Parametric Study of Inclined Pile Ultimate Capacity in Clay as Anchoring Solution for Deep Water Floating Wind Turbines

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ABSTRACT

The increase in investment in offshore wind farms and floating wind turbines due to environmental and energy needs has resulted in increased size of the rotors and going farther out to the sea where the winds are stronger. Consequently, the mooring systems must be designed for larger loads and deeper waters. With the trend towards deeper water applications, depending on the distance between the wind turbines in an offshore wind farm, the mooring load angle at the anchor’s padeye can vary from 30° in catenary systems up to more than 45° from the horizontal plane in taut systems. This fact highlights the importance of designing anchor systems with large vertical load components. A parametric investigation of the mooring capacity of inclined piles in comparison with vertical piles driven in extremely soft to very soft clay is conducted using finite element methods (FEM). The results show that pile inclination up to 30° can increase the mooring capacity by more than 50%. The study shows that the reduced mooring capacity due to large mooring angle of taut systems can partially be compensated by pile inclination. In addition, simple empirical models are developed to predict anchoring capacity and inclination efficiency. The model for anchoring capacity can estimate the capacity calculated by FEM with very good accuracy.

KEY WORDS: Floating Wind Turbine; Mooring Angle; Inclination Angle; Inclination Efficiency; Anchoring Capacity; Taut Mooring.

INTRODUCTION

The increase in investment in offshore wind farms and floating wind turbines due to environmental and energy needs has resulted in increased size of the rotors and going farther out to the sea where the winds are stronger (Equinor, 2023). While European trends show a clear tendency towards wind power projects being consented and planned in deeper waters, developing wind power projects in some areas poses technical challenges. Mooring difficulties related to deep waters, larger loads due to excessive wave heights, and non-homogeneous seabed conditions are identified as the main challenge (NVE, 2013).

Anchoring system solutions for deep-water floating offshore wind turbines can vary depending on the soil type and water depth. Piles, suction anchors, drag anchors, suction-embedded plate anchors and dynamically penetrated anchors are among the conventional anchoring solutions (Randolph, et al., 2005).

Monopiles and suction piles are widely studied and used as foundation solutions for seabed structures and floating structures (Andersen et al., 2005; Tjelta, 2015; Equinor, 2023; Nazari et al., 2020). Using these foundation solutions coupled with catenary or taut-line mooring systems are widely adopted to moor floating facilities for offshore oil and gas developments and are a potential anchoring solution for floating renewable energy facilities.

The padeye level should be selected such that the rotation of the pile is minimized and the displacements are only in form of translation in order to maximize the anchoring capacity. The horizontal capacity is maximized by positioning the padeye such that the suction anchor translates at failure without rotating. To maximize the holding capacity, it is common to attach the mooring line to the suction caisson at 60 to 70% of the embedded depth (Xiong et al., 2017). Likewise, Andersen et al. (2005) recommended positioning the padeye at 0.65 to 0.70 of the pile’s embedded depth for lightly overconsolidated clay, with the optimal depth decreasing slightly with increased loading angle. Andersen and Jostad (1999) suggest positioning of the padeye just below the optimal depth in order to ensure backward rotation at failure, thus reducing the potential for a crack to open at the trailing edge of the suction anchor.

Large trenches have been observed as a result of anchor chain-soil interaction in multiple offshore projects. Trenches extend backwards from where the chain emerges from the seabed under ambient mooring loads to relatively close to the caisson and with depths approaching the padeye depth (Sun et al., 2020). One of the first cases has been reported in the public domain by Bhattacharjee et al. (2014). Rui, et al. (2020) showed formation of visible trenches for significant mooring tension amplitudes in low-strength soils. Sun et al. (2020) identified three different types of mechanisms, namely trenching, tunneling and remolding in front of the suction anchor. The trenching mechanism is in the form of a progressive opening of a slot in the seabed by further