FLOW – SCOUR
P201103_003_Scour

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Introduction (I): What is scour?

Scour is erosion of sediment around a structure, caused by an imbalance in sediment transport.

Increase of sediment transport capacity around a structure due to:
1. flow contraction: increase in flow velocity
2. downflow + vortex development
3. increase of turbulence
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Types of scour:
- local scour = erosion of seabed material at a single foundation
- global scour = wider erosion around a structure consisting of multiple foundations…..jackets
- edge scour = scour around a scour protection

Introduction (I): What is scour?

multiple piles → global scour
In the design of an offshore structure, 2 options:

I. Take scour into account: increase material consumption

II. Apply a scour protection to maintain a constant fixation level

Option I

Scour formula are in many cases too conservative

- GL: \[ S_{eq} = 2.5 \times D_{pile} \]
- DNV: \[ S_{eq} = 1.3 \times D_{pile} \ (\text{std} = 0.7 \times D_{pile}) \ldots \ldots 2.0 \times D_{pile} \]

And formula are independent of local situation (water depth, sediment type, waves and currents, pile diameter)

Option II

Therefore, it is often decided to apply a scour protection

Again, existing guidelines / formulae result in conservative designs
Work packages:

A. **Scour Prediction Model (SPM)**
   that yields more reliable scour predictions than the existing formulae in the guidelines

B. **Scour Protection Design Model (SPDM)**
   that yields more optimized designs

C. **Scour Measurement System (SMS)**
   to obtain continuous bed level measurements around the monopile

D. **Scour behaviour of jacket foundations**
**Project phases**

**Phase I: modelling and lab testing**

- Setting up a generic **Scour Prediction Model** for monopiles, based on:
  - existing database of laboratory test results
  - sparse field measurements
  - new laboratory tests, focusing on timescales of scour & backfilling
  - numerical model simulations

- Development of a **Scour Monitoring System** to measure the development of the scour hole at the two monopiles without scour protection in the Luchterduinen wind farm
Phase I: modelling and lab testing

- Setting up of a generic **Scour Protection Design Model** for monopiles, based on:
  - existing database of laboratory test results
  - field validations from existing scour protections
  - new laboratory tests, focusing on dynamic rock gradings

- Submitting design approach (incl. test results) to relevant certifying bodies
Phase II: field measurement campaign in Luchterduinen

- The Scour Measurement System will be deployed in a one-year field measurement campaign at 2 unprotected monopiles in Luchterduinen
- 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 Scour Prediction Model
- The SPM will then be validated for a wide range of conditions (both current- and wave-dominated)

Phase III: analysis & publication of results
Current-induced scour
- Horseshoe vortex development at upstream side
- Vortex-shedding at lee-side
- Horseshoe vortex is dominant scour-inducing mechanism

Wave-induced scour
- Vortex regime is dependent on Keulegan-Carpenter nr
  \[ KC = \frac{U_{w,bed} \cdot T}{D} = \frac{2 \cdot \pi \cdot A_{w,bed}}{D} \]
- Horseshoe vortex only for very large KC-numbers
- Vortex shedding starts at KC = 1-7

Combined current-and-waves scour
- Hydraulic regime described by relative velocity:
  \[ U_{rel} = \frac{u_c}{u_c + U_{w,bed}} \]
  - \( U_{rel} = 0 \): waves-only (\( u_c = 0 \))
  - \( 0 < U_{rel} < 1 \): combined current and waves
  - \( U_{rel} = 1 \): current-only (\( U_{w,bed} = 0 \))
Monopile scour in combined current and waves

Example for offshore scour around a cylindrical pile

waves-only  combined current and waves  current-only

\[ S_{eq} / Dtanh(h_w/D) \]

\[ U_{rel} [-] \]

[source: Raaijmakers & Rudolph, 2008]
Scour development around monopile (I)

before test, initial flat seabed

before test, initial scour hole

after test

after test
Scour development around monopile (I)

Model test: transparent pile with camera and fisheye lens

Test 1, Tidal conditions
$u_c = 0.6 \text{m/s}$, $h_w = 29.5 \text{m}$
Flood direction
Left $\rightarrow$ Right

Flood current

Ebb current

Flat bed

Artificial scour hole

Deltarces
Scour around an unprotected pile
Scour (and backfilling) depending on conditions and time

interface detection per time step

colour gradient
distance [pixels]

scour prediction formulae

colour

Scour development with fitting - 25a-000011+r1200-01-e8-300
normalised

scour depth

time
Time development of scour
Validation against field measurements PAWP (I)

Collection of metocean data between surveys

sources: field measurements and numerical modelling

significant wave height $H_s$

peak period $T_p$

tidal current velocities

water depth
**Scour prediction model**

Computer model with empirical formulations for equilibrium scour depth and characteristic timescales

**Basic idea of model**

Every hydrodynamic condition has its own equilibrium scour depth and characteristic timescale.

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

Discretization:

\[
S_{n+1} = S_{eq,n+1} + (S_n - S_{eq,n+1}) \exp\left( -\frac{dt}{T_{char}} \right)
\]
Scour model results (Tanel Joon MSc thesis)

Luchterduinen | Innogy Nordsee | Triton Knoll
--- | --- | ---
Coordinates | 52.405N 4.154E | 53.979N 6.814E | 53.479N 0.837E
Water depth taken for study (MSL) | 20m | 30m | 15m
Spring tides (coastDat) | 0.9-1.0m/s | 0.6-0.7m/s | 1.5-1.6m/s
Scour depth Smax | 1.45D | 1.16D | 2.05D
Being conservative in your scour estimates can give problems with the natural frequency.
## Case study

### Cost of scour protection vs. additional steel

<table>
<thead>
<tr>
<th></th>
<th>Siemens 3.6MW</th>
<th>Siemens 6MW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Q10</td>
<td>Innogy</td>
</tr>
<tr>
<td>Mass free scour development [t]</td>
<td>509</td>
<td>758</td>
</tr>
<tr>
<td>Mass with scour protection [t]</td>
<td>401</td>
<td>630</td>
</tr>
<tr>
<td>Mass difference [t]</td>
<td>108</td>
<td>128</td>
</tr>
<tr>
<td>Mass difference %</td>
<td>27%</td>
<td>20%</td>
</tr>
<tr>
<td>Increased J-tube mass [t]</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Total mass difference [t]</td>
<td>128</td>
<td>148</td>
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<td>Total mass difference [t]</td>
<td>128</td>
<td>148</td>
</tr>
<tr>
<td>Scour protection [EUR]</td>
<td>252 120</td>
<td>316 380</td>
</tr>
<tr>
<td>Steel cost 1 500 EUR/t [EUR]</td>
<td>192 000</td>
<td>222 000</td>
</tr>
<tr>
<td>Difference [EUR]</td>
<td>60 120</td>
<td>94 380</td>
</tr>
<tr>
<td>Relative t savings</td>
<td>7.0%</td>
<td>7.5%</td>
</tr>
<tr>
<td>Steel cost 2 000 EUR/t [EUR]</td>
<td>256 000</td>
<td>296 000</td>
</tr>
<tr>
<td>Difference [EUR]</td>
<td>-3 880</td>
<td>20 380</td>
</tr>
<tr>
<td>Relative savings</td>
<td>-0.4%</td>
<td>1.3%</td>
</tr>
</tbody>
</table>
Scour protection vs added steel

- Siemens 3.6MW
  - 1.25D limit under 30m

- Siemens 6MW
  - 1D limit under 35m
Free scour development potential

- **Dogger Bank**
  - 9GW target capacity
  - Relatively low current velocities (compared to the rest of North Sea)
  - Moderate water depth (about 1/3 under 30m, rest up to 35m)
  - Total potential savings of about 225 million EUR*

- **Baltic Sea**
  - Total realistic development capacity of 40GW
  - Relatively low current velocities (compared to North Sea)
  - Relatively low water depths
  - Total potential savings of about 1 000 million EUR*

*Approximate savings calculated with 90 thousand EUR per turbine and using Siemens 3.6MW.
Example of armour grading stability

Test 4, Wave Conditions RP=1yr

\[ H_s = 7.7 \text{m} \quad \tau_p = 12.7 \text{s} \]

\[ h_w = 29.5 \text{m} \]

3 layer
10/200kg

3 layer
40/200kg

11-67kg HD
3 layer

45-223kg HD
3 layer

Deltaires
Enabling Delta Life
¿Questions?

¿Recommendations?