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Published in:
Book of Abstracts of the First International Conference on the Application of Physical Modelling to Port and Coastal Protection (CoastLab06)

Publication date:
2006

Document Version
Early version, also known as pre-print

CoastLab06, Book of Abstracts
© 2006, Porto, Portugal. ISBN xxx-xxxx-xx-x

SCOUR AROUNG MONOPILE FOUNDATIONS FOR OFF-SHORE WIND TURBINES

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1. Introduction

Since the first offshore wind farm had been built (Vindeby Lolland in 1991), the dimensions of the turbines are rising quickly: by now the diameter of the rotor reaches 90m and the pile diameter exceeds 4m. Monopile foundations, preferred to gravity ones for large pile diameters and shallow waters, suffers from severe scour and the toe needs to be protected.

Wind farms are possibly situated in environments characterized by strong influence of tides, wind-induced currents and waves. The scour process must be investigated also in these conditions, which are typical of fluvial hydraulics (Breusers et al., 1977; Sumer and Fredsøe, 1997; Melville and Coleman, 2000; Richardson and Davis, 2001; den Boon et al., 2004).

2. Objective

The objective of this paper is to characterize the erosion process around piles with large diameter (e.g. wind turbine monopile foundations) located on sandy seabed under the influence of unidirectional and tidal currents.

The tidal current effect, only briefly investigated (Escarameia, 1999), requires particular attention as the equilibrium scour hole and its evolution present different characteristics from the steady currents ones (Fig.1). Moreover, the effect of wave breaking has been investigated, in order to make a comparison with tests from literature with non-breaking waves.

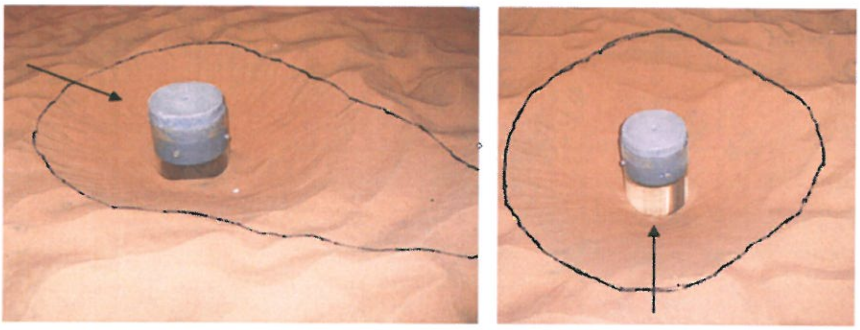

Figure 1. Scour holes caused by tidal and unidirectional currents. Physical model

3. Physical model

Physical model tests in mobile bed were carried out in the deep water wave flume of the Hydraulic and Coastal Engineering Laboratory of the Department of Civil Engineering, Aalborg University.

The flume is 25 m long 1.2 m wide and 1.5 m deep (Fig. 2). The sloping bed was designed in order to provoke wave breaking. The bed was constructed of concrete with a 4 m long sand box filled with fine sand (grain size was 0.15 mm) where the model was fixed. Sand was spread out in a thin layer across the slope. A two way recirculation system allowed the simulation of steady and tidal currents.

Currents and waves were measured beside the model by an acoustic Doppler velocimeter and two wave gauges, one of them close too the wave generator in order to allow waves separation into incident and reflected waves.

The tests covered a wide range of velocities (0.3÷0.5 m/s) and water depth (0.1÷0.3 m) and two pile diameters (0.1 m and 0.2 m). Tide was simulated by reverting the current velocity every half an hour for two hours (2 tidal cycles).

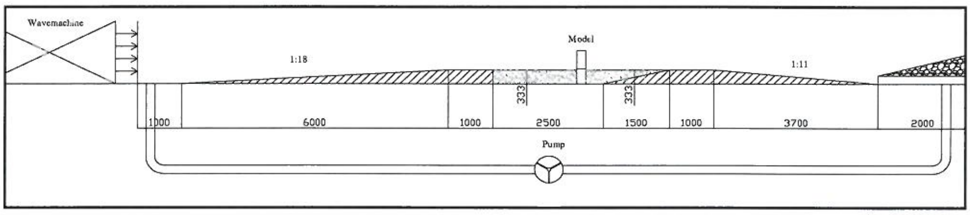

Figure 2. The wave flume; all measurements in millimeters.

The bed was levelled by an automatic profiler (Fig. 3) usually at the end of the steady current tests, but in some cases the time evolution of the scour was monitored. The measured grid was 1.5 m long by 0.93 m wide and the grid step was 1.5 cm by 1.5 cm.

Different types of scour protections are currently being tested in order to check their stability in presence of currents and irregular breaking waves.

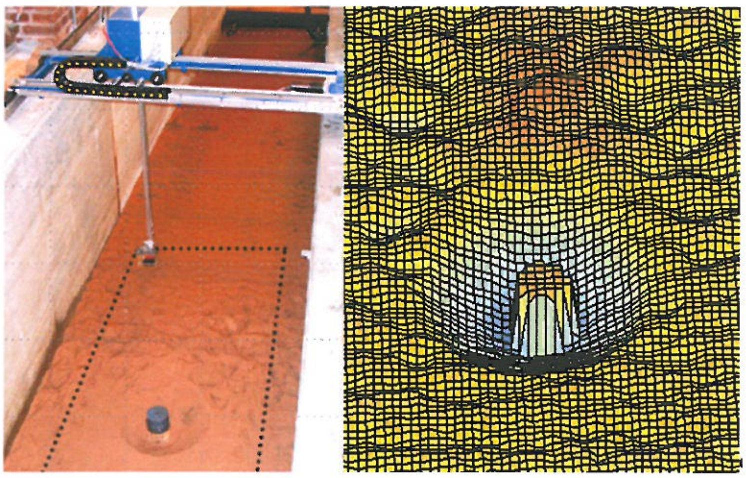

Figure 3. Automatic bottom leveling and obtained result.

4. Preliminary results

The equilibrium conditions can be reached only asymptotically during usual laboratory testing. A specific analysis, based on frequent observations of the scour during 5 tests, allowed the evaluation of the time scale of the scour process, which is proportional to the eroded volume and to the inverse of the transport capacity (Fig.4).

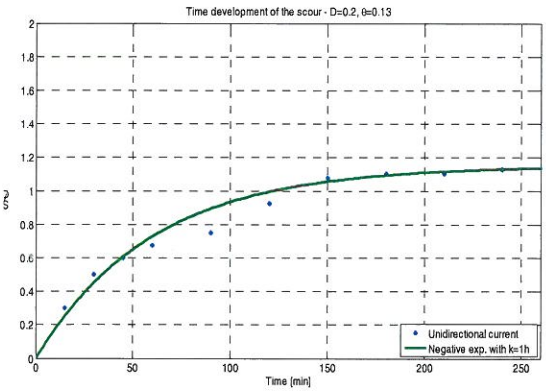

Figure 4. Evolution of erosion, approximated by an exponential function.

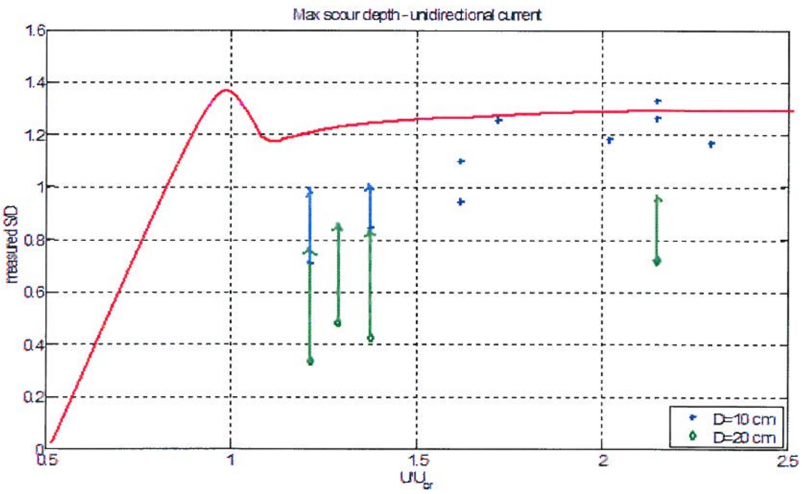

Figure 5. Corrected measurements of maximum observed erosion. The red line gives the expected erosion on the basis of literature indications.

A scaling rule was derived by simple observation and used to rectify the scour measurements into an equivalent equilibrium configuration. Fig. 5 shows the observed maximum scour depth after the adjustment accounting the limited duration of the tests.

If the sand mobility is sufficiently high to induce scour, the erosion is little dependent on mobility itself ($S/D\approx1.2$, S=maximum scour), which rather influences the time required for the development of the final erosion.

The physical experiments with waves showed that the effect of breaking waves has only a small influence on the scour hole development.

5. Ongoing analysis

Ongoing analysis may benefit from the detailed survey of the bed. For unidirectional current, the scour depth behind the pile increases monotonically toward an asymptote. The exam of the erosion in tidal conditions is more complicate due to the partial refilling of the eroded area when the current inverts its direction (Fig.6), and can be analysed by dividing the eroded area in a frontal, a rear and two lateral regions: maximum depth and total volume of the scour are derived from the detailed measurements. Non dimensional erosion diagrams, like those presented in Fig. 5, will be provided for tidal tests to describe the eroded volumes and depths for each of the considered regions.

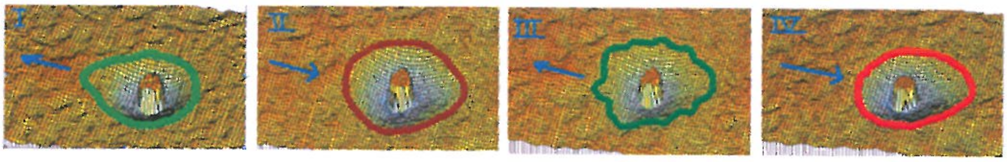

Figure 6. Evolution of the scour during the four tidal periods (I, II, III, IV). The direction of the current is indicated in blue.

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