A 3D elasto-plastic soil model for lateral buckling analysis

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ABSTRACT

Modeling the lay-down of pipelines and subsequently the in-service conditions for a pipeline involves definition of a pipe-soil interaction model. A generalized true 3D elasto-plastic spring element based on an anisotropic hardening/degradation model for sliding is presented. The basis for the model is the elasto-plastic framework. A generic format is selected, allowing different yield criteria and flow rules to be implemented in a simple way. The model complies to a finite element format allowing it to be directly implemented into a standard finite element code. Examples demonstrating the robustness of the model are presented.

INTRODUCTION

Modeling the installation and subsequent service condition of a pipeline is a complex task. The models for global analysis of a pipeline are most often based a Winkler approach. The models must thus comprise a robust beam description allowing for large displacements and a strategy for contact with the seabed. Once in contact, the interaction between the pipeline and the seabed must be described in a simple, yet realistic way. During pipelay the model should be able to describe touchdown with over-penetration and possible vertical suction breakout if the contact point is lifted later on as well as horizontal movements of the pipeline. In the operation phase when the pipeline is unburied or partially buried, the lateral soil resistance plays a significant role in on-bottom stability and lateral buckling. This paper concentrates on the modeling of unburied and partially buried pipelines and apply mainly to deepwater pipelines, where the loads governing the design are those related to walking (ratcheting) and lateral buckling, White and Randolph (2007).

Browsing the literature on this topic reveals a significant emphasis on experimental investigations of the problem using e.g. physical modeling in centrifuges or large-scale testing, Lambrakos (1985), Bruton et al. (2006), Bruton et al. (2007) and Cheuk et al. (2007). The experimental work gives valuable information on principal behavior and is vital for the calibration of models. Several parametric models have been developed accounting for vertical and horizontal resistance, Cathie et al. (2005) and White and Randolph (2007). However, the implementation of these observations into design models based on numerical methods appears to be restricted to Winkler models formulated in terms of systems of 3 uncoupled springs i.e. in vertical, lateral and axial direction. Moreover, several papers have been considering the relationship between vertical and lateral resistance (V-H

space), Cathie et al. (2005), White and Randolph (2007), but the generalization into three dimensions seems to be missing.

In this paper we will present a simple and robust 3D model based on elasto-plasticity that is able to capture what the authors assess to be the most significant effects related to deep-water pipelines. Therefore issues like wave and current induced liquefaction are not considered. However, looking at the lateral response of pipelines under liquefaction, Foray et al. (2006), the overall behavior appear to follow the same patterns, hence the present model may with a few corrections be used for such applications as well.

PIPE-SOIL INTERACTION CHARACTERISTICS

Once in contact, the interaction between the pipeline and the soil can be described in terms of 3 degrees-of-freedom; penetration into the seabed (normal to the seabed), axial movements along the axis of the pipeline and lateral movement perpendicular to the pipeline. For each degree-of-freedom a model needs to capture certain characteristics.

Lateral resistance of partially embedded pipelines

The main purpose for developing the present model for pipe-soil interaction is to be able to account for the lateral resistance of unburied or partially embedded pipelines in case there is risk of e.g. lateral buckling. As emphasized e.g. by the SAFEBUCK project, Bruton et al. (2006), the lateral resistance is highly dependent on the magnitude of the lateral movement as well as by the load history. Considering Fig. 1 the resistance can be divided into various phenomena:

(1) At monotonic loading the lateral resistance curve exhibits at first a rather stiff, almost linear elastic response until it reaches the peak resistance. As the lateral movement increases further, the resistance level will gradually decrease to a residual resistance level. This might cause instability leading to e.g. lateral buckling of a pipeline.

(2) If the pipeline is unloaded the response is almost linear elastic until the lateral resistance is reached in the opposite direction.

(3) During cyclic loading it is observed that the overall behavior resembles that of the monotonic condition. There exists a peak, which is traditionally attributed to suction. Once this suction is released the lateral resistance reduces to a residual resistance.