

Undrained Capacity of Suction Piles Subjected to Moment Loading

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In this study, undrained capacity of suction piles subjected to moment loading is examined using three-dimensional finite element analysis. The model was initially validated against well-established results in literature. The model was then used to investigate the effect of moment loading on vertical and torsional capacity by performing a sensitivity analysis by varying soil heterogeneity and suction pile geometry. The parametric study was carried out for suction piles with length to diameter ratios (L/D) varying from 1 to 7 embedded in soils with constant and linearly varying shear strength. The failure envelopes presented provide a better understanding and a simpler and quicker design method that can be readily used for the design of suction piles.

INTRODUCTION

Suction piles have been widely employed in the offshore energy industry to support various structures used for exploitation of oil and gas (e.g., for temporary or permanent mooring of floating offshore facilities), as well as offshore wind turbines. They have advantages over other conventional offshore foundation systems because of their large capacity and their relatively simple installation procedure. They are installed by pressure drawdown within the cylinder, referred to as “suction,” after partial penetration of the pile as a result of its submerged weight. These suction piles may be subjected to combined loading resulting from the submerged weight of the structure, environmental conditions, fishing gear interaction, and expansion or contraction of pipelines and jumpers. These loads applied to subsea structures—which are not generally applied at the centreline of suction pile on the seabed—will create moment and torsion applied to the suction pile.

The behaviour of suction piles can be investigated using experimental, analytical, or numerical approaches. Physical experiments are generally time-consuming and costly (Randolph and House, 2002; Wallace and Rutherford, 2017). Analytical methods are constrained to idealised cases (Aubeny et al., 2003; Zhang et al., 2010; Zhang and Ahmari, 2013). However, numerical simulations provide a suitable alternative to study the behaviour of suction piles under complex loading conditions.

A number of researchers have used numerical methods to study the behaviour of suction piles. These approaches have been applied extensively to shallow foundations in the past (Abyaneh et al., 2015, 2017, 2018; Bransby and Randolph, 1998). Zdravkovic et al. (2001) employed numerical analysis to investigate the effect of load inclination, skirt length, foundation diameter, soil adhesion, and soil anisotropy on the pull-out capacity of bucket foundations in soft clay. Taiebat and Carter (2005) performed three-dimensional finite element analyses to investigate the behaviour of caissons embedded in a homogeneous soil deforming under undrained conditions. The performance of the

caisson under separate axial (vertical), lateral, and torsional forces was investigated first, followed by the interaction of these forces with each other. Similar studies have been conducted to investigate the behaviour of suction piles under combined loadings (Chik et al., 2009; Mroueh and Shahrour, 2009; Hung and Kim, 2012, 2014; Ahn et al., 2014; Suroor and Hossain, 2015; Nouri et al., 2017; Saviano and Pisanò, 2017). However, to the authors’ knowledge, the effect of moment on the capacity of suction piles has not been investigated using numerical approaches.

This paper presents a three-dimensional numerical study of the effect of moment loading on vertical and torsional capacity of suction piles using a finite element approach. Different suction pile aspect ratios and soil strength profiles were adopted in the simulations. The model was first verified by comparing the results against well-established results in literature. The model was then used to examine the effect of moment loading on vertical and torsional capacity by performing parametric study varying aspect ratios and soil strength profiles.

DESCRIPTION OF THE MODEL

Finite element analyses were carried out using PLAXIS 3D (Brinkgreve et al., 2015). To facilitate finite element analysis, Python scripts have been developed to automate all preprocessing, processing, and postprocessing steps. The use of scripts has been further simplified by implementing it in an Excel spreadsheet. All the user has to do is to enter the input values into the Excel spreadsheet, which is then used for preprocessing, processing, and postprocessing, which will be performed automatically. The application of these scripts to conduct finite element analysis has numerous advantages. For example, finite element analysis can be carried out by users with minimum numerical knowledge or experience, as running the scripts is very simple, although it is still recommended that the results be checked by a numerical expert. Moreover, finite element analysis can be conducted more efficiently and consistently because all preprocessing, processing, and postprocessing steps are automated. This will result in a significant reduction in the development/design time and, consequently, enable the sensitivity analysis required for a research investigation or design optimization to be done within a reasonable time. Details of the models are provided in the following sections.

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KEY WORDS: Suction pile, bearing capacity, clay, combined loading, moment, finite element, design.