Pile driveability in difficult soils

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Outline

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- Pile installation in chalk
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  - Race Bank OWF
  - Lincs OWF
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Introduction
Introduction

Characteristics of chalk

- Porous, permeable soft limestone composed mainly of very fine grained crushable calcium carbonate (CaCO$_3$) particles.

- Relevant chalk characteristics for pile design and installation: **the intact strength** (directly related to porosity/density) and **the fracture condition** (defined by the CIRIA grade (Lord et al. 2002)).

Extent of chalk deposition in the north-west Europe (Mortimore 2002)
Introduction

CIRIA recommendations

- Based on limited database.
- Fixed shaft resistance values: 120 kPa for high-density chalk and 20 kPa in all other densities and grades.
Pile installation in chalk
Pile installation in chalk

Monopile installation experience

1. Westermost Rough OWF
2. Race Bank OWF
3. Lincs OWF
# Pile installation in chalk

## Back-calculation

- To improve the accuracy of driveability prediction.
- To validate SRD models.
- To calculate driving-induced fatigue damage.
- Equivalent stroke:

\[
 h_{eq} = \frac{h_{max}}{E_{max}} \times E
\]

## SRD formulation

Extension to known models:

- Grade D treated as clay, other grades $fs=20$ kPa
- End bearing: $q_b = \text{fraction of } q_c$
Westermost Rough OWF
Westermost Rough OWF

Site characterisation

- Area of approx. 35 km², 35 turbines, water depth 11-28 m LAT
- 6.5 m diameter monopiles
- Ground conditions: 10-50 m thickness of over-consolidated clay with some layers of sand overlying chalk bedrock.
- Three geotechnical units of chalk:
  - Structureless chalk (grade D)
  - Structured fractured chalk (grades B and C)
  - Structured assumed intact chalk (grade A)
Westermost Rough OWF - CPT

High-quality CPT profiles for positions A07, B01 and F07
Westermost Rough OWF - CPT

Selection of representative profile?

Low quality CPT records in chalk (E04 and E07)
Average value of qc for different chalk grades evaluated for each location at WMR where the pile penetrated into the chalk layer.
Westermost Rough OWF - backanalysis

Back-calculation results for WMR position A07

Overestimation!

Low hammer energy

Overestimation!
Westermost Rough OWF - backanalaysis

Indication of soil resistance from the driving record

- Decreased resistance with increased depth in chalk.

- SRD models applied to chalk do not accurately predict pile behaviour in these soil conditions.
Westermost Rough OWF - backnalaysis

Additional back-analysis results for WMR position A07 (Stevens, Toolan and Fox, and Alm and Hamre models)
Westermost Rough OWF - backnalayasis

Based on the results of back-analysis:

- Conventional design methods lead to significant overestimation of driving resistance and even premature refusal in low-density chalk.

- The actual installation was quite easy, deploying less than 20% of the hammer's maximum energy.

- Reduction of shaft resistance during driving, possibly due to development of large pore water pressures and remoulding of chalk in the zone closes to the pile.
Race Bank OWF

Site characterisation

- Area of approx. 74 km², 91 turbine, water depth 12-22 m LAT
- 6.5 to 7 m diameter monopiles, installed between 21 m and 33 m into the seabed.
- Complex geology at the site.
- Two distinct units of chalk:
  - Weathered/structureless chalk
  - Structured/intact chalk

Examples of recorded CPT data at Race Bank wind farm

early CPT refusal
Race Bank OWF - backnalaysis

Back-calculation results for ROW position T18

Significant overestimation!

~30% of max hammer energy
Race Bank OWF - backnalaysis

Indication of soil resistance from the driving record

- Gradual increase in resistance in chalk at ROW

- Toolan and Fox model, Alm and Hamre and Stevens SRD models lead to early refusal.

Significant overestimation!

Trend of gradual increase in resistance in chalk
Race Bank OWF - summary

Based on the results of back-analysis:

- Conventional design methods lead to significant overestimation of driving resistance and even premature refusal.

- The actual installation was quite easy.

- New SRD formulation for chalk is proposed - better fit.
Lincs OWF
Lincs OWF

Site characterisation

- Area of approx. 40 km², 75 turbines, water depth 8-18 m LAT
- 5.2 m diameter monopiles
- Chalk at LIC:
  - lower strong, intact zone (grades A, B, C)
  - upper weathered/glacially disturbed zone (grade D)
Lincs OWF - CPT

Examples of recorded CPT data at Lincs wind farm

early CPT refusal
Lincs OWF - backanalysis

Back-calculation results for LIC position LS01

- Underestimation
- Better fit

Max hammer energy

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Drive log
Toolan and Fox
Stevens et al.
Stevens et al. mod
Alm and Hamre
Toolan and Fox LIC

Top of chalk
**Lincs OWF - backanalysis**

**Indication of soil resistance from the driving record**

- Significant increase in soil resistance in chalk.
Lincs OWF - summary

Based on the results of back-analysis:

- Conventional design methods lead to underestimation of soil resistance in high-density chalk.
- Considerable tip resistance.
- Finding a relationship between the end-bearing and UCS is deemed a more reasonable approach in high-density chalk.
- Complexity of attaining a single set of calculation procedures.
Comparison of chalk
Comparison of chalk at different sites

Index properties of chalk material at WMR, ROW and Lincs offshore wind farms
Comparison of chalk at different sites

Relationships between UCS and dry density
Comparison of chalk at different sites

Soil resistance indicated by the driving logs at Westermost Rough, Race Bank and Lincs offshore wind farms
Summary and conclusions
Summary and conclusions

- Large variability in driving experience in chalk.
- Using conventional SRD models does not yield satisfactory results.
- Relatively low energy setting of the hammer during installation in low-density chalk.
- Easy installation in low-density chalk seems to result from reduction in shaft resistance during driving - remoulding of chalk close to the pile shaft.
- Underestimation of resistance in high-density chalk.
- Considerable tip resistance developing in high-density chalk.
- Difficulties due to lack of measurements.
«The future will either be green or not at all.»

Bob Brown

Thank you for your attention!