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The Effect of Skirted Foundation Shape on Response to Combined V-M-H Loadings

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ABSTRACT

The behaviour of skirted strip footings and circular footings subject to combined vertical, horizontal and moment loading has been studied using finite element and plasticity analysis of equivalent surface foundations. The shape of the yield locus for the two foundation geometries was found to be similar but the pure vertical, moment and horizontal capacities varied with the footing shape and soil strength profile. Design methods to allow for footing shape and soil strength profile have been recommended.

INTRODUCTION

When designing offshore foundations it is necessary to be able to calculate their capacity under monotonic combined total vertical (V), moment (M) and horizontal (H) load, as these are often the limiting conditions due to environmental loading.

Many design methods have been recommended to calculate the vertical capacity of strip or circular footings in uniform strength material, but these often rely on empirical shape factors rather than rigorous analysis to allow for the effect of the footing shape on the bearing capacity. Little work has been done to account for the effect of footing shape on the combined vertical, horizontal and moment loading response, especially in nonuniform soils.

Recent bearing capacity analysis of offshore footings subject to combinations of V, M and H loading has used the yield envelope concept (Tan, 1990; Murff, 1994; Butterfield and Gottardi, 1995; Houlsby and Martin, 1992; Dean et al., 1992; Salencon and Pecker, 1995; Ngo-Tran, 1996). For a given footing penetration, a yield envelope in V-M-H space describes the maximum loads that can be applied before failure and corresponding plastic footing penetration occurs. The yield envelope is written as:

$$f\left(\frac{V}{As},\frac{H}{As},\frac{M}{ADs}\right) = 0 \qquad (1)$$

where A is the area of the foundation, D is its diameter or breadth, and s is a representative soil strength or effective stress.

In order to be able to use the theorems of plasticity with the yield locus, displacements are measured at the points at which the loads are taken to act. Consequently, the normalised plastic work, W/ADs, can be written as:

$$\frac{W}{ADs} = \left(\frac{V}{AS}\right)\frac{\delta v}{D}+\left(\frac{H}{AS}\right)\frac{\delta h}{D}+\left(\frac{M}{ADs}\right)\delta\theta \qquad (2)$$

where $\delta v/D$ is the normalised incremental vertical footing displacement, $\delta h/D$ is the normalised incremental horizontal displacement, and $\delta\theta$ is the incremental footing rotation.

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KEY WORDS: Skirted shallow foundations, undrained, yield locus.

Bransby and Randolph (1997a) carried out both finite element analysis and upper bound plasticity analysis to investigate the behaviour of strip footings under combined loadings. Good agreement between the FE and upper bound results confirmed the accuracy of both analyses and the possible use of upper bound analysis as a design method. Recommendations were also given for a curve fit to describe the shape of the yield locus in full V-M-H space (Bransby and Randolph, 1998).

GEOMETRY OF SKIRTED FOUNDATIONS

Skirted foundations are being used increasingly offshore as an alternative to deep foundations in soils with low strength at the surface. In calcareous soils, where prediction of vertical pile capacity is problematical, they form a particularly attractive alternative to traditional foundations. The foundations consist of a footing with vertical skirts around the circumference (and sometimes internally) which penetrate the soil vertically and thus constrain its lateral movement beneath the footing. During vertical undrained loadings, the soil beneath the footing is fully constrained and so the load is transferred to the depth of the skirt tips where the soil is stronger, thereby increasing its bearing capacity. Skirted foundations also have uplift capacities of similar magnitude to their bearing capacity (Watson and Randolph, 1997) as suction within the skirt on pull-out leads to an inverse bearing capacity mechanism.

For any normally consolidated seabed deposit the undrained shear strength, s_u, will increase almost proportionally with depth, z. This is expressed as:

$$s_u = kz \qquad (3)$$

where k is the undrained shear strength gradient.

Immediately beneath the skirt tips, the undrained shear strength of the soil is defined as s_{uo}. As the strength is increasing with depth, this will affect the bearing capacity of the foundation. A dimensionless soil nonhomogeneity factor kD/s_{uo} is introduced to describe this variation with depth. For a skirted foundation in normally consolidated soil, $s_{uo} = kd$ and so $kD/s_{uo} \equiv D/d$.

Skirted foundations may often be approximated as circular in plan. However, previous analysis (Bransby and Randolph, 1997a, 1997b, 1998) investigated the behaviour of an equivalent surface strip footing in order to understand the main mechanistic behaviour of these types of foundations without the large computational requirements for full 3D finite element analysis. In this