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Scour below a subsea pipeline in time varying flow conditions

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ABSTRACT

This paper presents results of an experimental investigation into the time scale of local scour and backfill for a subsea pipeline in changing flow conditions, modelled as two consecutive but different flow conditions and as uniformly increasing flow velocities. Unidirectional current flow, waves and combined waves and current flow are all considered. Based on the results of the experiments, effective time scales of the scour and backfill are quantified and algorithms to predict the scour process in changing flow conditions are derived by accumulating the effects of the different flow conditions. It is found that these algorithms may be used to predict the scour observed in the experimental data reasonably well.

1. Introduction

Considerable progress has been made in the area of scour around subsea pipelines and cables in the past four decades due to the rapid growth of the offshore oil and gas industry and the offshore renewable energy industry (including, for example the development of additional offshore wind farms).

Most early investigations into local scour below subsea pipelines focused on a single flow conditions (i.e. the flow condition did not change during scour). These investigations have included two-dimensional physical model experiments to measure the extent and rate of scour in steady current [1–12] waves [13–15] and combined waves and current [16,17]. The three-dimensional local scour below a rigid pipeline has also been investigated experimentally in steady current [18,19], waves and combined waves and current [20]. In addition to these experimental investigations, in recent years, various numerical models for predicting two-dimensional scour processes have also been developed [21–29].

However, despite these earlier studies, scour development under time-varying flow conditions is arguably of more concerned for offshore pipeline design. This is because scour development may be most critical, for example, during the development of a storm in which seabed velocities are changing. Several researchers have therefore investigated scour around pipelines and other marine structures in time-varying flow conditions. For example, Fredsøe and Sumer [12] have performed experiments in waves only conditions to investigate the variation in scour development under a subsea pipeline following a change in wave climate. For this scenario they concluded that the final equilibrium scour depth is determined only by the final wave climate. More recently, Whitehouse [30] has suggested a time-stepping approach to predict the scour development in time-varying flow conditions. This approach is similar to that proposed by Briaud and Chen [31] to predict the scour depth at a cylindrical bridge pier for a random velocity-time history and multilayer soil stratigraphy. Harris and Whitehouse [32] have also used a similar modelling approach to development an engineering model (denoted as a ‘step’ model) to predict the development of scour through time around an offshore structure under current, waves and combined waves and current flow. Draper and An [33] investigated the stability of subsea pipelines during large storm flow conditions theoretically and experimentally. Most recently, Hong and Chiew [34] have compared different time dependent pier scour models under unsteady flow conditions. Based on each of these earlier studies it appears that a time-stepping approach may provide a reasonable model to capture changes in scour during time varying flow conditions. However, for pipelines this type of model has not yet been validating through comparison with experimental data for time varying waves and combined waves and current conditions.

Zhang and Draper [35] proposed an improved formula for predicting the time development of scour depth and a universal empirical formula for time scale of scour below subsea pipelines

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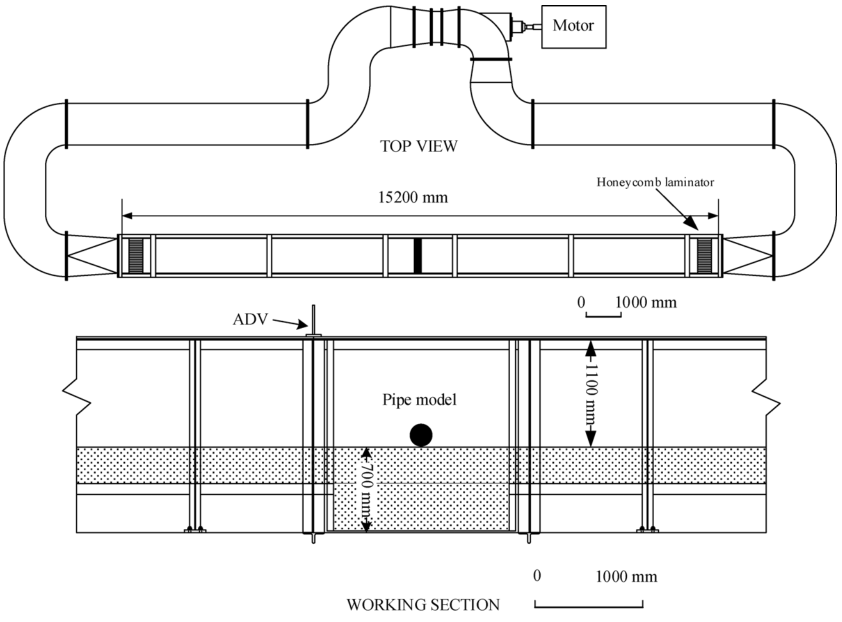

Fig. 1. Sketch of the large O-tube facility.

under current only, waves only and combined waves and current flow conditions. In this paper, this model is used as a starting point to develop algorithms to predict scour development in multiple independent flow conditions and uniformly increasing (ramp-up) flow conditions using a step model. To this end, a predictive method is described, and it is compared and validated against experimental data.

2. Experimental setup

2.1. O-tubes

The experiments undertaken in this investigation were performed in the O-tube flumes at The University of Western Australia. The O-tube flumes are fully enclosed recirculating water tunnels with a rectangular test section and a propeller-type pump driven by a motor. Two different size O-tubes were employed in this study, the large O-tube (LOT) and the mini O-tube (MOT) respectively.

The test section of the LOT is 17.6 m in length, 1.4 m in depth and 1.0 m in width (a sketch of the facility and model pipe is drawn in Fig. 1). A honeycomb laminator is installed at each end of the test section to reduce the level of turbulence. The LOT is able to generate a maximum steady current velocity of up to 3 m/s and an oscillatory flow velocity of up to 1–2.5 m/s, respectively, for wave periods of 5–13 s. By controlling the rotation direction and speed of the impeller using LABVIEW software on a local computer, the facilities are able to generate time-varying combined steady current and/or regular or irregular oscillatory flow. A detailed description of the LOT facility and its capabilities can be found in An and Luo [36]. A model pipeline with a diameter of 196 mm was used in the LOT tests, which was rigidly fixed at the centre of the test section (the test section is approximately 88 D in length) and extended across the full width of the test section. The sediment used in the LOT experiments was silica sand with median grain size of $d_{50} = 0.24$ mm and a geometric standard deviation of $\sigma_g = \sqrt{d_{84}/d_{16}} = 1.37$. The particle size distribution is shown in Fig. 2. The sediment was filled in the middle of the test section, covering a length of 15.7 m and a depth of between 0.3 m and 0.7 m (the deeper section covering approximately 1 m in length either side of the model pipe).

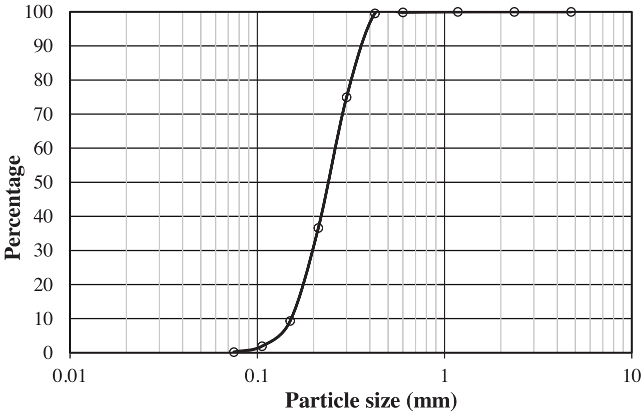

Fig. 2. Particle size distribution of the model sediment.

The MOT facility is approximately 5 times smaller than the LOT. The MOT facility is 2.5 m in breadth, 0.3 m in height and 6.4 m in length. The MOT test facility comprises a motor-impeller system, unplasticized polyvinyl chloride (uPVC) tube sections, two honeycomb transitions at each end of the test section, and one straight test section (the main components are indicated in Fig. 3). The diameter of the uPVC tube is 0.17 m, and there is a tapered section of 0.4 m in length to connect the circular uPVC tube to each end of the rectangular test section. A model pipeline with a diameter of $D = 50$ mm was used in the tests. The model pipeline was rigidly fixed in the middle of the working section, and its surface was smooth. The test cross-section of the MOT is 0.2 m by 0.3 m, with a length of 1.8 m (approximately 36 D in length). The bottom 0.11 m of the working section was filled with sediment. The same sediment as that used in the LOT test was used in the MOT tests.

2.2. Velocity measurements

A SonTek Acoustic Doppler velocimeter (ADV) was used to measure the velocity at a sampling rate of 50 Hz For steady current only flow conditions, the velocity profile across the depth was measured at 2 m (10 D) upstream of the model pipeline in the LOT. The velocity at each measurement point was obtained by averaging the data