

Structural Response of Offshore Monopile Foundations to Ocean Waves

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ABSTRACT

Offshore monopile foundations are one of the most commonly used foundation concepts in offshore renewable energy, especially in areas with relatively shallow water. They are characterised by relatively large geometric dimensions compared with other offshore pile foundations and are distinguished from onshore piles by suffering from harsh ocean environments during their lifetime. One of the most significant aspects is associated with the wave effect on the behaviour of monopile foundations. To date, research has been conducted in the development of numerical models, which are capable of providing sophisticated and flexible representations of the monopile foundations. In this study, a three-dimensional scaled boundary finite element model (SBFEM) is proposed to investigate the structural response of the monopile foundations when exposed to ocean waves. Unlike other numerical techniques, SBFEM provides an analytical solution in the radial direction with numerical approximation along the circumferential and top faces of the monopile foundation, which considerably reduces the computational effort. The SBFEM model is validated by an equivalent finite element model, by which favourable computational efficiency and reliable accuracy are demonstrated. Subsequently, a parametric study is carried out in terms of various wave properties to gain an insight into the monopile behaviour. The purpose of this study is to make recommendations for improving the design of offshore monopile foundations, when wave load is a dominant factor.

KEY WORDS: Offshore monopile foundations; ocean waves; structural behaviour; scaled boundary finite element model; three-dimensional

INTRODUCTION

Offshore wind farms, as a competitive resource of renewable energy, currently are, and potentially will be, gaining even more global popularity, as they provide higher economic returns and are less obstructive than onshore wind farms. Among the foundation concepts, monopile foundations have been receiving significant attention, particularly when the water depth is no more than 50 meters. They are characterised by a large but simple geometric configuration and localised seabed consumption, consequently simplifying the installation

process and minimising environmental disturbance. Furthermore, experience is available from the classic pile foundation topic, which has been studied for decades in both ocean engineering and geotechnical engineering. Monopile foundations, used in offshore renewable energy applications, are often identified by their relatively large diameter, compared with the commonly used pile foundations in other offshore applications; also, they differ from the deep pile foundation in geotechnical engineering since wave loads are considered as one of the key factors in monopile foundation design. Therefore, understanding of the monopile foundation behaviour subjected to wave loads in ocean environment is of great importance.

Progress has been achieved in the past few years regarding the monopile foundation behaviour under the lateral loading associated with winds, waves and the seabed, especially in Northern Europe, where offshore wind farm development was pioneered. Kellezi and Hansen (2003) presented both static and dynamic models of the foundation, however, they only addressed the geotechnical aspect, namely, the monopile-seabed interaction. Zaijier (2006) explored the foundation sensitivity to wave and wind loads by simply using excitation frequencies to represent the wave and wind influence. Achmus et al. (2009) developed a degradation stiffness model to account for the loading effect from the ocean waves. Eicher et al. (2003) studied the stress and deformation of a 1 m radius pile, a general offshore pile, under combined structural and wave loads. To date, there has been a dearth of explicit research in large-diameter monopile foundation behaviour under wave load conditions.

The objective of this study is to investigate the effects of the wave loads on monopile foundations and how the monopile responses to the variation of several key parameters of the wave loads. A three-dimensional numerical model is proposed herein based on SBFEM, which was first conceptualised by Wolf and Song (1996). By combining the advantages of two powerful numerical techniques, namely, the Finite Element Method (FEM) and the Boundary Element Method (BEM), the SBFEM has found its broad applicability in various engineering aspects. Wolf (2002), Doherty and Deeks (2003) and Khani (2007) employed this method to investigate the soil-structure interaction in geotechnical engineering, in which the superior performance of SBFEM over FEM and BEM in dealing with the unbounded nature of soil domain has been fully demonstrated. Yang (2006) and Yang and Deeks (2007) developed an automatic crack growth model using SBFEM, further validating its capability in dealing