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The Upheaval Capacity of Pipelines in Jetted Clay Backfill

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ABSTRACT

Offshore pipelines are often placed in the seabed by the process called jetting, which has implications for the resistance of the soil to upward pipeline movements. A series of centrifuge model tests has been conducted to investigate the uplift capacity and the load-displacement behaviour of pipelines buried in recently liquefied clay. Undrained uplift capacities were seen to be lower than the drained capacities. Recently liquefied clay may still be consolidating when pipelines are commissioned; the effective stresses in the soil (and thus the shear strengths) at the expected switch-on time have to be calculated in order to calculate the uplift capacity of the pipeline. A simple method is presented which predicts uplift capacity from the average degree of consolidation of the backfill.

INTRODUCTION

As the North Sea has matured as a producing region, pipeline activity has moved from large-diameter trunk pipelines to smaller in-field flowlines. These are often buried in the seabed, which provides protection from fishing activity and additional thermal insulation. The move to small-diameter pipelines has prompted the use of reel-lay techniques, requiring thicker-walled pipe to prevent buckling during the bending and straightening process. As a consequence of this new approach, upheaval buckling is promoted by the elevated temperatures (which lead to thermal expansion) and the high degree of lateral and axial soil restraint. The resulting compressive forces can result in the pipeline being forced upwards out of the trench—a phenomenon known as upheaval buckling. The backfill soil in the trench and the pipe weight contribute to prevent the upheaval buckling load imposed by the pipeline. However, the resistance to the upheaval load provided by the soil is difficult to calculate.

Pipelines are often placed in the seabed by jetting. A remotely operated vehicle (a trencher) with tracks is driven over the seabed. The trencher has a series of nozzles mounted in 2 jet legs which penetrate the seabed. Water is pumped out of these jets at high pressure to destroy the structure of the clay so the pipeline will sink into it. The action of a water jet on the clay is to cut a clearly defined section and depth, depending on the pressure at the jet and the nozzle diameter. During jetting, the structure of the seabed soil is likely to be broken down and may even liquefy completely. Following jetting, the backfill soil will consolidate and the soil strength will increase. This is particularly significant in clay soils where this process can take many months, especially when they have fully liquefied. This will make a large difference to the available upheaval buckling resistance of the soil. It is also possible that some lumps of clay could remain, and these would increase the strength of the backfill. Ascertaining the degree of liquefaction or hydraulic fracture, and the conditions under which these phenomena occur, is an area of ongoing research.

Because of industrial interest in the area of upheaval buckling, a number of models has been developed to predict the resistance to upward movement provided by the soil and pipeline system. Generally models have considered the seabed soil without considering disturbance of the material during pipe placement. The upheaval buckling behaviour of pipelines is typically calculated using subgrade reaction methods (e.g. Hobbs, 1984) where the pipeline behaviour is controlled by its bending and axial stiffness, EI and EA, and the soil-pipeline interaction is governed mainly by its uplift capacity (W) to vertical displacement (δ).

A typical buried pipeline is shown in Fig. 1, with a pipe diameter, D, and embedment depth, H. The pipe is assumed to be infinitely long because of the subgrade reaction approximation. The embedment ratio is defined as the ratio of the depth of embedment to the diameter of the pipe (e.g. H/D). An uplift force W_t (per unit length of the pipe) is required to move the pipe vertically upwards, so that it exceeds its capacity (i.e. the soil-pipeline system fails). In general, for a given pipe, this total ultimate uplift force, W_t, can be defined as:

$$W_t = W_u + W_P \tag{1}$$

where W_t is the total ultimate uplift capacity per unit length of pipe, W_u is the net ultimate uplift capacity per unit length of

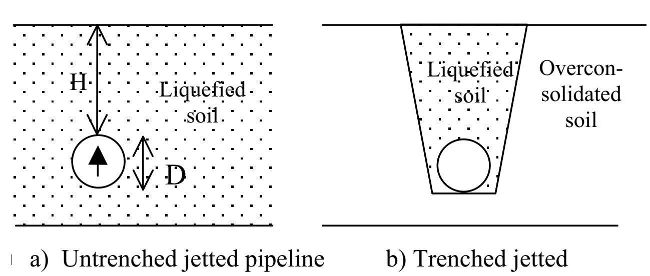

Fig. 1 Typical pipeline geometries

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