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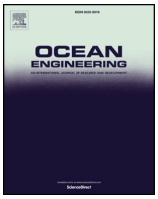

Observed changes to the stability of a subsea pipeline caused by seabed mobility

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ABSTRACT

High resolution bathymetry combined with structural modelling is used to estimate changes in the on-bottom stability of an offshore pipeline due to scour and sedimentation over an 11 year period. Detailed observations of post-lay embedment changes have been combined with the pipeline structural characteristics and an elastic-plastic model of soil resistance to estimate the vertical and horizontal stability of the pipeline using a finite difference solution to the beam bending equation. Application of the design approach indicates that post-lay increases to the critical (break-out) velocity of 1–2 m/s occur along the full 19 km of surveyed pipeline due to scour and sedimentation, which act to reduce load and increase soil resistance. The rate at which this increase in stability occurs with time is found to vary along the pipeline, and is dependent on the mechanism of pipeline lowering (i.e. whether the pipe lowered due to sagging into widely spaced scour holes, or by sinking into the shoulders between many closely spaced scour holes). By incorporating sediment transport into the pipeline design, the present results suggest potential for significant improvements in pipeline on-bottom stability and associated reductions in minimum required specific gravity and/or secondary stabilisation.

1. Introduction

Sediment mobility and, in particular, scour around pipelines has been an area of significant research effort for several decades; see, for example, the summaries provided in Sumer and Fredsøe (2002) and Whitehouse (1998). Despite this work and more applied studies (such as the work of Hulsbergen and Bijker (1989) on spoilers), the influence of sediment mobility on pipeline stability design has only been acknowledged in industry codes relatively recently (Det Norske Veritas, 2011). This acknowledgement corrects the erroneous assumption made in more traditional pipeline stability design that a pipeline on a mobile seabed will become unstable before the seabed itself becomes mobile (Palmer, 1996). However, the recent additions do not yet extend to specific guidance on how to predict changes to pipeline embedment due to sediment mobility, or how to make allowance for the associated changes in on-bottom stability in practise.

Recent and ongoing research aims to address this shortcoming. The present paper is part of a wider research effort in which ocean-pipeline-seabed interaction has been studied in a cross-disciplinary manner, combining hydrodynamic, sediment transport and geotechnical expertise (White et al., 2014). The overarching aim is to provide a balanced perspective on pipeline stability, giving seabed mobility due prominence in the work. Draper et al. (2015), for example, present the results of recent physical modelling tests using a unique recirculating flume (described in An et al. (2013)) to simulate scour-induced changes in pipeline stability and their sensitivity to the flow conditions, particularly the change in velocities during the development of a storm.

One of the key barriers to accommodating sediment mobility in pipeline design is that pipeline scour and sedimentation research is predominantly based on laboratory modelling; there is a lack of published information on the actual scour and sedimentation behaviour of pipelines in the field to compare against those results. Bruschi et al. (1997) discussed pipeline self-burial in the field, while Pinna et al. (2003) provided detailed observations for a particular pipeline. More recently Leckie et al. (2015) and Leckie et al. (2016a) have presented detailed analysis of sediment mobility-induced changes to pipeline embedment and spanning for pipelines offshore Western Australia (WA).

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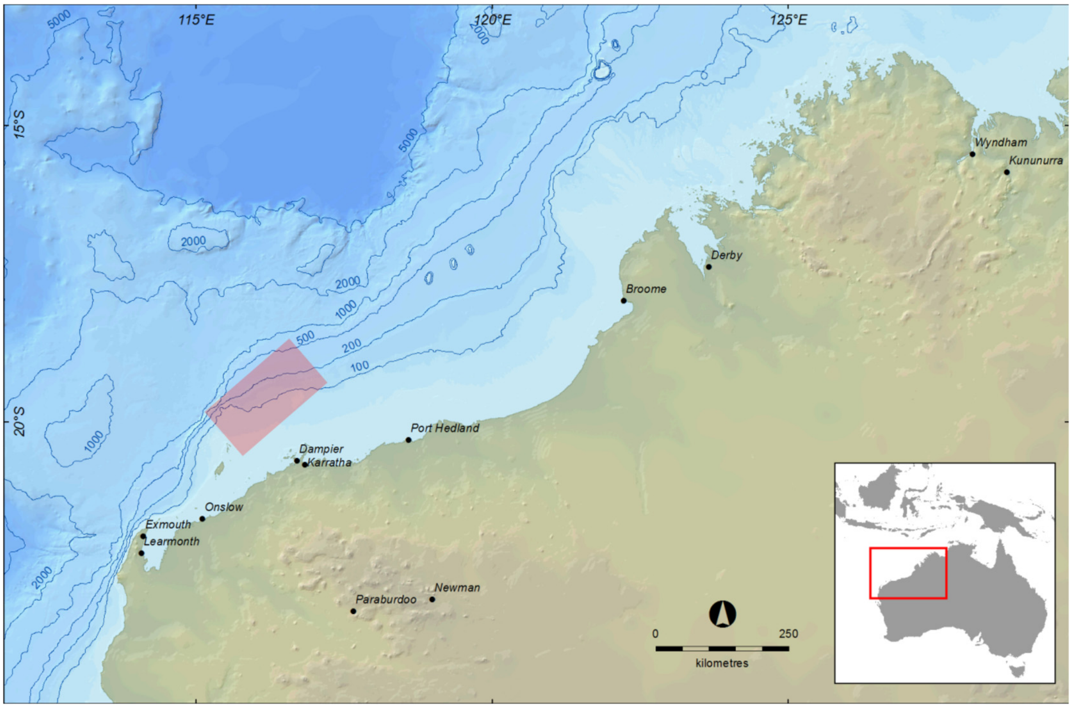

Fig. 1. Location of the pipeline and the bathymetry of the North West Shelf. Reprinted from Coastal Engineering, Vol 95, Jan. 2015, S. H. F. Leckie, S. Draper, D. J. White, L. Cheng, and A. Fogliani, “Lifelong embedment and spanning of a pipeline on a mobile seabed,” pp. 130–146, Copyright 2014.

Following on from the work of Leckie (2015, 2016a), this paper uses 11 years of field survey data to quantify changes in pipeline embedment and the associated changes in on-bottom stability due to sediment mobility for a pipeline offshore WA. A brief overview of the pipeline setting and the post-lay near-pipeline bathymetry is presented first, with an emphasis on the aspects of the geometry that have the greatest influence on pipeline stability. The evolution of the on-bottom stability of the pipeline is then considered under the action of a uniform perpendicular current. Finally, the sensitivity of pipeline stability to the pipeline specific gravity (S.G.) is examined to explore the implications of seabed mobility for pipeline design practice.

2. Pipeline setting and survey data

The first 6.5 years of sediment mobility-induced changes to the embedment and spanning of the pipeline considered herein are discussed in detail in Leckie et al. (2015) along with details of the pipeline structural properties and the geotechnical and metocean setting. In summary, the pipeline is 22.9 km long, has a nominal diameter of 12 in. (0.30 m) and was laid in 2001 offshore WA (see Leckie et al., 2015 and Fig. 1). The seabed soils are relatively uniform along the pipeline route, comprising carbonate sandy SILT (typical d_{50} = 0.07 mm) through the middle Kilometre Point (KP) range and carbonate silty SAND (typical d_{50} = 0.12 mm) at the two ends. The pipeline lies in 130 m of water depth, which is sufficiently deep that wave induced orbital velocities are negligible at this location. Rather, sediment transport is controlled by tide and internal wave-induced currents which flow perpendicular to the pipeline orientation. Current records from a nearby platform and results from erosion testing indicate that the seabed adjacent to the pipeline is mobile, on average, 7% of the time (a cumulative 25.6 days/year), while the whole seabed is mobile 0.04% of the time (a cumulative 3.5 h/year) (see Leckie et al., 2015).

Leckie et al. (2015) used annual survey data dating back to 2002, including (i) observations of span start and stop points from pipeline inspection video, and (ii) near pipeline bathymetry for three 200 m sections, which was extracted from historic two-source sonar footage using an image analysis technique described in Leckie et al. (2016b). The first 19 km of the same pipeline was surveyed again in 2013 using more modern multibeam bathymetry and the results made available to the authors after the publication of Leckie et al. (2015).

This 2013 bathymetry forms the basis of the work described in this paper, supplemented with comparisons to the earlier 200 m subsection datasets presented in Leckie et al. (2015). The 2013 multibeam dataset consists of a grid of points either side of the pipeline with a resolution of ~ 0.2 m centres. While the raw multibeam data is of high quality, post-processing of the data has been undertaken to remove occasional errors and artefacts from the dataset and to interpolate the level of the seabed through the sonar shadow section that exists beneath spanning sections of pipeline. The raw data, which was referenced to an absolute level, has been transformed to relative level bathymetry with the bottom of the pipeline acting as the reference point (see Fig. 2). To assist with computational time, the 0.2 m grid has been interpolated to a grid that has a curvilinear coordinate following the pipeline (with 0.1 m grid spacing) and a second coordinate normal to the pipeline (with 0.1 m grid spacing up to a distance 5 m either side of the pipeline centre). An example of the post-processed bathymetry is shown in Fig. 3.

Due to the difficulties in accurately interpolating the depth of shallow spans from multibeam data, visual confirmation from ROV video of the locations where spans start and stop remains the most accurate measure of these points, and has been used herein. While the post-processing produces good quality bathymetry through the sonar shadow region, the depths of very shallow spans ($< \sim 0.25D$) should only be taken as indicative.

3. Near pipeline bathymetry

3.1. Overview

Leckie et al. (2015) provide an overview of the post-lay changes in near-pipe seabed level that occurred between the laying of the pipeline in late 2001 through to 2008. At the time of the most recent survey in 2013, 40% of the pipeline was in span; a slight increase from the 2008 value of 38%, but within the ‘mature’ range described in Leckie et al. (2015). The mean number of spans per kilometre had reduced slightly

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