Coastal Engineering 95 (2015) 130–146

Contents lists available at ScienceDirect

Coastal Engineering

journal homepage: www.elsevier.com/locate/coastaleng

Lifelong embedment and spanning of a pipeline on a mobile seabed

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ARTICLE INFO

Article history:
Received 25 June 2014
Received in revised form 13 October 2014
Accepted 16 October 2014
Available online 7 November 2014

Keywords:
Pipeline embedment
On-bottom stability
Pipe–soil interaction
Scour
Sediment transport
Span

ABSTRACT

Seven years of field survey measurements of a subsea pipeline obtained using sonar profilers and underwater video indicate significant lowering of the pipeline into the seabed due to sediment mobility and scour. The majority of the lowering occurs within 2 years of pipeline laying and appears to result from sustained ambient tidal and soliton currents as opposed to large storms. The lowering results in an increase in pipeline embedment relative to the far field seabed of up to 0.8 times the pipe diameter (referenced at a distance ±8 D from the pipeline). At most locations along the pipeline, this increase in far-field embedment is uniform and occurs after the formation of many closely spaced scour holes. This suggests that the pipeline lowered mainly through sinking into the seabed at span shoulders, rather than sagging into widely spaced scour holes, for much of the pipeline length. A beam bending analysis confirmed the dominance of sinking, but did show some evidence of pipeline sagging, calculating deflections of up to 0.3 pipeline diameters at the time of surveying. In contrast to the traditional conception of span growth and self-burial, which conceives of complete pipeline burial as an endpoint, this pipeline primarily appears to exhibit 'self-lowering' towards a mature state that consists of a pseudo-static profile of alternating spanning and embedded sections that are distributed at regular intervals. The observed changes appear to be predictable given sufficient pipeline setting data, which suggests that they can be quantified in the stability design of new pipelines. This opens up the possibility of more efficient on-bottom stability design, as the beneficial shielding and support provided by the self-lowering process is not usually accounted for.

1. Introduction

The on-bottom stability of an offshore pipeline is a fundamental aspect of pipeline design and has a significant influence on cost (Tørnes et al., 2009). On Australia's North West Shelf, for instance, it is estimated that pipeline stabilisation measures — which may include, for example, concrete coating, rock dumping, trenching or rock bolting — contributed around 30% of the estimated $US4 million per kilometre cost of recent gas export pipeline projects (Randolph and Gourvenec, 2011). The on-bottom stability of a pipeline is affected by the hydrodynamic loading due to wave and current velocities, the structural response of the pipeline, local scour of seabed sediment and the resistance provided by the soil to pipeline movement. However traditionally on-bottom stability design methods have treated the seabed as immobile, unaffected by the actions of waves and currents (Palmer, 1996). A simplified soil response regime is normally adopted, with pipeline embedment either ignored, or a uniform (typically conservative) post-lay embedment value adopted along the entire pipeline.

The key problem with this traditional stability design approach is that the same wave and current velocities that load the pipeline also act to mobilise the seabed sediment (Palmer, 1996). This can lead to scour of sediment from beneath the pipeline, which in-turn can lead to the pipeline lowering into the seabed, ultimately increasing pipeline embedment and improving stability due to both the reduced exposure of the pipeline to hydrodynamic loading and the increased soil resistance to lateral movement. Although the latest version of the on-bottom stability design code DNV-RP-F109 (DNV, 2010) allows for the inclusion of additional embedment due to "piping" and "the action of waves and current", no quantitative guidance is provided on how to calculate this embedment. The changes to embedment and spanning are also important in thermal expansion design through their strong influence on lateral and axial soil resistance.

Laboratory experiments investigating scour beneath offshore pipelines suggest that the scouring processes which lead to changes in pipeline embedment can be split into a series of mechanisms. When a pipeline is first laid on the seabed it alters the local flow regime, establishing a pressure difference across the two sides of the pipeline (Sumer and Fredsøe, 2002). In areas where a small gap exists after the pipeline is laid — for example where the pipeline is unable to conform to the natural seabed bathymetry — amplified shear stresses can be sufficient to

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http://dx.doi.org/10.1016/j.coastaleng.2014.10.003
0378-3839/

promote scour beneath the pipeline directly. Alternatively, in areas where the pipeline is shallowly embedded after laying, if the pressure difference is large it can drive a seepage flow beneath the pipeline, which can result in the piping of sediment from beneath the pipeline and the establishment of a scour tunnel (Sumer et al., 2001).

Once a scour hole is established at an 'initiation point' (due to piping, for example) tunnel erosion will lead to deepening of the hole at a specific rate which is dependent on the near seabed velocities, the pipeline geometry and the pipeline embedment (Sumer and Fredsøe, 2002). The scour hole will also begin to extend along the pipeline, at a rate which is dependent on these same parameters in addition to the three dimensional geometry of the scour hole and the span shoulders (Cheng et al., 2009; 2014; Wu and Chiew, 2012).

Propagation of scour holes along a pipeline increases the total proportion of pipeline length in span, and can lead ultimately to pipeline lowering via two mechanisms. Firstly, if the scour holes are spaced far apart along the length of the pipeline, they can grow to be sufficiently long for the pipeline to sag into the scour hole (Fredsøe et al. (1988); Fig. 1(a)). Secondly, if the scour holes are regular and closely spaced (due to regular and closely spaced initiation points) the supporting length of seabed between scour holes will become very short well before the scour holes are sufficiently long for the pipeline to sag. Consequently the pipeline will lower by sinking into the supporting seabed when the imposed stress due to the pipeline weight exceeds the seabed bearing capacity (Sumer and Fredsøe, 1994).

For both mechanisms there is a net increase in the length-averaged embedment of the pipeline, measured relative to a far-field datum, as the pipeline lowers. However, in the case of lowering through sagging, variations in the resulting far-field embedment along the pipeline are likely to be more substantial (see Fig. 1), whilst for lowering due to sinking a relatively uniform far field embedment is possible. For both modes of lowering variations in embedment immediately adjacent to the pipeline (i.e. the local-field) are expected (Fig. 1).

Pipeline lowering events due to sagging or sinking are thought to be episodic in time, leading to successive increases in the length-averaged far-field embedment of the pipeline. Laboratory test data suggests that the ultimate far-field embedment that can be reached due to either mechanism of lowering appears to align well with the equilibrium scour depth measured under a fixed pipe for a given set of wave and current conditions (Sumer et al., 2001). Locally, at locations where the pipeline has settled into a scour hole, experiments also suggest that backfill and sedimentation may result in increases in local embedment; i.e. self-burial.

1.1. Existing observations of scour in the field

The scour and lowering processes described above are based on laboratory observations. In comparison there is only a limited amount of published information regarding observations of scour and pipeline lowering in the field. A notable exception is that of Bruschi et al. (1997) who reviewed the theory relating to scour, sediment transport and stability design. They noted that "natural lowering occurs for pipelines characterised by a high submerged weight which lay on an erodible seabed affected by strong environmental conditions". Unfortunately very few specific observations from the field are provided, however it is noted that "[t]ypical behaviour is for natural lowering to occur for long sections of the pipeline over a time scale of 2–5 years".

More recently Pinna et al. (2003) set out a series of observations of scour-induced changes to pipeline spanning over a period of 9 years

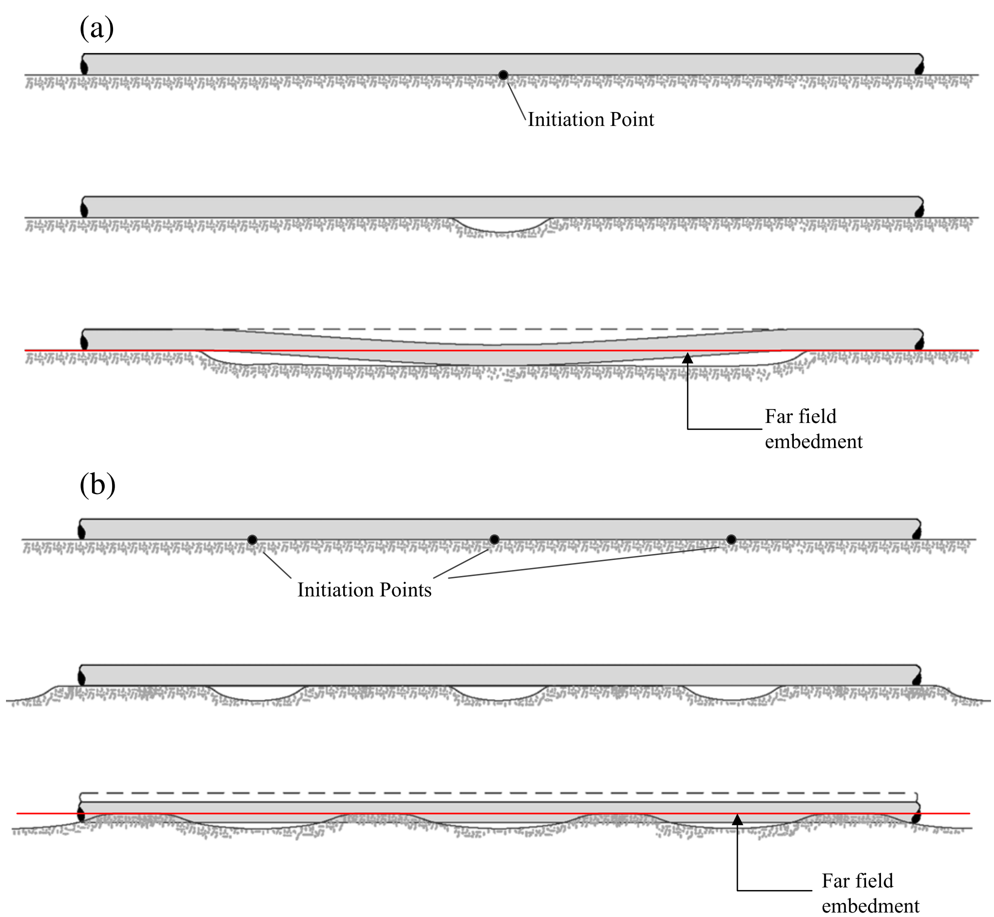

Fig. 1. Mechanisms of pipeline lowering (a) pipeline sagging into a single scour hole. (b) Pipeline sinking into multiple span shoulders.