Proceedings of the Eighteenth (2008) International Offshore and Polar Engineering Conference
Vancouver, BC, Canada, July 6-11, 2008

ISBN 978-1-880653-70-8 (Set); ISBN 1-880653-68-0 (Set)

Finite element analysis of the vertical penetration of 'on-bottom' pipelines in clay

Mark Fraser Bransby, Piotr Zajac, Shiraz Amman
Civil Engineering, University of Dundee
Dundee, Angus, UK

ABSTRACT

This paper reports a series of finite element analyses which were conducted to investigate the relationship between vertical pipeline load and pipeline burial for a pipeline resting on soft, undrained clay. The analyses investigated particularly the changes in deformation mechanism in the soil as burial increased and the effect of surface heave caused by the embedment on the bearing capacity. Results are presented from two different types of FE analysis. In one set, the pipeline was installed from above the soil surface using a large-strain formulation and soil heave occurred around the pipeline. In the second set of analyses, the pipeline was 'wished-in-place' at different embedment depths and penetrated vertically to failure using a small-strain formulation. The vertical capacity penetration curves from the two sets of analyses are compared with each other and with previously published solutions. Results show that the effect of the surface heave is not significant, but the unit weight of the soil should be considered when calculating the penetration depth of a pipeline.

KEY WORDS: pipeline, bearing capacity, 'on-bottom' stability, undrained.

INTRODUCTION

Offshore pipelines are often buried beneath the seabed to protect them from fishing activity, anchor snag loads and environmental loading (e.g. Cathie et al., 2005). However, a cheaper solution is to lay the pipeline directly on the soil surface if suitable stability can be proven. Thus, there is increasing interest in the 'on-bottom' stability of pipelines. In particular, it is expected that in deep water soft clay sediments that hydrodynamic loadings are small and self-weight/installation burial depths are sufficient to generate reasonable lateral restraint (e.g. Cathie et al., 2005; Bruton et al., 2006; White & Randolph, 2007).

To ensure stability of a pipeline, the capacity of the pipeline has to be known under conditions of combined vertical and horizontal loading. The system has similarity with a other offshore shallow foundations which experience such load combinations (e.g. Butterfield & Ticof, 1979; Nova & Montrassio, 1991; Tan, 1990; Martin' 1994). The condition of a spud-can foundation in clay is particularly relevant and one appropriate design method is to use the work-hardening plasticity framework (e.g. Nova & Montrassio, 1991; Tan, 1990) for its solution (Martin, 1994; Martin & Houlsby, 2000). For this case, the size of the combined loading failure envelope is scaled by the vertical bearing capacity which work hardens with plastic penetration.

Zhang et al. (1999, 2002) used the plasticity framework to examine the capacity of pipelines resting in sand. To date, research on pipelines on clay soil, where the soil response is presumed to be undrained, has concentrated on laboratory tests (e.g. Wagner et al., 1987) and empirical models for pipeline stability (e.g. Verley & Lund, 1995). More recently White & Randolph (2007) and Hodder et al. (2008) suggested failure envelopes and plastic potentials for use in design and Bransby et al. (2008) presented preliminary numerical results showing vertical (V) – horizontal (H) failure envelopes for pipelines resting on undrained soil. Most of these methods concluded that the size of the V-H failure envelope scales with the vertical (downwards) capacity (V_o) which varies as the plastic penetration of the pipeline increases.

The aim of this paper is to investigate how the capacity, V_o of pipelines under pure vertical loading increases with the penetration depth of the pipeline. This allows later determination of the failure envelope by the use of recommended failure envelope equations (e.g. White & Randolph, 2007; Hodder et al, 2008) and also provides more knowledge of the effects of the installation process. A series of numerical finite element (FE) analyses have been conducted. The analyses investigate the vertical load-displacement relationship which links the applied vertical load (during installation, or due to pipeline self-weight) to its plastic vertical penetration and compares results with previously published solutions (e.g. Murff et al., 1989; Aubeny et al., 2005; Barbosa-Cruz & Randolph, 2005).

The problem geometry is indicated in Figure 1. A pipeline of diameter D is placed on the surface of the seabed during pipe lay. During installation, additional vertical loading of the pipeline is caused by the dynamics of the installation process and so this load and the self-weight of the pipeline provide a maximum vertical load, $V = V_{max}$. The vertical load provokes plastic penetration, z^p of the pipeline into the seabed. After installation, the dynamic loads cease and so the remaining vertical load on the pipeline is due solely to its buoyant self-weight, W