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AALBORG UNIVERSITY

Experimental Evaluation of Backfill in Scour Holes Around Offshore Monopiles

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Background:

For offshore wind turbines the foundation cost can be up to one third of the total cost. It is therefore very important to optimize the design of the foundation.

Several types of foundation for offshore wind turbines exist, cf. Figure 1. The choice of foundation depends among others on the water depth and the soil conditions. The monopile foundation concept, in which an open-ended pile made of welded steel is driven into the soil, is often employed.

Around monopiles local scouring can take place due to current and wave action. In general, strong currents leads to large local scour holes and in contrast large waves leads to small local scour holes. The depth of local scour holes around offshore monopiles will therefore change depending on the sea conditions.

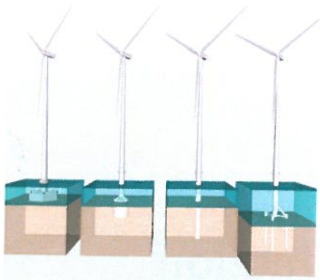

Figure 1. Foundation concepts for offshore wind turbines. From the left: gravitational foundation, bucket foundation, monopile foundation, and tripod foundation.

Large-scale experiment on backfill:

A backfill experiment has been concucted at the Large Wave Channel (GWK) in the Coastal Research Centre (FZK) in Hannover, Germany. The length, width and height of the wave channel were respectively 324 m, 5 m and 7 m. A pile with an outer diameter of 0.55 m was installed in the centre of the wave channel. A sand layer with a thickness of 1 m was placed around the pile. The median grain density of the sand was 0.15 mm. The water level was 3 m above the soil surface. The test procedure was as follows:

- A scour hole, with a scour depth of 0.7 m corresponding to 1.3*D*, was manually prepared, cf. Figure 2.
- The wave channel was filled with water and an irregular wave series with a significant wave height, H_{m0} of 1.06 m, a peak period, T_p, of 5.9 s, and a peak enhancement factor, γ, of 3.3, were generated. Hence, the Keulegan-Carpenter number and the Shields parameter were approximately 9 and 0.41, respectively. The scour depth was regularly measured during the generation of waves.
- After the generation of waves, water was drained from the wave channel. Soil samples were taken and cone penetration tests were conducted after the drainage of the channel.

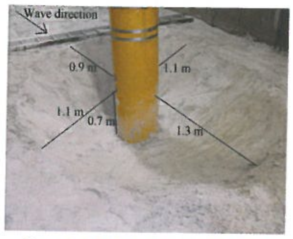

Figure 2. Scour hole prior to the wave generation.

Figure 3. Scour hole after the wave generation.

Time scale of backfilling:

As proposed by Hartvig et al. (2010) the following equation for the scour depth, *S*, were fitted to the measurements:

$$S = S_\infty + (S_0 - S_\infty) \cdot \exp\left(\frac{-t}{T}\right)$$

Hence a timescale, *T*, of 10 min were found. The normalised time scale of the backfilling process was determined from:

$$T' = \frac{\sqrt{g(s-1)d_{50}^{\,3}}}{D^2} T$$

A normalised time scale of 0.015 was estimated. In comparison Hartvig et al. (2010) reported a normalised time scale of 4.0 based on small-scale experiments. Hence, the backfilling process observed in the large-scale experiment is approximately 250 times larger than what would be expected based on small-scale tests.

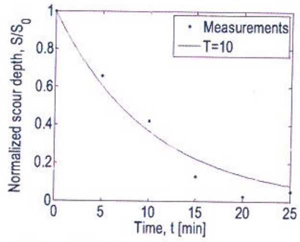

Figure 4. Variation of scour depth with time. The continuous curve is fitted with the measured scour depth and a time scale of 10 min has been estimated.

Relative density of backfilled soil:

The relative density of the backfilled soil material was found to be 80 % at the soil surface and around 60 % at the bottom of the backfilled scour hole, cf. Table 1 and Figure 5. Hence, the relative density of backfilled soil material can be expected to be dense.

Table 1. Relative density of the backfilled soil material determined by means of the soil samples.

Soil sample	Relative Density, ID [%]
1	70
2	85
3	90
4	80
5	76

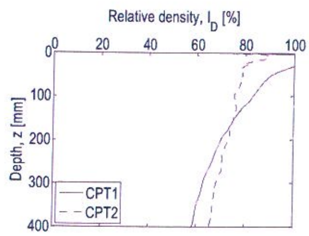

Figure 5. Relative density determined based on the cone penetration tests.

Conclusions

The following main conclusions can be drawn from the backfill experiment:

- The time scale of backfill is significantly larger than what is predicted by small-scale tests.
- The relative density of the backfilled soil material was found to be in the order of 60-80 % indicating a dense sand. Hereby, a high stiffness and strength of the soil can be expected.
- Due to the fast time scale and the high relative density of the backfilled soil material the steel material in the foundation will, when designing for the fatigue limit state, be exposed to a smaller number of cycles with high stresses. Hence, the wall thickness of the monopile foundation can be minimized.

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