Physical Modelling of Bucket Foundation under Long-Term Cyclic Lateral Loading

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ABSTRACT

Offshore wind farms are a promising renewable energy source. The monopod bucket foundation has the potential to become a reliable and cost-effective concept for offshore wind turbines. The bucket foundation must be designed by accounting for the cyclic loading which might endanger the turbine functioning. In this article a 1g physical model of bucket foundation under horizontal and moment cyclic loading is described. A testing program including four tests was carried out. Every test was conducted for at least 30000 cycles, each with different loading features. The capability of the model to represent the cyclic loading is discussed based on example results.

KEY WORDS: Bucket foundation; cyclic loading; dense sand; physical model.

INTRODUCTION

Wind converters are nowadays a promising alternative to fossil fuels. Over the last two decades a growing investment made wind energy feasible. The research has achieved encouraging results being capable of lowering significantly the price of wind energy. Onshore wind power plants are by now realistically in competition with fossil fuels. Over the last years the offshore wind energy cost dropped drastically, although it is still 2 to 3 times higher than that of coal or gas (Beedie, 2011). A key factor of the offshore wind farm overall cost is the foundation and its installation technology. In the last ten years a cost-effective foundation concept for offshore wind turbine has been developed at Aalborg University, the monopod bucket foundation. The bucket foundation, or suction caisson, was widely adopted by the oil and gas sector as an anchor for floating platforms or as a spread-out shallow foundation for jacket structures. Such foundation consists of an upturned steel bucket installed in 10-50 m water depth by means of a suction-assisted penetration. This installation technology is faster than usual installation procedures and avoids the use of heavy and specialized vessels. Further, the production of the bucket is less expensive than that of a jacket structure. For these reasons the overall CAPEX of an offshore wind farm can be markedly lowered by adopting the bucket foundations. The ultimate capacity and the installation procedure of the bucket foundation have been widely investigated and successfully put into practice (Ibsen, 2008; LeBlanc 2009). The dynamic response has been studied by Andersen et al. (2009). However, environmental forces in open sea areas are naturally cyclic under any weather conditions.

Further, when a soil is subjected to repetitive loading, several issues must be accounted for. The pore pressure can increase drastically and the soil strain can accumulate progressively leading to a general degradation of the soil. In turn, changes in natural frequency can occur to the structure and the wind turbine operation might be jeopardized. Besides, the rotation of the wind turbine is likely to accumulate due to unceasing cyclic loading. In Fig. 1, a wind turbine mounted on a bucket foundation and its rotation, \( \theta \), after a number of cycle, \( N \), is sketched.

Design methods for horizontally loaded monopiles are currently based on \( p-y \) curves which are rather simplistic and anachronistic. More appropriate design methods for evaluating the soil degradation and its effects on foundations must be addressed. In this respect some progress has been made the last years with researches such as Taşan (2011) and Lesny and Hinz (2007), which combined element tests, physical models and numerical models to assess the long-term behavior of cyclically loaded monopiles. The NGI method to evaluate the behavior of soil under cyclic loading must also be mentioned (Andersen, 2009). To the knowledge of the authors the only paper investigating bucket foundations subjected to horizontal cyclic loading through a physical model is Zhu et al. (2010). Numerical models have also been attempted (Ding et al., 2010).

Figure 1. Offshore wind turbine supported by a bucket foundation