Advanced Engineering Days

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A comparative study on the lateral displacement response of short monopiles with different plug materials

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Cite this study: Ertuğrul, Ö. L., & Canoğulları, F. D. (2023). A comparative study on the lateral displacement response of short monopiles with different plug materials. Advanced Engineering Days, 8, 39-42

Keywords
Monopile
Finite element method
Lateral displacement

Abstract

Today wind energy is regarded as a major source in the energy market and power generation. An offshore wind turbine is supported by a stable platform located above the ocean surface, together with a combination of rotor-nacelle-tower structure and the foundation. In the most often used system, the tower is fixed onto the monopile foundation by a transition piece. Monopiles are large-scale steel pipes that are often driven into the seabed by impact; their typical dimensions range from 8 m to 10 m in diameter, 30 m to 40 m in length, and weigh as much as 1000 tons. In this study, a small-scale monopile foundation with different plug materials is modeled using the Plaxis 3D finite element software.

Introduction

Wind is considered among the most significant and reliable sources of kinetic energy. With the utilization of wind turbines, the kinetic energy produced by constant winds can be utilized as a continuous and renewable source of electricity. The substructure and base support an offshore wind turbine and its rotor-nacelle-tower combination, which is situated on a stable platform. The tower is placed on a monopile foundation via a passage in the most widely used technique.

A typical monopile consists of a steel pipe, with the bottom part open and the top part closed. The diameter and length of the monopile vary depending on the project requirements, water depth, soil conditions, and the size of the turbine. Monopiles can be large-scale structures that can reach dozens of meters in diameter and extend deep into the seabed.

In the installation process, monopile hydraulic hammer or vibration equipment is used to crash into the seabed to the desired depth. The soil resistance and friction between the monopoly and the surrounding seabed provides the stability necessary for the wind turbine. By transferring the weight and loads from the wind turbine's tower and wings to the ocean floor, the monopile serves as the primary structure supporting the whole system.

Material and Method

Monopiles are the most common type of foundation used to support offshore wind turbines [1]. They may be installed and designed to accommodate a wide range of subsurface conditions. A monopile is a long and hollow steel tube that is driven up to 80 m into the sea floor. Some of the monopile protrudes above the sea floor to attach to the transition piece, connecting the monopile to the tower. The tower supports the nacelle and the rotor of the turbine. Monopiles must withstand the forces from wind, waves, ice, currents, and boats over the life of the turbine, which can be up to 50 years [2]. Figure 1 depicts a monopile with a diameter of 7.5 meters, which is located at the Gode Wind Offshore Wind Farm.

In literature, many methods are utilized in monopile design projects, however finite element approach stands out as the most versatile tool with powerful modeling capabilities. In this study, the short monopile model (H=8m) was produced using the Plaxis 3D [4] software and modeled as an empty hollow cylinder pile, a soil-filled steel pile, and a concrete-filled steel pile. It is known that monopiles are typically longer however, to minimize the complexity associated with the pile flexural deflections, a short model was considered to compare the effect of different inner plug materials including concrete.

The monopile geometry modeled with Plaxis 3D is shown in Figure 2.

Figure 1. A 7.5 m diameter monopile for Gode Wind Offshore Wind Farm [3]

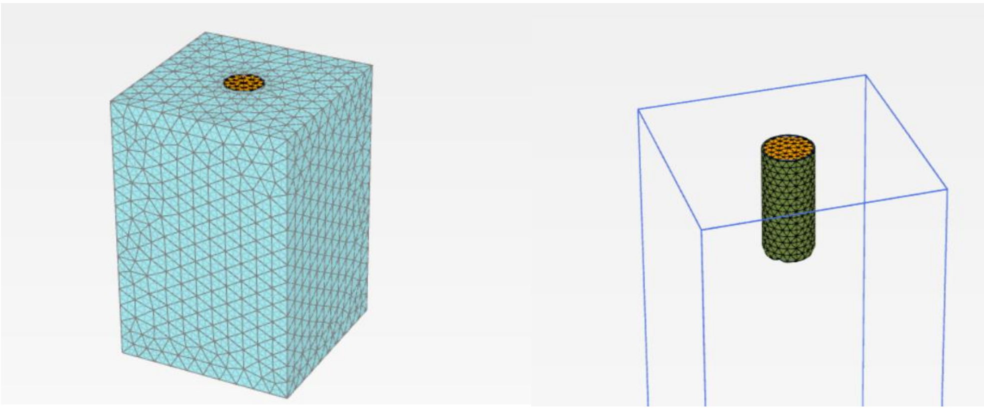

Figure 2. Perspective view of the monopile geometry

Table 1 provides the properties of the soil, monopile and concrete used in 3D modeling. Furthermore, the pile has been chosen to have a diameter of 1 m, a length of 8 m, and a steel thickness of 0.05 m. The modeling results of the short pile, simulated in three different setups, were compared.

In the modeling study, static analyses were carried out by applying a force in horizontal direction, without considering of dynamic and time varying nature of wind and wave loads. The applied horizontal load in all three analyses is 1000 kN.

Table 1. Properties of the soil, monopile and concrete

	Unit weight (kN/m^3)	Modulus of elasticity (kN/m^2)	Poisson ratio	Angle of internal friction (°)
Soil	19	$50x10^3$	0,3	30
Monopile	78	$210x10^9$	0,2	-
Concrete	24	$25x10^6$	0,2	-

Results and Discussion

According to the results of static analysis, the total horizontal displacement obtained for the hollow cylindrical pile model is 4.56 mm, for the soil-filled pile model is 4.26 mm and for the concrete-filled pile model is 3.82 mm. Horizontal displacement contours obtained through finite element analyses are shown in Figure 3. It is observed that a concrete inner plug within the monopile significantly decreases the lateral displacements and the reduction in displacements is 6.5% for the ordinary soil plug and 16.2% for the concrete infill. The decrease in the displacements is very promising, since the wind turbines requires very strict tilting requirements in order to run properly during service lifespan.

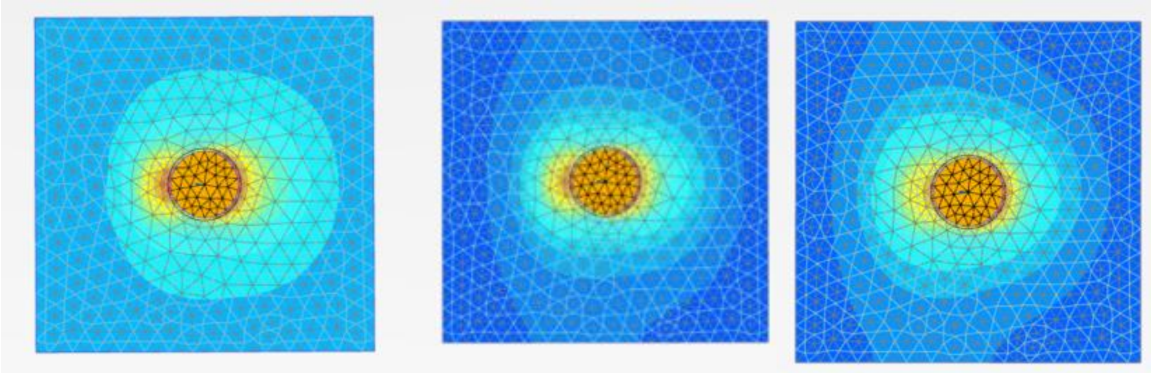

Figure 3. Horizontal displacement contours a) hollow cylindrical pile model b) soil-filled pile model c) concrete-filled pile model

An examination of the horizontal displacement values of the pile in contour view also supports the previous finding about the horizontal displacements of the monopile. The reduced displacements in the soil also decrease the extent of the yield zone around the pile body, which decreases the amount of soil softening thus contributing to the lateral resistance. The graph showing the horizontal displacement as a function of pile depth for three different models is presented in Figure 4. Av investigation of the Fig.4 also shows that there is a well observed rotation point at -6.25-meter elevation along the pile body, which is approximately 20 percent of height above the pile bottom.

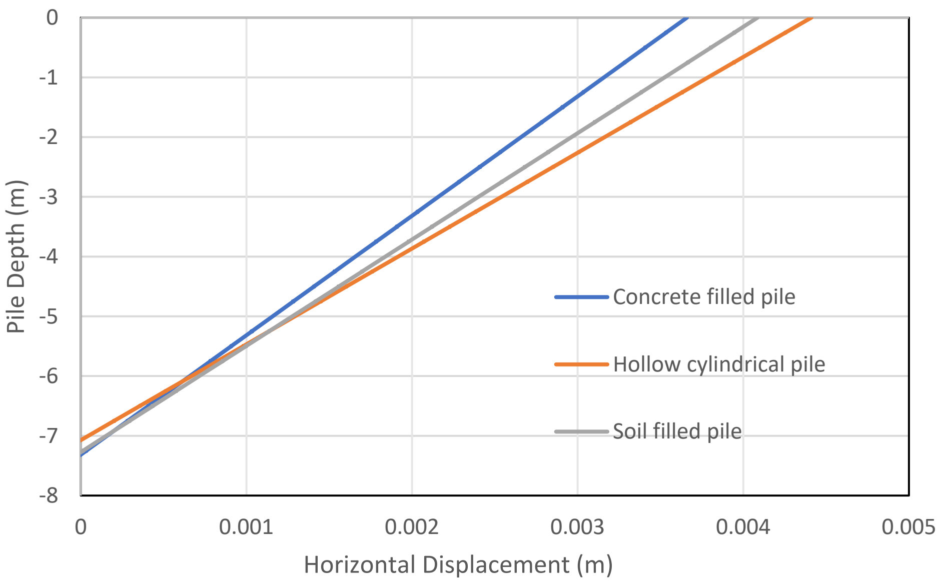

Figure 4. Pile depth - horizontal displacement curves for three model

Conclusion

For the preliminary design of monopiles, different loads are taken into consideration. These loads are the self-weight of the whole structure, lateral wind and wave loads and turbine blade loadings. Most significant load for the monopiles supporting the wind turbines are the lateral loads. In this study, short monopile models with different inner plug materials were analyzed under a constant lateral load and the lateral displacement of the monopile body is compared. Main motivation of this analyses is to investigate the effect of inner plug characteristics on the lateral displacement of the monopile. Analyses results indicated that stiffer inner pug materials are reducing the lateral displacements of the pile body. The reduction in the displacements of the monopile top may reach up to 16% which is considered a very important decrease since the lateral displacement reduction on top of the tower will be higher. It is well known that wind turbines are running under strict tilting requirements hence stiff infill plugs within the monopile body may provide significant cost reductions in the overall cost of the wind turbine structures resting on monopiles.

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