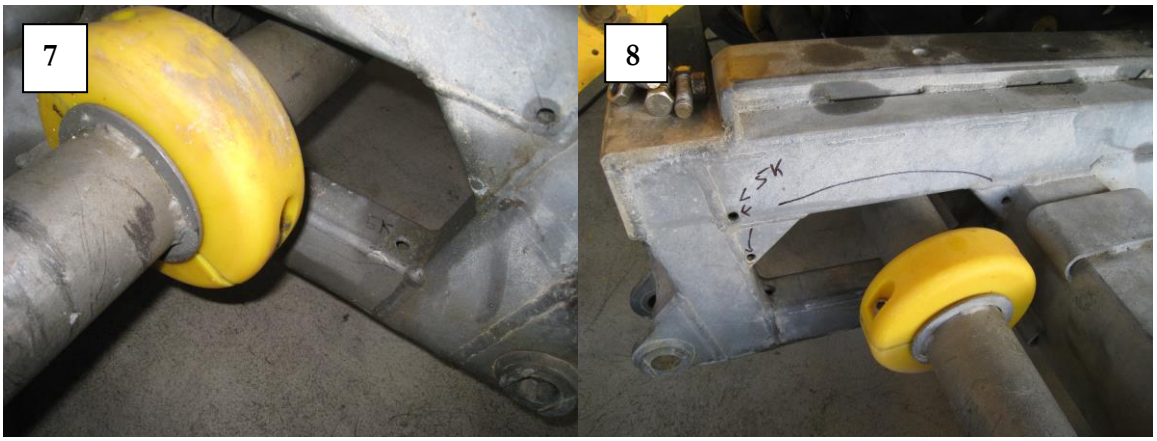

Bilde 3. Tre steder i rammen ble det målt konsentrasjon av kvikksølv på over 50 000 ng/m$^3$.



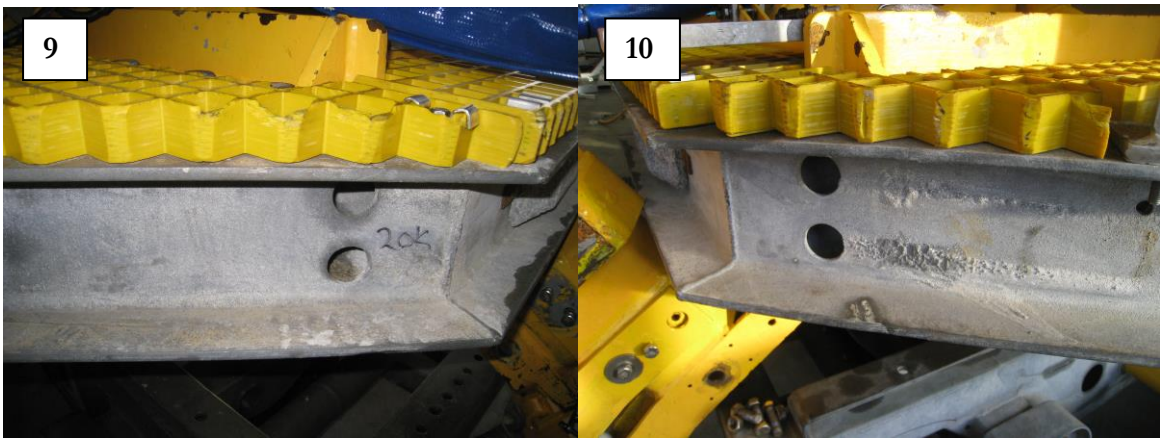

Bilde 4. I rammen på dette stedet ble det målt 10-12 000 ng Hg/m$^3$, mot 10 000 og 35 000 forrige gang.




Bilde 5. I rammen på dette stedet ble det målt 900-3000 ng Hg/m$^3$.
Bilde 6. I rammen på dette stedet ble det målt mindre enn 1000 ng/m$^3$, mot 5000 ng/m$^3$ 6. februar.




Bilde 7 og 8. I rammen på disse stedene ble det målt lavere enn 2000 ng/m$^3$, mot 5000 ved forrige måling.




Bilde 9. I rammen her ble det målt 6000 ng/m$^3$, mot 20 000 forrige gang.
Bilde 10. I rammen her ble det målt 2500-3000 ng/m$^3$.

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 varierte 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
– an institute in the Environmental Research Alliance of Norway

# REPORT

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| Title | Report No.. | Date |
|---|---|---|
| Environmental monitoring during survey by submarine U-864 outside Fedje in 2014 | 6642-2014 | 6.5.2014 |
| | Project No. O-13342 | Pages 50 |
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| | Geographical area Fedje | Printed NIVA |

| Client(s) | Client ref. |
|---|---|
| DOF Subsea Norway | Håvard Berge |

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 |





*Sigurd Øxnevad*
Project Manager

*Morten Schaanning*
Research Manager

ISBN 978-82-577-6377-0

# 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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**Appendix C. Turbidity data** **43**

# 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:

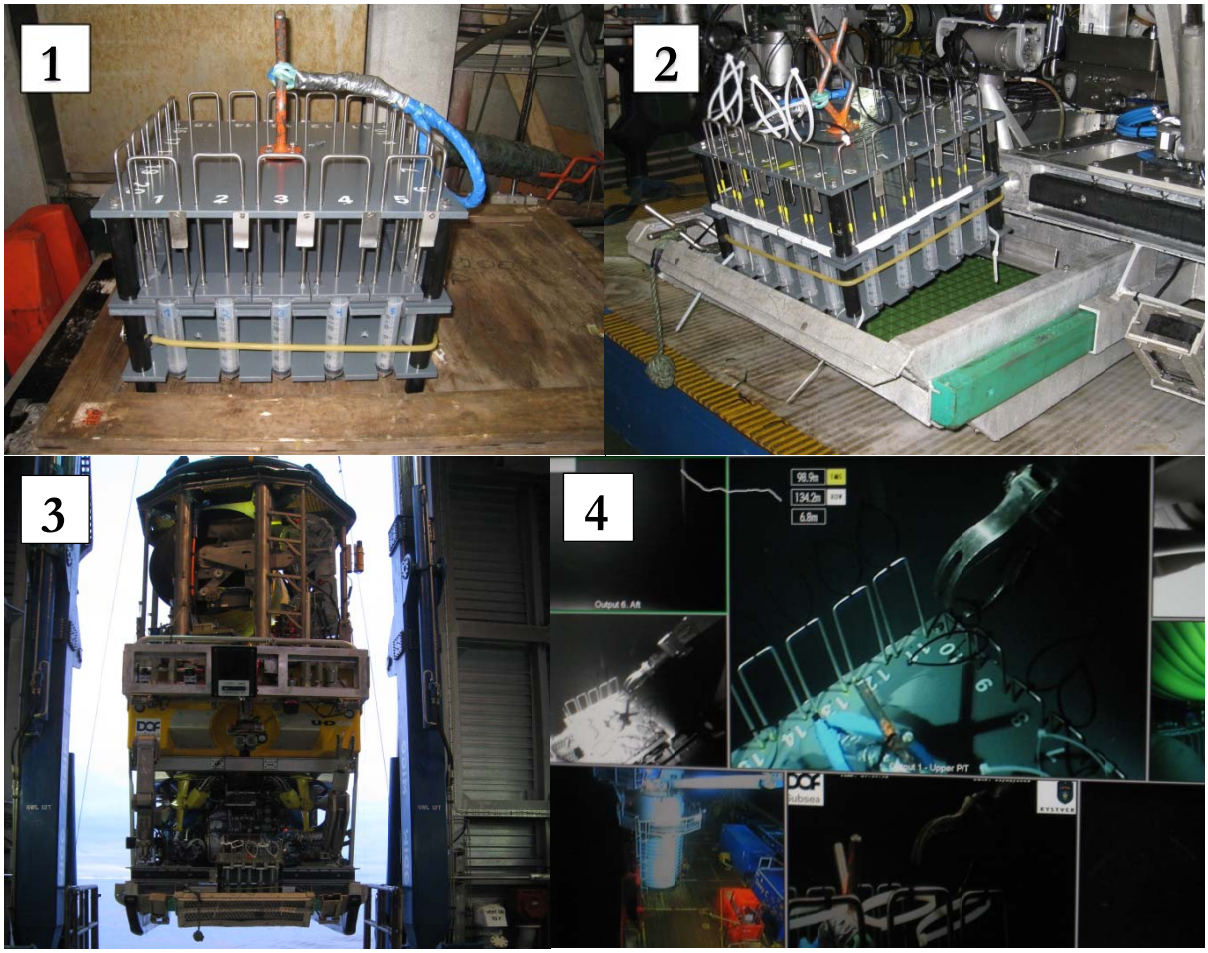
- Seal-in the polluted area, utilizing sand with special characteristics
- Retrieve the mercury cans from the keel section and seal-in the polluted area

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.

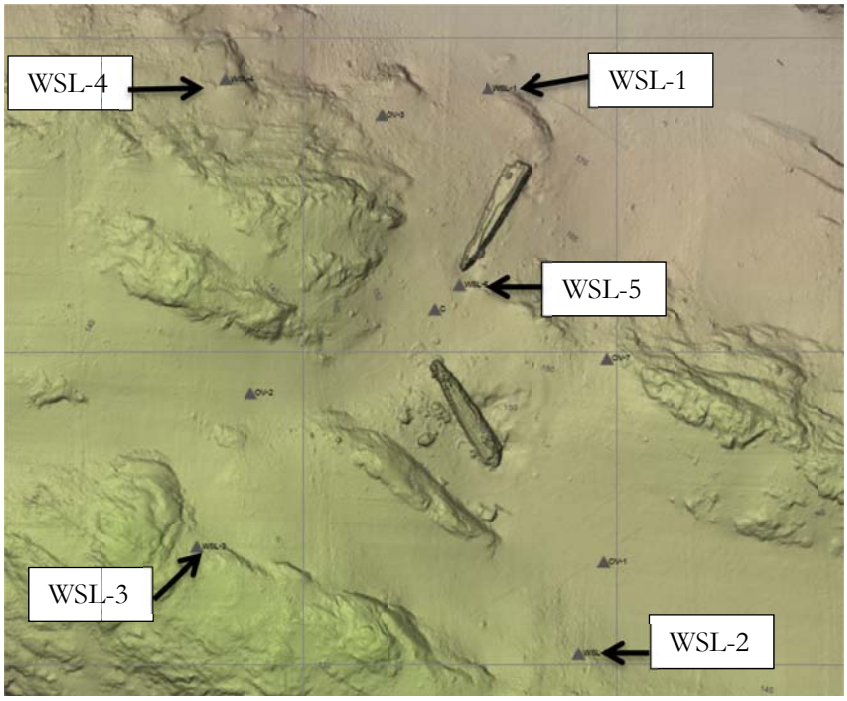


Figure 1. Water samples were collected around the wreck of submarine U-864 for analysis of mercury.

## 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<br>Background | Class II<br>Good | Class III<br>Moderately polluted | Class IV<br>Bad | Class V<br>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.

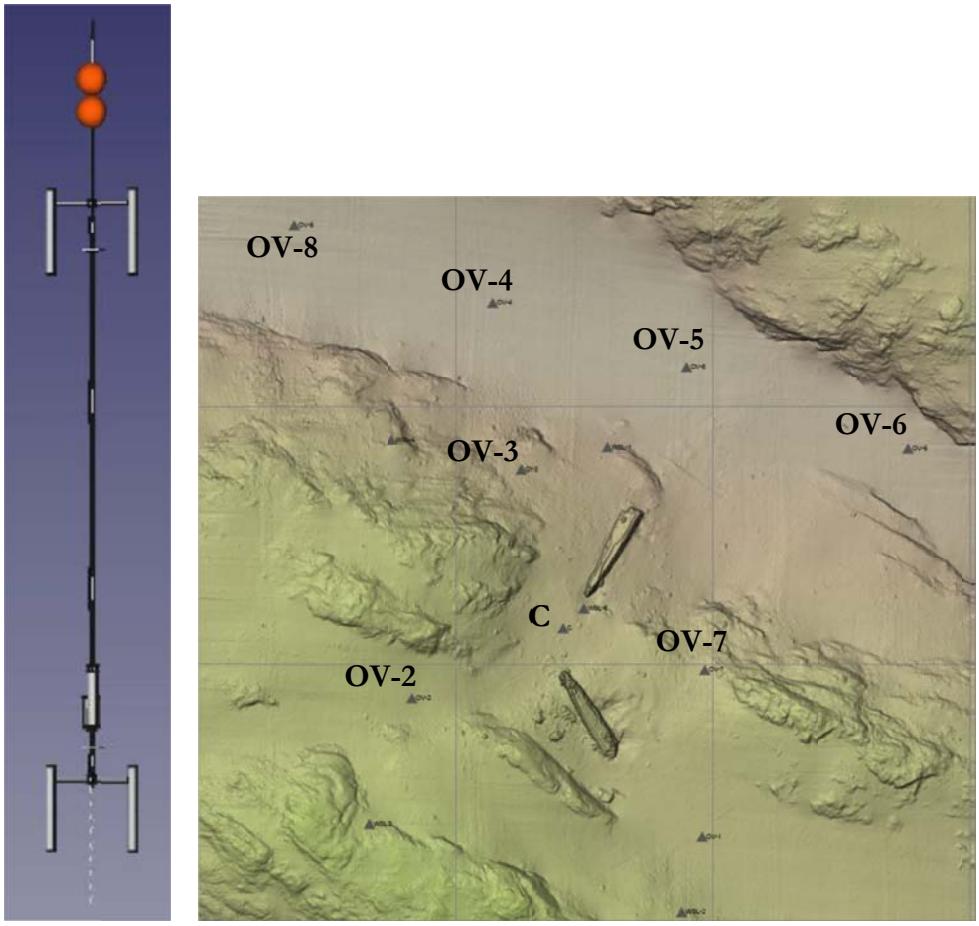



Figure 2. Turbidity rigs were deployed on 7 stations (OV-2 - OV-8) around the submarine wreck, and one turbidity sensor was mounted on the water current meter rig (C).

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).

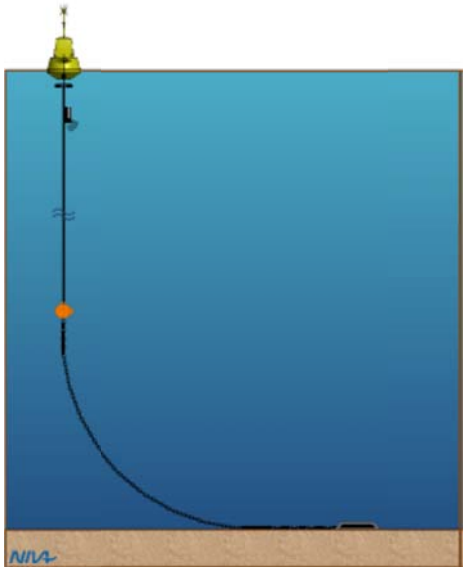




Figure 3. Figure of surface buoy with mooring, and picture of surface buoy outside Fedje (photo: Sigurd Øxnevad, NIVA).

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 $\rho_s$ is the density of the particle (2.7 g/ml), $\rho$ and $\mu$ 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 ($\rho_s$) 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.

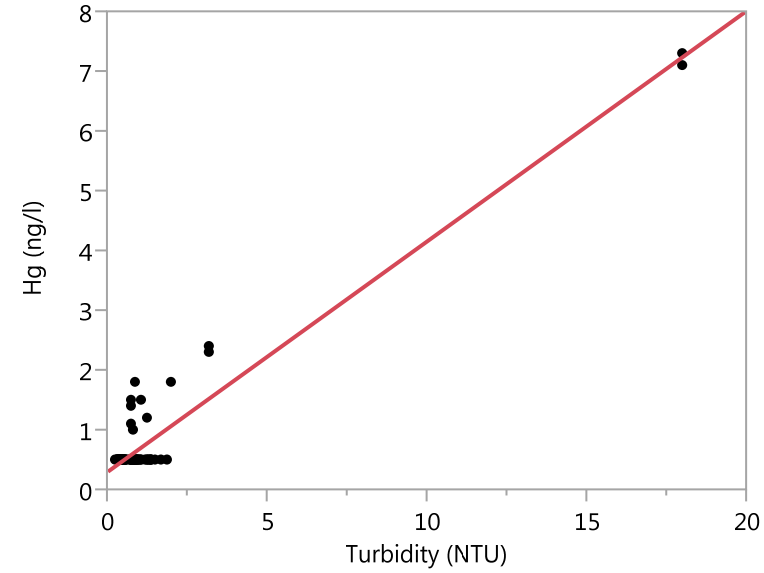
## 3.5 Monitoring of turbidity and water current

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.

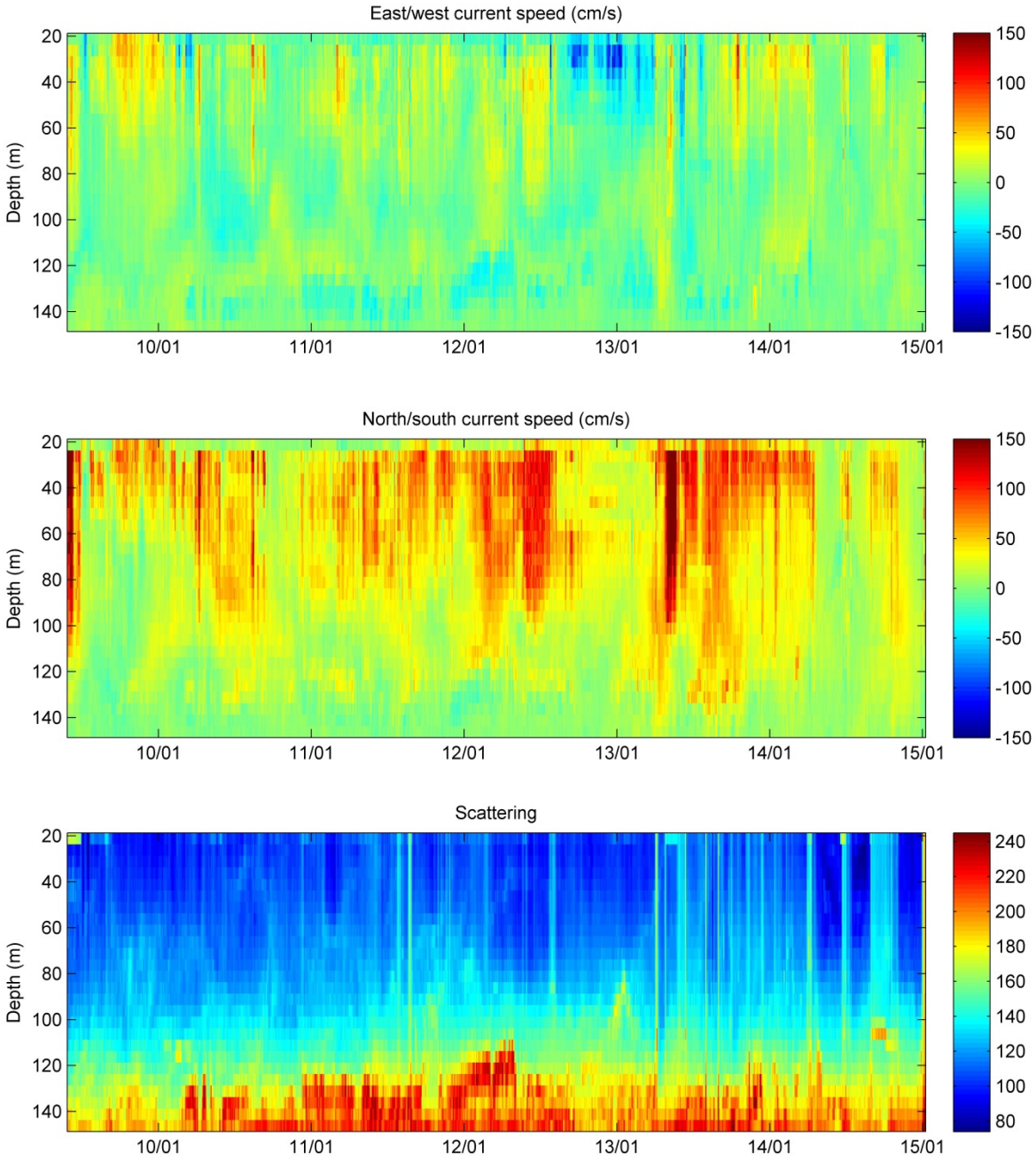



Figure 5. Upper panel: Current speed in the east-west direction. The color scale indicates the current speed in cm/s. Middle panel: Current speed in the north-south direction. The color scale indicates the current speed in cm/s. Bottom panel: Scattering from the ADCP current meter, indicating the particle concentration in the water column.

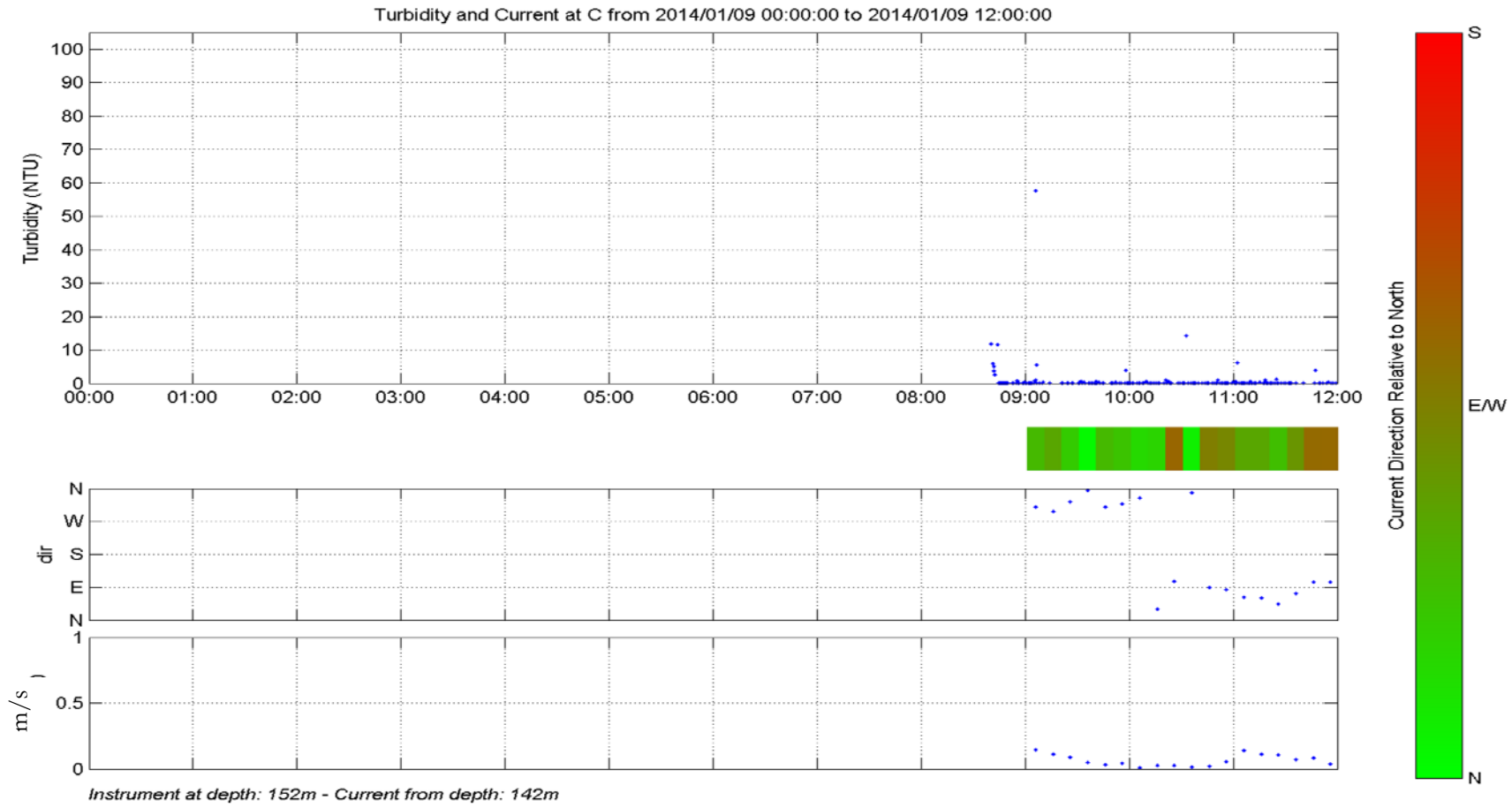
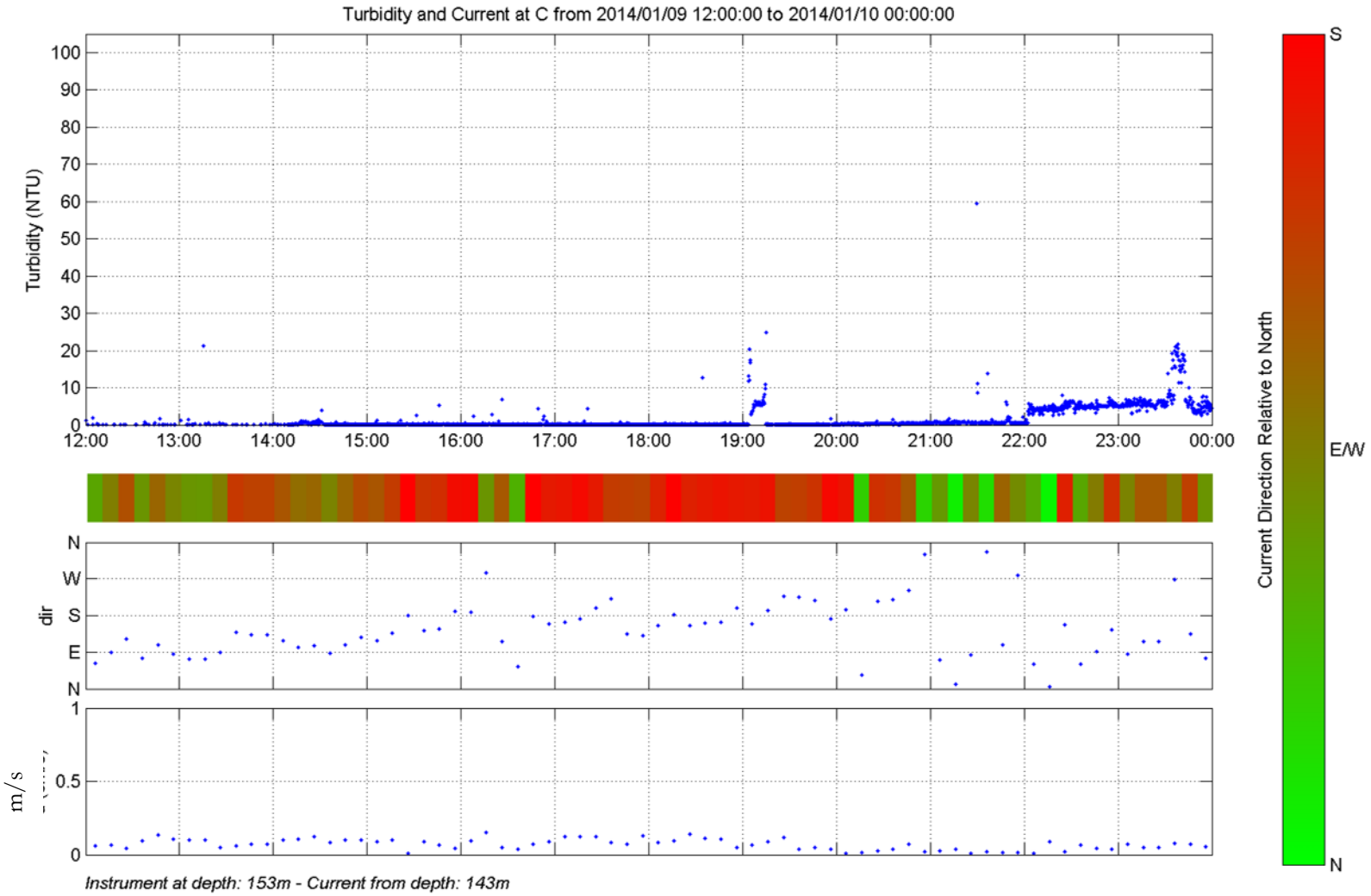
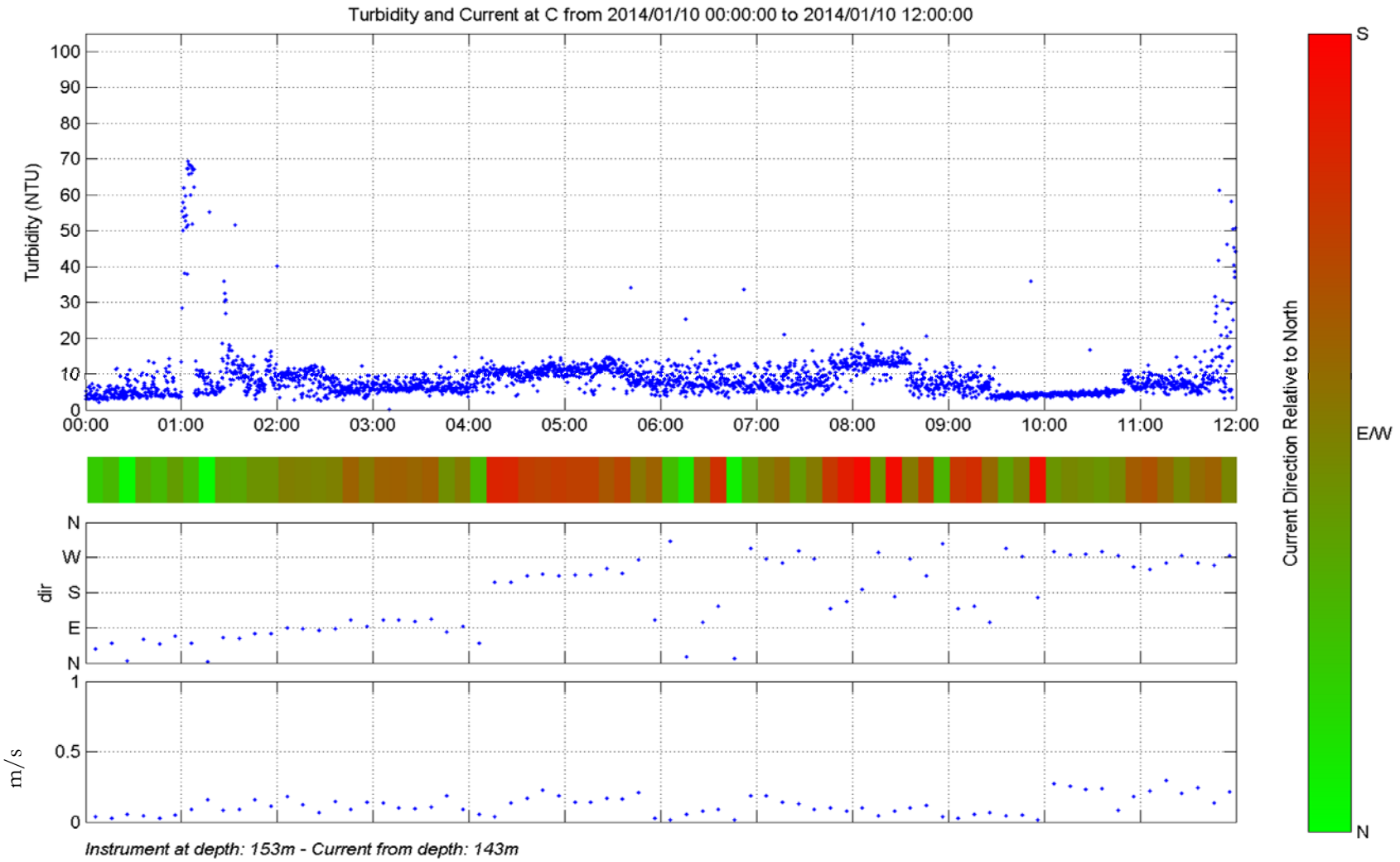
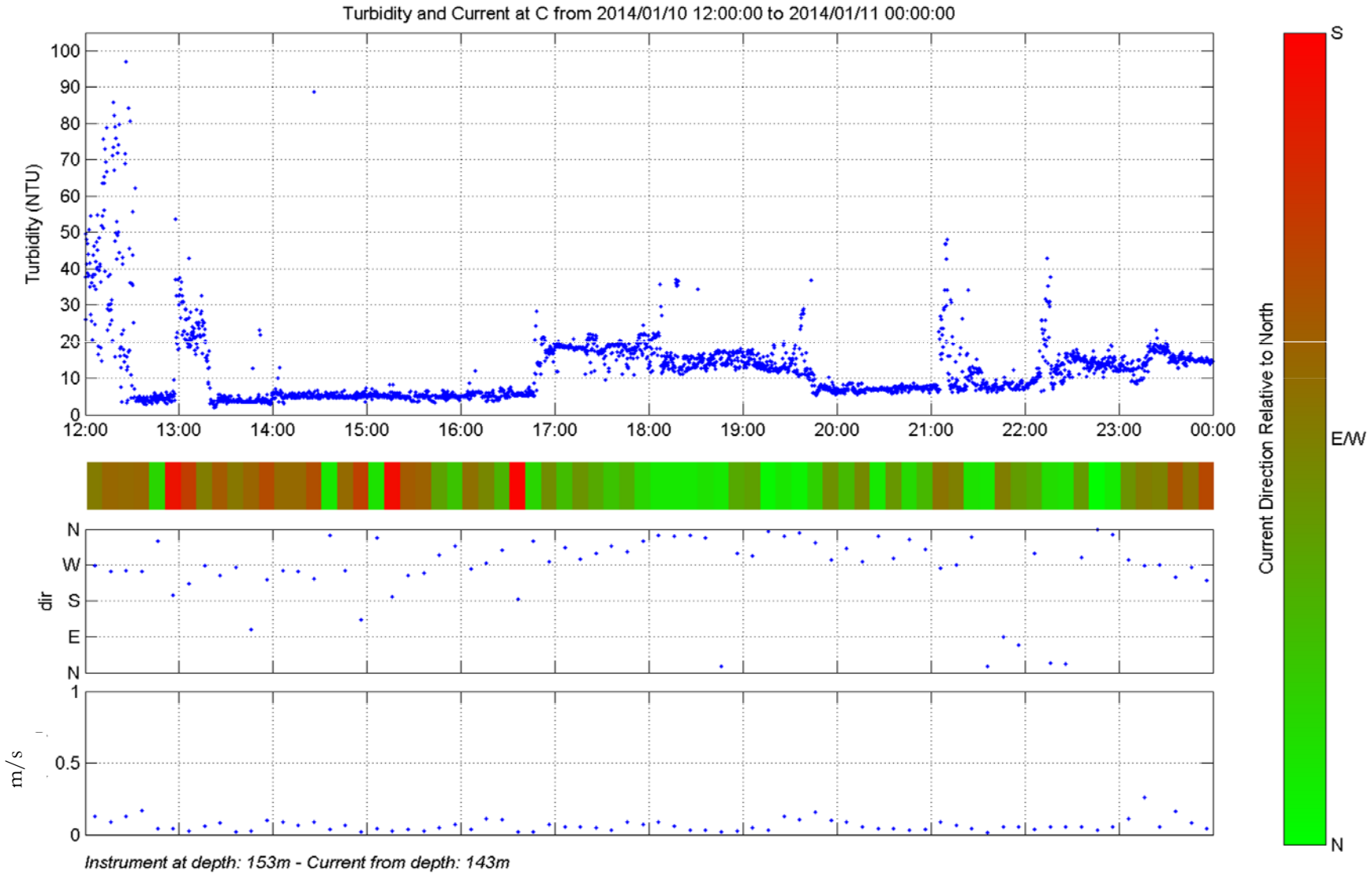
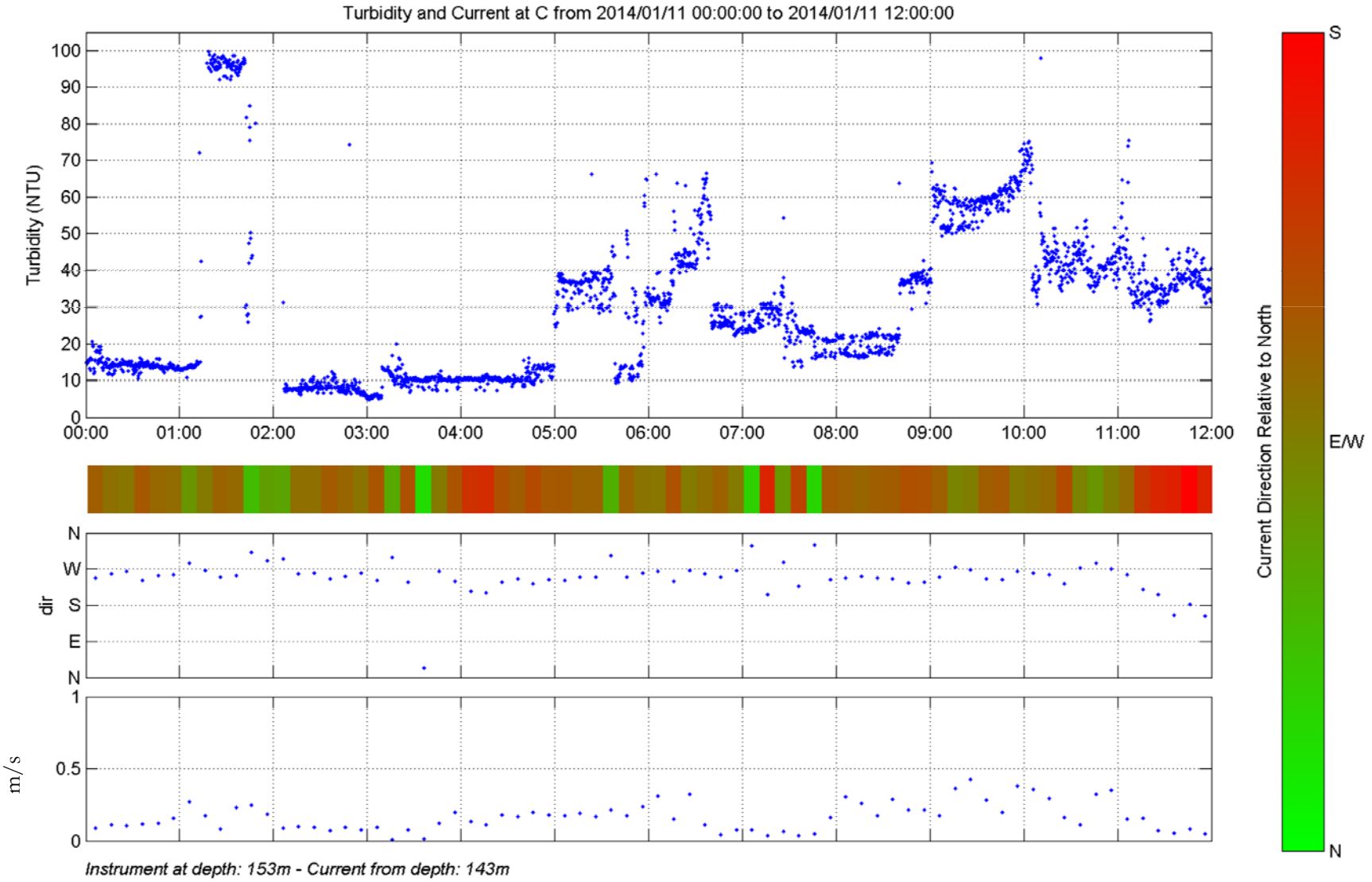


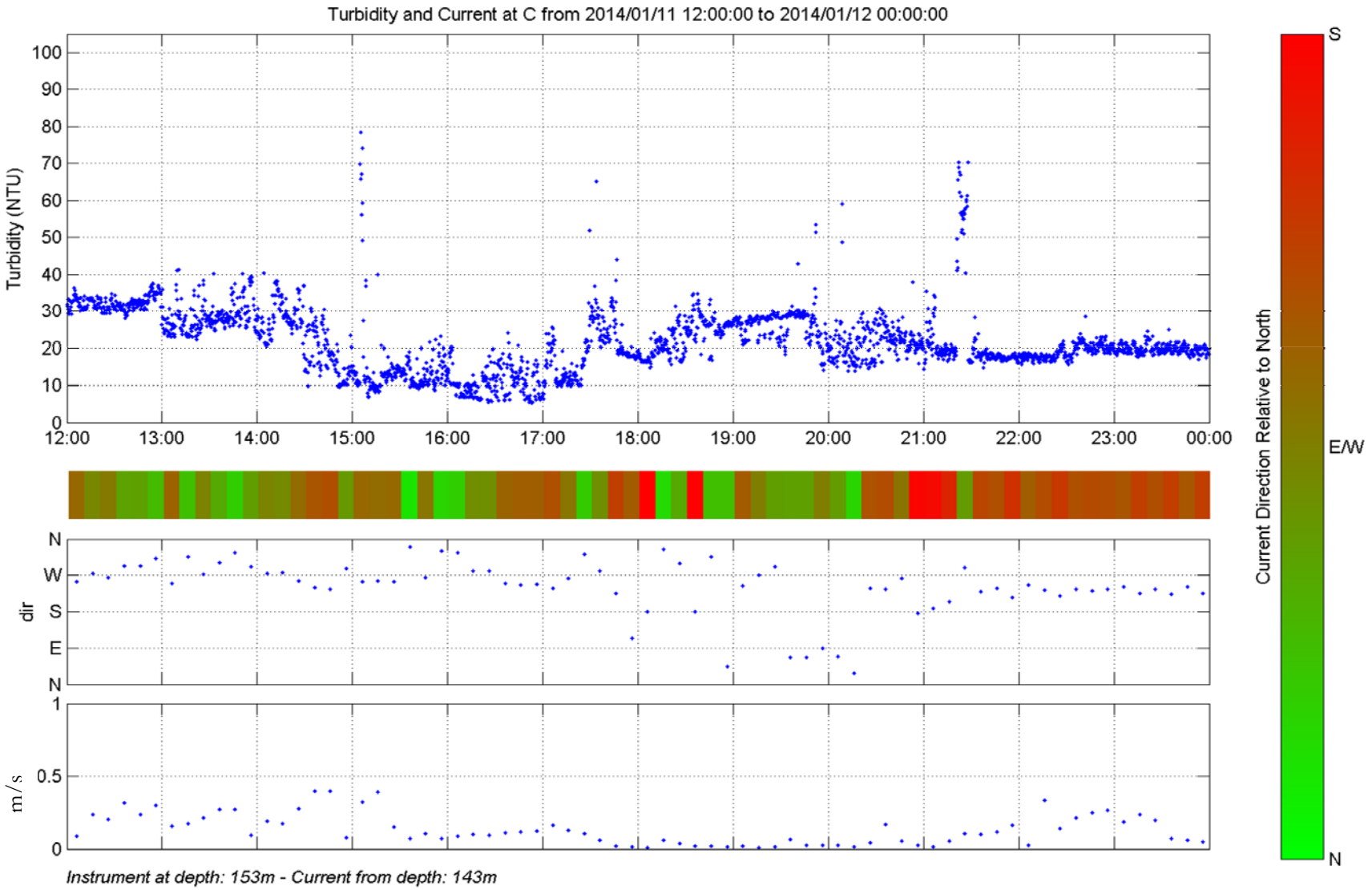

Figure 6. Turbidity and water current monitored at station C (between the two wreck sections). Data are presented in time series plot for turbidity, horizontal current direction and magnitude. Colour patches represent current direction relative to north. Assuming subsea operations were mainly located 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….

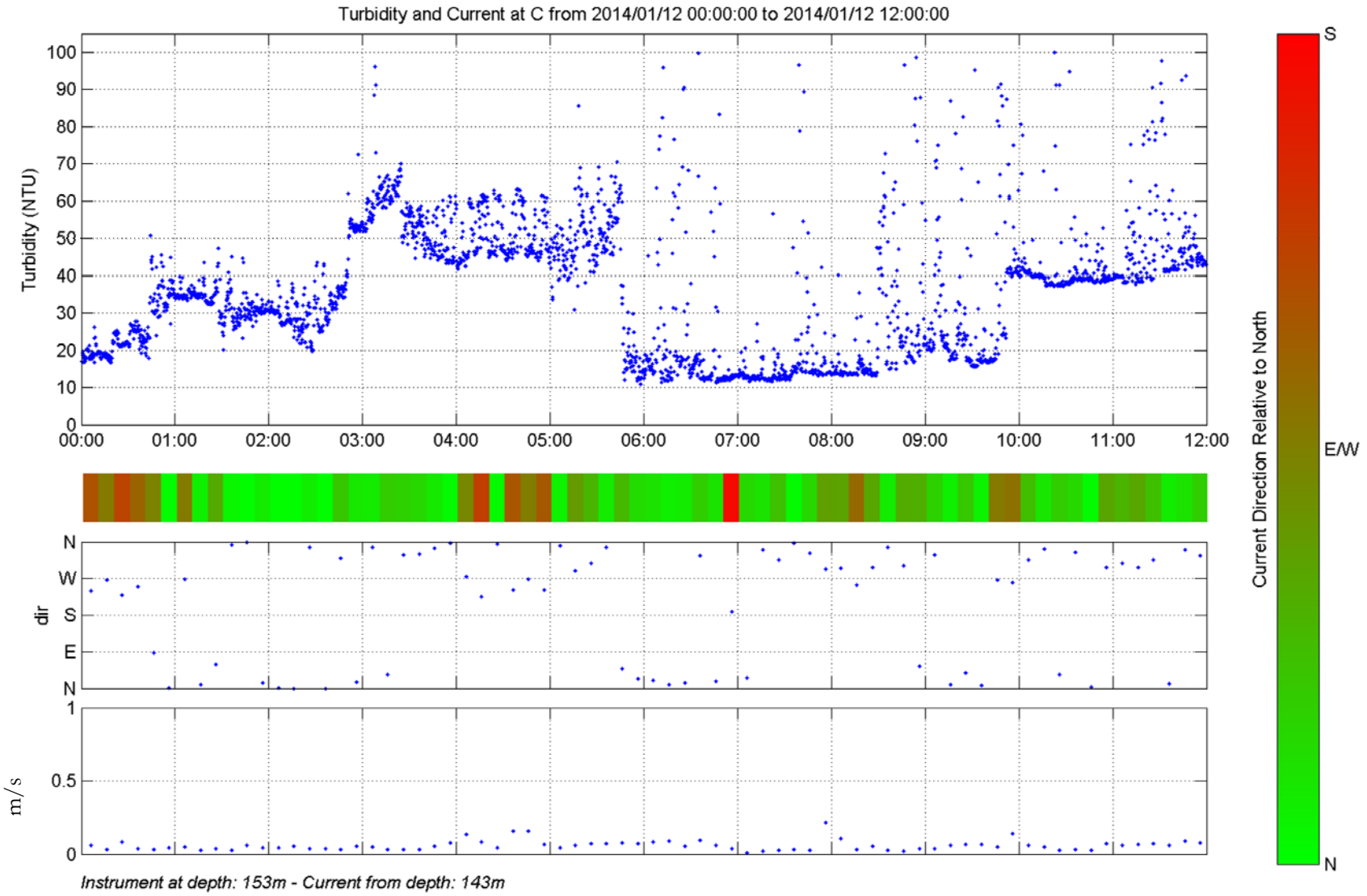

Turbidity and Current at C from 2014/01/09 12:00:00 to 2014/01/10 00:00:00
Turbidity (NTU)
100
90
80
70
60
50
40
30
20
10
0
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
00:00
dir
N
W
S
E
N
m/s
1
0.5
0
Instrument at depth: 153m - Current from depth: 143m
Current Direction Relative to North
S
E/W
N

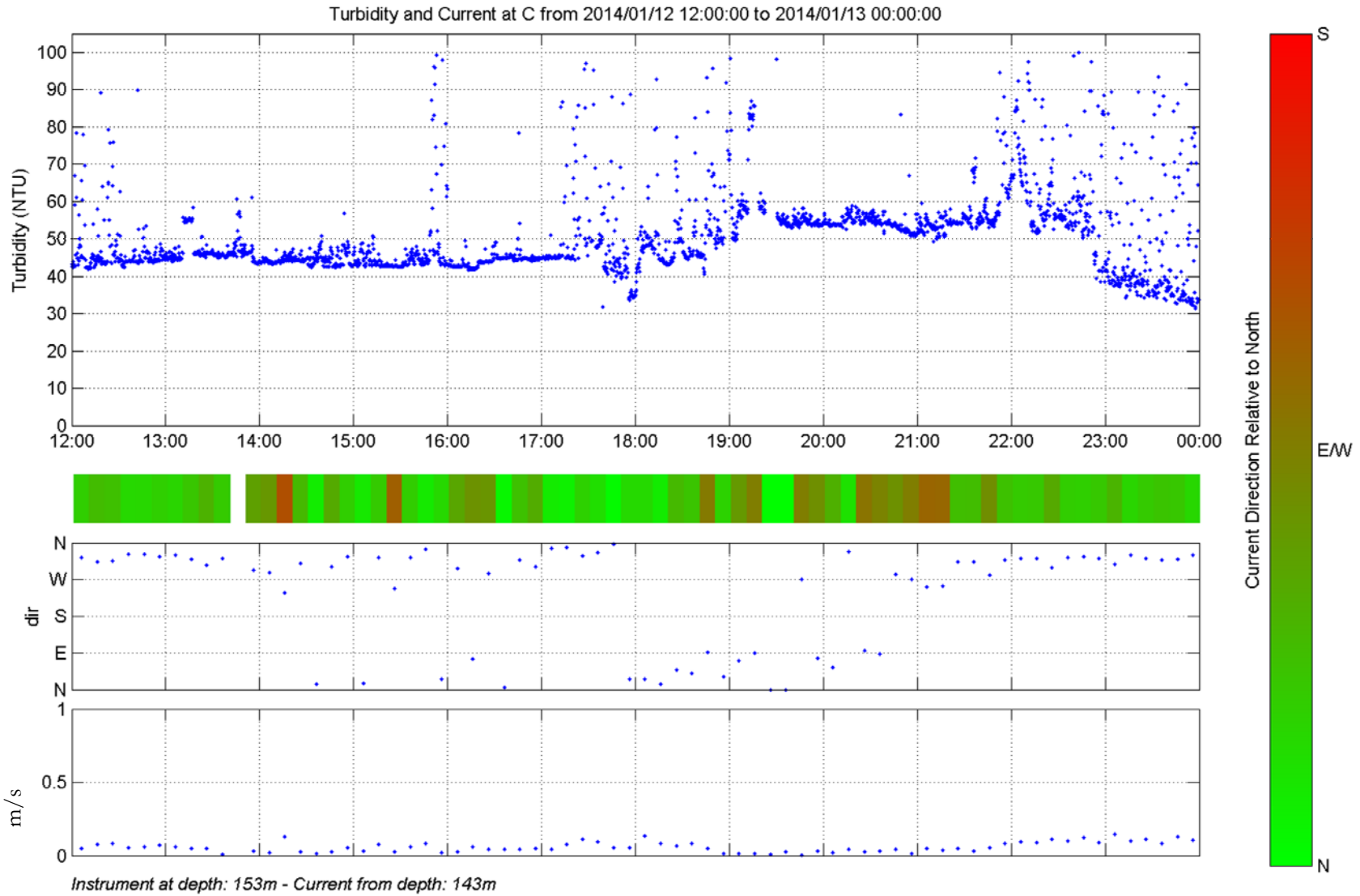

Turbidity and Current at C from 2014/01/10 00:00:00 to 2014/01/10 12:00:00
Turbidity (NTU)
100
90
80
70
60
50
40
30
20
10
0
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
dir
N
W
S
E
N
m/s
1
0.5
0
Instrument at depth: 153m - Current from depth: 143m
Current Direction Relative to North
S
E/W
N

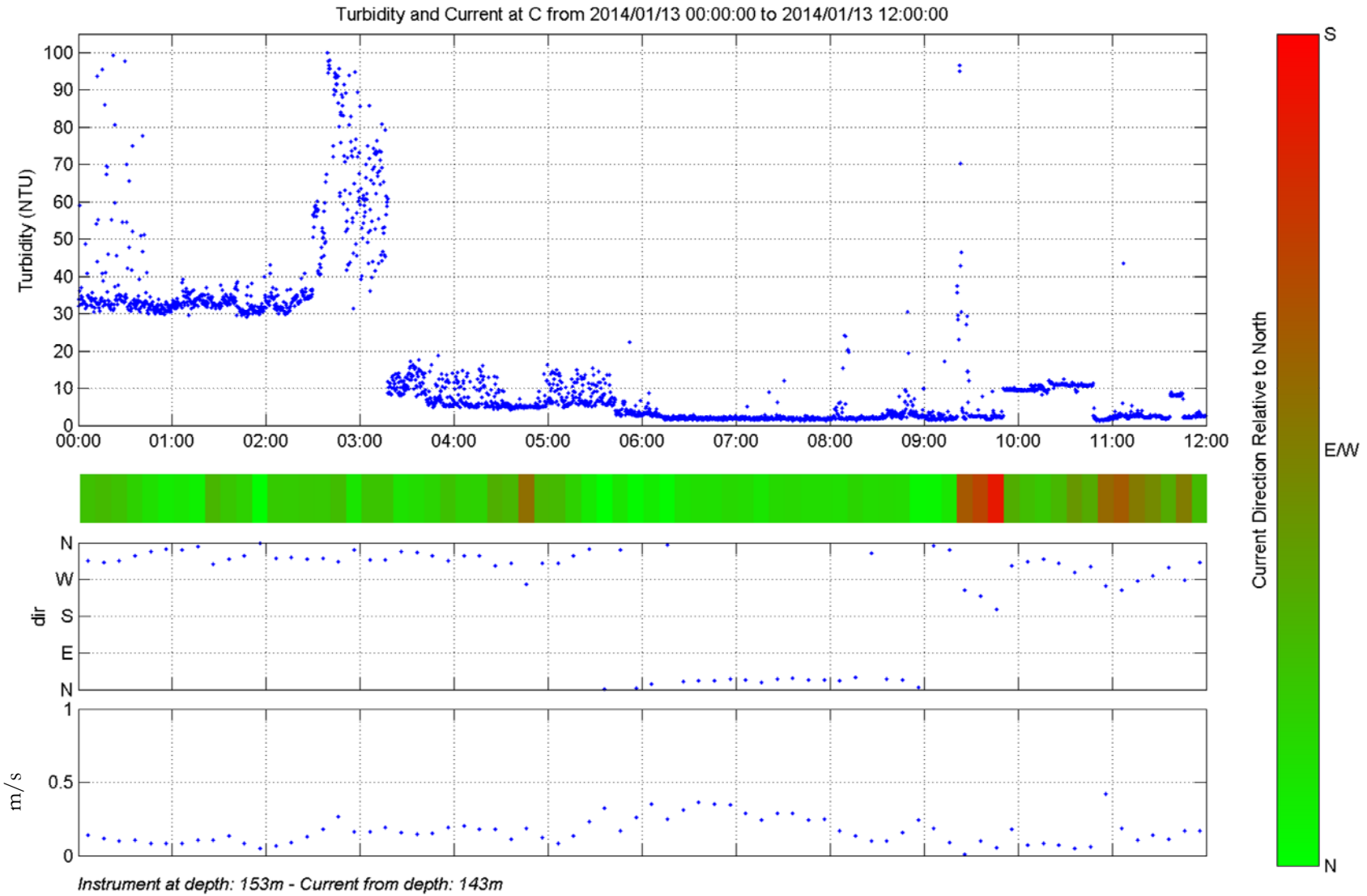

Turbidity and Current at C from 2014/01/10 12:00:00 to 2014/01/11 00:00:00
Turbidity (NTU)
100
90
80
70
60
50
40
30
20
10
0
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
00:00
dir
N
W
S
E
N
m/s
1
0.5
0
Instrument at depth: 153m - Current from depth: 143m
Current Direction Relative to North
S
E/W
N

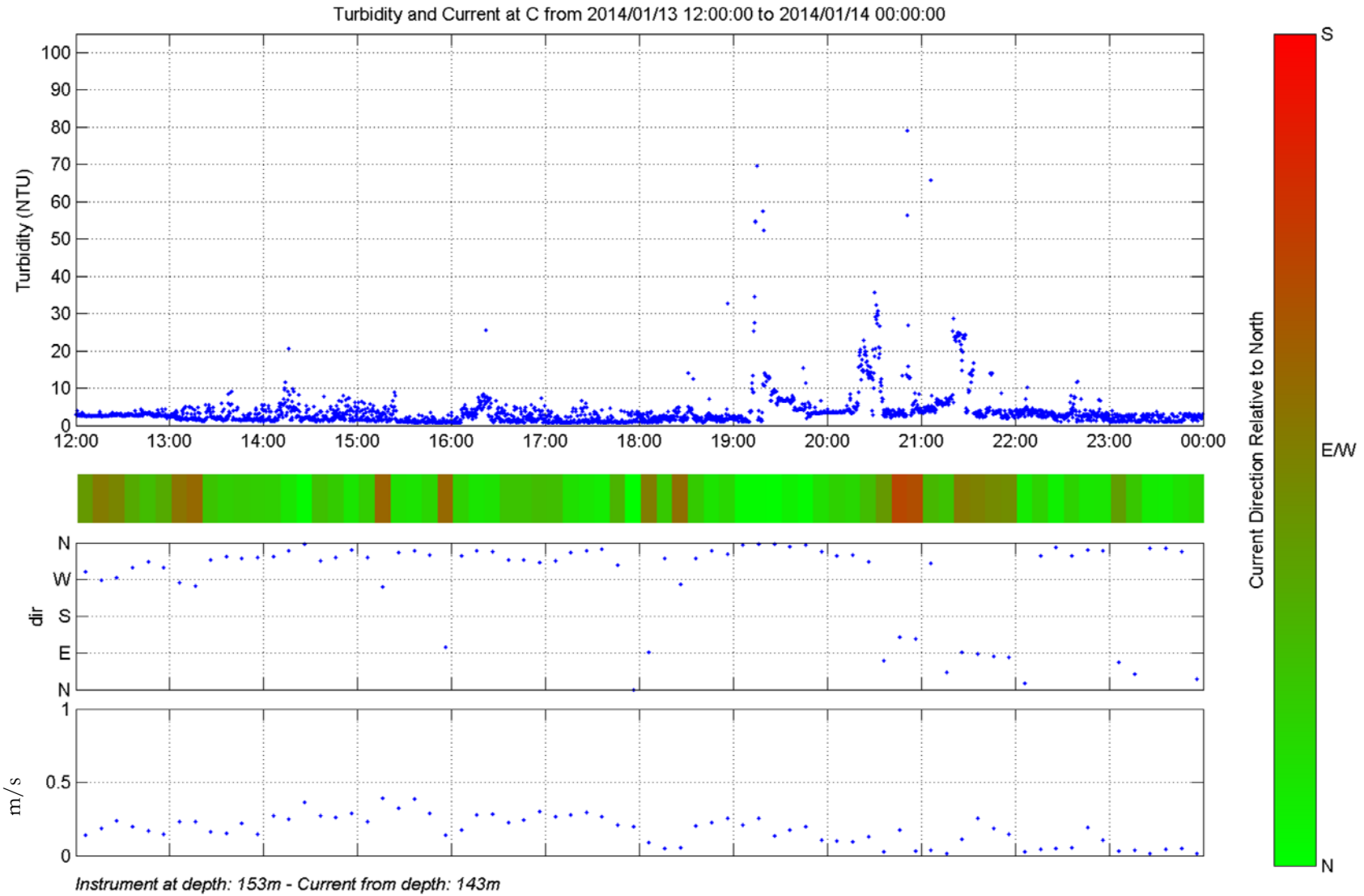

Turbidity and Current at C from 2014/01/11 00:00:00 to 2014/01/11 12:00:00
Turbidity (NTU)
0
10
20
30
40
50
60
70
80
90
100
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
dir
N
W
S
E
N
m/s
0
0.5
1
Current Direction Relative to North
S
E/W
N
Instrument at depth: 153m - Current from depth: 143m

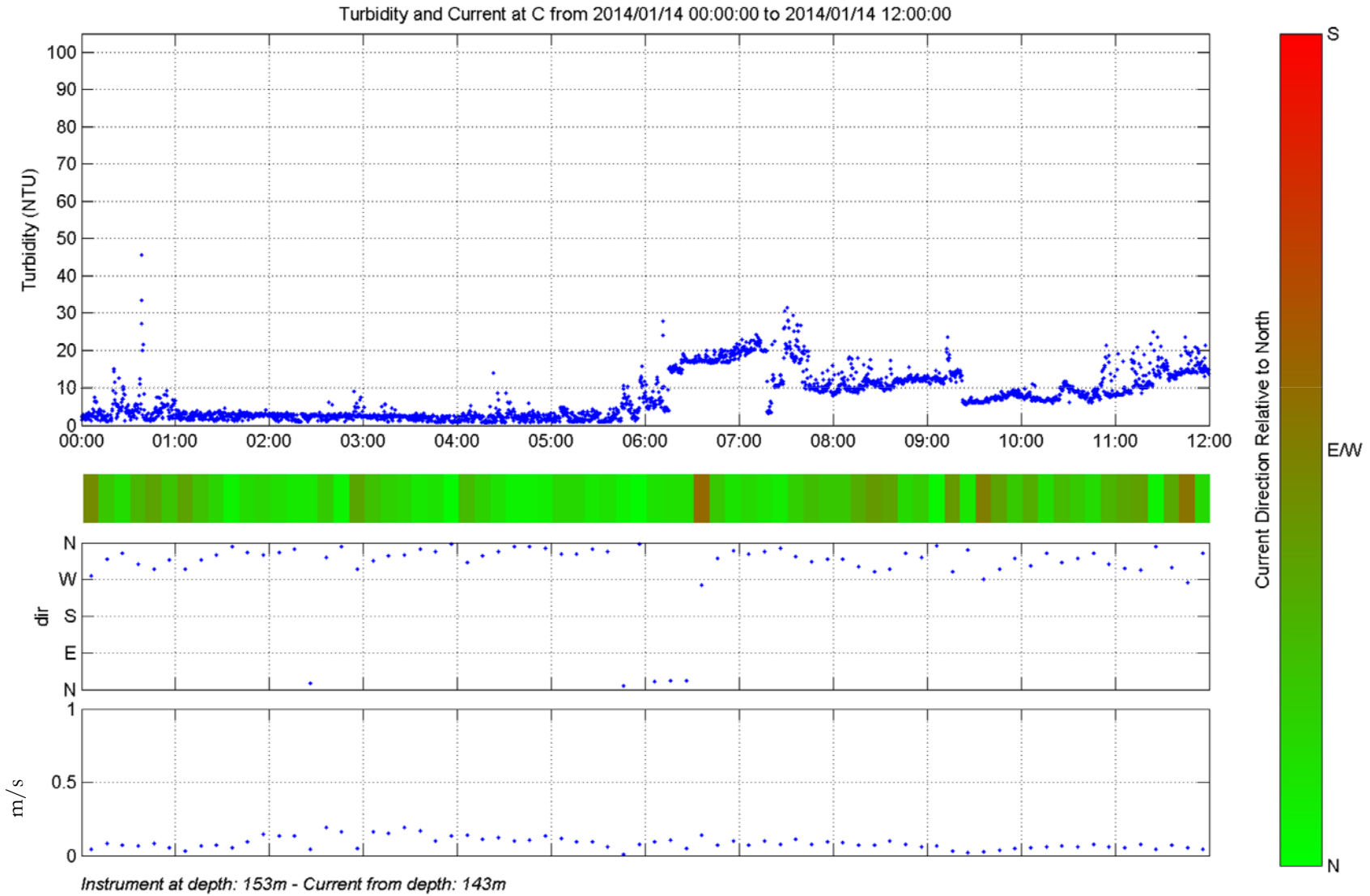

Turbidity and Current at C from 2014/01/11 12:00:00 to 2014/01/12 00:00:00
Turbidity (NTU)
100
90
80
70
60
50
40
30
20
10
0
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
00:00
dir
N
W
S
E
N
m/s
1
0.5
0
Instrument at depth: 153m - Current from depth: 143m
Current Direction Relative to North
S
E/W
N

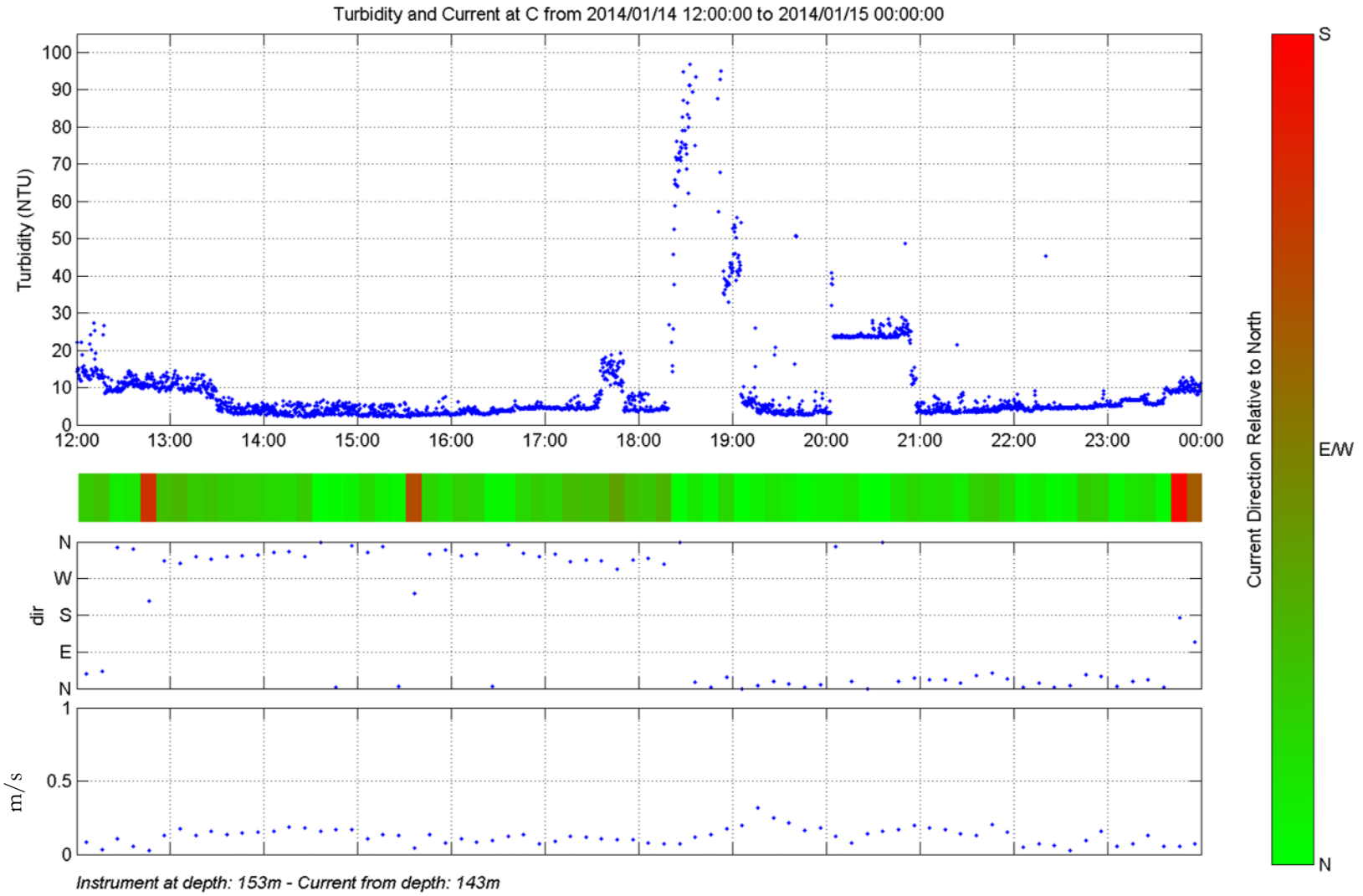

Turbidity and Current at C from 2014/01/12 00:00:00 to 2014/01/12 12:00:00
Turbidity (NTU)
100
90
80
70
60
50
40
30
20
10
0
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
dir
N
W
S
E
N
m/s
1
0.5
0
Instrument at depth: 153m - Current from depth: 143m
Current Direction Relative to North
S
E/W
N

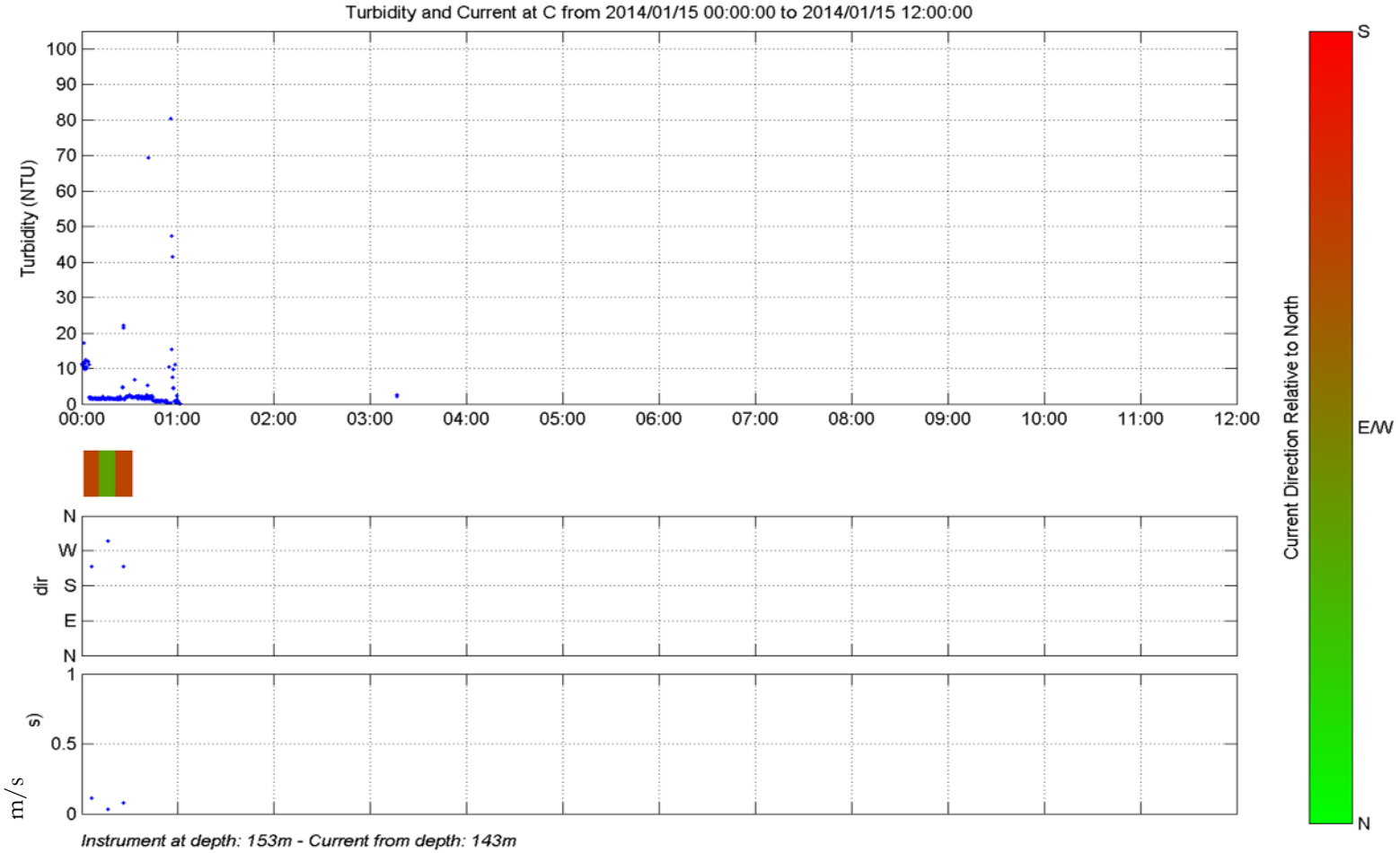

Turbidity and Current at C from 2014/01/12 12:00:00 to 2014/01/13 00:00:00
Turbidity (NTU)
100
90
80
70
60
50
40
30
20
10
0
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
00:00
dir
N
W
S
E
N
m/s
1
0.5
0
Instrument at depth: 153m - Current from depth: 143m
Current Direction Relative to North
S
E/W
N


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
60
50
40
30
20
10
0
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
dir
N
W
S
E
N
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 2014/01/13 12:00:00 to 2014/01/14 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
18:00
19:00
20:00
21:00
22:00
23:00
00:00
dir
N
W
S
E
N
m/s
1
0.5
0
Instrument at depth: 153m - Current from depth: 143m
Current Direction Relative to North
S
E/W
N


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
0
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
dir
N
W
S
E
N
m/s
1
0.5
0
Instrument at depth: 153m - Current from depth: 143m
Current Direction Relative to North
S
E/W
N


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
18:00
19:00
20:00
21:00
22:00
23:00
00:00
dir
N
W
S
E
N
m/s
1
0.5
0
Instrument at depth: 153m - Current from depth: 143m
Current Direction Relative to North
S
E/W
N


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
0
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
dir
N
W
S
E
N
m/s
1
0.5
0
Instrument at depth: 153m - Current from depth: 143m
Current Direction Relative to North
S
E/W
N

## 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/m² 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/m² 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.

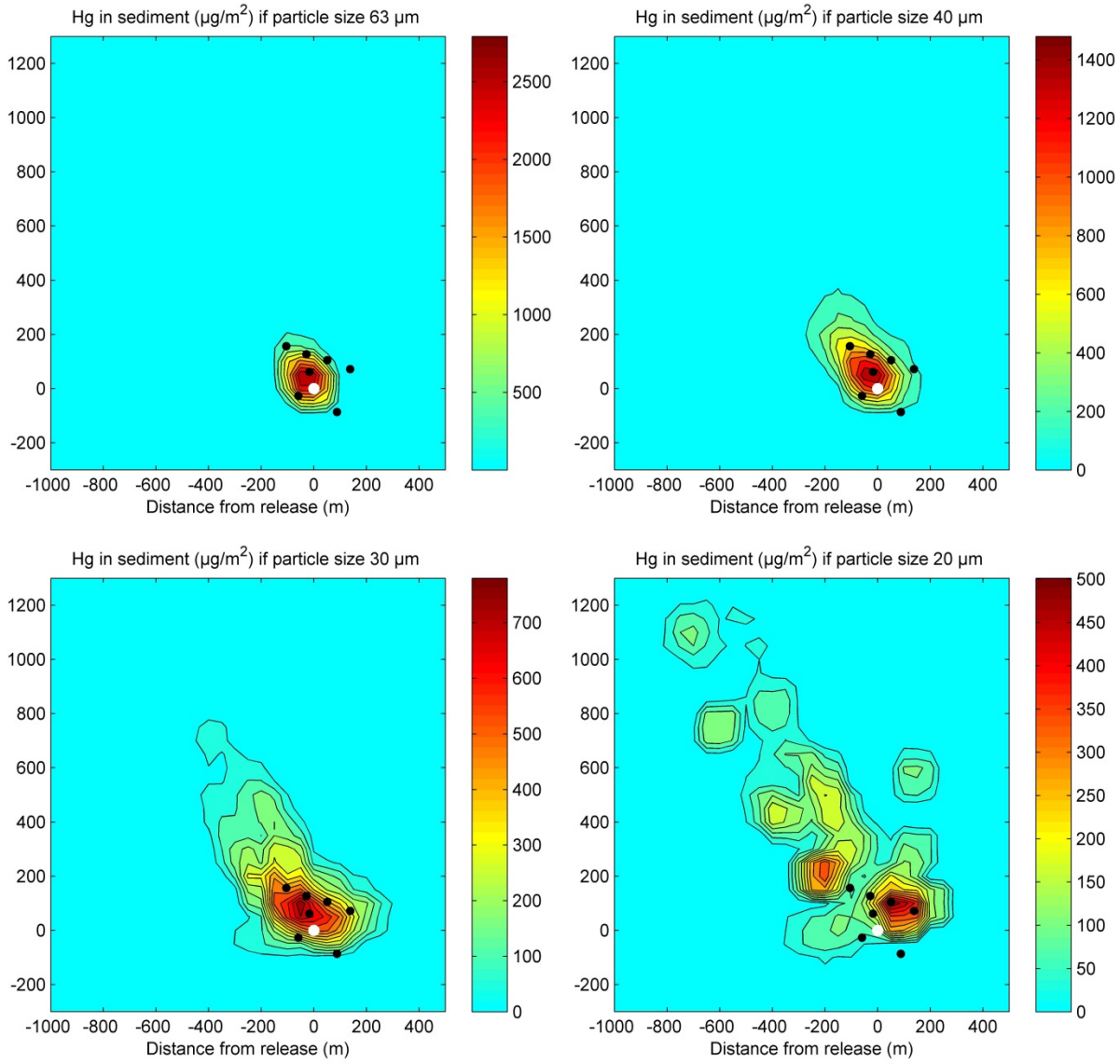



Figure 7. Results from the modelling of sedimentation of mercury (µg Hg/m² of the bottom) during the operation at Fedje 9.-15.01.2014. The model is based on measurements of currents and turbidity at station C (white circle) and sediments trapped at station OV8. The black points represent the positions 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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Schaanning M., A.Staalstrøm og K.Sørensen, 2007. Miljøkonsekvens-vurdering - Utslipp av forurensete sedimenter til overflatelaget i deponiområdet ved Malmøykalven. NIVA rapport 5513-2007. 90 s.

Sørensen, K., Aas, E., Faafeng, B., Lindell, T. 1993. Fjernmåling av vannkvalitet – videreutvikling av optisk satelittfjernmåling som metode for overvåking av vannkvlitet. NIVA rapport 2860-1993.

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** |

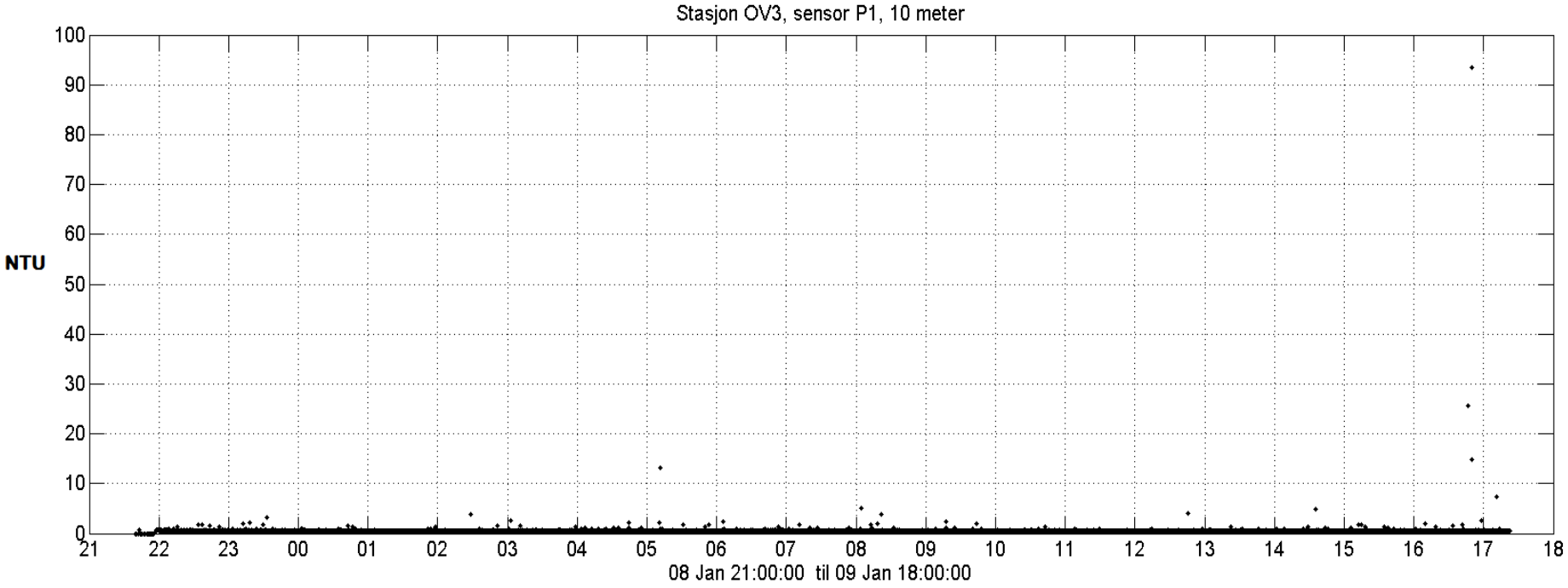
# Appendix B. Mercury in water samples

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.

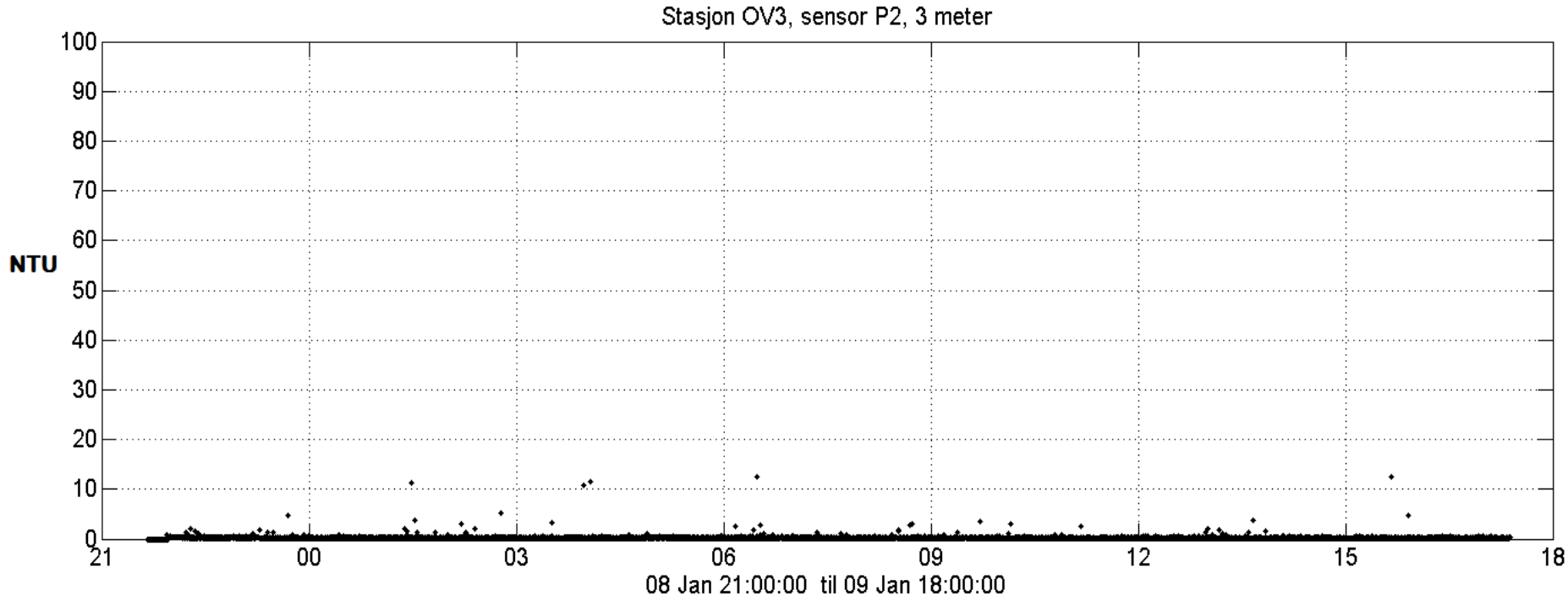
| Date | Time | Station | Elevation over seabed | Turbidity | Concentration ng Hg/l |
|---|---|---|---|---|---|
| 10. Jan | 09-10 | WSL-3 | 3 m | 0.77 | <1.0 |
| | 09-10 | WSL-3 | 10 m | 0.77 | <1.0 |
| | 09-10 | WSL-4 | 10 m | 0.79 | <1.0 |
| | 09-10 | WSL-4 | 3 m | 0.83 | <1.0 |
| | 09-10 | WSL-1 | 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 |

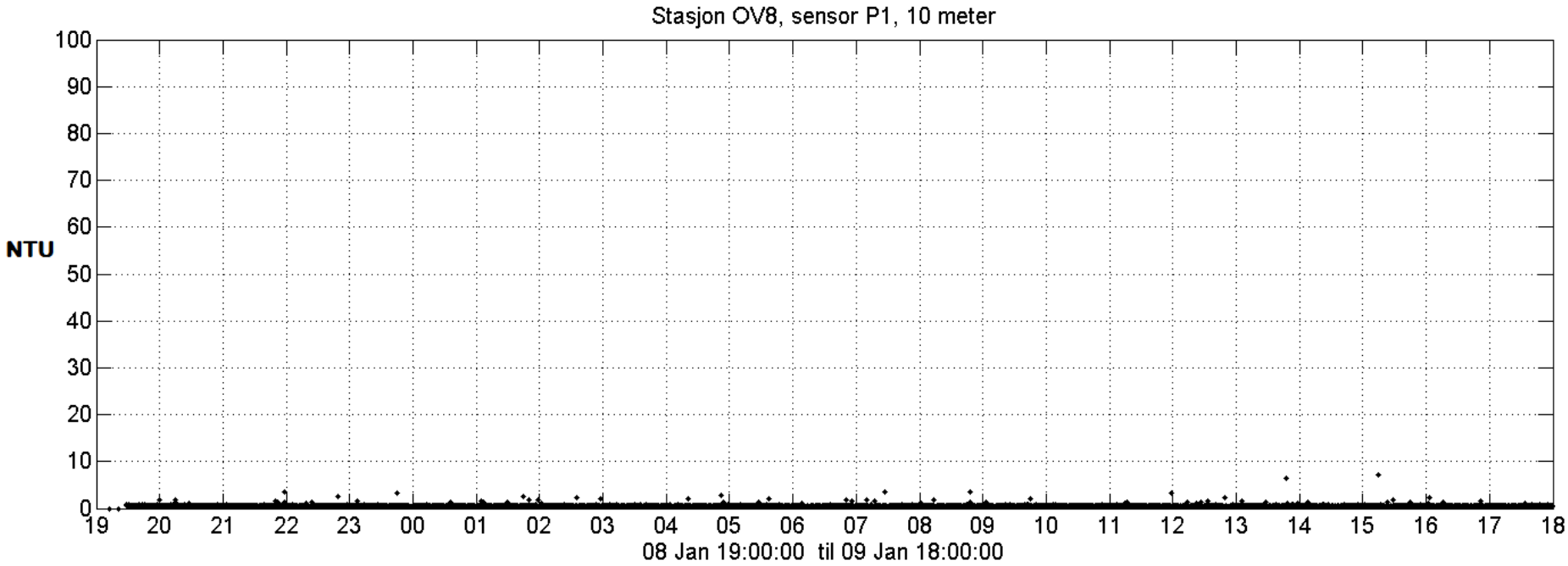
# Appendix C. Turbidity data



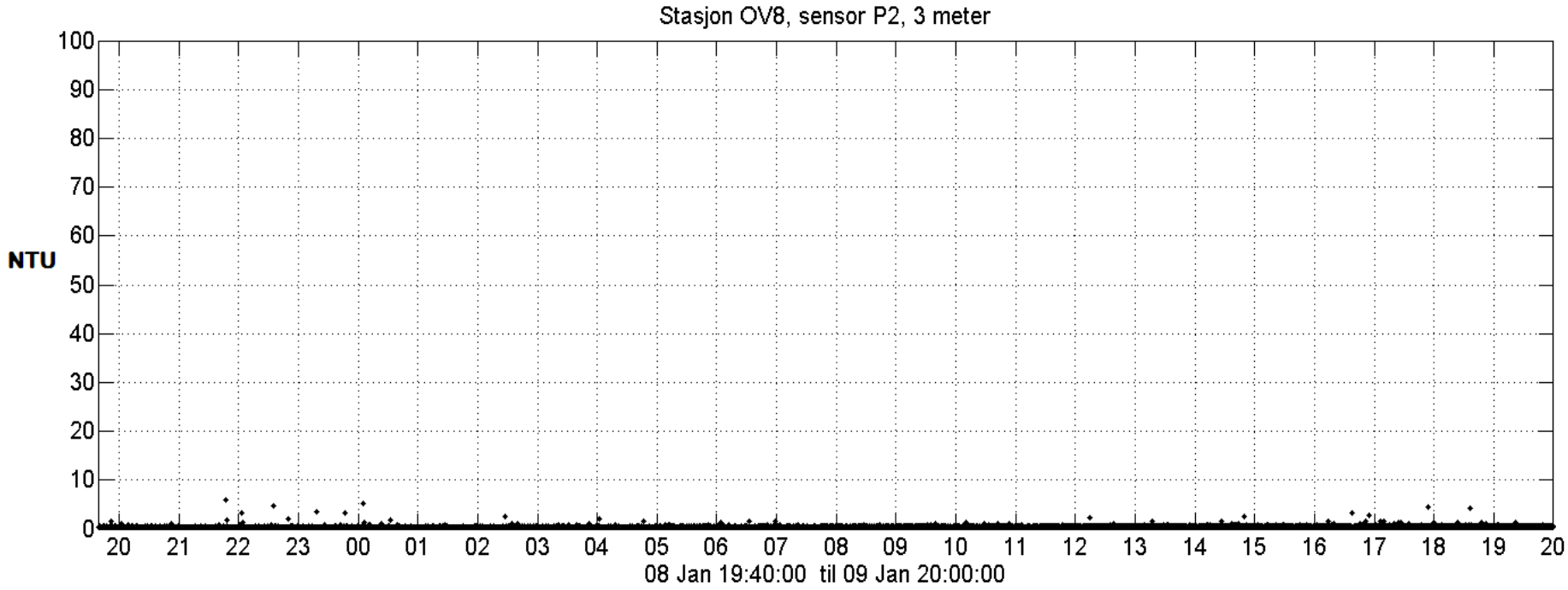

Turbidty measurements from station OV3 at 10 m above the seabed. Time is shown in UTC time.



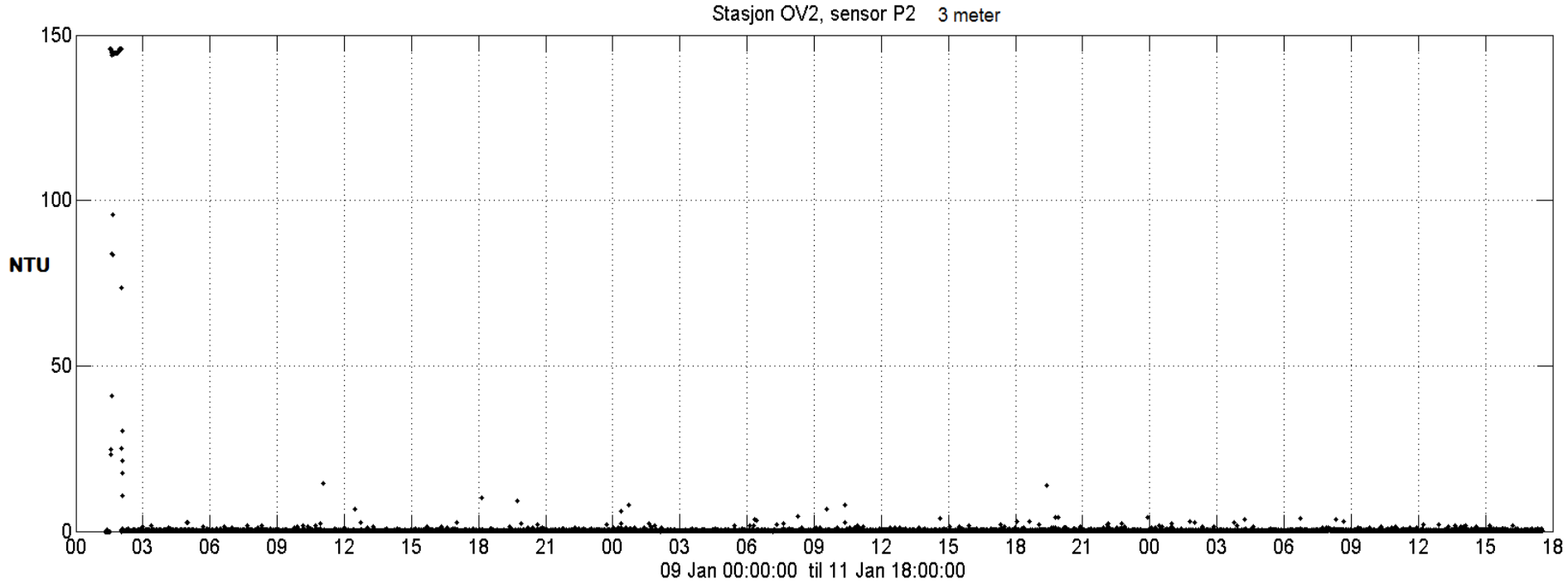

Turbidity monitored at station OV3 at 3 m above the seabed. Time is shown in UTC time.



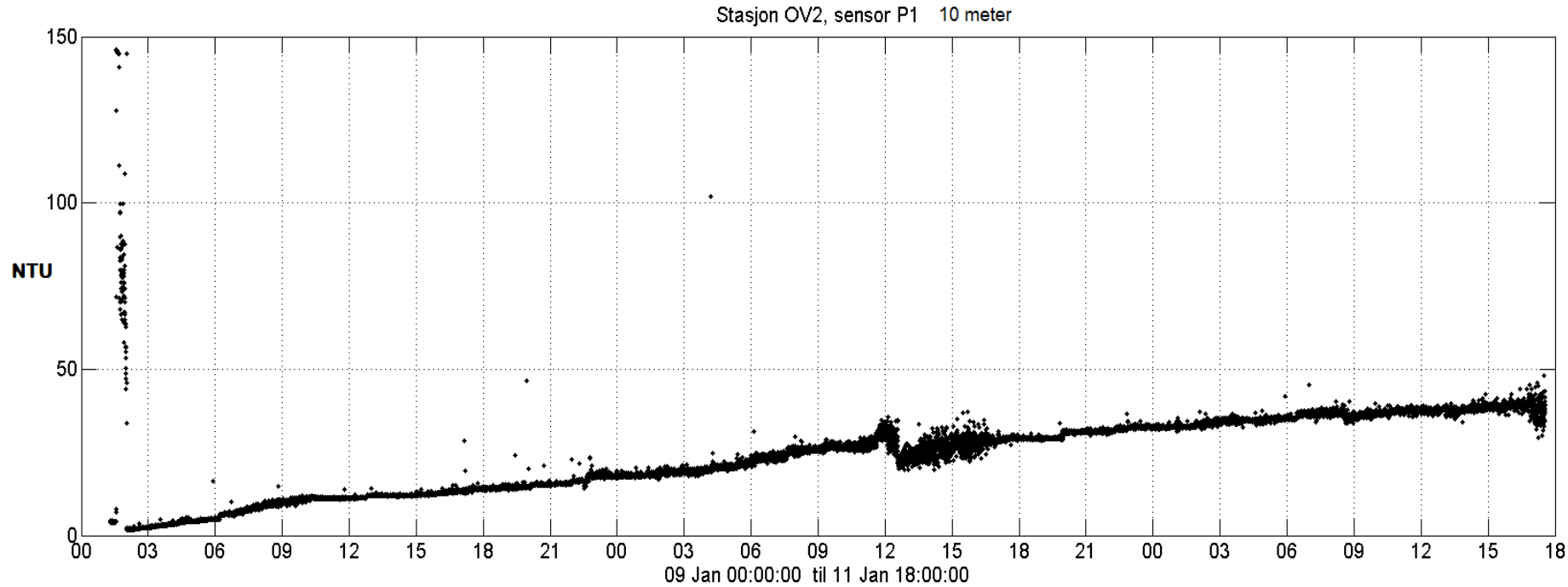

Turbidity monitored at station OV8 at 10 m above the seabed. Time is shown in UTC time.



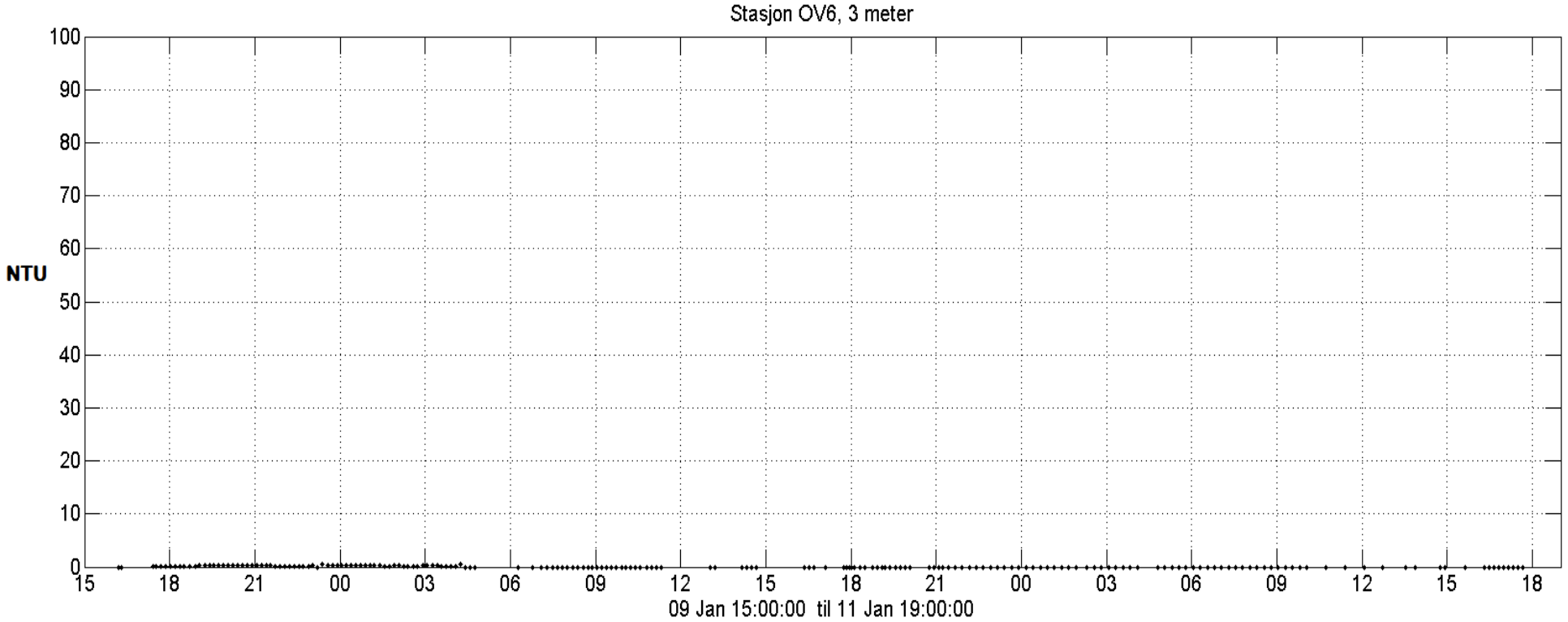

Turbidity monitored at station OV8 at 3 m above the seabed. Time is shown in UTC time.



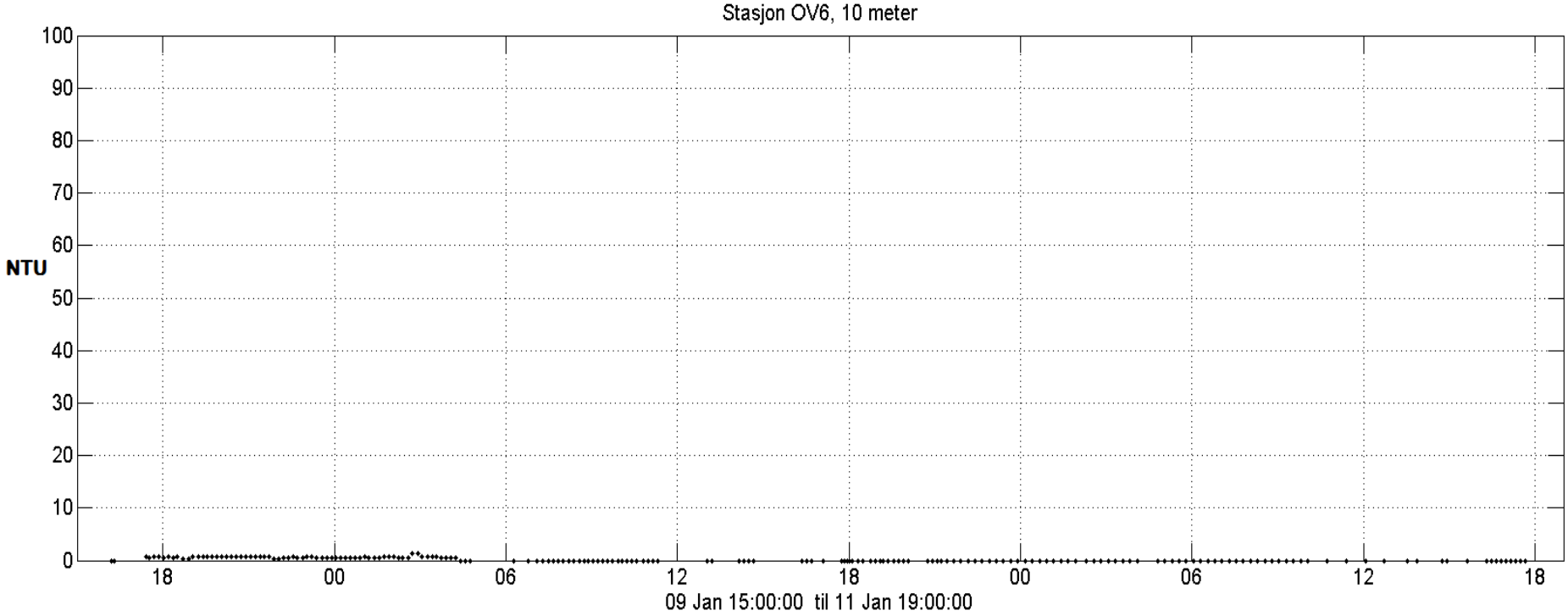

Turbidity monitored at station OV2 at 3 m above the seabed. Time is shown in UTC time.




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 V1.01

MILJØTILTAK VED VRAKET AV U-864

# Fremdriftsanlyse for Alternativ 1 “Tildekking”

DNV GL AS

Project name: Miljøtiltak ved vraket av U-864
Report title: Fremdriftsanlyse for Alternativ 1 “Tildekking”

DNV GL AS [Business Area]
Project Management & Technical Services Program
P.O.Box 300
1322 Høvik
Norway
Tel: +47 67 57 99 00

Task and objective:

Utført av:
Nicolaj Tidemand (DNV GL AS)

Revidert av:
Carl Erik Høy-Petersen (DNV GL AS)

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» herunder Alternativ 1 Tildekking (heretter kalt Alternativ 1) 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.

# 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. Følgende forutsetninger er lagt til grunn:

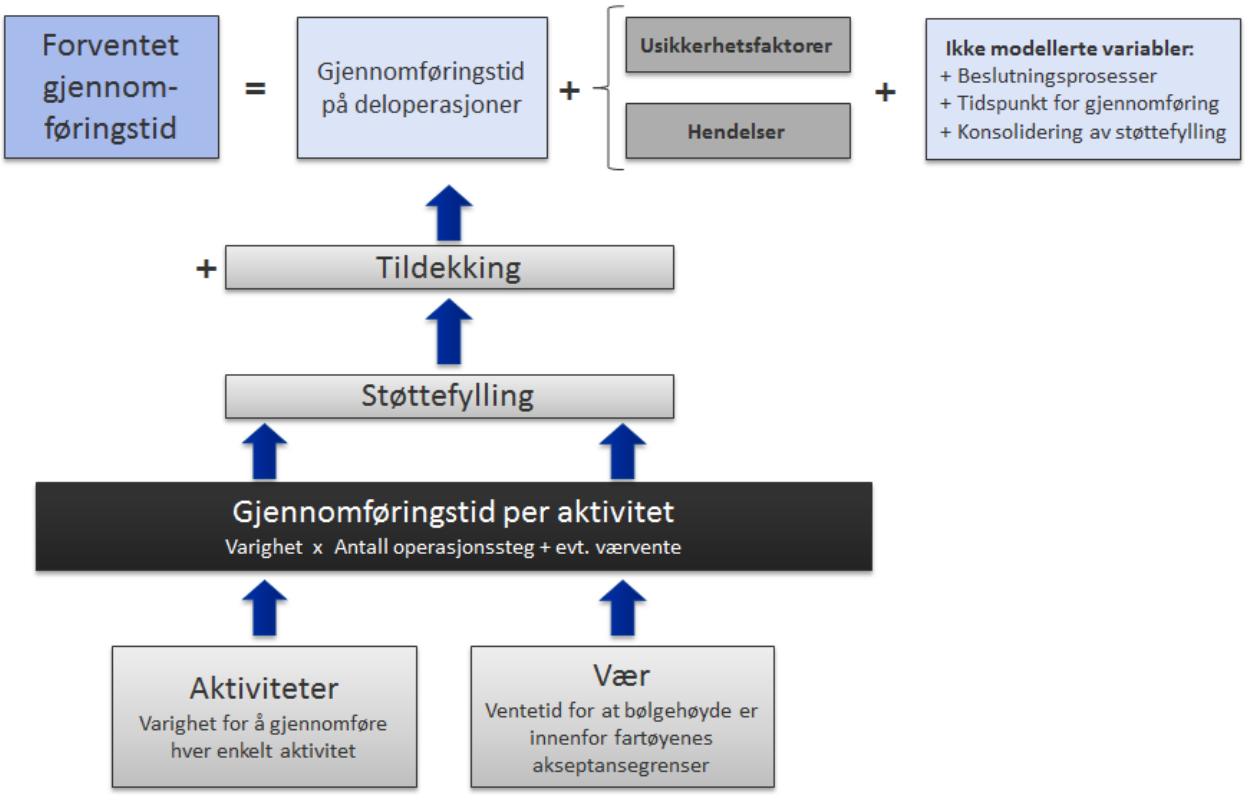
- Kun gjennomføringstiden av å bygge støttefyllingen, operasjon for heving av kvikksølvflasker og å legge ut tildekkingsmassene er analysert.
- Støttefyllingen trenger tid for konsolidering av massene for å gi tilstrekkelig bæreevne. Dette er analysert til å være minst ett år, og derfor valgt som varighet 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.
- 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.

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.

[1] http://www.marin.nl/web/JIPs-Networks/Public/Safetrans.htm

I Figur 1 er en prinsippskisse av modellen vist.

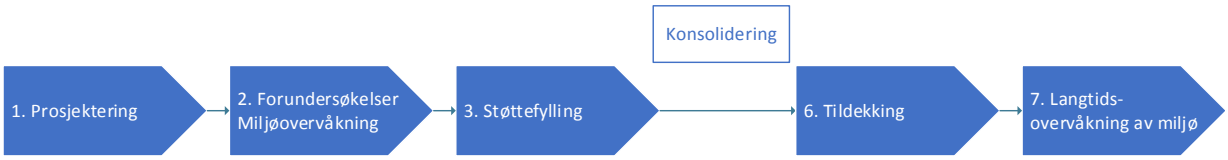



**Figur 1 Modell for analyse av gjennomføringstid**

Som figuren over viser, beregnes forventet gjennomføringstid for å legge ut støttefylling og tildekking hver for seg. I tillegg til summering av estimatusikkerhetene, så vil den forventede gjennomføringstiden også påvirkes av identifiserte usikkerhetsfaktor og hendelser. For detaljert beskrivelse av alle variabler se kapittel 0.

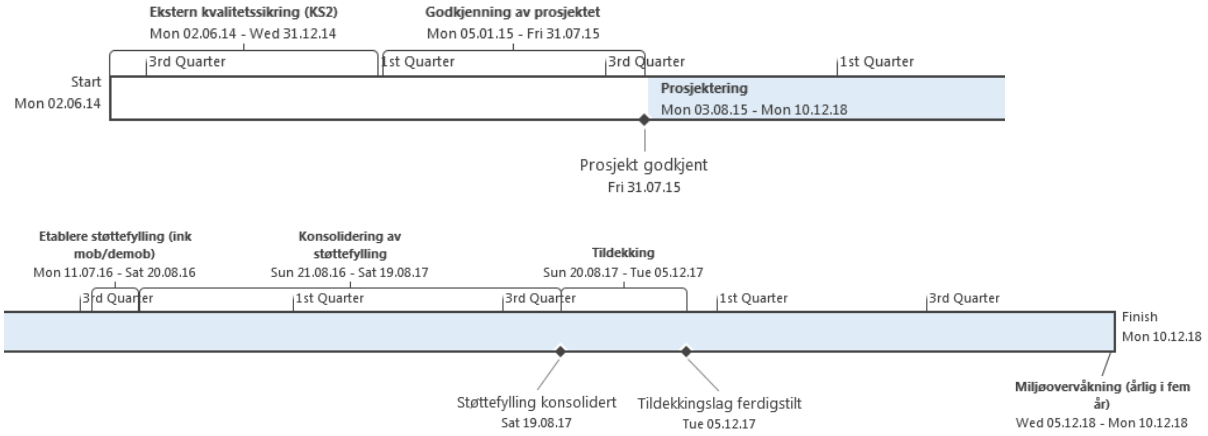
# 3 PROSESS OG AKTIVITETER

Figur 2 viser den overordnede prosessen for tiltaket. Som beskrevet i Figur 1, er det prossessteg 3 og 6 som er analysert mht. gjennomføringstid. Prossessteg 4 og 5 (hhv. «Heving av last» og «Kvikksølv til godkjent mottak») gjelder ikke Alternativ 1 «Tildekking».




**Figur 2 Overordnet prosess for Alternativ 1**

I Figur 3 er prosjektets tidslinje og Gantt-diagram (med delprosesstegene for 3 og 6) presentert. Varigheten for de enkelte stegene gjenspeiler mest sannsynlig varighet (mode). Tidspunkter og varighet for prossessteg 0, 1, 2, 3.99 og 7 er kun veiledende, og vil kunne endres basert på beslutningsprosesser, valg av gjennomføringshastighet og hvilken tid på sesongen de ulike operasjonene best gjennomføres.




| WBS | Task Name | Duration | Start | Finish |
|---|---|---|---|---|
| 0 | Tildekking | 1181 days? | Mon 02.06.14 | Mon 10.12.18 |
| 0 | Valg av tiltak basert på Forprosjekt og KS2 | 305 days? | Mon 02.06.14 | Fri 31.07.15 |
| 1 | Prosjektering | 876 days | Mon 03.08.15 | Mon 10.12.18 |
| 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 |
| 3.1 | Miljøovervåkningsprogram | 50 days | Mon 04.07.16 | Mon 22.08.16 |
| 3.0/3.2 | Etablere støttefylling (ink mob/demob) | 41 days | Mon 11.07.16 | Sat 20.08.16 |
| 3.99 | Konsolidering av støttefylling | 364 days | Sun 21.08.16 | Sat 19.08.17 |
| 6 | Tildekking | 108 days | Sun 20.08.17 | Tue 05.12.17 |
| 6.1 | Miljøovervåkningsprogram | 108 days | Sun 20.08.17 | Tue 05.12.17 |
| 6.0/6.2 | Tildekking av sjøbunn (ink mob/demob) | 96 days | Fri 25.08.17 | Tue 28.11.17 |
| 6.2.4 | Oppmåling av bunn m/bathymetri | 4 days | Mon 04.09.17 | Thu 07.09.17 |
| 6.2.8 | Oppmåling av blandingslaget m/bathymetri | 4 days | Tue 19.09.17 | Fri 22.09.17 |
| 6.2.9 | Oppmåling av tildekkingslaget m/bathymetri | 5 days | Wed 29.11.17 | Sun 03.12.17 |
| 6.2.10 | Sluttprøvekontroll av sedimenter | 2 days | Mon 04.12.17 | Tue 05.12.17 |
| 6 | Tildekkingslag ferdigstilt | 0 days | Tue 05.12.17 | Tue 05.12.17 |
| 7 | Miljøovervåkning (årlig i fem år) | 6 days | Wed 05.12.18 | Mon 10.12.18 |



**Figur 3 Tidslinje og Gantt diagram for Alternativ 1**

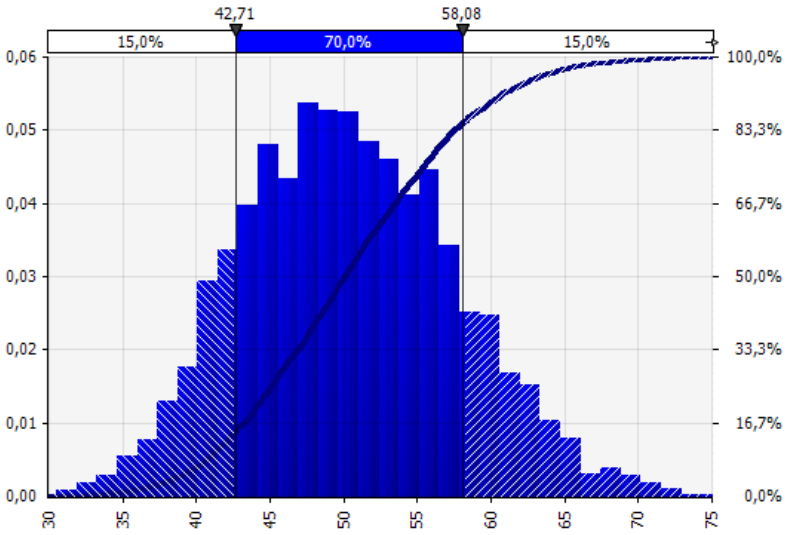
Varighetene på aktivitetene i figurene over er forventede varigheter inklusive påslag for usikkerhetsfaktorer. Usikkerheten i varighet for alle offshore-operasjonene (hovedprosess 3 og 6) er analysert og resultater gjengitt i kapittel 4.

# 4 RESULTATER

Nedenfor presenteres resultatene fra analysen av gjennomføringstid for å etablere støttefylling og tildekke forurensede masser.

## 4.1 Støttefylling

Resultatene av analysen for gjennomføringstid for å etablere støttefyllingen er vist nedenfor.

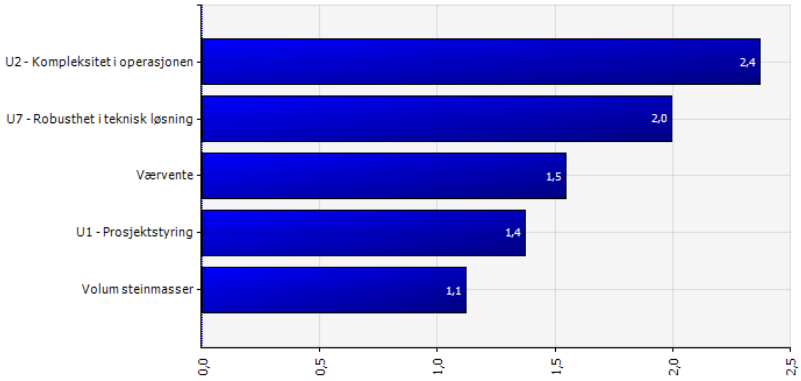



| Analyseresultater | |
|---|---|
| Forventet gjennomføringstid | 50 |
| p15-verdi | 43 |
| p50-verdi | 50 |
| p85-verdi | 58 |
| Standardavvik | 7 |
| Relativt standardavvik | 14 % |

**Figur 4 Sannsynlighetstetthetsplott, S-kurve og resultater for støttefylling (antall dager) – forventet gjennomføringstid: 50 dager**

Analysen viser at den forventede gjennomføringstiden for etablering av støttefyllingen er 51 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 de fem variablene som bidrar mest til usikkerhetene i gjennomføringstid listet i et tornadoplott




**Figur 5 Tornadoplott[2] 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.

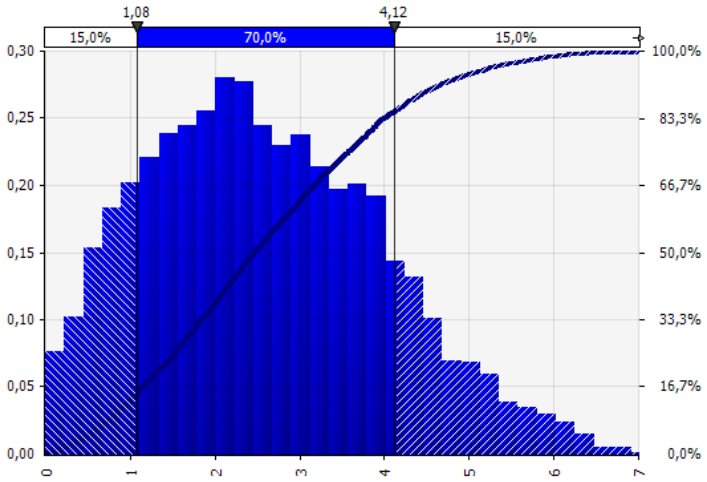
[2] Verdien angir hvor mye total gjennomføringstid vil øke dersom angitte variabel øker med ett standardavvik.

- **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 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.
- **Værvente.** Fartøyene som benyttes i operasjonen har krav til maksimal bølgehøyde under operasjon. Se Figur 6 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 at:

- prosjektet blir godt prosjektert 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 raske og effektive grep kan gjøres dersom gjennomføringen støter på utfordringer.

Figuren nedenfor vises et sannsynligtetthetsplott og s-kurve over værvente for etablering av støttefyllingen.

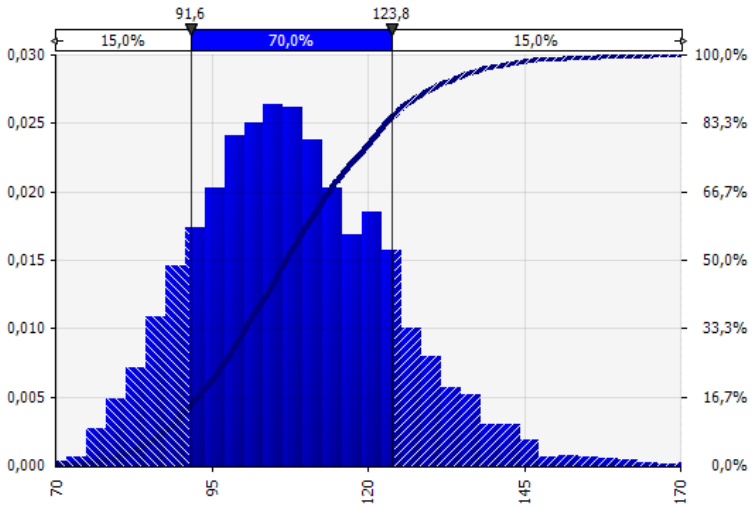



**Figur 6 Sannsynligtetthetsplott over værvente ifm etablering av støttefylling (antall dager)**

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.

## 4.2 Tildekking

Resultatene av analysen for gjennomføringstid for å tildekke tiltaksområdet med rene masser er vist nedenfor.

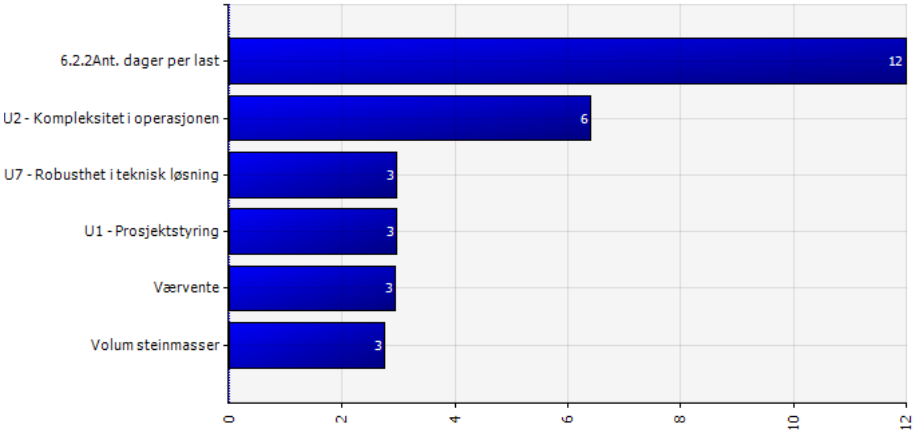



| Analyseresultater | |
|---|---|
| Forventet gjennomføringstid | 108 |
| p15-verdi | 93 |
| p50-verdi | 106 |
| p85-verdi | 124 |
| Standardavvik | 15 |
| Relativt standardavvik | 14 % |

**Figur 7 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 de seks variablene som bidrar mest til usikkerhetene i gjennomføringstid listet i et tornadoplott.




**Figur 8 Tornadoplott[3] 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

[3] Verdien angir hvor mye total gjennomføringstid vil øke dersom angitte variabel øker med ett standardavvik.

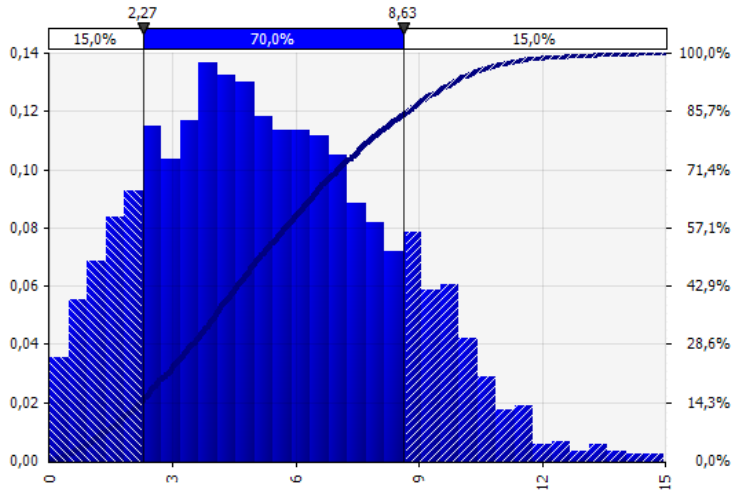
13 turer for å legge ut de ca 160.000 $m^3$ med stein. Dersom hver tur tar 1 dag lengre, vil det medføre at gjennomføringstiden øker med 13 dager.

- **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 6 som viser forventet værvente.
- **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 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 9 Sannsynligtetthetsplott og S-kurve over værvente (ant. dager) ifm etablering av støttefylling**

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.

# 5 BESKRIVELSE AV VARIABLER

## 5.1 Estimatusikkerhet

I tabellen nedenfor beskrives variablene som har innvirkning på varigheten av operasjonene.

**Tabell 1 Estimatusikkerheter for Støttefylling og Tildekking**[4]

| CBS | Støttefylling | P10 | Mode | P90 | Forventet |
|---|---|---|---|---|---|
| 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) | | | |

[4] 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.

## 5.2 Usikkerhetsfaktorer

I tabellen under er det listet de usikkerhetsfaktorene som har innvirkning for gjennomføringshastigheten. For U2, U6 og U7 er disse satt 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 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 % | 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. | |
| **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.

## 5.3 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 3 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.<br>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. | | | | |

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# Vedlegg V1.02

MILJØTILTAK VED VRAKET AV U-864

# Usikkerhetsanalyse Alt. 1 “Tildekking”

DNV GL AS

Project name: Miljøtiltak ved vraket av U-864
Report title: Usikkerhetsanalyse Alt. 1 “Tildekking”

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

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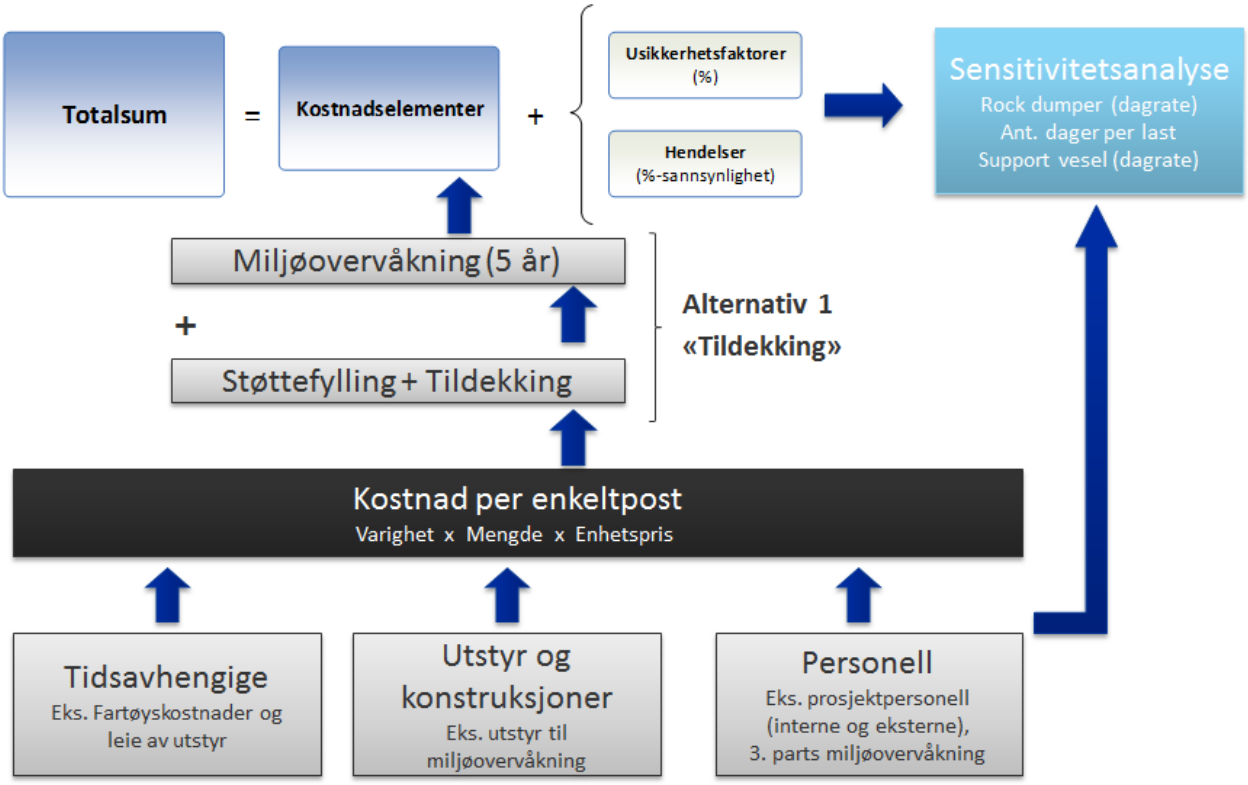
# 1 INNLEDNING

I dette vedlegget er resultatene fra usikkerhetsanalysen av kostnader for «Miljøtiltak ved vraket av U-864», herunder Alternativ 1 Tildekking (heretter kalt Alternativ 1) 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:




**Figur 1 Prinsippskisse av kostnadsmodellen**

Som det fremgår av figuren over, dekker Alternativ 1 kostander for støttefylling, tildekking 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**:

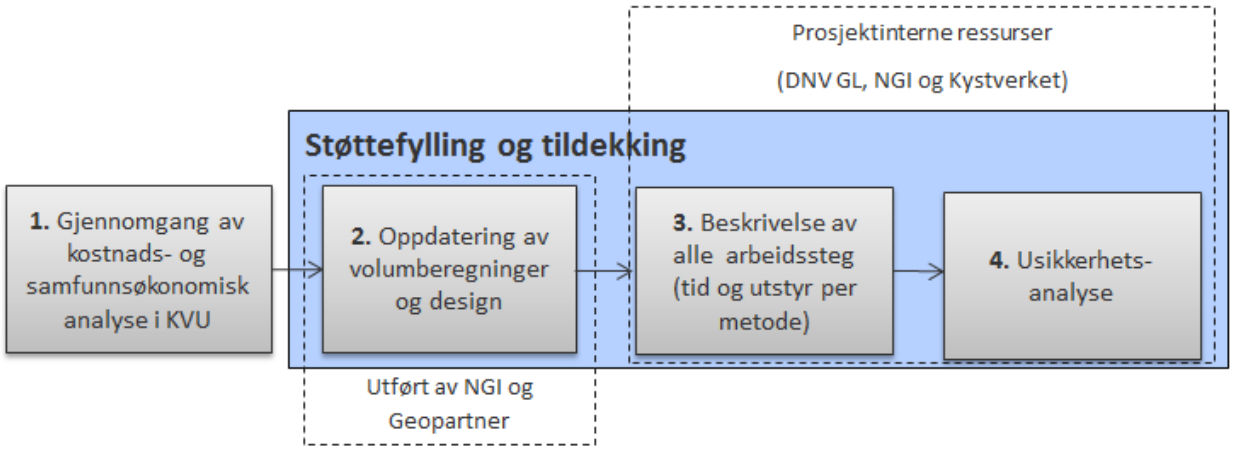
- Kostnadene dekker de aktiviteter som er beskrevet i kapittel 3.
- Alle kostander er i 2014 priser, fremtidige utgifter er ikke diskontert.
- Alle enkeltkostander er eks. merverdiavgift (MVA), men total MVA er beregnet og oppgitt.
- Eurokursen som er benyttet er 8,2 kr/Euro.
- Alle resultater som er 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 V1.01. Noe avvik fra dette er dekket av usikkerhetsanalysen, mens større utsettelser eller forsinkelser som vil kreve replanlegging av prosjektet er ikke kostnadsvurdert.

# 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 2 Prosess for usikkerhetsanalyse av kostnader**

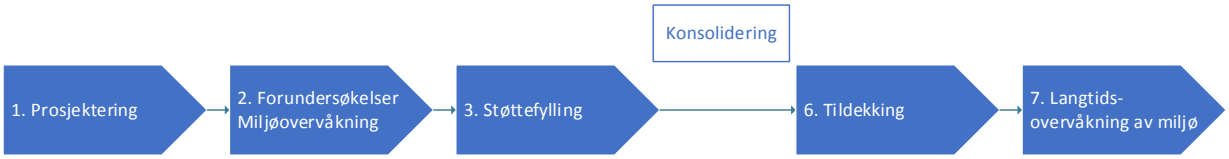
Nedenfor gis en kort beskrivelse av hvert trinn i figuren over. Nummereringen i listen under viser til numrene i tekstboksene i figuren.

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. 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.
3. Ressurser fra DNV GL og NGI har beskrevet aktivitetene i de hovedprosessene som omhandler utlegging av støttefylling og tildekking.
4. 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 2 og 3. Følgende fagfelt har vært involvert i disse prosessene: marine operasjoner, geoteknikk, miljø, 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.

# 4 PROSESS OG AKTIVITETER

## 4.1 Overordnet prosessbeskrivelse

I figuren nedenfor er den overordnede prosessen for Alternativ 1.




**Figur 3 Overordnet prosess for Alternativ 1**

Under hver hovedprosess/delprosess er det laget en CBS for hver enkelt aktivitet med tilhørende kostnadskode. Disse er beskrevet i neste kapittel.

## 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) |
| 1.1.1 | Kystverkets ressurser |
| 1.1.2 | Innleide ressurser |
| **1.2** | **Engineering** |
| 1.2.1 | Engineering (videreutvikling av løsning for tildekking og heving av last) |
| **1.3** | **Forundersøkelser** |
| 1.3.1 | 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) |

### 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:

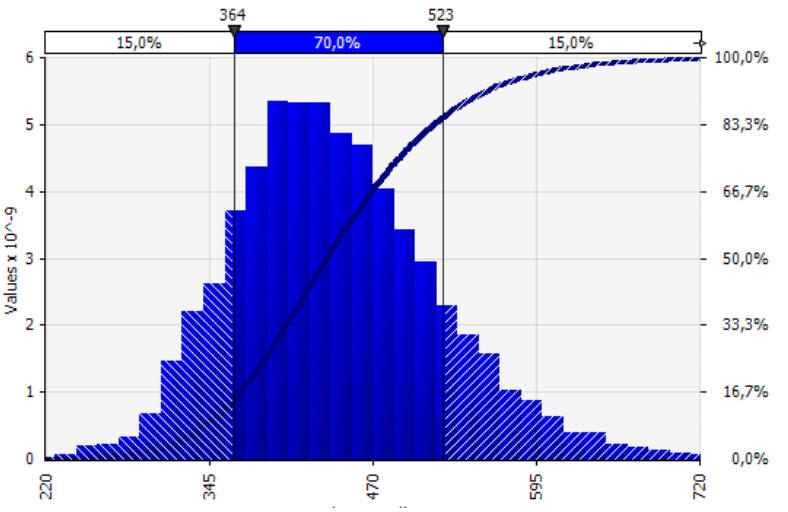
- **Værvente.** Området der U-864 ligger (Fedje) er værutsatt, og en del av fartøyene som brukes har krav til maksimal bølgehøyde under operasjon. Overstiges maksimal bølgehøyde under operasjonen, må hele eller deler av operasjonen vente til været bedres. Dette er ivaretatt i analysen. Det skilles mellom 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.

# 5 RESULTATER

Nedenfor presenteres resultatene fra analysen av Alternativ 1.

## 5.1 Totalkostnader

Resultatene fra usikkerhetsanalysen av kostnader er presentert nedenfor. Påslag for usikkerhetsfaktorer og hendelser er inkludert:




| Analyseresultater (eks. MVA) | |
|---|---|
| Forventet kostnad | 440 |
| p15-verdi | 360 |
| p50-verdi | 430 |
| p85-verdi | 520 |
| Standardavvik | 80 |
| Relativt standardavvik | 18 % |
| MVA | 106 |

**Verdier i MNOK 2014 eks MVA, avrundet til MNOK 10.**

**Figur 4 Resultater av usikkerhetsanalysen for Alternativ 1.**

Som det fremgår av resultatene over, så:

- er forventet kostnad for hele prosjektet MNOK 440.
- vil prosjektet med 70 % sannsynlighet ha en kostnad mellom MNOK 360 og MNOK 520.
- vil de totale kostnadene for MVA være MNOK 110.
- er relativt standardavvik 18 %.

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:

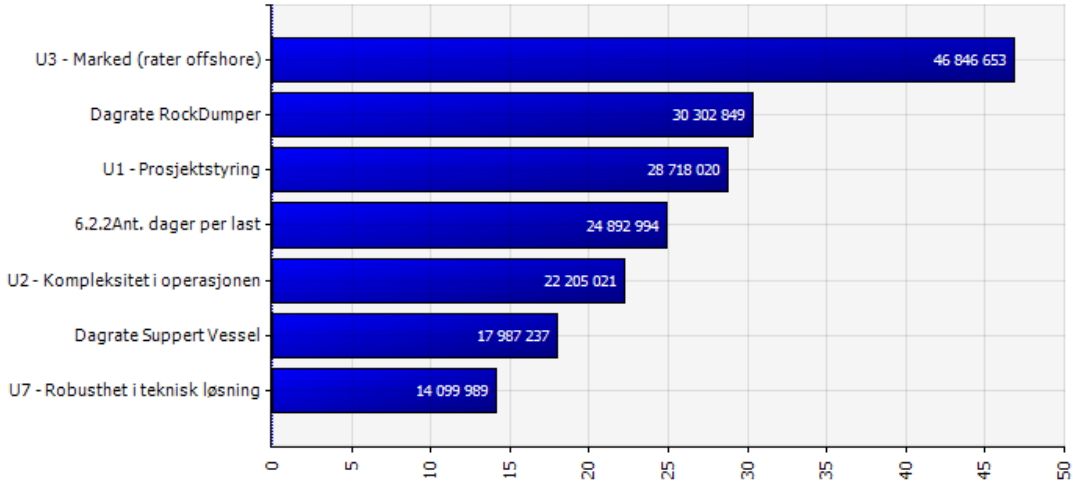
**Tabell 1 Kostnader per underpost (MNOK 2014 eks. MVA)[1]**

| Heving av last [Kombinasjon] | | |
|---|---|---|
| **Totalkostnad ink. usikkerhetsfaktorer og hendelser** | | **442** |
| **Id** | **Kostnadspost** | **394** |
| | | **52** |
| 1.1 | Prosjektstyring | 41 |
| 1.2 | Engineering | 5 |
| 1.3 | Forundersøkelser | 5 |
| 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 |
| **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** | **42** |
| U1 | Prosjektstyring | 11 |
| U2 | Kompleksitet i operasjonen | 11 |
| U3 | Marked (rater offshore) | 0 |
| U4 | Marked (råvarer og konsulenttjenester) | 0 |
| U5 | Vær | 19 |
| U7 | Robusthet i teknisk løsning | 0 |
| U8 | Ambisjonsnivå for miljøovervåkning | 1 |
| **H** | **Hendelser** | **7** |
| H2 | Må hente steinmasser til tildekking i utenfor Bergens-regionen | 7 |
| **M** | **MVA** | **106** |

[1] «X» indikerer at CBS-nummeret er en kombinasjon av de kostnadspostene som tilhører «Rulle, «Rigg» eller «Krybbe».

## 5.2 Usikkerhetsdrivere

I tornadoplottet under er de syv variablene som bidrar med mest usikkerhet listet.




**Figur 5 Tornadoplott for Alternativ 1**[2]

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.

- **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).
- **Dagrate RockDumper:** Leiekostnad (kr/døgn) for steindumperfartøyet.
- **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.
- **Antall dager per last:** Denne variablen er usikkerheten i 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**. Dette er den variabelen som bidrar med mest usikkerhet, og representerer usikkerhet knyttet til antall arbeidssteg, nødvendighet av spesialutstyr og gjennomføring av forundersøkelser mv.
- **Dagrate Support vessel:** Leiekostnad (kr/døgn) for støttefartøyet.

[2] 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.

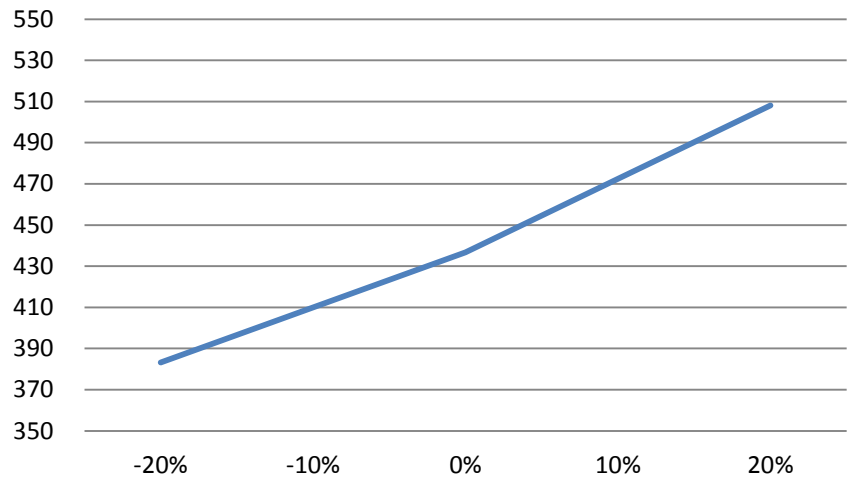
- **U7 Robusthet i teknisk løsning**. Valg av teknisk løsning for å gjennomføre en operasjon for heving av last vil i seg selv kunne øke eller redusere kostnadene betydelig ut fra 1) hvor lang tid operasjonen vil ta å gjennomføre, 2) hvor mye utstyr/spesialutstyr som kreves og 3) antall og type fartøy som er nødvendig. Videre vil robusthetene i løsningen innvirke på i hvor stor grad man er rustet til å møte uforutsette hindringer.

## 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 *U3 Marked (rater offshore), Dagrate RockDumper* og *U1 Prosjektstyring*

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.

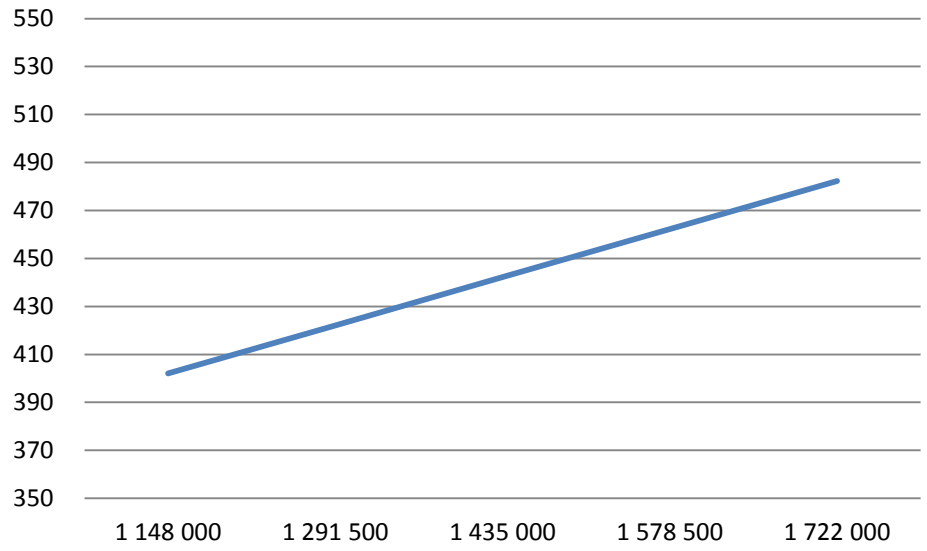
**U3 Marked (rater offshore)**




**Figur 6 Sensitivitetsanalyse av «U3 – Marked (rater offshore)»**

Denne usikkerhetsfaktoren varierer totalkostnadene fra ca. MNOK 380 til MNOK 510 for hhv. p10-verdien og p-90-verdien.

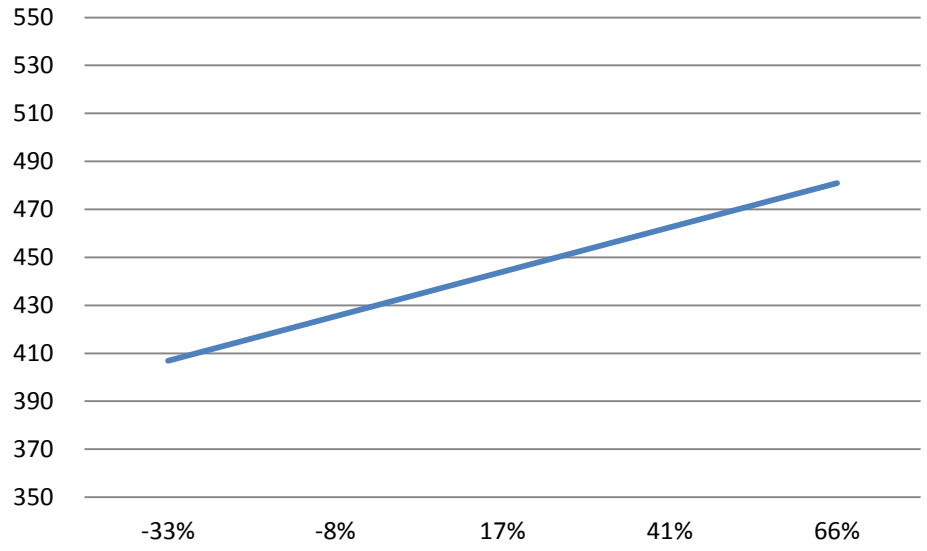
**U2 Dagrate Rock Dumper (steindumpefartøy)**




**Figur 7 Sensitivitetsanalyse av «Dagrate Rock Dumper (steindumpefartøy)»**

Denne usikkerhetsfaktoren varierer totalkostnadene fra ca. MNOK 400 til MNOK 480 for hhv. p10-verdien og p-90-verdien.

**U1 Prosjektstyring**



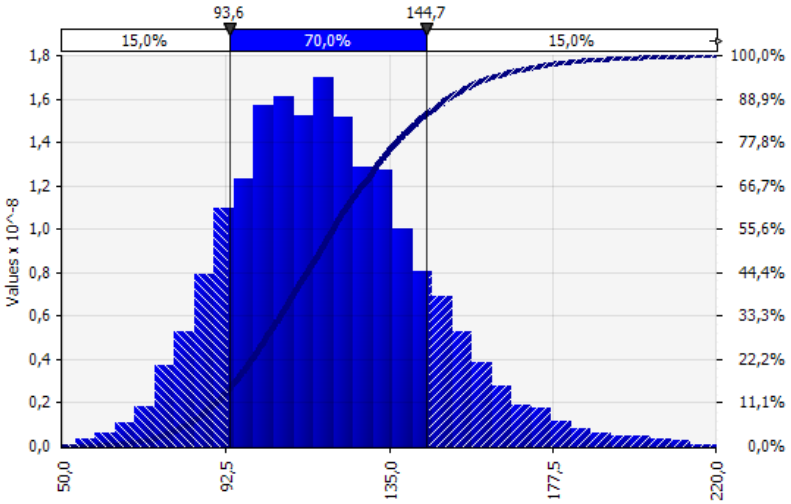

**Figur 8 Sensitivitetsanalyse av «U1 - Prosjektstyring»**

Denne usikkerhetsfaktoren varierer totalkostnadene fra ca. MNOK 410 til MNOK 480 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 og tildekking. Påslag for usikkerhetsfaktorer og hendelser er inkludert:

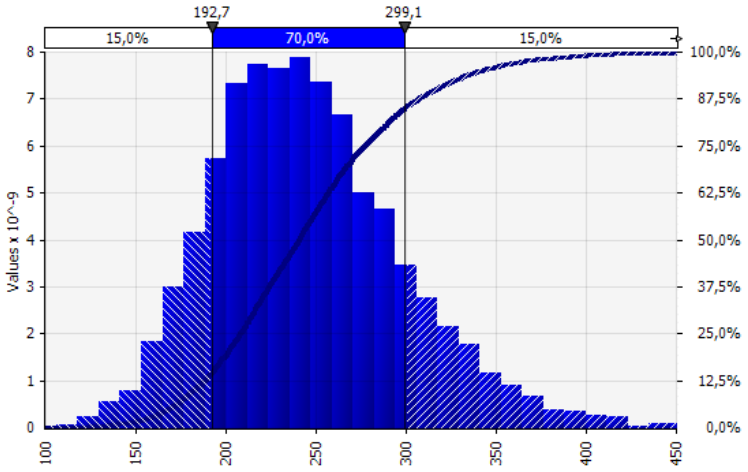
**Støttefylling**




| 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**

**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**

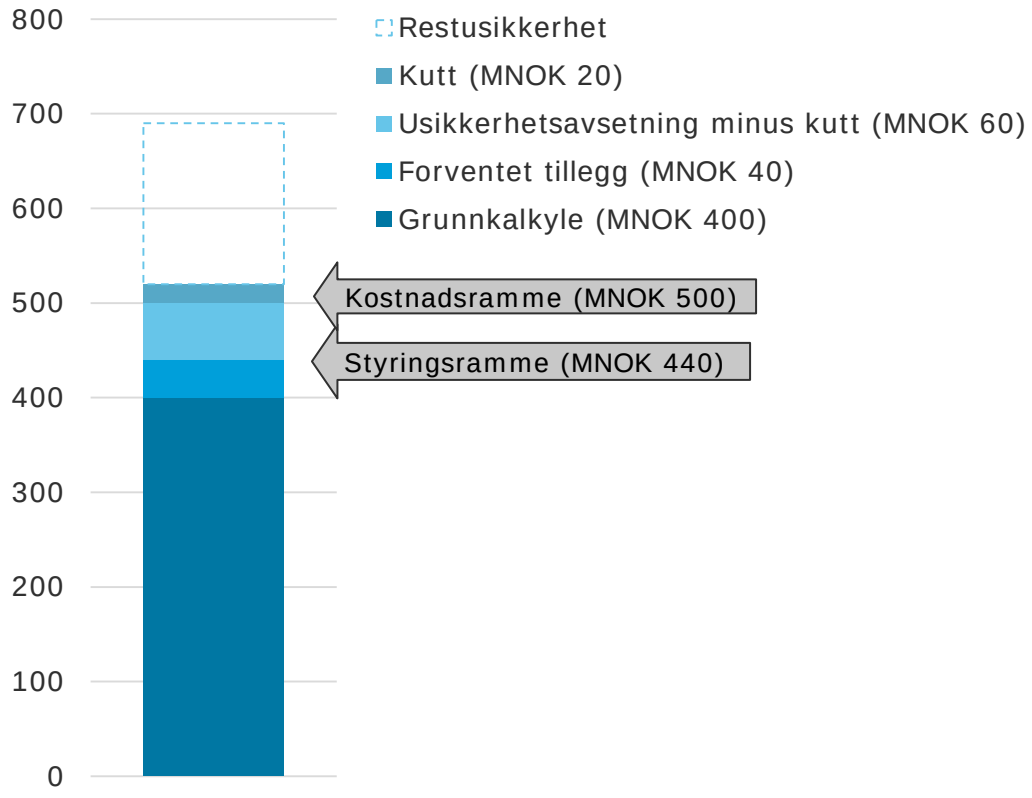
| K | Beskrivelse | 22 |
|---|---|---|
| K1 | Optimering av tildekkingslag | 10 |
| K2 | Redusere miljøovervåkning etter tiltak fra fem til to undersøkelser | 12 |

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.

## 5.6 Styringsramme

Prosjektets kostnads- og styringsramme er vist i figuren under.




**Figur 9 Styringsrammer**

# 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 V1.01.

## 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 |
|---|---|---|---|---|---|
| | Support vessel | -20 % | 630 000 | 20 % | 630 000 |
| | 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 |
| 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 | | | |

| CBS | Prosjektering | P10 | Mode | P90 | Forventet |
|---|---|---|---|---|---|
| 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<br>1 000 | 26<br>1 200 | 48<br>1 700 | 32<br>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 %<br>120 | 78 412<br>150 | 5 %<br>180 | 78 412<br>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 %<br>120 | 156 824<br>150 | 5 %<br>180 | 156 824<br>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<br>Utstyr: U2 (¼), U4, U7 (¼) | | | |

**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<br>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*<br>*3m: 9% sannsynlig over*<br>*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 | |
| **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

En hendelse er tatt med i usikkerhetsanalysen av kostnader.

| | Hendelse | p | P10 | Mode | P90 | Forventet |
|---|---|---|---|---|---|---|
| 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.<br>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. | | | | |

## 6.4 Prosjektorganisering

I tabellen nedenfor er type ressurser og det respektive antall årsverk listet for prosjektorganisasjonen som er ansett nødvendig for Alternativ 1.

| Ressurs | Intern/ ekstern | Type ressurs | ÅV Rulle |
|---|---|---|---|
| Prosjektleder | KYV | PL | 3,00 |
| Prosjektstyringskoordinator | KYV | PL | 3,00 |
| Kommunikasjonsansvarlig | KYV | Sr | 3,00 |
| Leder Kontraktsadministrasjon | Kons | SrKons | 2,00 |
| Leder Operasjon | Kons | SrKons | 2,00 |
| Leder Miljøovervåkning | KYV | Sr | 3,00 |
| Kontroller | KYV | Jr | 1,00 |
| Kvalitet/HMS | KYV | Sr | 1,50 |
| Fagrådgivning (Miljø/Geoteknikk/Marine Op.) | Kons | SrKons | 6,00 |

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 V1.03

MILJØTILTAK VED VRAKET AV U-864

# Kvalitativ risikoanalyse Alt. 1 “Tildekking”

DNV GL AS

| | |
|---|---|
| Project name: | Miljøtiltak ved vraket av U-864 |
| Report title: | Kvalitativ risikoanalyse Alt. 1 “Tildekking” |

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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 1 Tildekking» (heretter kalt Alternativ 1). 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 V1.01 og V1.02.

# 2 GENERELT OM ANALYSEN

## 2.1 Bakgrunn:

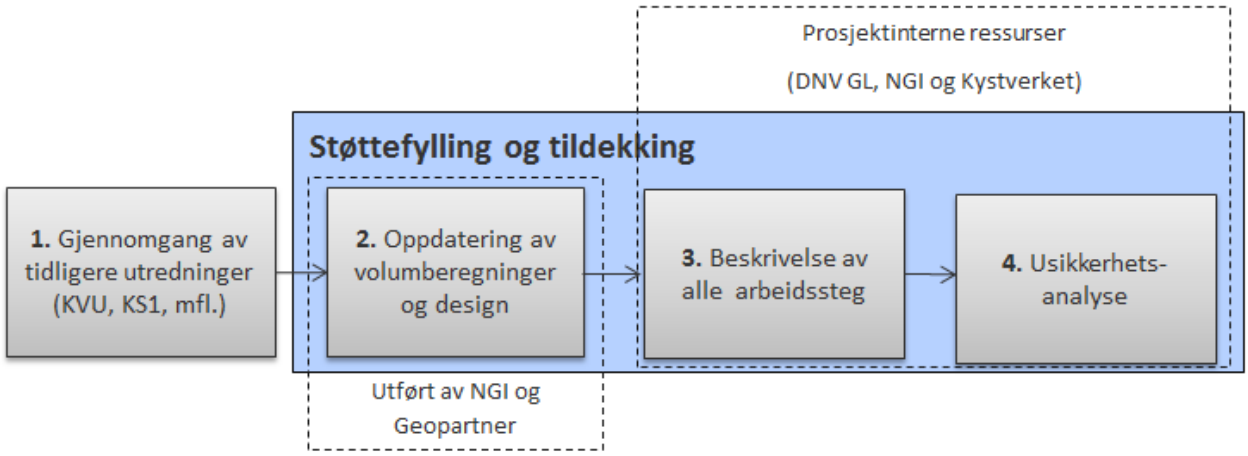
Hensikten med denne analysen er å fange opp de viktigste risikoene som kan redusere måloppnåelsen til prosjektet dersom de inntreffer. Målene som risikoene måles mot er

- 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:

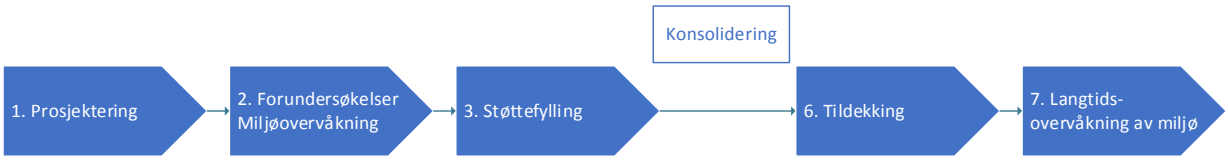
Under utarbeidelse av Sentralt Styringsdokument (SSD) har det vært gjennomført en rekke arbeidsmøter og et større antall vedlegg/rapporter er utarbeidet. I tillegg har tidligere utredninger vært gjennomgått. Underveis i dette arbeidet har prosjektet notert ned mulige hendelser som kan inntreffe underveis i operasjonene og som kan redusere måloppnåelsen til prosjektet. Disse hendelsene har blitt analysert opp mot etablering av støttefyllingen og 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 ulikt 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 samlet gjennom tidligere utførte utredninger.
2. 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.
3. Det ble utarbeidet en overordnet prosess for alternativ 3 (se Figur 2). Denne ble i risikoanalysen benyttet til å identifisere risikoer i hvert prosessesteg, i grensesnittet mellom to prosessesteg, samt overordnet for hele prosjektet.




**Figur 2 Hovedprosesser og delprosesser for Alt. 1 «Tildekking»**

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.

4. Når 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 presenteres i 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 forutsettes iverksatt.

**Avgrensninger**:

- Endringer i rammevilkår som innebærer vesentlig forsinket gjennomføring av prosjektet (jf. Vedlegg V3.01) er ikke vurdert.

# 3 SANNSYNLIGHET- OG KONSEKVENSSKALA SOM ER BENYTTET I RISIKOVURDERINGENE

De følgende skalaene er benyttet for å vurdere risikoenes henholdsvis sannsynlighet og konsekvens. Skalaen ble i utgangspunktet utarbeidet på engelsk da samme formulering er benyttet av bergingsselskaper i deres egne risikovurderinger av de foreslåtte 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)<br><br>Hendelsen medfører ingen negative akutte effekter på økosystemet. Dette kan sammenliknes med:<br>• 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)<br><br>Hendelsen medfører ingen negative kroniske effekter på økosystemet. Dette kan sammenliknes med:<br>• 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).<br><br>Hendelsen medfører ingen negative akutte effekter på økosystemet. Dette kan sammenliknes med:<br>• Ingen vannkonsentrasjoner er høyere enn klasse III, som tilsvarer maksimum 0,07 µg Hg/.<br>• Ingen sedimentkonsentrasjoner er høyere enn klasse III, som tilsvarer maksimum 0,86 mg Hg/kg, over et større areal utenfor tiltaksområdet.<br><br>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).<br><br>Hendelsen medfører ingen negative kroniske effekter på økosystemet. Dette kan sammenliknes med:<br>• Ingen vannkonsentrasjoner er høyere enn klasse II, som tilsvarer maksimum 0,048 µg Hg/l.<br>• Ingen sedimentkonsentrasjoner er høyere enn klasse II , som tilsvarer maksimum 0,63 mg Hg/kg, over et større areal utenfor tiltaksområdet.<br><br>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).<br><br>Hendelsen medfører negative akutte effekter på økosystemet. Dette kan sammenliknes med:<br>• Vannkonsentrasjoner er høyere i klasse IV, som tilsvarer maksimum 0,14 µg Hg/l.<br>• 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).<br><br>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).<br><br>Hendelsen medfører negative kroniske effekter på økosystemet. Dette kan sammenliknes med:<br><br>• Vannkonsentrasjoner i klasse III, som tilsvarer maksimum 0,071 µg Hg/l.<br>• 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).<br><br>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).<br><br>Det forventes negative akutte effekter på økosystemet. Dette kan sammenliknes med:<br><br>• Vannkonsentrasjoner i klasse V, som tilsvarer > 0,14 µg Hg/l.<br>• 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).<br><br>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).<br><br>Det forventes negative kroniske effekter på økosystemet. Dette kan sammenliknes med:<br>• Vannkonsentrasjoner i klasse IV, som tilsvarer maksimum 0,14 µg Hg/l.<br>• 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).<br><br>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).<br><br>Det forventes omfattende negative akutte effekter på økosystemet. Dette kan sammenliknes med:<br>• Vannkonsentrasjoner som er 5 ganger eller høyere enn klasse V, som tilsvarer >= 0,7 µg Hg/l.<br>• 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 forues med konsentrasjoner >0,86 mg Hg /kg.<br><br>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).<br><br>Det forventes omfattende negative kroniske effekter på økosystemet. Dette kan sammenliknes med:<br><br>• Vannkonsentrasjonersom er 5 ganger eller høyere enn klasse V, som tilsvarer >= 0,7 µg Hg/l.<br>• 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.<br><br>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 1. Først presenteres det totale risikobildet for hele Alternativ 1, deretter for hvert enkelt risikomål.

Hvert av numrene som vises i matrisene henviser til en konkret risiko. For komplett liste over alle risikoer (sortert på ID-nummer), se Tabell 4 i kapittel 4. Definisjon av skala for sannsynlighet og konsekvens er presentert i kapittel 3.

## 4.1 Overordnet risikobilde

I matrisen nedenfor er det totale risikobildet for Alternativ 1 presentert. Det er totalt identifisert 23 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** | | | | | |
| **Høy** | | 265 | 295 | | |
| **Middels** | | 269 | 267 | | |
| **Lav** | 207<br>231 | 205<br>236<br>240 | 96 | 154<br>228 | |
| **Veldig lav** | 2 4<br>206 | | 72<br>214<br>232<br>241<br>293 | | |
| **Teoretisk mulig** | | 233 | 230 | 18 | |
| **Sanns. ↑<br>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): 1 stk
- Moderate risikoer (gule): 6 stk
- Lave risikoer (grønne): 16 stk

Den kritiske risikoen er presentert nedenfor:

| *ID* | *Navn* |
|---|---|
| R-0295 | Aktivister interfererer med operasjonen => operasjonen forsinkes og/eller skade på materiell |

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** | | | | | |
| **Veldig lav** | | | 293 | | |
| **Teoretisk mulig** | | | | | |
| **Sanns. ↑ Kons. →** | **Veldig Lav** | **Lav** | **Mid-dels** | **Høy** | **Veldig høy** |

**Tabell 6 Operasjonell risiko**

| | | | | | |
|---|---|---|---|---|---|
| **Veldig høy** | | | | | |
| **Høy** | | 265 | 295 | | |
| **Middels** | | | 267 | | |
| **Lav** | 207 | | 96 | 154 | |
| **Veldig lav** | 2 4 | 72 | 214 241 293 | | |
| **Teoretisk mulig** | | | 18 | | |
| **Sanns. ↑ Kons. →** | **Veldig Lav** | **Lav** | **Mid-dels** | **Høy** | **Veldig høy** |

**Tabell 7 Miljørisiko, kort sikt**

| | | | | | |
|---|---|---|---|---|---|
| **Veldig høy** | | | | | |
| **Høy** | 265 | | | | |
| **Middels** | | 267 | | | |
| **Lav** | 96 | 205 | | 228 | |
| **Veldig lav** | 2 4 241 293 | | 72 | | |
| **Teoretisk mulig** | | | | 18 | |
| **Sanns. ↑ Kons. →** | **Veldig Lav** | **Lav** | **Mid-dels** | **Høy** | **Veldig høy** |

**Tabell 8 Miljørisiko, lang sikt**

| | | | | | |
|---|---|---|---|---|---|
| **Veldig høy** | | | | | |
| **Høy** | 265 | | | | |
| **Middels** | | 267 269 | | | |
| **Lav** | 205 231 | 236 240 | 228 | | |
| **Veldig lav** | 2 4 72 206 | | 232 | | |
| **Teoretisk mulig** | | 233 | 18 230 | | |
| **Sanns. ↑ Kons. →** | **Veldig Lav** | **Lav** | **Mid-dels** | **Høy** | **Veldig høy** |

## 4.2 Konklusjon

Risikoanalysen har identifisert totalt 23 risikoer for Alternativ 1. Analysen viser at det totale risikonivået ligger i området moderat til lav, der kun en risiko er vurdert å være kritisk (rød). Den kritiske risikoen omhandler hendelsen at aktivister saboterer eller forsinker operasjonen, noe som kan medføre større forsinkelser som er kostnadsdrivende. Det er identifisert seks moderate (gule) risikoer, hvorav fire knyttes til operasjonell risiko og fire til miljø på lang sikt. Av fire sistnevnte, er to av disse relatert til prosjektorganisering og planlegging. Kun tre risikoer er relatert til personell, to av disse er moderat risiko, den siste lav risiko.

Totalt sett er risikobildet for Alternativ 1 moderat til lavt. Det er ikke avdekket kritiske risikoer knyttet til miljø hverken på kort eller lang sikt.

# 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.

**Tabell 9 Liste over alle risikoer**

| *ID* | *Navn* | *Beskrivelse* | *Til-dekking* |
|---|---|---|---|
| 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.<br>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 |
| 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.<br>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 |
| 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.<br><br>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 |
| 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 |

| ID | Navn | Beskrivelse | Til-dekking |
|---|---|---|---|
| R-0096 | Skade eller feil på utstyr under operasjon -> operasjonen stoppes og medfører vesentlig forsinkelse | Problemer under løft/rulle:<br>- Feil løfteutstyr<br>- Feil i wire tromler<br>- Større uventede bevegelser i løftefartøy<br>- Problemer med hiv-kompensering<br><br>Tildekking:<br>- Skader eller feil på fall pipe utstyr kan medføre skader på personell.<br>- Repetitive operasjoner kan medføre stor slitasje på utstyr.<br>- 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<br>OSAFE |
| R-0154 | Dårligere værforhold enn planlagt for -> operasjonen blir vesentlig forsinket | Lokasjonen utenfor Fedje er eksponert for vær og bølger.<br>Operasjonen trenger et vesentlig værvindu for å kunne gjennomføres.<br>Dårlige værforhold vil kreve at operasjonen stoppes midlertidig. | 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 område, derfor er dette tatt hensyn til i designet av tildekkingen.<br><br>Materialet som er tenkt brukt som erosjonsbeskyttelse spesifiseres for å være stabilt under de faktiske hydrodynamiske påvirkningene.<br><br>Forventet påvirkning fra jordskjelv: Fra GeoPartners rapport:<br>"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.<br><br>The overall conclusion is that earthquake loading is not critical for the wreck encapsulation and seabed capping."<br><br>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).<br><br>Evt. skader vil fanges opp av planlagt miljøovervåkning og kan repareres. | ENVLT ENVST |

| ID | Navn | Beskrivelse | Til-dekking |
|---|---|---|---|
| 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.<br><br>Ikke forventet at strømmen i området vil påvirke presisjonen i vesentlig grad. | ENVLT |
| 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.<br><br>Cappingmaterialet kan være for finkornet til å kunne installeres presist dersom det er kraftig strøm. Krever at fall pipe er nær bunnen ved utlegging.<br><br>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).<br><br>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 |
| 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.<br><br>Risikoen vurderes ikke til at være større enn ved normal skipstrafikk | 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.<br><br>Feil gjennomføring, eller feil i design kan medføre at utglidning. | ENVLT ENVST |
| 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 |
| 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 |

| ID | Navn | Beskrivelse | Til-dekking |
|---|---|---|---|
| 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.<br><br>Cappingen kan designes slik at det kan tåle nødankring. Dette er dog meget kostbart og ligger ikke inne i beregnet volum av tildekkingsmasser. | 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 |
| 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.<br><br>Gassbobler kan genereres "naturlig i sedimentet" (eks metan). | 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.<br><br>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 |
| R-0241 | Tildekkingsmassene er forurenset => Tilførsler av ny forurensning ved capping | Hvis ikke tildekkingsmaterialet sjekkes for forurensninger kan dette inntreffe | ENVST OSAFE |

| ID | Navn | Beskrivelse | Til-dekking |
|---|---|---|---|
| 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.<br><br>Dersom ikke Kystverkets prosjekt klarer å få til et effektivt samarbeid med:<br>- Forsvaret (spesielt EOD-personell)<br>- Sentrale underleverandører<br><br>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.<br><br>Kostnadsanalysen viser at dette er den nest høyeste driveren av usikkerhet. | 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.<br><br>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 |
| 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 |
| 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 |
| R-0295 | Aktivister interfererer 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 |

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