Experiences with omitting scour protection and allowing scour in Eneco Luchterduinen

from scale modelling and field measurements towards a new design method for scour prediction

with contributions of:

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What is scour and why bother?

Scour is erosion of seabed sediment around a structure caused by a local increase in sediment transport.

Scour:
- Lowers the pile fixation level, affecting the eigen frequency, reducing fatigue life (monopiles).
- Causes undermining of the footings, reducing the bearing area (GBS, suction cans, spud cans).

[Sumer and Fredsøe, 2001]
Hamlet already asked the important question

To protect, or not to protect: that is the question!
Whether 'tis nobler in the mind to suffer
The slings and arrows of outrageous scour,
Or to take armour against a sea of troubles

loosely based on Hamlet (Shakespeare, 1602)
Two ways to take scour into account in design

**Allow scour**

- Predict scour depth
- Available guidelines:
  - GL: \( S = 2.5 \times D_{\text{pile}} \)
  - DNV: \( S = 1.3 \times D_{\text{pile}} \)
- Take scour into account in pile design

**Protect against scour**

- Applying a scour protection at the seabed
- No guidance in guideline
- Optimization by model tests: more dynamic designs are often possible
Two ways to take scour into account in design

Steel vs. Rocks
Scour development in time $S(t)$ follows an exponential relation until equilibrium:

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

in which:

$S_{eq}$ = equilibrium scour depth

$T_{char}$ = characteristic timescale

Both parameters are dependent on:

- water depth
- seabed conditions
- pile diameter (or more general structure characteristics)
- hydrodynamic climate (distinction between wave- and current-dominated conditions)

For all possible combinations $S_{eq}$ and $T_{char}$ have to be determined by means of:

- Scale model tests (most reliable)
- Numerical modelling (in the future)
Scale model tests at Deltares
Scour Prediction Model

- Calculation model to predict dynamic scour development
- Location- and structure-dependent scour prediction
- Distinguishes between wave- and current-dominated scour
- Allows for scouring and backfilling
- Calculates years of scour development in < 1 minute
- Completely based on scale model tests: requires validation against field data!

**Flow Chart of Scour Prediction Model**

**Inputs**
- Dynamic
- Time series: Met-ocean conditions
- Static inputs
- Structure dimensions
- Sediment/soil parameters
- Initial scour depth \( S_0 \)

**Calculation**
- Scour depth \( S_n \)
- Sediment mobilization
- \( \text{MOB} > 0.5 \)
- \( \text{MOB} \leq 0.5 \)
- Rel. current velocity
- \( U_{\text{rel}} > 0.5 \)
- \( U_{\text{rel}} \leq 0.5 \)
- Equilibrium scour depth
- Wave-dominated → Raaijmakers approach
- Current-dominated → Sheppard approach
- \( S_n < S_{\text{eq},n+1} \) → scouring
- \( S_n > S_{\text{eq},n+1} \) → backfilling
- Characteristic time
- Scour characteristic time
- Backfill characteristic time
- Scour after time step \( dt \)
- \( S_{n+1} = S_{\text{eq},n+1} + (S_n - S_{\text{eq},n+1}) \exp\left(-\frac{dt}{T}\right) \)
Field Measurement Campaign in Luchterduinen

- Field measurements at 2 unprotected monopiles (WTG-30, WTG-42) in Eneco Luchterduinen
- To validate the equilibrium scour depths and characteristic timescales of the Scour Prediction Model
- Simultaneous hydrodynamic data were collected as input for the Scour Prediction Model
- One year of measurements allows for validation of the SPM for a wide range of conditions (current- and wave-dominated)
Setup of scour measurement sensors

- 3 Nortek scour monitors per pile
- 4-beam echo sounder (12 signals / pile)
- under beam angles of 10, 20, 30 and 45°
- supplemented with multibeam surveys
Scour development until dynamic equilibrium takes about 1-1.5yr (in Luchterduinen!)

- Backfilling of the 2-3m deep cable trench took about 9-10 months
- The scour pit is now about 5-5.5m deep = 1.0-1.1*D_{pile}
- The dynamic scour depth will probably stabilize next year around 6m = 1.2*D_{pile} (according to design)
- The diameter of the scour pit is about 5*D_{pile}
- The side slopes are about 1:2
- The scour holes in Luchterduinen are very similar to the scour holes in the laboratory tests on scale ~1:40!
Significant wave height \( H_s \) [m]

Peak period \( T_p \) [s]

Water depth \( h_w \) [m]

Current velocity \( U_c \) [m/s]
Faster scour development during spring tide with low waves
Current vel. $U_c [m/s]$

Significant Wave height $H_s [m]$

Scour depth $S [m]$

Backfilling of scour hole during storms

2014 2015
Model assumptions:
- Non-cohesive soil (= sandy seabed)
- Based on >100 simulations with different hydrodynamic time series (different starting times)
- Valid for unprotected monopiles; small differences in map for different pile diameters
Scour: to protect or not to protect?

Cost of scour protection vs. additional steel

Blue colours mean there is a real potential for leaving out the scour protection

*Case I

*Case II

*Case III
Conclusions

- Hamlet was right! You should question yourself on the topic of scour.
- The Luchterduinen scour measurement campaign yielded very useful data to validate the Scour Prediction Model.
- All scour processes were well captured, both in space and in time.
- With the results in FLOW-SCOUR significant savings can be achieved, both by omitting and by applying a scour protection.
- The optimal choice depends on:
  - Location (water depth, hydrodynamic climate, current vs. waves)
  - Turbine type and size
  - Soil conditions
  - Substructure design
  - Developer and contractor (equipment, CAPEX vs. OPEX)
- Potential reduction of LCoE is ~1% and is very project-specific.
Follow-up project

Joint-Industry-Project

Handbook Scour Protection Methods

submitted for TKI-WOZ R&D call open for additional participants
¡Thank you for your attention!
¿Questions?

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Dolwin Alpha and Dolwin Gamma tested in Deltares’ Atlantic Basin