An experimental study of cyclically loaded monopod suction caisson foundations for offshore wind turbines

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Introduction

There has been a recent increase in interest in the understanding of suction caisson behaviour, owing to the possibility of them becoming a feasible foundation option for offshore wind turbines. This novel type of foundation has been used previously in the oil and gas industry in deep water applications such as jacket and floating structures.

Gravity bases and piles might be a foundation solution to offshore wind turbines, but both are more expensive and time consuming compared with the suction caisson option. Two suction caisson arrangements have been suggested for the wind turbine foundations (Byrne and Houlsby, 2003). One uses multiple caissons (tripod, quadruped or the use of an even greater number of caissons); and the other one is a monopod.

Significant differences exist in the conditions encountered in the wind turbine and in the oil and gas applications. For example, the depth of the water is shallower and as a proportion of the gravity forces, the horizontal forces and overturning moment (wind, waves and currents) are much larger (Byrne and Houlsby, 2003).

Therefore, investigation is necessary to study the cyclic response of suction caissons under low vertical loads. For the case of multiple caissons, the compression to tension transition in vertical load governs the soil-footing response, whereas for the monopod case, horizontal and moment loads control the response. A bearing capacity failure is not expected to occur, because at large displacements, very large bearing capacities are mobilised.

Experimental results

The purpose of this investigation was to study the response of different model scale suction caissons in the laboratory under cyclic combined loads, i.e. vertical, moment, and horizontal loads $(V, M/2R, H)$ and their corresponding vertical, rotational, and horizontal displacements $(w, 2R\theta, u)$.

A computer controlled loading rig was used to carry out the testing. Two aspect ratios of caisson were tested, $L/2R = 0.5$ and 1. The former is most suitable for sandy soil and the latter is thought to be applicable for foundations in clay. The soil used in the experiments was a dry, loose white Leighton Buzzard sand.

Tests were conducted holding a low vertical load whilst a cyclic rotational displacement of increasing amplitude was applied for ten cycles. Figure 1 shows ten rotational cycles applied to a diameter $2R = 293$ mm suction caisson at a rate of $2R\dot{\theta} = 0.02$ mm/s. The response is hysteretic and is possible to observe stiffness degradation during each cycle. Figure 2 shows the proof of the second Masing rule, which states that the shape of unloading and reloading curves is the same as that of the doubled initial curve. The first Masing rule can also be confirmed in Figure 2. It states that the tangent slope of the reloading curves is identical to the tangent slope of the initial curve. A comparison amid different cyclic loading tests was made by plotting peak values of moment load and associated rotational displacement in each cycle.

Figure 3 depicts the case of increasing vertical load from 0 N to 200 N, for a loading ratio $M/2RH = 1$. There is an asymptotic moment resistance in the test with $V = 0$N. On the other hand, the remainder of the tests show an increase in their moment resistance after each cycle.

Therefore, it is worth noting that there is a favourable effect on the caisson response when V increases. Moreover, if the same peak values of moment load are plotted against the corresponding vertical displacement, there is observable uplift or settlement of the suction caisson.

Figure 4 shows these curves for the same tests plotted in Figure 3. The caisson uplift becomes 5% of its radii for $V = 0$ N diminishing with the increase of V. For $V = 100$ N the caisson rocks almost without vertical displacement. Settlement occurs for a very high vertical load $V = 200$ N.

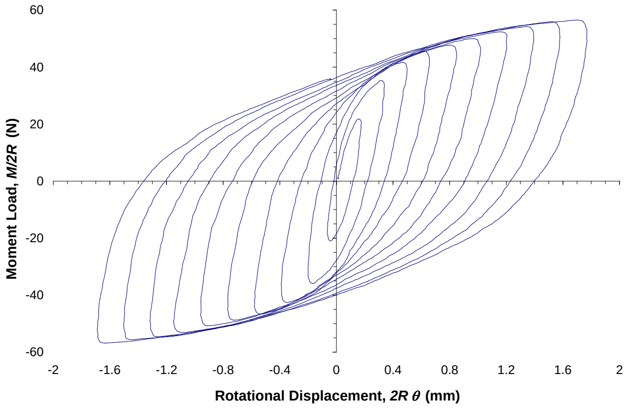

Figure 1: Typical cyclic rotational test. Test T79_13_1: $V = 50$ N, $M/2RH = 1$ and $L/2R = 0.5$

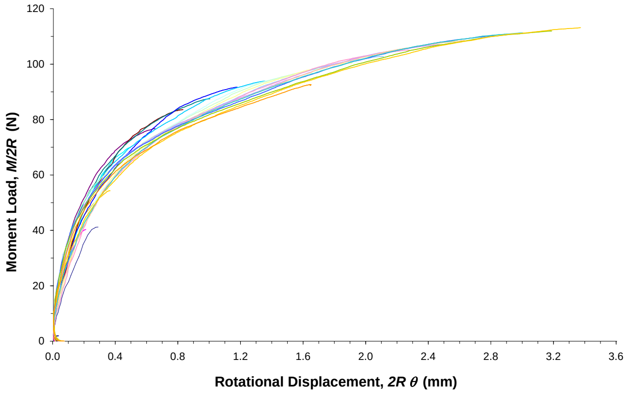

Figure 2: First and second Masing's rule. The initial loading doubled, reversals and reloadings relocated. Test T79_13_1: $V = 50$ N, $M/2RH = 1$ and $L/2R = 0.5$

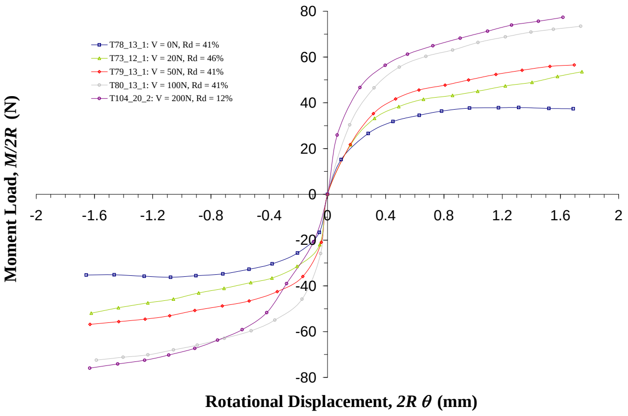

Figure 3: Peaks of moment load versus rotational displacement. $M/2RH = 1$ and $L/2R = 0.5$

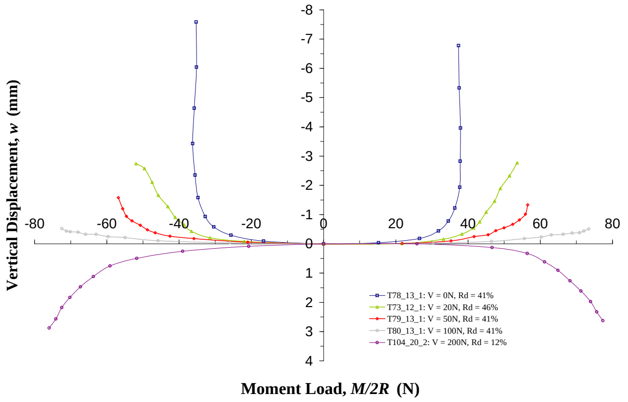

Figure 4: Peaks of moment load versus vertical displacement. $M/2RH = 1$ and $L/2R = 0.5$

Comments

From the analysis, is possible to note the beneficial effect of the vertical load, since a higher resistance is obtained when the vertical load is increased. Furthermore, uplift of the suction caisson was observed as long as the vertical load is less than the horizontal or moment loads.

Clear stiffness degradation during each cycle was observed. All the tests proved to obey the Masing rules.

These experimental results will be used to construct a continuous hyperplasticity model. Finally, further investigation will be necessary to include caisson installation by suction and cyclic tests with analysis of pore fluid pressure evolution.

Byrne, B.W. and Houlsby, G.T. (2003) Foundation for offshore wind turbines, *Phil. Trans. of the Royal Society of London*, Series **A 361**, 2909-2300