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Reliability-based Evaluation of Offshore Design Approaches for Tensile Piles in Noncohesive Soil

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In this study, 60 deterministic offshore pile design cases for typical ranges of the pile properties and tension loading as well as typical soil conditions for the North Sea were compared with reliability-based designs regarding the corresponding failure probability, where typical soil variability and model errors were assumed for the stochastic subsoil model. On the basis of a new calibration approach, quality factors for each design method with respect to the most likely outcome regarding the failure probability were derived. With the so-obtained quality factors, an enhanced evaluation of each deterministic design method as well as the safety level in terms of the required global safety factor is possible.

INTRODUCTION

In the near future, several offshore wind farms are to be built in the North Sea to satisfy the demand for a high amount of renewable energy in Germany. As most shallow-depth sea areas have already been exploited, a number of projects will be located in sea areas with relatively high water depths (exceeding 40 m). For such water depths, jacket and tripod support structures with mainly axially loaded foundation piles will probably be employed in most cases.

The axial bearing resistance of such piles is normally estimated according to the recommendation of the American Petroleum Institute (API, 2014) by applying the so-termed Main Text method. However, several investigations (e.g., Lehane et al., 2005; Cathie, 2012) have shown that the application of the Main Text method, at least for foundation piles of wind energy converters, is not reliable and may lead to a significant deviation compared with the real in situ bearing capacity.

To enhance the reliability of design methods, four additional cone penetration test (CPT)-based design methods—namely, ICP, UWA, Fugro, and NGI—were recommended within API (2014). These methods were calibrated on pile field tests, where basically the skin friction of a pile and the end bearing are estimated on the basis of the cone resistance measured in a CPT. Although it is believed that the proposed CPT-based methods are more reliable than the API Main Text method, care should be taken in the application of these methods, because experience is limited. Indeed, the application of the CPT-based methods leads in practice to a high deviation in the required pile length within a design.

In this study, different pile-soil systems were designed deterministically and investigated regarding the failure probability with reliability-based approaches. By applying a new calibration approach, quality factors for each design method were derived. Based on these quality factors, an enhanced evaluation of a certain design method in question regarding the reliability of the predicted tensile bearing capacity can be done. Moreover, a more reliable as well as more robust deterministic design can be achieved by taking the proposed quality factors into account. In this study, only the tension bearing resistance of a single offshore foundation piles is investigated. The reliability of the substructure including redundancy effects is not addressed in this study. A companion study regarding the compressive bearing resistance has been done by Schmoor and Achmus (2018).

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KEY WORDS: Quality factors, partial safety factors, RBD calibration, offshore pile design.

PILE-SOIL SYSTEMS UNDER CONSIDERATION

For the performed study, typical site conditions for the North Sea and typical ranges for the foundation pile properties were assumed.

Because the subsoil in the German North Sea mostly consists of dense sands with only limited intermediate cohesive layers, two idealized CPT profiles for homogeneous dense ($D_r = 0.75$) and very dense ($D_r = 0.90$) sands were considered, where the mean value of the grain size at 50% of the grain size distribution was chosen to be $\mu_{D50} = 0.4$ mm. The mean value of the effective unit weight was assumed to be $\mu_{\gamma'} = 10$ kN/m^3 in both cases, because this value represents a reasonable estimate for both soil densities.

The choice of pile properties depends on the type of support structure for the wind turbine, the water depth, and the subsoil condition at the desired location. In general, it can be said that pile slenderness ratios (embedded length to diameter) between $L/D = 15$ and $L/D = 40$ are used for jacket support structures of offshore wind turbines. Thereby the pile outer diameter of usually applied open-ended piles is varying between $D = 1$ m and $D = 3$ m, where the pile-embedded length is commonly chosen to be between $L = 20$ m and $L = 60$ m. The regular pile wall thickness, which is mostly used, can approximately be determined by $t = D/50$. Figure 1 shows the considered pile properties and soil conditions.

DESIGN METHODS

Within the ultimate limit state design for foundation piles of offshore support structures, it has to be ensured that the environ-