The seismic performance of suction caisson anchors subjected to tensile loading for floating offshore wind turbines

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ABSTRACT

This study investigates the seismic performance of a suction caisson anchor with static vertical tensile loading using 3D finite element analysis, in the context of a floating offshore wind turbine tension leg platform. A non-linear dynamic analysis was conducted using the advanced UBC3D-PLM constitutive model calibrated against cyclic element tests and centrifuge experimental data. Orthogonal horizontal and vertical components of a strong ground motion were applied to the model with varying peak ground acceleration and vertical tensile loading applied to the anchor. The results suggest resilience to anchor pull-out during seismic loading in liquefiable soils, even with vertical tensile loading applied at twice the drained vertical tensile capacity of the anchor and subject to seismic loading at a PGA of 0.5g.

KEY WORDS: Liquefaction; UBC3D-PLM constitutive model; suction caisson; tensile loading, finite element; floating offshore wind.

INTRODUCTION

Floating offshore wind is expected to generate 300GW by 2050 (DNV, 2023), unlocked by the development of vast areas of ocean considered too deep for fixed bottom foundations. Interest in the technology has been shown globally including in the UK, Europe, US, Brazil, Australia and Asia. Many of these regions are seismically active, and an important design consideration is the liquefaction potential of the seabed, which could reduce the capacity of the holding anchor and lead to pull-out failure.

The first arrays of floating offshore wind turbines (FOWTs) have been deployed in shallow water at significant cost (e.g. Hywind Scotland, Kincardine, and WindFloat Atlantic). To reduce the levelized cost of energy (LCOE) shared moorings (Hall and Connolly, 2018; Connolly and Hall, 2019; NYSERDA, 2021), shared anchors (Diaz et al, 2016; Hallowell et al, 2018; Fontana et al., 2018, Chen et al, 2021, Pillai et al. 2022), novel concepts for mooring (e.g. HoneymoonTM and tendon leg platform (TLP) designs are being proposed (e.g. Hexicon’s TLP, Glosten’s PelaStarTM). There is also consideration to transition from catenary to semi-taut or taut mooring (Catapult, 2022). In shallow or deeper water, many of these designs will require anchors that are axisymmetric and can sustain vertical tensile loading.

There has been little research on the seismic performance of anchors within liquefiable soils. One study using an advanced soil constitutive model focused on catenary mooring and the performance of the suction caisson anchor after seismic loading was maintained (Esfeh and Kaynia, 2019). Other researchers simulated a TLP anchored with a slender pile, taking into account the pile-tendon-platform interaction and suggested pile head displacements during liquefaction are sustainable (Tsiafas et al., 2021; Chaloulos et al., 2021). The seismic performance of suction caisson anchors subject to tensile loading in liquefiable soils is less well investigated. Industry guidance that relates to the seismic design of anchors for FOWT is also limited, and the seismic design of anchors is often assessed under the ISO standards (ISO 19901-2, 4 & 7) adopted by the oil and gas sector, that can lead to conservative and costly design.

This study models the seismic performance of a suction caisson anchor installed in undrained loose to medium dense sand with static vertical tensile loading using 3D finite element (FE) analysis, in the context of a FOWT TLP, or moorings that develop vertical tensile loading on the anchor. A non-linear dynamic analysis was conducted using the advanced UBC3D-PLM constitutive model, calibrated against cyclic element tests and centrifuge experimental data. Seismic loading was applied to the model scaled to different peak ground accelerations (PGA). To assess the potential for anchor pull-out during seismic loading in liquefiable soils, static vertical tensile loading was applied to the anchor at twice the drained vertical tensile capacity. The results are presented in terms of pore pressure generation, excess pore pressure ratio r_u, accumulation to the onset of liquefaction, and anchor displacement.

METHODOLOGY

Anchor and loadings

The modelling scenario consisted of a suction caisson anchor with diameter 10m, height 15m and wall thickness 0.04m. The anchor has a drained vertical tensile capacity of 14400kN, determined through pull-out tests conducted in the FE model. The anchor was sized to have a capacity in excess of the anchor loads predicted by modelling a 5MW FOWT TLP under severe sea states (NREL, 2010). The capacity of the anchor in the upper 3m was neglected to allow for potential scouring