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NUMERICAL AND PHYSICAL MODELLING OF THE PORE PRESSURE DEVELOPMENT AROUND A MONOPILE FOUNDATION

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1 INTRODUCTION

Offshore wind has favoured the use of monopile foundation due to its simplicity in design, construction and industrial scalability. The stability of the monopile foundations can be affected not only by the direct action of wave loads but also by the response of the surrounding seabed. Numerical and physical modelling can be used to simulate the wave-structure-seabed interaction and accurately predict the wave-induced seabed response around the monopile foundation.

Within this context, a 3D coupled numerical model is developed to investigate the excess pore pressure development around a monopile foundation and the accompanying changes in the effective stress of the seabed soil. In addition to the coupled hydrodynamic-geotechnical analyses, physical model tests have been performed at the Coastal & Ocean Basin (COB) in Ostend (BE) within the SOILTWIN project in December 2023. These tests provide insight into the soil behaviour around the monopile foundation based on pore pressure measurements. The comparison of the numerical results with experimental data is essential for an improved calibration of the numerical model as well as for a better understanding of the soil response under various wave loading conditions. The experimental setup and the initial findings will be discussed during the conference.

2 PHYSICAL MODELLING AND MEASUREMENT OF PORE PRESSURES

Laboratory tests have been performed at the COB to investigate the effect of the waves on the monopile and the surrounding foundation in a controlled environment, to better characterise the soil behaviour in terms of pore pressure development around the monopile under wave action. The basin has dimensions 30.0 x 30.0 x 2.3 m (L x W x H) and has a deep circular pit in the centre with a diameter of 3 m and a depth of 3.1 m (Figure 1(a)). In these experiments, the bottom level of the central pit was adjusted to 1.20 m depth. This was achieved by placing three concrete blocks at the pit's base, with a concrete disc positioned atop these blocks. A scaled monopile of 0.219 m diameter (scale 1:23), made of stainless steel, was fixed at the pit bottom. Differential pore pressure sensors were installed below the mudline in multiple depths around the monopile; namely the pore pressure was measured in front, behind and at the two sides of the monopile. Subsequently, the central pit was filled with sand up to the basin's bottom level and the sand was compacted using the undercompaction methodology presented by Ladd (1978). The experimental setup, including the monopile and the wave gauges around it is shown in Figure 1(b). The pile was exposed to both regular and irregular long-crested waves. Moreover, the effect of short-crested waves on the pore pressure development in the sand around the monopile foundation was investigated. This kind of measurement is a multifaceted and complex process including genuine 3D effects. The performed measurements mainly include: wave conditions and pore pressures. The unique dataset of this testing campaign will be used to assess the pivotal wave conditions affecting pore pressure development and to validate the coupled hydrodynamic-geotechnical numerical model.

First achieved experimental results show that the inserted pile foundation considerably modifies the distribution of pore pressures in the seabed; namely, the maximum pore pressure increases around the foundation, particularly at the waveward side of the monopile. The pore pressure amplitude gradually attenuates inside the soil foundation and its decrease depends on the selected wave conditions as well as the soil characteristics. Based on these results, the effect of different water depths, wave heights and wave periods on the pore pressure distribution around the monopile foundation will be further investigated.

(a) (b)

Figure 1. Overview of (a) the Coastal & Ocean Basin in Ostend (Belgium) and (b) the experimental setup including the monopile and the wave gauges around it.

3 NUMERICAL MODEL

The hydrodynamic numerical model is developed using OpenFOAM®, an open source Computational Fluid Dynamics (CFD) software. The olaFlow open source solver is implemented to allow for wave generation and absorption at the boundaries. The wave domain is governed by the three-dimensional Volume Averaged Reynolds Averaged Navier-Stokes (VARANS) equations for two incompressible phases (water and air) using a finite volume discretization. The volume of fluid (VOF) method is applied for the free surface tracking.

The seabed model is developed in ABAQUS, a finite element software, in order to investigate the wave-induced dynamic response of the poroelastic seabed, considering the inertia effects and the compressibility of solid and pore fluid, using continuity and momentum balance equations. The wave-induced pore pressures at the seabed surface are obtained using the three dimensional hydrodynamic model and are applied as a boundary condition to the seabed model. In the present work, one-way coupling is applied, due to the fact that the movement of the monopile and the seabed transformation are considered to have negligible effects on the wave propagation.

The numerical results will be compared with the experimental data to provide a better understanding of the mechanism of wave-induced soil response around the monopile foundation and result in a high fidelity, calibrated numerical model.

4 CONCLUSIONS

Physical model tests have been performed at the COB to investigate the wave-induced seabed response and, more specifically, the pore pressure development around a monopile foundation. This experimental campaign innovates on a pore pressure measurement set-up, using differential sensors to resolve pressure magnitudes of several Pascals and provide a unique dataset of pore pressure measurements around a monopile foundation under various wave conditions. Within the same study, a 3D coupled numerical model is developed based on a VARANS wave model and a poroelastic seabed model using one-way coupling. The results of the numerical model will be validated using the pore pressure measurements at the COB. The experimental setup and the first results will be presented at the conference.

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