

Seabed Characterisation and Models for Pipeline-Soil Interaction

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ABSTRACT

Pipelines and flowlines represent major cost items in the development of deepwater fields. Accurate modelling of the axial and lateral pipe-soil resistance can lead to significant cost reductions by optimising design. Critical design issues include axial motion, or walking, of pipelines due to cyclic thermal changes, lateral buckling due to thermal expansion, and fatigue damage to risers in the touchdown region. Traditionally, interaction between a pipeline and the seabed has been simplified into frictional models for axial and lateral resistance during walking or buckling. Improving these models is a priority, but is hampered by (i) difficulties in characterising the behaviour of very low strength, near surface, seabed soils and (ii) a lack of detailed understanding of the soil mechanics of pipe-soil interaction. The cylindrical geometry of a pipeline invites comparison with the behaviour of tubular piles. Recent advances in pile design methods generated by considering the underlying soil mechanics indicate that the same potential exists for improving the understanding of pipeline behaviour. The paper describes recent advances in measuring the low shear strengths associated with near-surface seabed soils, using both in situ methods in the form of cylindrical (T-bar) and spherical penetrometers, and laboratory shear tests at very low effective stresses. The relationship between penetration resistance and the vertical and lateral resistance of pipelines is explored, taking account of the depth of burial, and cycles of movement. New approaches for assessing the axial and lateral resistance of on-bottom pipelines are described. Future trends and recent developments are summarised.

KEY WORDS: Pipelines; deep-water; shear strength; penetration resistance; friction; soil resistance, pipe-soil interaction

INTRODUCTION

New offshore oil and gas fields are being developed at increasing distance from land, and in increasingly deep water. As a consequence, the cost of in-field flowlines and pipelines exporting product to shore is of growing significance in the overall field development. In turn this has prompted generic and site-specific studies to improve design models in an effort to reduce costs without compromising reliability. At shallow and moderate water depths, the critical geotechnical design issues are generally associated with lateral stability of the pipeline under wave and current action. In deep water, however, the most critical design issues are more typically pipeline buckling and axial 'walking' or ratcheting, associated with thermal expansion and contraction of the pipeline with successive start-up and shut-down cycles.

In deep water it is rare for pipelines to be deliberately embedded, for example by trenching or ploughing. Instead, they are laid on the seabed, embedding by a certain amount through a combination of self-weight and the additional contact stresses acting in the touchdown zone during the laying operation. The amount of embedment, or penetration of the seabed, must be estimated in order to assess the in-

service resistance to axial and lateral motion. For pipeline diameters in the range 0.3 to 0.8 m, and seabed penetration by perhaps 20 to 80 % of the diameter, the seabed properties in the upper 0.1 to 0.7 m are crucial for design calculations. Accurate characterisation of the seabed at such shallow depths is challenging, not just because of the very low shear strengths exhibited by most deep-water deposits but also because of the very low effective stress levels (a few kPa only), and thus material response that falls outside the common experience for geotechnical design.

An overview of pipeline geotechnical design has been provided by Cathie et al. (2005). Additionally, a series of papers presented at the 2006 Offshore Technology Conference (Brown et al.; Brunner et al.; Bruton et al.; Carr et al., Mebarkia) summarise current industry practice in respect of the geotechnical design of deep-water, high temperature and high pressure pipelines. Over the last decade advances in understanding have come from joint industry projects such as SAFEBUCK (www.safebuck.com, Bruton et al. 2006) and HOTPIPE (Spinazze et al., 1999), which have included extensive physical modelling to explore pipeline-soil interaction during penetration, axial shearing and lateral motion under monotonic and cyclic displacement paths.

The present paper focuses on the fundamental aspects of pipeline-soil interaction under different modes of deformation, rather than the