EXTENDED VALIDATION OF DYNAMIC DESIGN FORMULA FOR SCOUR PROTECTION AROUND MONOPILES

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1.   Introduction

To transform Europe into a highly energy-efficient, low carbon economy, wind energy is one of the commonly applied renewable energy sources, with minimal human, ecological and environmental impacts. However, in order to evolve offshore wind energy to a competitor of the primary energy resources, the cost efficiency of this technology needs to be further improved. A critical part is the scour protection around the monopile foundation of the wind turbine.

Due to the presence of a monopile, the current field is disturbed and local scour occurs around the foundation. A scour protection is applied to prevent scour development near the construction and to guarantee the pile's stability. Instead of designing a statically stable scour protection, allowing no damage to the top layer, smaller rock elements can be used for the scour protection. The advantages are both the lower cost of the elements as well as the need for fewer filter layers. However, allowing movement of some stones without causing failure of the scour protection, implies that the development of damage in time needs to be investigated and the damage needs to be incorporated in the design formula of the protection. This paper investigates the damage to the scour protection by physical model tests and verifies a dynamic design formula to calculate the required stone size for a scour protection around a monopile foundation in a combined wave and current climate.

2.   Design of a scour protection under combined wave and current load

Only recently, the combined wave and current loads on a scour protection around a monopile are examined (e.g. den Boon *et al.,* 2004; Hansen and Gislason, 2005; Grune *et al.,* 2006; Whitehouse *et al.,* 2006 and De Vos *et al.,* 2011; 2012). De Vos (De Vos *et al.,* 2011; 2012) formulated one of the few design methods for a scour protection in a combined wave and current loading, which is further validated in this research.
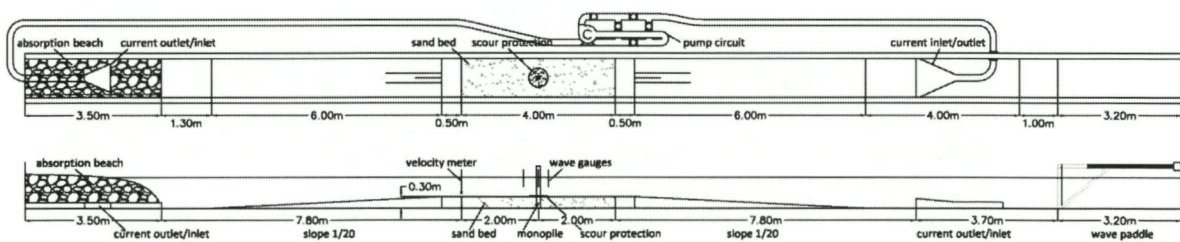

Figure 1. Experimental set-up in the wave flume (top: plan view; bottom: cross section).

2.1 Methodology of the experiments

Small scale tests are performed on the scour protection of a monopile, under combined wave and current loads, to extend the validation of the design method. A sand bed is positioned in the middle area of a wave flume, in which a monopile is founded (Figure 1). Around the pile, a geotextile filter is installed on the sand bed and differently coloured circles of rocks are constructed to form the scour protection (Figure 2), with a total extent of five times the pile diameter. The colours are used to visually assess the damage to the scour protection. In addition, a profiler maps the scour protection before and after each test, enabling the comparison of both profiles and consequently the extraction of the damage that occurred to the profile.

2.2 Existing damage formula

A first set of tests was performed by De Vos (De Vos, 2008) on a scale 1/50, to assess the influence of the wave conditions, the current velocity, the filter type and the grading and size of the rock scour. Also some limited

variation of the water depth was tested. From these tests De Vos (De Vos, 2012) extracted a damage formula, allowing the designer of the scour protection to calculate the required stone size corresponding to a certain damage level S_{3D}. This damage formula is given in Eq. [1], with the damage level S_{3D} as a function of wave period $T_{m-1,0}$, orbital velocity U_m, steady current velocity U_c, number of waves N, stone size D_{n50}, relative stone density s, water depth d and a number of empirical coefficients a_0, a_1, a_2, a_3, a_4 and b_0.

$$\frac{S_{3D}}{N^{b_0}} = a_0 \frac{U_m^3 T_{m-1,0}^2}{\sqrt{gd}(s-1)^{3/2}D_{n50}^2} + a_1 \left(a_2 + a_3 \frac{\left(\frac{U_c}{w_s}\right)^2 (U_c + a_4 U_m)^2 \sqrt{d}}{gD_{n50}^{3/2}} \right) \qquad [1]$$

The scour protection is composed of concentric circles with diameters that are multiples of the pile's diameter, and each ring is further subdivided in sections with magnitude equal to the cross section of the pile. The damage to each subarea $S_{3D,sub}$ is defined as the ratio of the eroded volume to the stone diameter D_{n50} times the area of the subsection. The damage number of the subarea that is most eroded is assigned as damage number S_{3D} of the scour protection.

2.3 Extended experimental study

From practical application of the design formula, the need arose to expand the formula's validity range. As the installation of offshore windmill farms is progressing rapidly, designers encounter environmental and structural conditions that differ from the tested ranges of De Vos (De Vos, 2008). Hence, additional tests with broader parameter ranges are needed. Another request from the industry is the possibility to assess the total damage to the scour protection, in view of its maintenance. Moreover, further validation of the damage formula within the ranges tested by De Vos is imperative.

Therefore, new tests are being executed at the wave flume of Ghent University from January till April 2012. The range of water depths is further extended, and waves with larger peak periods are included as well to incorporate Atlantic wave conditions. Also the diameter of the pile is varied (pile diameters equal to 0.050m, 0.100m and 0.125m), to test its influence on the damage. Furthermore, the set of tests with a current opposing the waves is extended, to further investigate the damage under this combined current and wave interaction.

Figure 2. Experimental set-up: scour protection on a sand bed around monopile.

3. Results and discussion

This research targets the study of the influence on the damage to the scour protection of (a) the direction of the flow to the waves, (b) the water depth, (c) the pile diameter and (d) the wave period. Moreover, the effect of these parameters will be incorporated in the design formula for the scour protection, and an assessment of the total damage to this scour protection will be formulated. More detailed results will be presented in the paper.

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