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Continuous Pipe Penetration in Clay

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ABSTRACT

The load-penetration response of a pipe in clay is of fundamental importance to the on-bottom stability assessment of a pipeline and the interpretation of T-bar penetrometer data. This paper aims to summarize the findings of a series of large strain large deformation numerical analyses performed to simulate the continuous load-penetration response of a smooth pipe section with particular emphasis on the transition from a shallow bearing capacity mechanism to a deep plastic flow mechanism and elucidates on the practical implications of the key findings.

KEY WORDS: Pipe; penetration, on-bottom stability; clay; finite element, Eulerian

INTRODUCTION

In a deepwater oil and gas development, a pipeline is often laid directly on the seabed. The on-bottom stability of the as-laid pipeline is strongly influenced by the pipeline embedment depth. The pipeline embedment depth has a significant effect on both the hydrodynamic loads acting on the pipeline as well as the lateral soil resistance provided by the seabed. Therefore, an accurate prediction of the vertical load-penetration response of a pipe section, especially at embedment depths of up to 0.5 pipe diameter, is imperative for a reliable on-bottom stability assessment.

The second area of interest in which the vertical load-penetration response of a pipe is of particular interest concerns the adoption of a T-bar penetrometer for measuring the undrained shear strength, s_u of cohesive soils, especially in soft deepwater sediments. The current state-of-practice involves the adoption of a constant T-bar factor of 10.5 for the conversion of T-bar penetration resistance to the undrained shear strength of the soil. White et al. (2010) pointed out that a constant T-bar factor is only applicable when the full-flow mechanism is operative. Puech et al. (2010) further noted that there is insufficient information on the failure mechanisms at very shallow penetration, especially within the first 0.2-0.3 m below seafloor.

Prior to the recent work of White et al. (2010), this subject has been primarily addressed in a discontinuous manner by separating penetration response into two broad categories of shallow penetration and deep penetration. This paper aims to summarize the findings of a series of large strain large deformation numerical analyses performed to simulate the continuous load-penetration response of a smooth pipe section with particular emphasis on the transition from a shallow bearing capacity mechanism to a deep plastic flow mechanism. This paper focuses on the practical implications of the key findings. The full detail of the numerical studies can be found in Tho et al. (2012b).

NUMERICAL MODEL

Due to difficulties associated with severe mesh distortion, a Lagrangian-based finite element analysis is incapable of simulating continuous pipe penetration into the seabed. As the analysis proceeds, severe mesh distortion leads to the subsequent imminent termination of the solution process due to negative volume phenomenon. The Eulerian finite element technique in which the finite element mesh remains stationary throughout the analysis while the material is allowed to move from element to element is found to be particular viable for such problem. The spatial position of the nodes is fixed and the finite element mesh undergoes zero distortion during the analysis. Consequently, mesh distortion does not occur despite the material undergoing large deformation and the problem associated with severe mesh distortion as in the case of a Lagrangian analysis is naturally circumvented in an Eulerian analysis. Further details on the application of the Eulerian finite element technique to simulate penetration problems in geomechanics can be found in Tho et al. (2012a).

The Coupled Eulerian-Lagrangian analysis technique in Abaqus/Explicit is employed for the analysis. The pipe is modeled as a Lagrangian rigid body and the soil domain is modeled as an Eulerian deformable body. The schematic representation of the finite element model is shown in Fig. 1. Owing to symmetry, only half of the pipe and the corresponding soil domain need to be included in the finite element model. In the simulation, the pipe is prescribed a displacement of 10 times its diameter and the corresponding reaction force acting on the reference point at the centroid of pipe is recorded. The Tresca material model with an associated flow rule is adopted to model the clay. A consistent E_u/s_u ratio of 300 is adopted for all analyses and undrained condition is simulated by setting the Poisson's ratio to 0.495.