Dansk Spuns- & Rammedag 2015

Buckling of XL monopiles during installation

Ramning af monopæle og maskinudvikling

Ulrik Muurholm Hansen

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My profile

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- Education: Master of Science in Civil Engineering, Technical University of Denmark
- Company: COWI 1703 Marine & Foundation Engineering department (since 2011)
- Title: Structural designer
- Reference projects: HR 3 & KF AC Transformer Platforms, DanTysk OWF Detailed Design, Formosa 1 OWF.

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Agenda

Introduction

Buckling during installation

Results and conclusions

Introduction

- About WMR
  - 11 km off Yorkshire coast covering 35 km^2
  - 35 SWT-6.0-154 (Siemens) turbines (210 MW)
  - MP foundations with OD 6.5 m (D/t=120)
  - Water depth 10-25m
  - Completion of foundation installation by GeoSea 25-May-2014.

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Introduction

- About BBW02
  - 8 km from shore in Liverpool Bay covering 40 km^2
  - Owner and developer is DONG Energy
  - 32 V164-8.0 MW (Vestas) turbines (256 MW)
  - MP foundations with OD 7.097m
  - Water depth 4-17 m.

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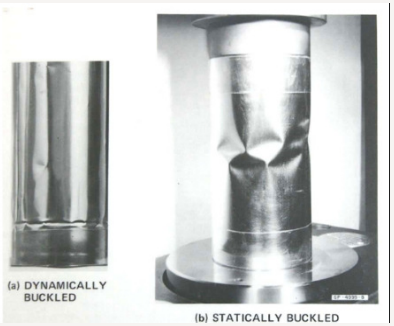
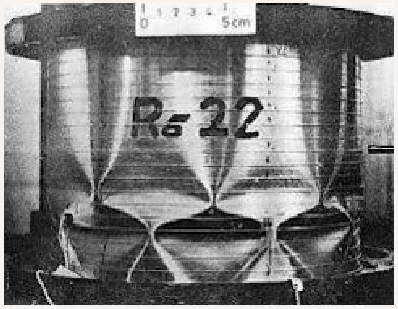
Introduction (cont.)

- Project describtion
  - DONG asked COWI to investigate whether local shell buckling of MPs during installation (impact driving) was an issue
  - Offshore guideline limitations:
    - NORSOK N004: D/t<120
    - ISO19902: D/t≤120
    - EN 1993-1-6: 20≤r/t≤5000
    - (LBA, MNA, GNIA, GMNIA)





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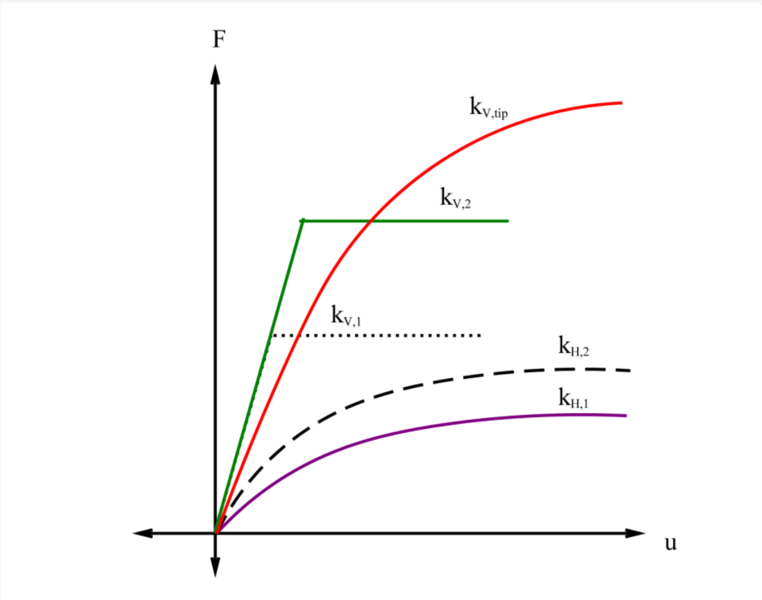
Buckling during installation

The physics of pile driving



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Buckling during installation

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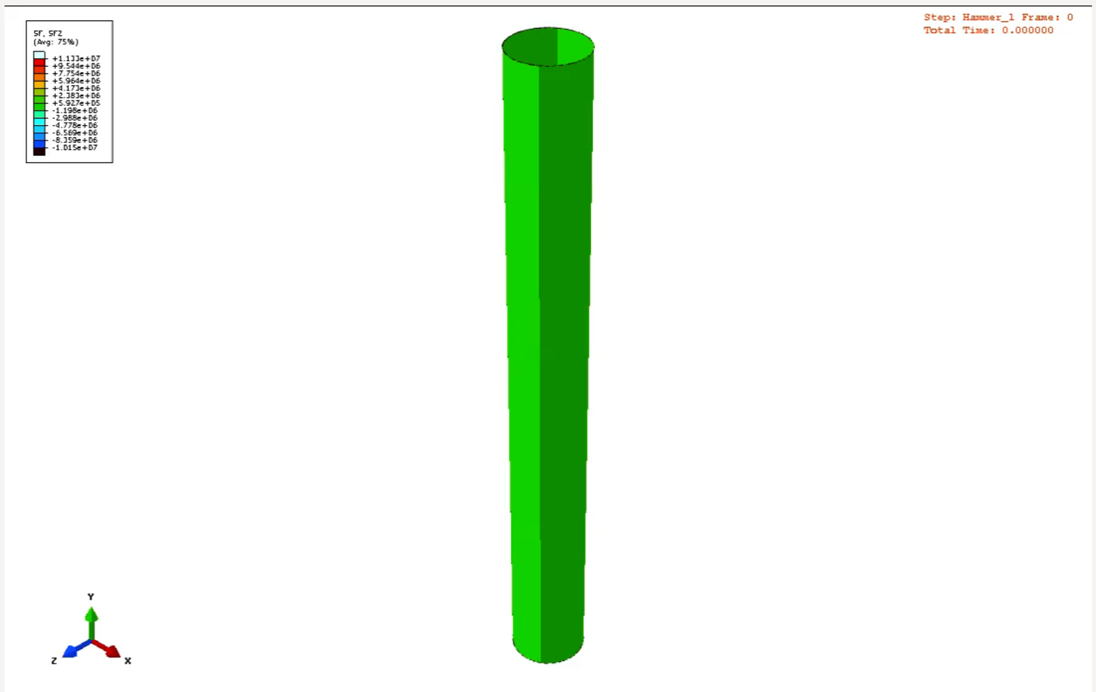

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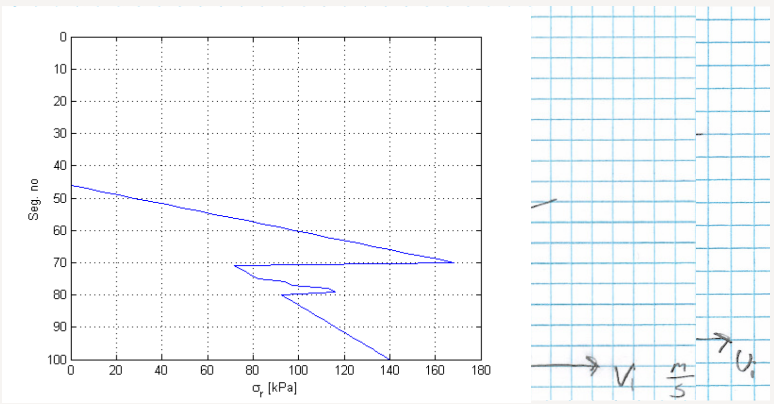
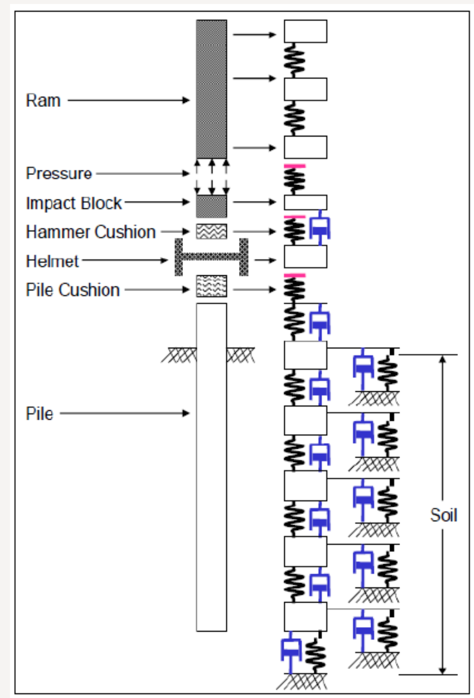
Buckling during installation

GRLWEAP – Stress Wave Propagation Modelling

- GRLWEAP output
  - Normal stress in pile
  - Radial soil pressure inside/outside pile
  - 35 locations, 100 segment, approx. 30 driving depth for two soil models.

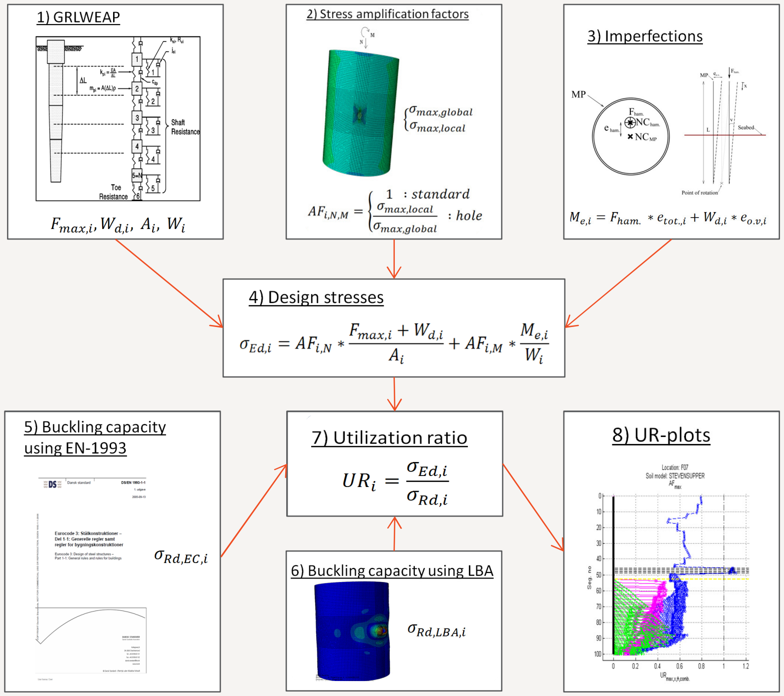




Buckling during installation (cont.)

Shell buckling verification

- Obtain normal force and cross-sectional parameters from GRLWEAP
- Determine stresses near cable entries
- Account for imperfections (hammer misalignment and MP out-of-verticality)
- Determined shell design stresses (axial, hoop, shear)
- Apply EN1993-1-6 for buckling verification
- Determine capacity near cable entries LBA method
- Determine UR in relation to shell buckling
- Report results.



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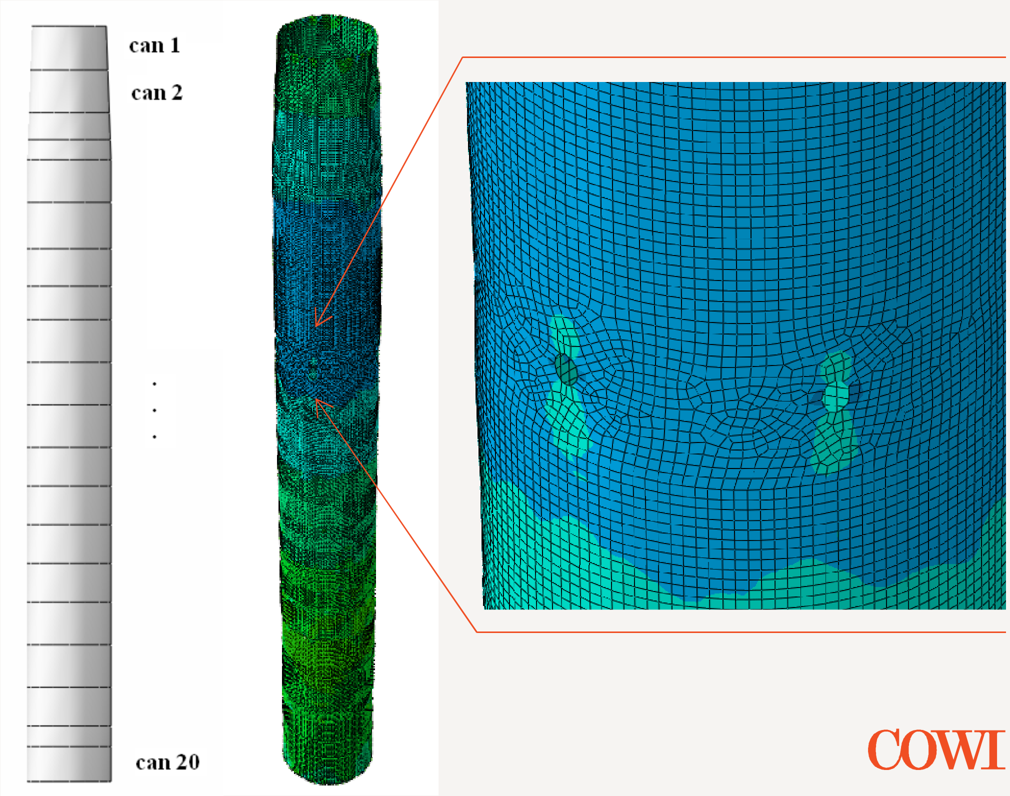
Buckling during installation (cont.)

Detailed Dynamic FEA Model

- Non-linear geometry
- Elastic-perfectly-plastic material behaviour for structural steel
- Non-linear boundary conditions (soil) including viscous damping
- Imperfections explicitly modelled when applying GMNIA method.



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Buckling during installation (cont.)

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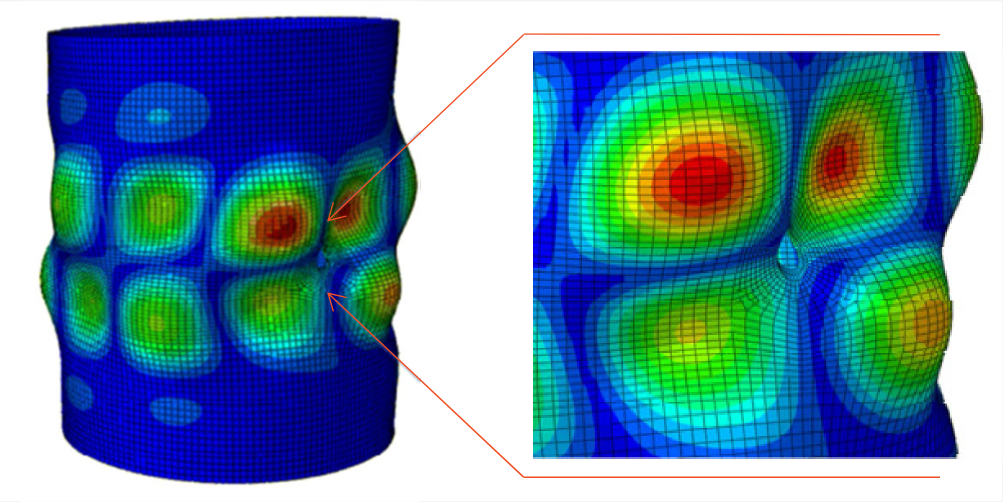

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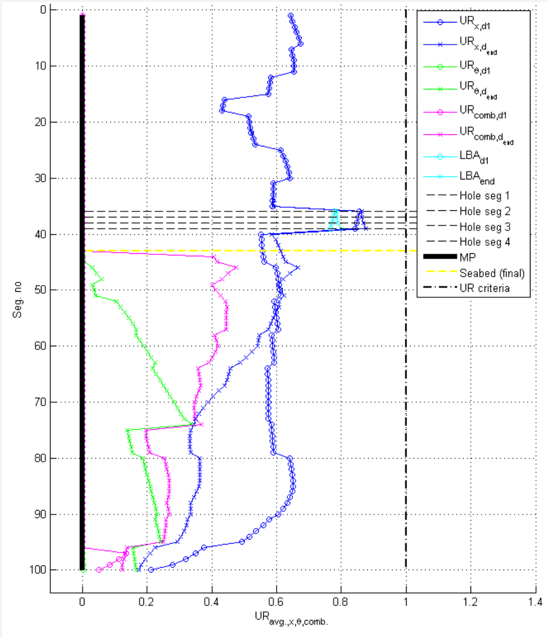
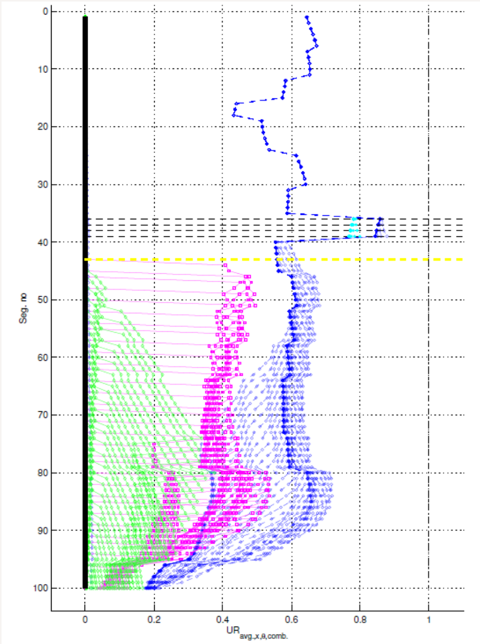
Results and conclusions

WMR results

› UR_x , UR_θ, $UR_{comb.}$ for 35 locations for approx. 30 driving depths for 100 pile segments





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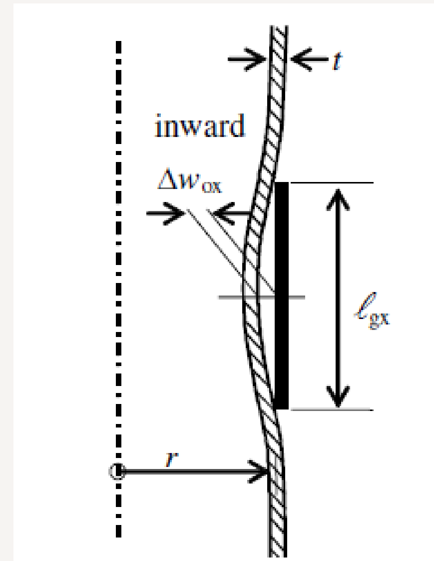
Results and conclusions (cont.)

WMR Results

- For all 35 MP locations the local shell buckling utilisation ratio was found to be below 1.0 for both upper- and lower bound soil conditions. The quasi-static EN1993-1-6 approach was applied (LBA, MNA etc.)
- For the most critical MP location a highly detailed dynamic FEA was carried out
- For large imperfections local yielding at dents and dimples may occur. Possible mitigation measures are, stricter requirements to fabrication tolerances, lowering of the D/t ratio for specific MP cans, take advantage of higher yield strength for rapid loading, reduce hammer impact force
- The final MP design is unknown to COWI.



$$U_{0x} = \frac{\Delta w_{0x}}{l_{gx}}$$

$$l_{gx} = 4\sqrt{r * t}$$

$$l_{gx} = 4\sqrt{2880mm * 50mm} = 1518mm$$

$$\Delta w_{0x} = 1518mm * 0.016 = 24.3mm$$

Results and conclusions (cont.)

BBW02 results

- For one MP position a parameter study on, steel grade, fabrication tolerances, and hammer sizes was carried out
- Higher steel grade i.e. S420 instead of S355 is less beneficial compared to stricter requirements to fabrication tolerances
- The maximum allowable D/t ratio is highly dependant on the radial soil stresses which generate hoop stresses in the MP
- Dependant on the choice of hydrohammer and radial soil stresses the D/t ratio for the specific site can be increased to 140.

Results and conclusions (cont.)

General

- D/t ratios for MPs are still increasing and at some point it might not be possible to install MPs by impact driving due to large slenderness of the structures
- More advanced methods may be utilized in order to verify the shell buckling capacity e.g. dynamic GMNIA taken into account rapid loading effects
- Increasing D/t ratios should go hand in hand with lower fabrication tolerances.

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Thank you!