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Propagation buckling in deep sub-sea pipelines

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ABSTRACT

The paper investigates buckle propagation in deep sub-sea pipelines. Experimental results are presented using ring squash tests and hyperbaric chamber tests, and are compared with a modified analytical solution and with numerical results using finite element analysis. The experimental investigation was conducted using commercial aluminium pipes with diameter-to-thickness (D/t) ratio in the range 20–48. In contrast to conventional cylindrical pipe, a faceted cylindrical geometry is also investigated. Preliminary analysis of a faceted pipe shows that a substantial increase in buckling capacity can be achieved for the same D/t ratio.

1. Introduction

The recent failure of Deepwater Horizon in the Gulf of Mexico (April 2010) and the resulting oil spill (40,000–60,000 barrels/day) that took months to contain is a reminder of the risk involved in deep sub-sea hydrocarbon exploration. Another recent spill that also took months to contain was the Montara West Atlas rig in Australia, in August 2009. The environmental and economic impact of these catastrophes is substantial and will take many years to quantify. Most of the available hydrocarbon reserves are located in remote ultra-deep sub-sea regions (over 1500 m depth) and exploration in such regions poses many engineering challenges. Hence, it is vital to develop engineering solutions that will allow safe and economical realization of these resources.

A sub-sea pipeline can experience a number of structural instabilities, such as lateral (snaking) buckling, upheaval buckling, span formation and propagation buckling. Among these, propagation buckling is the most critical one, particularly in deep water, and can quickly damage many kilometres of pipeline. A local buckle, ovalization, dent or corrosion in the pipe wall can quickly transform the pipe cross-section into a dumb-bell (or dog-bone) shape that travels along the pipeline as long as the external pressure is high enough to sustain propagation. The lowest pressure that maintains propagation is the propagation pressure which is only a small fraction of the elastic collapse pressure of the intact pipe. This results in a substantial increase in the material and the installation cost of the pipeline, since design is therefore governed by propagation pressure.

Many researchers have investigated various aspects of this problem since it was first presented by Mesloh et al. [1,2] and Palmer and Martin [3]. Most notably is the extensive work of Kyriakides (for example [4–6]) and Calladine [7,8]. Recent books by Kyriakides [9] and Palmer and King [10] provide comprehensive review of this problem and the associated literature. Xue and Hoo Fatt [11] investigated buckle propagation in corroded pipelines. A number of solutions to guard against buckle propagation (and the resulting increase in the wall thickness of the pipeline) were proposed such as buckle arrestors [9], pipe-in-pipe system [6], sandwich pipe system [12] and ring-stiffened pipelines [13].

This paper will first propose a modification to the lower bound solution presented by Palmer and Martin [3]. A summary of experimental results using ring squash tests as was proposed by Kamalarasa and Calladine [7] will follow. Experimental results conducted on 3 m long pipes in a hyperbaric chamber and finite element analysis results verified against the experimental results will also be presented. Finally, a new pipeline design will be proposed that has the potential to increase the propagation buckling capacity without increasing the wall thickness of the pipeline. It is expected that this new design will have additional benefits in alleviating other possible instabilities that may take place in the pipeline.

2. Analytical solution of propagation pressure

A number of empirical formulae have been proposed to estimate propagation pressure as a function of D/t (diameter to wall-thickness ratio) and the material yield stress (e.g. [1,2]). However, the first analytical solution for propagation pressure in a sub-sea pipeline was presented by Palmer and Martin [3]. When compared with experimental results, the Palmer and Martin (PM) solution underestimates the propagation pressure.

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