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Evaluation of p-y Approaches for Large-Diameter Piles in Layered Sand

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The p-y method according to the offshore guidelines is usually applied for the design of laterally loaded piles. However, a number of modified p-y approaches for piles in noncohesive soils were proposed in the recent years to account for the effect of the pile diameter. These approaches were developed for piles in homogeneous soil but are used in current engineering practice for piles in layered sand as well. Concerning this matter, this paper presents a comparative evaluation of the existing p-y approaches for piles in layered sand by means of three-dimensional numerical simulations. Two large-diameter piles in widely varied layered sand representing a monopile and a pile of a lattice structure for the foundation of an offshore wind energy converter are considered. It is demonstrated that the effect of the layering is limited; that is, the deviations of the analytical results from the numerical results are predominantly associated with the deviations obtained for homogeneous sand. An occasionally used overlay procedure to adapt the p-y curves depending on the adjacent soil layers is shown to have not only a small impact on the analytical results but also some major deficiencies with regard to a reliable consideration of the layering.

INTRODUCTION

Offshore wind energy converters (OWECs) are commonly supported by driven pile foundations. Monopiles are the preferred foundation concept for small and moderate water depths (Fig. 1, left). The monopile is predominantly affected by lateral forces and overturning moments as a result of the acting environmental and operational loads. For larger water depths, several piles are applied on a lattice structure similar to a jacket or a tripod (Fig. 1, right). In this case, the foundation piles are loaded mainly axial associated with the push–pull mechanism caused by the moment loading. However, the piles are likewise loaded to a significant amount by lateral forces and head moments.

The piles transfer the lateral load to the subsoil by bedding pressures acting on the pile shaft. Large pile dimensions are necessary to carry the considerable lateral loads acting on the OWEC foundation. Thus, monopiles have, depending on turbine type and water depth, diameters up to $D = 8$ m along with small ratios of embedded length to diameter $L/D < 5$, resulting in a relatively stiff pile behavior. By contrast, piles of lattice structures have smaller diameters up to $D = 2.5$ m but much larger ratios $L/D > 10$ that become necessary because of the severe axial loading. Hence, the piles of lattice structures usually behave flexibly.

The geotechnical design of pile foundations for OWECs has to ensure the structural integrity and restrict the deflections to tolerable limits for the serviceability of the turbine. Furthermore, the foundation stiffness–and with that, the eigenfrequency of the structure–has to be arranged within tight limits to minimize the structural fatigue loading (Arany et al., 2016). For all these design aspects, it is common practice to use the p-y method. At this, the soil resistance is modeled by distributed uncoupled springs acting normal to a beam element representing the pile (Fig. 1, center). For offshore engineering purposes, the corresponding nonlinear spring characteristics (p-y curves), describing the bedding resistance p in dependence on the lateral displacement y, are defined by the offshore guidelines (OGLs) of the American Petroleum Institute (2014) and DNV GL (2016). In these guidelines, "static" and "cyclic" p-y curves are distinguished. Most of the design calculations are carried out applying cyclic p-y curves to take the degradation of ultimate capacity and the accumulation of deflection due to cyclic loads acting on the OWEC foundation into account. Only in calculations regarding the pile stiffness for determination of the overall structure's eigenfrequency are static p-y curves used. However, the cyclic p-y curves base on the static curves and account for the cyclic case by just (slightly) modifying the static approach. Therefore, a deficient formulation of the static p-y curves also indirectly affects the predicted lateral deflection and the ultimate capacity of the pile foundation. This paper deals with the suitability of the static p-y curves.

Based on experience gained in the oil and gas industry during the last few decades, the OGL method is supposed to be sufficiently accurate for slender piles with diameters up to two

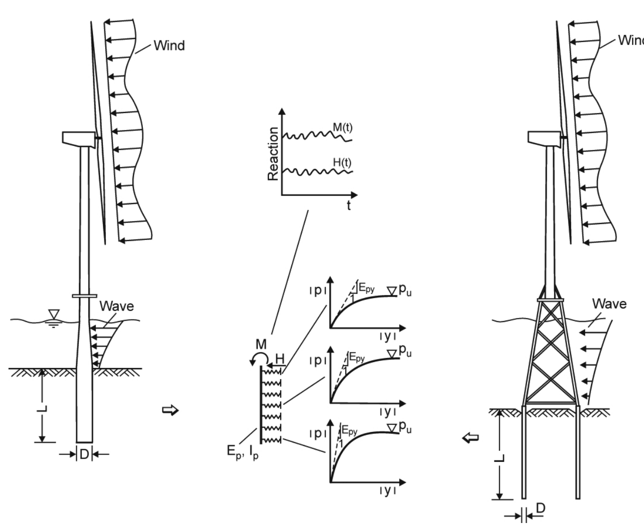

Fig. 1 Schematic sketch of an OWEC with monopile foundation (left) and jacket foundation (right); idealization of a laterally loaded pile by the p-y method (center)

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