3rd Annual
Advanced Submarine Power Cable and Interconnection Forum
Enhancing Cable Installation, Reducing Repair Cost and Increasing Cable Innovation to Guarantee Maximum Return on Investment

Official Conference Hashtag #BISsub14

16th - 18th June 2014
Angleterre Hotel, Berlin, Germany
Anchor Penetration Trials in the North Sea to Optimize Cable Burial Depth
→ Tennet is responsible for the grid connection of offshore wind farms in the German sector of North Sea

→ HVAC and HVDC grid connection

→ ~ 1500 km of HVAC or HVDC subsea power cables installed, contracted or tendered (without interconnectors)

→ Preplanings for another ~1800 km of cables
Anchor Penetration Trials in the North Sea
Dr. Anja Drews / Christian Maushake · June 2014

Burial depth of seacables
Regulations and risks

**Required burial depth of sea cables**

- **1.5 m** outside shipping channels
- **3.0 m** inside

**Complex in terms of**

- **Costs** (increasing dramatically with every dm)
- **Technology** (in areas with difficult soil conditions)

**Treatment of cable burial requirements within German consenting processes so far:**

- No individual risk based assessment of burial depth for cables required
  - *Exception Nearshore Areas:* 1,5 – 5 m DoB - *in dependence of sediment mobility*
- Assessment of likelyhood of damage by anchors required
- Statistical approach vrs. single case
  - risk potential is seen by anchor maneuvers in emergency cases and disasters
Motivation

Challenges of 3 m DoB
- 3 m is no industry standard, no guarantee reaching 3 m
- seabed conditions – stiff clays in parts of the routes
- no dredging due to environmental constraints
- remedial trenching exposes cable to a higher risk of damage during installation
- survey – higher measurement uncertainties
- repair – longer times for recover and new reburial challenges

Advantages of a reduced burial depth
- meets industry standards in cable burial
- larger market to deploy burial tools
- time reduction in cable laying operations
- time reduction for cable recover in case of a repair, easier de- and reburial
  - less disturbance for ship traffic
... agreed upon investigations to determine the real penetration depths of anchors into the seafloor

- Anchor penetration trials have been conducted from the 30.04. – 03.05.2013 offshore in the German North Sea
Traffic Analysis to determine a design ship

<table>
<thead>
<tr>
<th>Fractile</th>
<th>Lenght (m)</th>
<th>dwt (t)</th>
<th>TEU</th>
<th>Tmax (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 %</td>
<td>&lt; 140</td>
<td>13500</td>
<td>800</td>
<td>7,6</td>
</tr>
<tr>
<td>75 %</td>
<td>&lt; 212</td>
<td>37000</td>
<td>2600</td>
<td>10,8</td>
</tr>
<tr>
<td>80 %</td>
<td>&lt; 231</td>
<td>46000</td>
<td>3300</td>
<td>11,8</td>
</tr>
<tr>
<td>90 %</td>
<td>&lt; 294</td>
<td>80000</td>
<td>5700</td>
<td>14,5</td>
</tr>
<tr>
<td>95 %</td>
<td>&lt; 333</td>
<td>100000</td>
<td>7100</td>
<td>14,5</td>
</tr>
</tbody>
</table>

Cargo ship with 80.000 dwt

-> Chose of an Hall anchor of 10.5 t according to GL tables on correlation on anchor mass and dead-weight of ships
Anchor Penetration Trials in the North Sea

Dr. Anja Drews / Christian Maushake  ·  June 2014

Test anchors

holding capacity –
Hall: 4-6 x its mass-weight – 470 kN to 690 kN,
AC 14: 8-11 x its mass-weight – 620 kN to 950 kN

Up to 294 m length / 80000 DWT

Hall ~11.7 to.

HHP AC14 ~8.3 to.

~ 364 cm

~ 280 cm

~ 197 cm

~ 196 cm
Vessels and tasks

**Guardian**
Survey vessel: ROV, MBES
- ROV inspection during anchor pulls
- Post-pull MBES surveys

**Esvagt Connector**
Offshore Tug: Anchorhandling
- Anchor handling and pulling (Bollard pull max. 107 to.)

**Wega**
Survey vessel: SSS, SES (MBES)
- Pre-pull survey (SSS / SES)
- Post-pull survey (SES, SSS)

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3 test sites with different soil conditions reflecting the interaction between anchor and seabed

UG „BSH NORD“
Loosely layered finesand

UG „BSH SÜD“
Medium dense sand with some silt

UG „VTG“
Densely packed Sand with stiff clay layers

UG „VTG“ survey box

3 test sites
2 anchors (Hall, AC14)
3 pulls each anchor

18 pulls
Anchor trial procedure

Pre - pull - survey
Side scan sonar and Sediment Echosounder survey on every test site
→ Soil conditions,
→ detection of obstacles,
→ finalization of drop positions

Anchor pulls
→ Move offshore tug to drop position
→ Dropping anchor
→ ROV video check of anchor position and alignment
→ Anchor pull up to 80 to. (load cell) or anchor break out
→ ROV Video check of final position
→ Recover anchor

Post - pull - survey
→ SSS, MBES and SES survey of anchor track
Anchor Penetration Trials in the North Sea

Dr. Anja Drews / Christian Maushake · June 2014
Start of an Anchor pull as recorded by ROV video
Position V2
After Anchor pull – anchor has graded in as recorded by ROV video
Position VTG Position AC14
Combined SSS / SES survey of anchor tracks (Post – pull survey)

1. Anchor Penetration Trials in the North Sea
2. Dr. Anja Drews / Christian Maushake
3. June 2014
Detection of anchor penetration depth
… as performed with SES processing software ISE

- Digitize seafloor → ISE (semi-)automatically
- Identify anchor track(s)
- Re-Digitize the level of „un-disturbed seafloor“ in the zone influenced by the anchor → ISE manually
- Overwrite seafloor level → ISE automatically
- Detect depth of influence (anchor penetration depth) → ISE target picker
Penetration depth $\Delta z$ (m)

Pulling force (t)

SES - Echoplots

ID: 591
$\Delta z : 0.88$

ID: 51
$\Delta z : 0.56$

ID: 52
$\Delta z : 0.38$

ID: 59
$\Delta z : 0.23$

ID: 53
$\Delta z : 0.16$

ID: 54
$\Delta z : 0.11$

ID: 58
$\Delta z : 0.72$

ID: 56
$\Delta z : 0.56$

ID: 55
$\Delta z : 0.13$

ID: 57
$\Delta z : 0.29$

Pull 1

Pull 2

area  Nord
Pos  N5
Typ  Hall
Length  87 m
Max. pull  58 t
Max. $\Delta z$  0.88 m
Penetration depth $\Delta z$ (m)

Pulling force (t)

SES - Echoplots

ID: 15  $\Delta z : 0.25$
ID: 14  $\Delta z : 0.10$
ID: 13  $\Delta z : 0.26$
ID: 12  $\Delta z : 0.28$
ID: 11  $\Delta z : 0.07$

ID: 111 $\Delta z : 0.28$
ID: 110 $\Delta z : 0.21$
ID: 19  $\Delta z : 0.25$
ID: 17  $\Delta z : 0.17$
ID: 16  $\Delta z : 0.33$

area: VTG
Pos: V1
Typ: AC14
Length: 107 m
Max. pull: 73 t
Max. $\Delta z$: 0.33 m
Anchortrack (SSS)

Penetration depth $\Delta z$ (m)

Pulling force (t)

SES - Echoplots

Area: VTG

Pos: V6

Typ: Hall

Length: 26 m

Max. pull: 80 t

Max. $\Delta z$: 0.51 m
Anchor Penetration Trials in the North Sea

Dr. Anja Drews / Christian Maushake  ·  June 2014
BSH - Süd – Anchortracks

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Anchor Penetration Trials in the North Sea

Dr. Anja Drews / Christian Maushake  ·  June 2014

BSH - VTG – Anchortracks

AC14

Hall

1. pull  2. pull  3. pull

3 pulls!
### Anchor test
#### Summary of all anchor pulls

<table>
<thead>
<tr>
<th>Position</th>
<th>Anchor</th>
<th>tracklength</th>
<th>Max. pull</th>
<th>Max. Δ z</th>
</tr>
</thead>
<tbody>
<tr>
<td>N1</td>
<td>AC14</td>
<td>67 (2x)</td>
<td>620</td>
<td>0.65</td>
</tr>
<tr>
<td>N2</td>
<td>Hall</td>
<td>92 (2x)</td>
<td>640</td>
<td>0.70</td>
</tr>
<tr>
<td>N3</td>
<td>AC14</td>
<td>57</td>
<td>820</td>
<td>0.69</td>
</tr>
<tr>
<td>N5</td>
<td>Hall</td>
<td>87 (2x)</td>
<td>580</td>
<td>0.88</td>
</tr>
<tr>
<td>N6</td>
<td>Hall</td>
<td>92 (2x)</td>
<td>650</td>
<td>0.78</td>
</tr>
<tr>
<td>S1</td>
<td>AC14</td>
<td>63</td>
<td>860</td>
<td>0.33</td>
</tr>
<tr>
<td>S2</td>
<td>AC14</td>
<td>20</td>
<td>950</td>
<td>0.28</td>
</tr>
<tr>
<td>S3</td>
<td>AC14</td>
<td>102</td>
<td>640</td>
<td>0.34</td>
</tr>
<tr>
<td>S4</td>
<td>Hall</td>
<td>23</td>
<td>760</td>
<td>0.28</td>
</tr>
<tr>
<td>S5</td>
<td>Hall</td>
<td>27</td>
<td>720</td>
<td>0.28</td>
</tr>
<tr>
<td>S6</td>
<td>Hall</td>
<td>22</td>
<td>800</td>
<td>0.26</td>
</tr>
<tr>
<td>V1</td>
<td>AC14</td>
<td>107 (3x)</td>
<td>730</td>
<td>0.33</td>
</tr>
<tr>
<td>V2</td>
<td>Hall</td>
<td>27</td>
<td>750</td>
<td>0.34</td>
</tr>
<tr>
<td>V3</td>
<td>AC14</td>
<td>20</td>
<td>780</td>
<td>0.19</td>
</tr>
<tr>
<td>V4</td>
<td>Hall</td>
<td>24</td>
<td>790</td>
<td>0.26</td>
</tr>
<tr>
<td>V5</td>
<td>AC14</td>
<td>31</td>
<td>800</td>
<td>0.67</td>
</tr>
<tr>
<td>V6</td>
<td>Hall</td>
<td>26</td>
<td>800</td>
<td>0.67</td>
</tr>
</tbody>
</table>

- Max. penetration depth less than 1.0 m*
- Critical VTG area less than 0.8 m*
- Pulling forces comply and exceed the holding power of anchors -> results are realistic

(*including measurement uncertainties)
Results & Conclusions

Measured Results
• No anchor penetration deeper than 1m has been observed (including all measurement errors)
• Anchor crown resists on seabed after drop

Additional calculations and interpretations
• The fluke tip to shank distance may be used as an estimate for the penetration depth (1,0 m and 1,2 m for AC14 and Hall respectively)
• Addition of geometry error gives a theoretical maximum penetration depth of 1,2 m
• Extrapolation to a 29 t anchor gives a theoretical penetration depth of 1,6 m

Changes in the burial requirements in the German North Sea
• Results have been accepted by the consenting authorities
  • Burial depth requirements have been reduced from 3 m to 1,5 m
  • Result will be integrated into the new offshore grid plan 2014
Data Availability and outlook

One of the best documented large scale experiment on anchor penetration

Reports and Videos will be made public available on the SCUK web page

or

send me an email with your request: anja.drews@tennet.eu

Future research using the recorded experimental data:

- Numerical Modelling of test results – PhD thesis at the Technical University of Hamburg – Harburg

- JIP Safetrech – development of numerical models on anchor behaviour, Research project lead by Deltares