

Model Testing to Reveal the Mechanics of Pipeline Ploughing in Mega-Ripples

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ABSTRACT

The paper reports an investigation of offshore pipeline plough behaviour in regions of seabed mega-ripples. Of particular interest is how the drag force and trench geometry are affected. Information was achieved by conducting a series of reduced scale laboratory tests using a 1/50th scale model plough. A parametric study revealed that the wavelength and amplitude of the sand waves with respect to the plough length are the key parameters influencing plough-sand wave interaction. The results have implications for offshore pipeline installers when encountering these geo-hazards.

KEY WORDS: pipeline plough; seabed; mega-ripples; trench depth; drag forces.

INTRODUCTION

An offshore pipeline plough is used to cut a trench in the seabed in which a pipeline is placed and backfilled (Palmer, 1979). The important aspects of plough performance are the velocity at which the plough can be dragged and the cover depth that is achieved (Cathie & Wintgens, 2001). Without sufficient cover depth, pipelines may be vulnerable to upheaval buckling, requiring expensive remedial rock-dumping or multiple plough passes may be required to achieve the required depth. The velocity of the plough depends on the drag force-velocity relationship (Palmer, 1999; Brown et al., 2006) for the plough as offshore vessels pull at a relatively constant drag force. If the required soil resistances are larger, the plough will have to go more slowly, resulting in potential cost and time over-runs. All prediction models, to date, concern only the performance of ploughs in uniform, level sea beds and use empirical relationships (e.g. Reese & Grinstead, 1986; Cathie & Wintgens, 2001).

This paper aims to investigate the performance of a plough in zones of mega-ripples. These are areas of seabed which contain regular surface features (Allen, 2000; Morrow & Larkin, 2007). Allan (2000) described these features as ripples, megaripples, sand waves depending on their size. The two main geometric parameters of the waves are their wavelength, L and their amplitude, h (measured peak to trough). The smaller features are particularly problematic as they undergo continuous changes. Hence, the exact morphology of the mega-ripples may change between the time when a pipeline route is surveyed and the time of pipeline installation and so they may not be able to be avoided.

In order to investigate plough performance in areas of mega-ripples a series of laboratory model tests were conducted. These utilized a 1/50th scale model plough as described by Bransby et al. (2005). The tests are used to reveal the interaction of the model plough with sand waves with a range of amplitudes and wavelengths and concentrate particularly on the achieved trench depth and the plough tow forces required in the different conditions. The experimental methods are reported first, before the results are presented and discussed.

EXPERIMENTAL METHODS

Introduction

A series of laboratory tests were conducted using a 1/50th scale model plough using testing apparatus previously described by Brown et al. (2006). All tests were carried out in loose, dry sand but for different seabed morphologies. Dry sand was used to isolate the ‘static’ (i.e. without rate effects) terms of the plough force relationships as drained soil response would have been provoked. A much larger parametric array of tests would be required to study also the effect of tow rate on the plough-wave interaction and this should be performed in the future.

Details of the series of tests is given in Table 1. Three wavelengths and three different amplitude ratios (h/L) were investigated. The three wavelengths selected were 1000 mm, 500 mm and 300 mm. These correspond to full-scale wavelengths, $L = 50$ m, 25 m and 15 m and so correspond to large mega-ripples or small sand waves (Gass et al, 1984). The model plough was 344 mm long and so these wavelengths correspond to 2.91, 1.45 and 0.87 times the plough length.

The waveform created in the sand model took the form of a cosine wave:

$$y = y_o + \frac{h}{2} \left(1 - \cos \frac{2\pi}{L} x \right), \quad (1)$$

where y is the height of soil, y_o is the height of a flat bed without waves, x is the horizontal position and $h/2$ is the amplitude. Wave geometries were selected with constant amplitude to wavelength ratios (h/L) to ensure that they were self-similar. Consequently, all tests with $h/L = 0.1$ had a bed-form with a maximum slope inclination of 17.4°