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H-adaptive FE Analysis of Bearing Capacity of Skirted Foundations

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ABSTRACT

This paper reports the results of finite element and upper bound calculations of the bearing capacity of offshore skirted foundations, embedded in cohesive soil where the strength varies linearly with depth. The finite element method uses *h*-adaptive mesh refinement, where the strain error is first evaluated by means of superconvergent patch recovery (SPR) techniques, and is then used for mesh density control. The mesh density is also related to the degree of non-homogeneity of soil and the criteria for minimum element size and displacement increment are chosen to give accurate finite element results. The finite element values of bearing capacity are shown to be bounded by the upper bound solutions and previously published lower bound values, demonstrating the reliability of the approach. It is also found that the soil above the level of the skirt tips contributes significantly more to the bearing capacity for circular foundations than for strip foundations.

KEY WORDS: bearing capacity; offshore skirted foundation; non-homogeneous soil; plasticity solutions; finite element analysis; *h*-adaptive mesh refinement

INTRODUCTION

In offshore engineering, shallow skirted foundations are being used increasingly as alternatives to deep (piled) foundations to support huge gravity structures for hydro-carbon extraction, even where the seabed comprises soft sediments. Skirted shallow foundations are more attractive because of the ease of installation, particularly the much shorter installation time, which can be a significant consideration in areas subjected to frequent rough weather.

In soft sediments, the variation of shear strength with depth is a critical factor, both in determining the necessary skirt depth, but also as it affects the bearing capacity factor relating the ultimate vertical foundation stress to the undrained shear strength at the level of the skirt tips. The present paper focuses in particular on situations where the undrained shear strength s_u increases more or less linearly with depth z, expressed as:

$$s_u = s_{um} + kz \qquad (1)$$

where s_{um} is the soil strength intercept at mudline (the seabed) and k is the strength gradient. Due to the large size of foundations, the degree of non-homogeneity kB/s_{um} (B is the foundation width or diameter) can be very high. Therefore the non-homogeneity of the soil cannot be ignored in bearing capacity analysis. Additionally, the presence of the soil above the level of the skirt tip may enhance the bearing capacity, especially where the skirt depth exceeds 20 % of the foundation width.

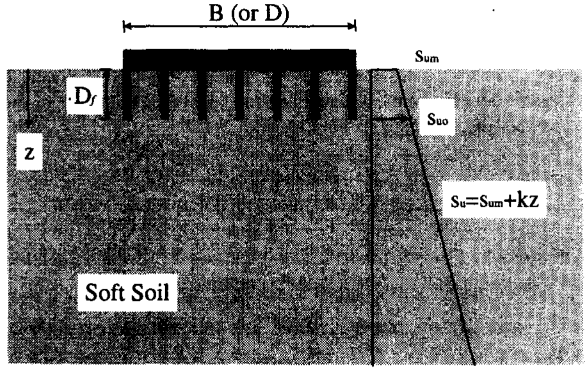

Figure 1. Skirted foundation on soft soil

The bearing capacity of foundations with pre-embedment on non-homogeneous soil has been studied by many researchers using plasticity theory. Martin (1994) looked at the bearing capacity of spudcan foundations for jack-up rigs, using a computer implementation of the method of characteristics. He examined the effect of foundation embedment in combination with those of the angle of the conical spudcan base, roughness of the base, and strength gradient with depth. He presented lower bound estimates of bearing capacity factors. A more extensive lower bound study for flat rough foundations with limited embedment has been published by Tani and Craig (1995), again based on the method of characteristics.

In numerical analysis, the finite element method has been used extensively in engineering design. However, the accuracy of the numerical results is still a major concern, particularly where non-linear material response occurs. Here, finite element analysis is undertaken, in which optimal meshes are generated using *h*-adaptivity based on a