Scour

FLOW – R&D Theme 2: Support Structures

Theme meeting, May 16th 2014

R&D line: 2.1 Site Conditions & Loads
Project Objectives - Scour

• Better understanding of the development of scour around wind turbine foundations, to allow more cost efficient foundation designs.

A. Development of a Scour Prediction Model (SPM) to predict scour around monopiles.
B. Development of a Scour Protection Design Model (SPDM) to design an optimized scour protection
C. Development and application of a continuous Scour Measurement System (SMS)
D. Preliminary investigation into the scour behaviour of jacket foundations.
## Project Deliverables

<table>
<thead>
<tr>
<th>Deliverable</th>
<th>Delivery date</th>
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<tbody>
<tr>
<td>Test programs for GEMINI and Luchterduinen (protected and unprotected monopiles. Both projects are finished and delivered as final reports to Van Oord)</td>
<td>Q2 2013</td>
<td>V</td>
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<tr>
<td>Paper on Scour Prediction Model and the consequences for monopile design, published at EWEA Offshore 2013</td>
<td>Q4 2013</td>
<td>V</td>
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<tr>
<td>Presentation at Windkracht 2014 on FLOW-SCOUR project</td>
<td>Q1 2014</td>
<td>V</td>
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<tr>
<td>Abstract submitted at ICSE, Perth, December 2014, on Scour Protection Design Model and on numerical modelling techniques of scour; not yet known whether they will be awarded.</td>
<td>Q1 2014</td>
<td>V</td>
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Offshore application

- 2 Monopiles without scour protection
- Scour hole depth assumed to be max. 1.3* diameter ≈ 7m
- Monopile outer diameter: 5m (same as other MPs)
- Max. penetration 38 m (Incl. depth scour hole)
- Max. mass 610 tons

Wind Turbine Positions: 43 x Vestas V112 - 3MW
Scour vs. Scour protection:

1. Take scour into account in pile design: increase steel consumption
2. Apply a scour protection to maintain a constant fixation level

Option 1
- Scour formula are in many cases too conservative
  - GL: \( \text{Seq} = 2.5 \times D_{\text{pile}} \)
  - DNV: \( \text{Seq} = 1.3 \times D_{\text{pile}} \) (std = \(0.7 \times D_{\text{pile}}\)) ...... \(2.0 \times D_{\text{pile}}\)
- Formula are independent of local situation
  (depth, sediment, waves and currents, pile diameter)

Option 2
- Existing guidelines / formulae result in conservative designs
- Much more dynamic scour protection designs are possible
1. Scour Prediction Model
   - Laboratory test program
   - Numerical simulations
   - Field measurement campaign

2. Scour Protection Design Model
Scour development in time $S(t)$ follows an exponential relation until equilibrium:

$$\frac{S(t)}{S_{eq}} = 1 - \exp\left(-\frac{t}{T_{\text{char}}}\right)$$

in which:

$S_{eq}$ = equilibrium scour depth
$T_{\text{char}}$ = characteristic timescale

Both parameters are dependent on:
• water depth
• seabed conditions
• pile diameter (or more general structure characteristics)
• hydrodynamic climate (wave- and current-dominated conditions)

Determine $S_{eq}$ and $T_{\text{char}}$ for all possible combinations by means of:
• Scale model tests
• Numerical modelling
Scour Prediction Model – Laboratory tests

Before test, initial flat seabed

Before test, initial scour hole

After test

After test
Scour Prediction Model – Laboratory tests
Besides scale modelling, also numerical modelling (in openFOAM) is adopted to fill the database of scour results: computations take weeks!
Scour Prediction Model – Field measurements

- Field measurements at 2 unprotected monopiles (WTG-30, WTG-42) in Luchterduinen during one year
- To validate the equilibrium scour depths and characteristic timescales of the Scour Prediction Model
- The scour depth will continuously be measured along a minimum of 4 rays at both piles
- Simultaneous hydrodynamic data needs to be collected as input for the SPM
- One year of measurements will allow for validation of the SPM for a wide range of conditions (current- and wave-dominated)
Scour Prediction Model – Field measurements

Amount of outliers, Beamangle 10°

- **Signal 1**
  - #outliers(red) = 0.01%
  - $\sigma = 0.050m$
  - $\mu = 9.7m$

- **Signal 2**
  - #outliers(red) = 0.00%
  - $\sigma = 0.034m$
  - $\mu = 9.7m$

- **Signal 3**
  - #outliers(red) = 0.17%
  - $\sigma = 0.038m$
  - $\mu = 9.7m$

Amount of outliers, Beamangle 20°

- **Signal 1**
  - #outliers(red) = 0.00%
  - $\sigma = 0.064m$
  - $\mu = 10.2m$

- **Signal 2**
  - #outliers(red) = 0.00%
  - $\sigma = 0.031m$
  - $\mu = 10.2m$

- **Signal 3**
  - #outliers(red) = 0.13%
  - $\sigma = 0.024m$
  - $\mu = 10.2m$

Amount of outliers, Beamangle 30°

- **Signal 1**
  - #outliers(red) = 0.01%
  - $\sigma = 0.042m$
  - $\mu = 11.2m$

- **Signal 2**
  - #outliers(red) = 0.00%
  - $\sigma = 0.063m$
  - $\mu = 11.2m$

- **Signal 4**
  - #outliers(red) = 0.17%
  - $\sigma = 0.049m$
  - $\mu = 11.1m$

Amount of outliers, Beamangle 45°

- **Signal 1**
  - #outliers(red) = 0.01%
  - $\sigma = 0.041m$
  - $\mu = 13.4m$

- **Signal 2**
  - #outliers(red) = 0.00%
  - $\sigma = 0.064m$
  - $\mu = 13.4m$

- **Signal 3**
  - #outliers(red) = 0.22%
  - $\sigma = 0.190m$
  - $\mu = 13.3m$
1. Problems with existing formula
   • Very conservative
   • Only for conventional protection design
   • Only for static protections

2. New formula
   • Different protection types (conventional, single grading, static, dynamic)
   • Fitted and validated against lab measurements
Conclusions

1. Significant savings can be achieved, both by omitting and by applying a scour protection
2. The optimal solution depends on:
   • Location (water depth, hydrodynamic climate, current vs. waves)
   • Turbine type and size
   • Soil conditions
   • Substructure design
   • Developer and contractor (e.g. type of equipment)
3. A Scour Prediction and Scour Protection Design Model are required, as both guidelines can be very conservative
Setup of Scour Monitoring System

- Acoustic measurement system
- 3 sensors per pile
- 4 beams at different angles
- Tested at quay in IJmuiden, results are good.
- Attachment of sensors to foundation pile under development
- Continuous monitoring
Look ahead

• Installation of Foundations Q3 2014

• Monitoring 2014-2015
  – 1 full year of monitoring (Nortek acoustic profiler).
  – Correlate with wave & current data from innovative metbuoy

• Calibration / validation of Scour Prediction Model

• Discussion with certifying bodies / developing new guidelines 2014-2015
Technology Readiness Level

- Current level: TRL3-4
- After installation (2014): TRL8
Cost reduction

• Cost reduction based on FLOW Cost model: 0.3%

• Cost reductions very site specific

• Omission of scour protection beneficial at locations with small current velocities and large wave heights

• Scour Prediction Model will help in decision making

• Scour Protection Design Model will help optimising design (certified)
¡Thank you for your attention!

¿Questions?