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Monopod Bucket Foundations Under Cyclic Lateral Loading

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The monopod bucket foundation has the potential to become a cost-reducing substructure for offshore wind turbines. To avoid problems during the energy converter operation, the long-term effect of cyclic loading must be considered in the design of the foundation. In this paper, a 1-g testing rig is adopted to extend the knowledge of bucket foundations under lateral cyclic loading. The test setup is described, and a comprehensive experimental campaign is presented. The effect of some important system parameters on the long-term plastic rotation is analysed. Key aspects of the cyclic load behaviour of bucket foundations are discussed.

INTRODUCTION

To make offshore wind competitive in the energy market, cost-effective foundations and installation technologies must be developed. The monopod bucket foundation has the potential to become a cost-reducing solution for offshore wind turbines (Ibsen, 2008). Bucket foundations, also known as suction caissons, are shallow skirted foundations with a circular cross-section of diameter D and an embedded skirt of length d. This foundation has been adopted for decades in the oil and gas industry as an alternative to drilling or driving for anchoring mooring buoys (Senpere and Auvergne, 1982) or as a foundation for jackets (Tjelta, 1994; Bye et al., 1995). A picture of a monopod bucket foundation for met mast placed on the deck of an installation vessel is shown in Fig. 1. This full-scale structure was installed at Dogger Bank in the British Sector of the North Sea. The dimensions of this structure are $D = 15$ m, $d = 7.5$ m, and wall thickness $t = 30$ mm. The installation consists of two phases: first, the foundation penetrates the seabed for a few meters by its own weight, and second, the skirt is fully embedded by suction-assisted penetration. This installation technology prevents the generation of noises that can be harmful to marine mammals. Furthermore, the installation process can potentially be reversed, making possible the recovery of the structure at the end of its lifetime. The installation procedure for and the response of shallow skirted foundations under general monotonic loading are widely explored in the literature (Houlsby and Byrne, 2005; Houlsby et al., 2006; Gourvenec, 2007; Villalobos et al., 2009; Barari and Ibsen, 2012; Achmus, Akdag, and Thieken, 2013; Ibsen et al., 2014).

Understanding the effect of cyclic loading on offshore foundations is crucial. DNV (2014) states that repeated loading may lead to irreversible soil deformation (and thus irreversible foundation displacement) that could jeopardize the turbine operation. When designing in the serviceability limit states (SLS) and the fatigue limit states (FLS), one should account for this by calculating the cumulative displacement with an adequate method. Another important consequence of repeated loading is that it may lead to changes in the natural frequency of the system and, in the worst case, trigger resonance. Lately, much research has been devoted to these particular issues. Andersen (2009) presents a framework to estimate the settlements of shallow foundations subjected to cyclic loading due to storms.

Numerical models of monopiles were developed by Achmus et al. (2009) and subsequently by Depina et al. (2013). Monopiles were also tested in single gravity physical models by Peralta (2010) and Taşan et al. (2011). Centrifuge modelling was attempted by Watson and Randolph (2006) who carried out an experimental campaign on bucket foundations and derived fatigue contours for a few hundred cycles. More recently, Klinkvort and Hededal (2013), Garnier (2013), and Kirkwood and Haigh (2014) ran lateral cyclic loading centrifuge tests on monopiles. Achmus, Thieken, et al. (2013) performed numerical simulations of bucket foundations under cyclic loading through the use of the stiffness degradation method (Achmus et al., 2009) and investigated the effect of the load magnitude, relative density, and embedment

Fig. 1 Large-scale monopod bucket foundation on the deck of a jackup vessel (courtesy of Universal Foundation A/S)

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