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Numerical Modelling of Large-Diameter Steel Piles at Horns Rev

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Large-diameter piles (4-6 m) are often used as foundations for offshore wind turbines. They are of a traditional design, based on a Winkler-type approach employing *p-y* curves as proposed in current design regulations for offshore wind turbines. The *p-y* curves for piles in sand have been developed based on tests of flexible piles. In contrast, monopiles for offshore wind turbines behave more like rigid piles, *i.e.* they merely rotate when subjected to large horizontal loads and moments implying a "toe kick". Hence, the deformation behaviour of the piles, and thereby the soil, in the case of large diameter monopiles are very different from the conditions from which the *p-y* curves are derived.

In this paper, results of numerical calculations, conducted by means of the commercial three-dimensional finite difference program FLAC^{3D}, of the load-deflection behaviour of a monopile for an offshore wind turbine are presented and compared to the results obtained by means of a traditional Winkler-type approach employing the currently recommended *p-y* curves. The two approaches are compared based on a monopile used as a foundation for a wind turbine at Horns Rev located in the North Sea. Drained conditions and a static load scenario are considered. The outer diameter of the pile is 4 m whereas the embedded length is 22 m. The pile is located primarily in sand. The classical Mohr-Coulomb model based on soil parameters derived from special cone penetration tests (CPTs) has been employed to model the soil in FLAC^{3D}.

It can be concluded that the monopile behaves as a relatively rigid pile implying that only one point of zero deflection exists. The deflections at sea bed level and at the pile toe, determined by means of FLAC^{3D}, are 62% and 225% greater, respectively, compared to the deflections predicted by a Winkler approach. The total deflections estimated using FLAC^{3D} and the Winkler model at sea bed level are 43.5 mm and 26.8 mm, respectively. Further, the accumulated rotations at sea bed level are 0.31° and 0.26°, respectively, with FLAC^{3D} giving the latter rotation. Whereas the maximum moments in the pile predicted by FLAC^{3D} and the Winkler approach are equal.

The Winkler approach is, compared to FLAC^{3D}, generally non-conservative in terms of determining deflections of non-slender large diameter piles for wind turbines. The reason is that the *p-y* curves for piles in sand significantly overestimate the stiffness of the soil, especially at great depth. Moreover, extreme care should be taken in the estimation of the soil stiffness associated with the constitutive soil models employed in commercial programs such as FLAC^{3D}. Further research is needed to develop new *p-y* curves for large diameter piles in sand.

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