Undrained Capacity of Surface Footings Subjected to Combined V-H-T Loading

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ABSTRACT

Subsea structures such as pipeline end terminations (PLETs) or pipeline end manifolds (PLEMs) can be subjected to combinations of vertical (V), horizontal (H) and moment (M) loadings, during installation and normal operational conditions. In addition these structures may also experience significant horizontal loads and torsional loads from fishing gear interaction or when pipeline jumper connections are made which result in a more stringent design condition than the in-plane (V-H-M) loading.

In this paper, the combined vertical, horizontal and torsion (V-H-T) load capacities of circular, square and rectangular surface foundations have been studied numerically. 3D finite element analyses have been coupled with simplified analytical methods to produce failure envelopes of the foundations for undrained clay conditions. Horizontal load has been applied in both longitudinal and transverse directions of the rectangular footings subject to torsional loading.

The results confirm that H-T load combinations produce only shear failure immediately below the base of foundation. Therefore the horizontal and torsional capacity can be determined directly using the interface shear strength between the foundation and soil. In addition, the results show that H-T failure envelopes are a function of the length (L) to breadth (B) ratio where B is the foundation dimension normal to the horizontal load direction and L is the foundation dimension in the horizontal load direction. Finally, modifications to the V-H-M failure envelope are suggested to account for the resultant reduction in the ultimate sliding capacity as a proportion of the ratio of applied torsional load and ultimate torsional capacity.

KEY WORDS: Surface footings, Foundations, Offshore, Torsion, Numerical modelling.

INTRODUCTION

PLET (Pipe Line End Terminations) structures typically comprise a bottom structure frame (mudmat) and main structural frame which supports the pipeline connectors and an installation system. To protect the PLET from dropped objects and fishing trawls, a protection structure is also sometimes included in the design. The PLET bottom structure frame or mudmat distributes the load from the main frame to the seabed while the main structural frame supports valves, hubs and installation aids. (Antani et al. 2008)

Due to the loads from the connectors on the main frame, the mudmat is commonly subjected to combinations of vertical, horizontal and torsional loading. When the loads applied at valves or hubs are orthogonal to the pipeline and load application points are located far away from the centre of the structure, torsion loading becomes a major load component. In particular, if a fishing trawl board makes contact with the edge of structure then the mudmat is predominantly subjected to horizontal (sliding) and torsion loads.

Various studies regarding the behaviour of caissons and piles subjected to combined axial and torsion loads have been conducted numerically and experimentally (e.g. Randolph, 1981, Chow, 1985, Georgiadis, 2005 and Taiebat and Carter, 2005). However, there have been very little investigation on surface footings subjected to combined sliding and torsion loads. Finnie and Morgan (2004) presented equations to assess pure torsional capacity. They also proposed relationship between torsional and sliding as follows;

\[
\left( \frac{H}{H_o} \right)^n + \left( \frac{T}{T_o} \right)^m = 1
\]

where, H and T are the mobilised horizontal and torsion load and H_o and T_o are the ultimate capacities. The powers, ‘n’ and ‘m’ are dimensionless parameters depending on foundation geometry. For circular and square foundations, they recommended \( n = m = 1.75 \) and for rectangular foundation ranges for \( n = 1 - 2 \) and \( m = 2 - 2.5 \) were suggested. However, the equations proposed have not been rigorously investigated under combined loads, especially under the combination of V-H-T and for the directional effect of the horizontal load application on a rectangular foundation.

The aim of this paper is to extend study of shallow foundation capacity to include failure mechanisms under combined vertical, horizontal and...