ABSTRACT

Offshore wind farms are developing rapidly to mitigate global climate change. Currently, monopiles, circular steel pipe piles ranging from 4.0 m to 7.5 m in diameter, dominate the offshore wind turbine foundations. Many planned offshore wind farms will be founded in the North Sea in sandy soil. At present, the monopile foundation design is based on guidance from the offshore oil and gas industry (API, 2007; DIN, 2005; DNV, 2011; GL, 2005). However, the load conditions of offshore wind turbines are quite different from the offshore oil and gas structures. Offshore wind turbines are dynamically sensitive and subjected to large moments and strong lateral loading, while offshore oil and gas structures are dominated by the hugh self-weight. Therefore, the guidance for offshore oil and gas foundations is not always appropriate for natural frequency of offshore wind turbines. Considering the lack of knowledge regarding the monopile response of offshore wind turbine in the guidance, centrifuge tests were carried out on monopile foundations in dry sand to better understand the fundamental natural frequency of offshore wind turbines.

Results from the shear wave velocity measurement agreed with existing theoretical values in the literature. Expressions related to effective stresses and small-strain shear moduli were established in both loose and dense sand based on the results. The natural frequencies of tested piles were measured according to four variables including pile diameter, pile embedment depth, pile free length and relative density of sand. Results suggest that the pile diameter has a significant impact on the natural frequency. In the centrifuge test, 1.9 m diameter monopiles had natural frequencies 3.65 times higher than the 0.635 m diameter monopiles, indicating that the natural frequency can increase rapidly with the growth of monopile diameter. Regarding pile free length, the 1.9 m diameter pile groups and the 0.635 m diameter pile groups both experienced a decline in approximately 35% in the natural frequency as the free length increased from 10 m to 15 m. The results indicate that if the free length of monopile increases, the natural frequency will decrease. Results also showed pile embedment depth and relative density of sand have a slight impact on the natural frequency. The natural frequency increased linearly as the embedment depth increased. The natural frequency is slightly higher in dense sand than in loose sand. These four parameters should all be carefully considered in the monopile design. A simple model was also established to estimate the mass of soil participating in the vibration, which can be in turn used to predict the natural frequency with the known soil mass.