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Silent piling for offshore jacket foundations in sand: DEM and centrifuge modelling

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The race to decarbonise the economy has led to an exponential growth of offshore wind farm developments across the globe. While monopiles are the dominating installed foundations, jacket structures are expected to be more and more common, as wind farms extend to deeper waters [1] and innovative technologies are required to alleviate some important challenges. Firstly, straight shafted piles are not particularly efficient to sustain large tensile demand induced by the push-pull axial loading of the foundations. Secondly, stricter regulations on underwater noise make mitigation methods for pile driving more expensive and silent piling techniques could be used as an alternative [2]. Figure 1(a) describes a new screw pile foundation that meets those two challenges [3]. The foundation is installed by rotary jacking, which avoids any impact related noise. The pile is composed of a large upper shaft, that is designed to resist the lateral load applied by the jacket structure, and a smaller lower shaft which reduces the torque demand during installation. A helix is attached close to the pile tip, to provide an enhanced axial resistance and facilitates the installation of the pile [4]. The main challenge during the pile installation is the very low reaction force that may be available offshore at the pile head, which consists only of the pile self-weight and the installation tool. The aim of this work is to demonstrate that screw piles can be installed for offshore applications by rotary jacking at low reaction force, via (geotechnical centrifuge, [2]) and numerical (DEM, [5]) modelling.

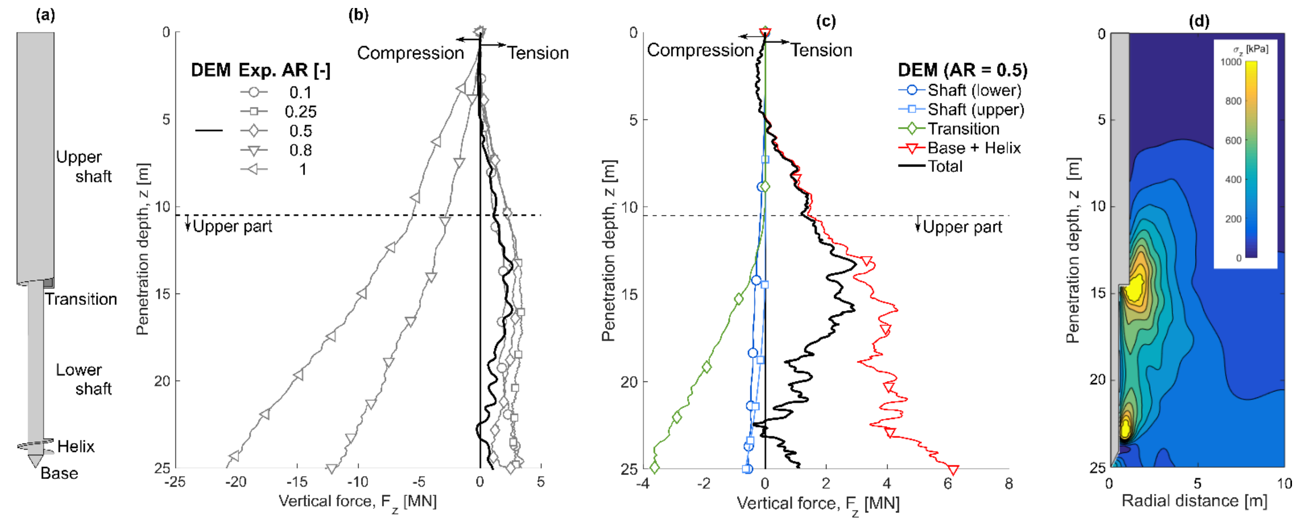

Figure 1: (a) Sketch of the silent pile; (b) Comparison of vertical force measured during installation in centrifuge experiments and DEM for different Advancement Ratios (AR); (c) Split of the vertical force contribution between the different parts of the pile, DEM simulation (AR =0.5); (d) Vertical stress around the pile at the end of installation, DEM simulation (AR = 0.5).

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Figure 1(b) compares the vertical installation force measured in the centrifuge with a DEM simulation, as a function of the advancement ratio (AR), defined as the vertical displacement of the pile during one rotation normalised by the helix pitch. Figure 1(b) shows that at constant installation rate (fixed AR), the lower ARs lead to a tensile force measured at the pile head, i.e. the pile pulls on the installation actuator. The DEM simulation of is in good agreement with the centrifuge result at the same AR and shows that the vertical force trend reverts to a compressive value once the upper part of the shaft enters the ground.

Figure 1(c) shows the vertical force associated with each pile component during the DEM simulation (AR = 0.5). The greatest penetration resistance (lowest negative value) is the transition piece, reaching -4MN, when the pile tip reaches a depth of 25m. The shaft penetration resistance is small and probably reduced by the rotary movement that changes the inclination of the shear stress along the shaft, as explained in previous publications [6]. The base and helix contributions are largely positive (in tension), as described in Figure 1(c). Consequently, the tension (“thrust”) created by the helix compensates the penetration resistance of the rest of the pile and enables its penetration with a very low reaction force applied at the pile head.

The effect of the AR on the helix behaviour was previously explained as follows [7, 8]. Helix overflighting (AR< 1) forces a displacement of the sand particles upwards. This forced displacement is opposed by the existing soil, which acts as a non-linear spring, which is progressively compressed. The soil above the helix is then compressed, as depicted in Figure 1(d), which represents the vertical stress in the sand bed and around the pile. Another effect of the pile overflighting is the considerable reduction of the vertical stress under the helix, which facilitates the pile penetration. On the contrary, a large compressive stress under the transition piece is at the origin of its large penetration resistance and its geometry may need to be further optimised.

In the field, where the pile head condition is a constant reaction force, the AR will simply vary such that the thurst provided by the helix will compensate the pile penetration resistance. Results shown in Figure 1(b) prove that there exists a set of AR between 0.10 and 1.00 such that the necessary force is equal to zero at any depth, thus ensuring the fasibility of its installation at low reaction force, providing a torque of 23MNm can be applied.

The physical and numerical modelling of a new type of pile have shown that it is a viable option to support jacket structures, as it can be installed without driving and with a very limited reaction force. The DEM simulations have revealed the underlying mechanisms explaining the centrifuge results, while centrifuge results were used to validate the DEM simulations. This project showed that the combination of the two techniques is very powerful to speed up technology development.

Contributor statement

BC: Conceptualisation, Methodology, Formal Analysis, Visualisation, Writing original draft. MB: Conceptualisation, Project administration, Funding Acquisition, Methodology, Review & Editing. MH, MO: Conceptulisation, Methodology, SupervisionReview & Editing

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