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A laboratory study of the effect of installation parameters on the lateral behaviour of monopiles in sand

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Monopiles are the predominant type of foundation used for offshore wind turbines. The increase in size of monopiles and the stricter environmental regulations in terms of underwater noise levels has motivated the development of alternatives to the conventional impact-driving method of monopile installation. One of the alternatives is the (axial) vibratory installation, which has been previously studied in field [1, 2, 4] and laboratory [3, 5] conditions. However, there is limited knowledge on the effects of vibratory installation (and how these effects differ from those caused by impact-driving) on the lateral response of monopiles.

This extended abstract presents the results of an ongoing Join Industry Project (SIMOX – Sustainable Installation of XXL Monopiles) which aims at comparing different installation methods from the point of view of driveability, noise emissions and lateral response. The present abstract particularly focuses on the lateral response of monopiles. As a first step towards the large-scale onshore field tests to be executed in 2023, a laboratory study was conducted at the Water-Soil Flume at Deltares, in Delft (NL), which consists of a tank with 9.0 m of length, 5.5 m of width and 2.5 m of depth, with a multipurpose wagon on rails above it (Figure 1). The tank was filled with saturated Sibelco S90 sand up to a height of 2.4 m in compacted layers of 50 cm.

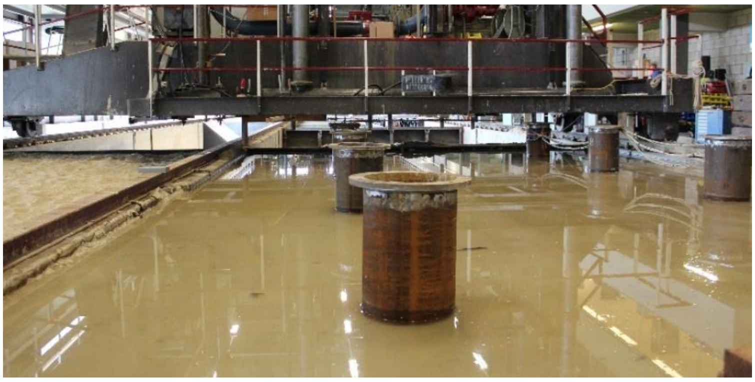

Figure 1: Water-Soil Flume at Deltares, with scaled piles installed in sand.

The experimental programme consisted of 4 batches (batches 1, 2 and 3 with dense sand and batch 4 with medium-dense sand) in which piles of diameter D = 32 cm, embedded length L = 1.5 m and wall thickness t = 4 mm or 10 mm were installed and loaded laterally. While batch 1 focused on driveability aspects, in the other three batches 8 piles were installed (per batch) and subsequently subjected to lateral loading. The centre-to-centre distance between piles was 8D in the loading direction and 6.5D perpendicular to the loading direction. The distance between the piles and walls of the tank was 4.3D. All distances were larger than the minimum distances recommended in the literature [6]. The piles were installed with two different methods: vibratory-driven, using a hydraulic vibro-hammer APE-23 with an eccentric moment of 1.3 kg.m, and impact-driven, using a dropping weight impact-hammer HL750. For each method, selected installation parameters were varied, namely the vibratory frequency and lowering speed of the crane for

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vibrated piles, and dropping mass and fall height for the impact-driven piles. Lateral loading was applied at the pile head by means of an in-house built lateral loading device consisting of an electric motor connected to a spindle. The lateral displacements were measured by a magnetostrictive linear position sensor, independent of the lateral loading system. The loading regime consisted of an initial monotonic loading up to 25% of H_{ult} (where H_{ult} is defined as the load at which the pile exhibits a displacement of 0.1D at ground level – obtained from 3D FE analyses), followed by cyclic loading (1000 cycles for most piles) and a final monotonic stage up to the maximum load.

The different combinations of lowering speeds of the crane (low, high) with the different frequencies of the vibro-hammer (low, high) led to different types of vibratory installation: crane controlled or free hanging. Under crane-controlled installation, the full weight of the pile-hammer system is sustained by the overhead crane, hence the crane load measured by a load cell oscillates around the static weight of the pile-hammer system. Under free-hanging conditions, on the other hand, the load taken by the crane is zero, meaning that the weight of the pile-hammer system is fully taken by the soil – both by shaft friction and tip resistance.

The results in dense sand showed that the initial monotonic response of the piles is affected by the vibration mode, and not by the installation frequency or penetration speed alone. While the crane-controlled vibrated piles exhibited lateral stiffness similar (i.e. slightly lower) to the impact-driven piles, the free-hanging vibrated piles showed markedly lower lateral stiffness compared to the other piles. The softer behaviour observed for these piles could be attributed to various reasons, such as the difficulty in controlling the pile verticality during installation. For all free hanging piles, inclination was observed approximately half-way through installation, which was corrected in the final part of installation. The exact inclination during installation was not measured, which will be done in the onshore field tests. The test results showed, however, that during cyclic loading the differences in lateral stiffness decrease, i.e. the softest piles in the initial monotonic stage were the ones that exhibited the largest gain in lateral cyclic stiffness, whereas the stiffest piles in the initial loading stage were the ones with the smallest increase in stiffness during cyclic loading.

Contributor statement

Anderson Peccin da Silva: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – Original Draft. Mark Post: Conceptualization, Investigation, Methodology, Project administration, Supervision, Resources, Validation, Writing – Review & Editing. Ahmed Elkadi: Conceptualization, Funding acquisition, Investigation, Project administration, Supervision, Writing – Review & Editing. Federico Pisanò: Conceptualization, Writing – Review & Editing. Evangelos Kementzetzidis: Conceptualization, Writing – Review & Editing.

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