Offshore & Dredging Engineering

Technische Universiteit Delft

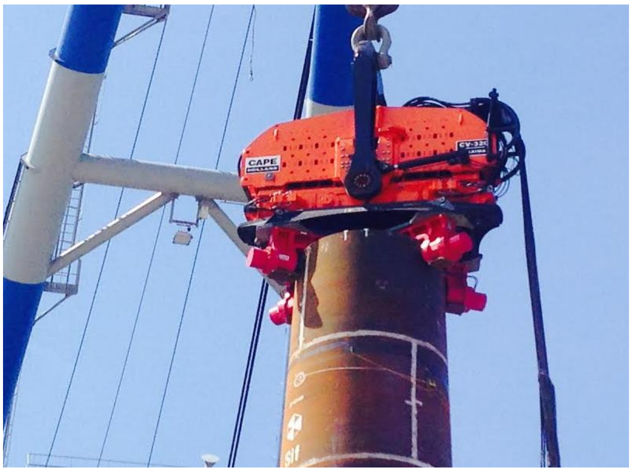
A study on the lateral behaviour of vibratory driven monopile foundations for offshore wind turbines

In current practice, monopile foundations are widely adopted to support offshore wind turbines. Monopiles are 5-8 m diameter open-ended steel tubes driven into the seabed by means of hydraulic hammers, whose employment causes remarkable underwater noise and, possibly, harm to marine life. Conversely, driving monopiles through continuous 20-40 Hz vibration has proven beneficial in terms of penetration rate, fatigue damage and noise emission when compared to hydraulic driving. While vibratory techniques have been extensively applied to many onshore pile installations, the offshore wind industry is currently exploring the possibilities of vibratory driving in relation to monopiles, with the aim of minimising both noise emissions and installation costs.

Offshore monopile foundations have to accurately maintain the vertical alignment of wind turbines over several decades under continuous lateral loading. Monopile foundations are designed according to standards that use the p-y method for lateral loading conditions. Currently, it is not known whether the p-y method can be used for the design of vibratory driven monopile foundations for offshore wind turbines. The effects introduced during vibratory pile installation (e.g. alteration of the stress and density) are quite important to consider in the analyses as the lateral bearing capacity and load-displacement behaviour of a pile depends on the properties and the stress state of the soil. These effects are incorporated in the p-y method for hydraulic driving only.

This thesis study is devoted to investigate the effect of vibratory driving on the lateral response of a monopile in dense sand. For this purpose, a numerical study is conducted via 3D finite element (FE) calculations. The PLAXIS 3D program is used to set up a soil-monopile FE model, in which the non-linear sand behaviour is reproduced through the well-known Hardening Soil (HS) elastic-plastic model. The HS soil parameters are calibrated on the basis of cone penetration tests executed before and after the vibratory installation of a 4 m diameter test pile in dense to very dense sand layers at the Maasvlakte. Finally, the FE results are re-interpreted in a p-y fashion and compared to the p-y formulation proposed by the American Petroleum Institute (API).

In the considered case study, FE results indicate that vibratory installation has only slight effect on the initial lateral stiffness of the soil-monopile system, mainly visible at approximately half pile length. The results derived from FE results and API guidelines exhibit systematic discrepancies. Such discrepancies may be attributed to a number of factors, including the lack of material continuity and 3D effects in p-y spring models, as well as the different assumptions on the depth distribution of soil stiffness in the API method and the FE model developed in this study. In conclusion, the adoption of different approaches to soil-monopile lateral modelling seems to produce higher discrepancies than those attributable to considering/neglecting the effect of vibratory driving.



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