Experimental Setup for Cyclic Lateral Loading of Monopiles in Sand

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ABSTRACT

The majority of all offshore wind turbines are installed on monopiles, i.e. large diameter stiff piles. During the environmental loading of the wind turbine, the monopile is subjected to millions of load cycles which might cause a permanent rocking rotation (tilt) of the wind turbine. In this paper, the influence of the number of load cycles on the permanent rocking rotation of the monopile is investigated by means of a new 1g mechanical testing rig capable of providing more than 40,000 load cycles. The experimental setup is described and compared with previous small-scale tests and the result from one cyclic load test is evaluated.

KEY WORDS: small-scale; model; tests; monopiles; cyclic; long-term; sand.

INTRODUCTION

In the offshore wind turbine industry, the most widely used foundation type is the monopile; a large steel cylinder with diameter, \( D \), of 4 m to 6 m and embedded length, \( L \), of 20 m to 30 m. During the lifetime of a wind turbine, the monopile foundation is subjected to few load cycles with large amplitudes, caused by the strong storms, and also to millions of load cycles with low or intermediate amplitudes that may cause failure in the fatigue or serviceability limit states (FLS and SLS respectively), (Wichtmann et al. 2008). This long-term cyclic loading might cause a change in the stiffness of the surrounding soil, which might lead to a permanent rocking rotation (tilt) of the wind turbine. Due to the efficiency of the wind turbine, strict demands for the rotation and the stiffness of the entire structure are normally made. The maximum accumulated rocking rotation at seabed is specified by the wind turbine supplier and is normally 0.5°. As for the stiffness demand, it must be assured that the natural frequency of the combined structure is in the range between the rotor frequency (approx. 0.3 Hz) and the blade passing frequency (approx. 1 Hz) (LeBlanc et al. 2010). Because of these demands, the rotation and stiffness have shown to be the primary drivers in the design of offshore wind turbines, hence SLS and FLS are usually controlling the design.

When designing monopiles today, the design standards DNV (2010) and API (2007) are used. Both standards recommend the \( p-y \) curve method which for sand is formulated by Reese et al. (1974) and O’Neil and Murchison (1983). The formulation is based on theory and a few tests on flexible piles used in the oil and gas industry with slenderness ratios \( L/D \) around 30. In contrast, the stiff, large diameter monopiles used for offshore wind turbine foundations have a ratio smaller than 10. Thus, when using the design standards for the offshore wind turbine foundations, the formulation is used outside its verified range. In the matter of cyclic loading, the formulation accounts for this by multiplying a constant to the static curve. The \( p-y \) curves are designed primarily for evaluating the ultimate capacity, and consequently the accumulated rotation at seabed and change in stiffness are poorly explained. Further, neither the influences of the installation method, difference in loading amplitude or number of load cycles are considered. Thus, more knowledge about the influence of cyclic loading on the soil pile interaction is necessary for accurate determination of the accumulated rotation and change in stiffness. In order to evaluate theories and validate numerical predictions, in-situ and large-scale testing is the best tool, but also the most expensive and time-consuming. Long and Vanneste (1994) and Lin and Liao (1999) both evaluated full-scale tests and proposed different expressions for the accumulated displacement. Long and Vanneste (1994) suggested the accumulated displacement to be expressed by a power function whereas Lin and Liao (1999) used a logarithmic expression. Both however agreed on treating the displacement after the first cycle as a separate factor. Even though the full-scale measurements are informative, the findings are based on a limited number of cycles (50 and 100, respectively) and thus, in order to truly understand the behaviour of the stiff piles during long-term, lateral cyclic loading, further investigation is needed. Because full-scale testing is expensive and time-consuming, the recent choice for evaluating the cyclic behaviour has been numerical modelling and small-scale testing.

In this paper, a new 1g testing rig for modelling the environmental loading on a stiff monopile foundation in sand is described and discussed in proportion to recent small-scale testing carried out by Peng et al. (2006), Peralta and Achmus (2010), and LeBlanc et al. (2010). In contrast to recent research, this new testing rig provides measurements.