The Effects of Pile Shape on the Lateral Capacity of Monopiles used as Wind Turbines Embedded in Sand Deposits

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ABSTRACT

Offshore wind power generators are potential for generating renewable energy in the world. Nevertheless, foundation systems that are capable of withstanding higher load capacities are required to generate more energy per structure. In recent years many structures like piled footings, un-piled footings, tripods and tetrapod foundations have been extensively investigated for offshore wind turbines. Although many of these studies have been successful, still most wind farms around the world are constructed by conventional monopile structures, which are mainly circular hollow steel tubes. In this paper the ultimate lateral capacity and the stiffness of a monopile structure used as an offshore wind turbine installed in shallow waters is investigated by the aid of finite element analysis. The response of the structure is investigated through three dimensional finite element analyses in sand deposits with considering an elasto plastic material for the monopile. Moreover, the stiffness and the ultimate lateral capacity of a circular pile/tower is compared with the results obtained from a square, rectangle and a regular hexagon pile/tower to illustrate that a squared pile/tower configuration has the highest stiffness and ultimate lateral capacity compared to all other configurations.

KEYWORDS: Monopile foundation; offshore wind turbine; Finite element analysis; static response; pile shape; pile stiffness; pile’s ultimate lateral capacity.

INTRODUCTION

Due to the high level of pollution generated by fossil carbon fuels, it is widely accepted that the world must rapidly move towards renewable energies. Wind energy seems to be a very practical substitute for fossil fuels for generating electricity, but obstacles to fully harness this energy still remain. The most common wind turbine foundation used in practice is a hollow circular pile (or monopile) constructed out of steel. The wind acting at the hub level for these structures can generate high moments at the foundation level while the vertical loads are low. In recent years many new structures have been proposed and extensively investigated by conducting centrifuge tests or by carrying out numerical analysis to illustrate how the stiffness and the ultimate lateral capacity of the structures can be enhanced compared to a monopile foundation. Some of these new proposed structures are tripod foundation systems (Sender, 2009), piled footings (Dixon, 2005; Stone et al., 2007; Stone et al., 2010; Lehane et al., 2010), un-piled footings (Byrne et al., 2002) and suction caissons (Houlsby et al., 2005). However, the benefits of these proposed structures have been illustrated, in practice many onshore and offshore wind farms are still constructed by monopile structures, similar to the Egmond aan zee farm constructed in the North Sea off the Dutch coast in 2006 and the Horns Rev wind farm located on the west coast of Denmark, which was constructed in 2002.

The lateral response of a single pile has been investigated by many scholars such as Matlock and Reese (1960), Broms (1964), Poulos (1971), Randolph (1981), Barton (1982), Fleming et al (1992), Prasad and Chari (1999) and Zhang et al (2005 & 2009). Some of these studies emphasis on the stiffness of the monopile structure (Poulos, 1971) while others concentrate on the ultimate lateral capacity of the structure (Broms, 1964; Fleming et al., 1992 and Zhang et al., 2005 & 2009).

Offshore wind turbines are mainly under dynamic loading patterns, which are induced by the action of the waves and the wind. In this paper the monopile structures are installed in two different sand deposits with considering a shallow water depth of 5m, and the load acting on the tower’s head is considered to be static. By considering the pile/tower as an elasto plastic material and considering a static load condition, the ultimate lateral capacity of the monopile structures can be checked in respect to the methods adopted by Broms (1964), Fleming et al (1992) and Zhang et al (2005) to illustrate, which method is well suited for these structures. Although, many monopile designers only consider the stiffness of the structure, it is crucial to study the ultimate lateral capacity of such structures too, as there have been reports of total failure of such structures around the world. In addition, by considering a static load scenario it can be illustrated, which component, that is the pile/tower or the soil is more likely to fail under a lateral loading regime, similar to the centrifugal tests conducted by Stone et al (2010) and Lehane et al (2010) on piled footing structures.

In this paper, the stiffness and the ultimate lateral capacity of monopile