

Implementation of a Force-Resultant Model Describing Spudcan Load-Displacement Behaviour Using an Implicit Integration Scheme

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ABSTRACT

This paper describes the numerical formulation of a force-resultant model describing the elasto-plastic load-displacement behaviour of a spudcan foundation in clay. The formulation uses an implicit integration scheme, which has the advantages of numerical efficiency and insensitivity to increment size. Importantly to the user, step-size does not require determination before investigating “unknown” problems. Implementation of the model as a user element subroutine for the commercially available finite element program ABAQUS is described. The formulation presented ensures optimum compatibility with the incremental-iterative solution scheme employed by ABAQUS itself, and therefore allows efficient integration with the range of structural elements available in ABAQUS. The implementation is verified against established analysis problems, including the pushover of a jack-up structure.

KEY WORDS: macroelement, force-resultant model, spudcan, jack-up, clay, offshore engineering

INTRODUCTION

Numerous “force-resultant” models based on the framework of work-hardening plasticity theory have been developed to encapsulate directly the load-displacement behaviour of shallow foundations on various soil types. A key motivation for this has been the ability to incorporate such models within standard structural finite element programs, though few methods for achieving this have been published. Therefore, this paper comprehensively describes an appropriate numerical formulation.

A force-resultant model describing the behaviour of the inverted conical “spudcan” footings found on offshore jack-up platforms is used as the illustrative example. The model was developed by Martin (1994) and Martin & Houlsby (2001), and is named Model B. Here the model is implemented as a user element (UEL) subroutine, coded in FORTRAN, for the commercial finite element program ABAQUS

(HKS, 1998). An implicit integration algorithm is adopted, and the resulting advantage of insensitivity to increment size is demonstrated. Verification of the integrated structural-geotechnical analysis capability is provided through a monotonic pushover analysis using ABAQUS two-dimensional beam elements for the jack-up structure, while the foundations are simulated using multiple instances of the Model B user element.

NUMERICAL MODELLING TECHNIQUE

Foundation Model

Model B was developed to predict the load-displacement response of spudcan footings on clay soil under combined vertical, moment and horizontal (V, M, H) loading. The model is based on strain-hardening plasticity theory and is analogous to classical soil plasticity models such as Cam Clay. However, instead of using stresses and strains, it is formulated using the footing force-resultants (V, M, H) and their work-conjugate displacements (w, θ, u) defined in Fig. 1. A full description of Model B is available in Martin (1994) and Martin & Houlsby (2001), and therefore only a succinct version is presented here. The model comprises four basic components:

1. Yield function: defines an enclosed boundary of elastically attainable states of load. The full six-parameter yield surface is shown in Fig. 2 and is expressed in functional form as:

$$f(V, M, H, w^p) = \left(\frac{M}{2Rm_0 V_0} \right)^2 + \left(\frac{H}{h_0 V_0} \right)^2 - 2e \left(\frac{M}{2Rm_0 V_0} \right) \left(\frac{H}{h_0 V_0} \right) - \bar{\beta}^2 \left(\frac{V}{V_0} \right)^{2\beta_1} \left(1 - \frac{V}{V_0} \right)^{2\beta_2} = 0 \quad (1)$$

where the eccentricity of the elliptical cross-sections in the $M-H$ load plane is determined by: