Jay Ryan and Eric Jas, Atteris Pty Ltd, Australia, **discuss the future of the on-bottom stability design of subsea pipelines and the advances being made in Australia.**

The missing link

What is on-bottom stability?

The answer to this question varies depending on the method the designer chooses to, or must, adopt. In short, a 'stable' pipeline does not move when affected by any external loading that may occur, in particular steady and oscillatory (wave induced) on-bottom currents. This approach is known as 'absolute stability'. Throughout its development, however, defining the criteria for pipeline stability has included allowing the pipeline to displace a predefined distance in a predefined loading condition; whether the distance is arbitrary or limited by the mechanical strength of the pipeline depends on the designer. This approach is generally known as 'dynamic stability', given the fact that a full dynamic analysis is required to predict the displacement of the pipeline during a design storm event.

The principles behind on-bottom stability are simple (Figure 1). On one side there are loads acting on the pipeline that have a destabilising effect. These are the hydrodynamic loads, lift, drag and inertia. On the other side there are effects that act to stabilise the pipeline. These include the friction between the pipeline and seabed, and the passive resistance provided by the seabed when a pipeline is partly buried or trenched. If the hydrodynamic loads can be balanced by the interaction between the pipeline and the soil, movement of the pipeline can be limited, or mitigated all together.

There are three main interactions that take place when a pipeline is installed subsea that affect stability. They are the interactions between the fluid (water) and the pipe (fluid-pipe); the interactions between the pipe and the soil (pipe-soil); and the interactions between the fluid and the soil (fluid-soil).

Fluid-pipe interactions result in hydrodynamic loading of the pipeline. These loads depend on the wave and steady current conditions acting on the pipeline, but also depend on the diameter, and the degree of burial (or embedment) or trenching of the pipeline.

Pipe-soil interactions result in friction between the pipeline and the seabed, and passive resistance of pipeline movement. These factors depend primarily on the properties of the seabed, as well as the contact force (resultant of the lift force and submerged weight of the pipeline), the diameter, and degree of self burial or trenching of the pipeline.

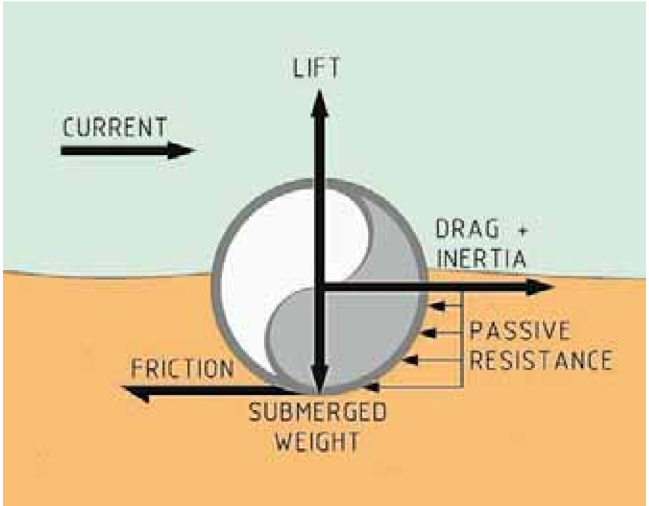

Figure 1. Force model of subsea pipeline stability.

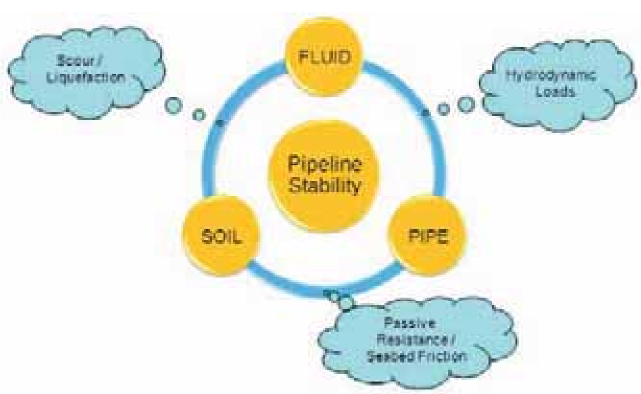

Figure 2. Fluid-pipe-soil model.

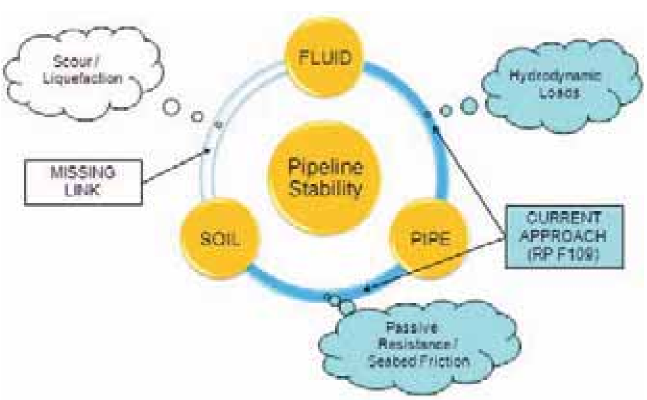

Figure 3. The missing link in the current approach.

Fluid-soil interactions result in seabed instabilities such as scour and liquefaction. Scour can loosely be defined as erosion of the seabed, but also includes sediment transportation in general. Liquefaction is a complicated phenomenon where cyclic stresses on the seabed build-up the pore pressure in the soil, thereby weakening the soil and eventually leading to the soil behaving like a fluid. These seabed instabilities are primarily dependant on the soil properties and the wave and steady current properties. They are also a function of the pipeline diameter and degree of burial. Scour and liquefaction can also lead to changes in the degree of burial or profile of the pipeline.

It is clear from the brief descriptions above, that each of the interactions is not independent but rather depends on the other interactions and their effect on certain parameters. For example, the degree of pipeline burial is affected by scour and liquefaction (fluid-soil), and in turn affects the hydrodynamic loads acting on the pipeline (fluid-pipe), as well as the passive resistance provided by the soil (pipe-soil). This interdependency between the three interactions is summarised by the term “fluid-pipe-soil model” (Figure 2).

Current approach

The current approach of assessing the on-bottom stability of subsea pipelines includes modelling of the fluid-pipe and pipe-soil interactions interdependently. The latest recommended practice from Det Norske Veritas titled DNV RP F109 - On-bottom Stability Design of Marine Pipelines (F109) (Ref. 1) was released on 2007 and outlines the most recent approach in the industry. In the framework of F109, the designer can assess the lateral stability of the pipeline using a dynamic stability method, a generalised stability method, and an absolute stability method.

Using the dynamic stability method, the designer models the lateral displacement of the pipeline over time while subjected to the design seastate condition and the hydrodynamic loads that are generated during this condition. This analysis includes the effects of small displacements in the pipeline that would typically lead to burial of the pipeline and consequently an increase in passive resistance.

The generalised stability method uses a set of non-dimensional parameters including the Keulegan-Carpenter number, the non-dimensional soil density and the steady to oscillatory current ratio and several others. Given these parameters, design curves are used to determine the minimum submerged weight of the pipeline in order to limit pipeline movement to 10 times the pipeline diameter. This analysis assumes that the pipeline is resting on a flat seabed.

The absolute stability method is a quasi-static analysis of the balance between the hydrodynamic loads, the friction and passive resistance provided by the soil, and the submerged weight of the pipeline. In order for the pipeline to be considered stable, a force balance between the lateral hydrodynamic load, and the friction and passive resistance provided by the seabed must be satisfied. In other words, the friction and passive resistance provided by the seabed must be greater than the maximum lateral hydrodynamic load acting on the pipeline. The submerged weight of the pipeline

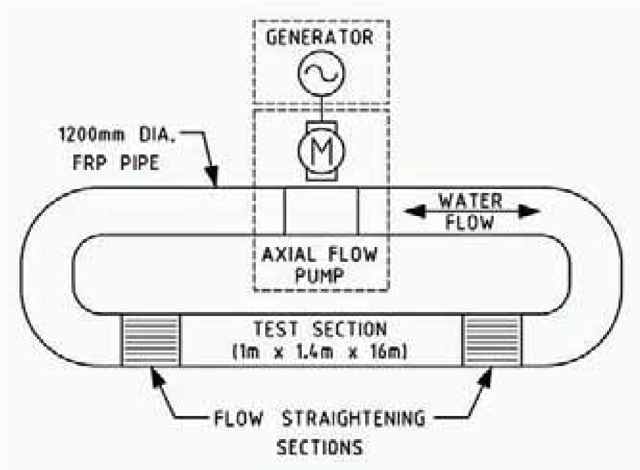

Figure 4. Schematic diagram of O-Tube.

must also be greater than the maximum lift load acting on the pipeline.

However, assessing the on-bottom stability of pipelines is not constrained to F109, and several 3-dimensional, fully dynamic Finite Element models have been developed by the pipeline engineering industry. These software packages typically model the response of the entire pipeline subjected to a storm using irregular waves, and resting on a seabed with given properties. The results of these modelling campaigns can then be used to assess the pipeline according to the limit state mechanical design criteria that apply.

Fluid-pipe-soil model

Overall, the assessment of on-bottom stability has come a long way in the last 50 or so years, with updated wave models, hydrodynamic models, and soil models. However, all of the current methods consider only the fluid-pipe and pipe-soil interactions interdependently, and most consider the fluid-soil interactions, or seabed instabilities, as an afterthought or a separate analysis (Figure 3).

The reality is that the full fluid-pipe-soil interdependency must be modelled if the industry is to obtain accurate results and decrease the conservatism inherent in the current approach. This becomes particularly important when considering fully dynamic models that attempt to predict the displacement of the pipeline over time. Currently, these models do not typically consider the fluid-soil interactions that take place. These interactions indeed alter the hydrodynamic loading and passive resistances over time, placing a question mark on the accuracy of a fully dynamic model that does not consider these effects.

It is argued by Palmer et al that the seabed may become unstable well before the pipeline does.[2] Consequently, assuming the seabed is stable for an on-bottom stability analysis is fundamentally flawed as stated by Palmer. It must be noted however, that modelling the full fluid-pipe-soil interactions is itself an incredibly complex task to do numerically, or with finite element analysis techniques. And to date, the industry has not seen a model that performs this task reliably.

The future

The increasing number of gas pipeline projects occurring in Australia's North West Shelf (NWS) has sparked interest in this area from pipeline operators, engineering companies and universities. There have been instances on the NWS where the seabed along large diameter gas pipelines is believed to have experienced combinations of scour and liquefaction leading to significant changes in the burial profiles of the pipeline, and possibly pipeline floatation. This has led Atteris Pty Ltd to re-evaluate the standard approach to on-bottom stability design, and initiate new, ground breaking research programs aimed at understanding fluid-pipe-soil interactions and assessing pipeline stability more appropriately.

Given the complexity of performing the task using numerical techniques, physical model testing has been proposed to simulate pipelines on a seabed subject to wave induced and steady currents.

Physical model testing

These challenges to conventional thinking regarding stability design have ultimately led to plans for a state-of-the-art hydraulic laboratory to be built at the University of Western Australia.

Construction is well underway of a fully recirculating system that has the capacity to model steady state and oscillatory current combined by pumping water around a circuit of FRP piping and glass panelled test section.

The test section consists of a 1 m x 1 m flow section and a 1 m x 0.4 m soil deposit section immediately below the flow section. This will allow modelling of a pipe resting on a soil seabed with both subjected to steady and oscillatory currents. It will be possible to model a 10 in. pipeline at full scale, and a 40 in. pipeline at a scale of 1:5.

The so called 'O-Tube' will be capable of modelling currents up to 3 m/s with periods as low as 5 seconds. The pump will consist of a control system in order to subject the model pipeline to an entire representative storm series. A schematic diagram of the O-Tube is displayed in Figure 4.

The initial instrumentation to be installed will allow the measurement of hydrodynamic loads on the pipe, pore pressures in the soil, displacements of the pipe, threshold passive resistances of the soil, and the scour depths and profiles of the seabed. All of these parameters will be recorded throughout the tests in order to fully understand the processes taking place.

The expected impact of the O-Tube on the on-bottom stability design methodologies for subsea pipelines is enormous. This is the first time that fluid-pipe-soil modelling of subsea pipelines has been undertaken at the scale, and with the capacity and instrumentation levels seen in the O-Tube.

The O-Tube may be used for two different, though related, purposes.

The first is analysing pipeline stability from a project specific standpoint. The use of design metocean conditions, soil conditions, and pipeline parameters can be analysed for on-bottom stability within the O-Tube, possibly during detailed design, in order to optimise the design of the pipeline. This approach would be a departure from the current approach used by the industry and may prove to reduce some of the conservatism and misunderstanding inherent in the current approach. Reducing this conservatism may reduce the amount of concrete weight coating needed to be installed on the pipeline, or the amount of secondary stabilisation required, such as trenching or the installation of rock berms and gravity anchors. Reducing the amount of primary and secondary stabilisation required would have sizable cost benefits to an offshore development.

The second purpose is to utilise the O-Tube for a broader research programme aimed at establishing quantifiable relationships between the fluid-pipe-soil interactions that take place. This type of work would involve the measurement of hydrodynamic loads, passive resistances, pore pressure build-up, and scour depths independently while varying the functional parameters in order to further define the relationships that apply. This process would include an intensive testing programme and would have the capacity to rewrite the codes and recommended practices that are currently in place.

The O-Tube is currently under construction and is expected to be operational by October 2009.

Conclusion

The future of the on-bottom stability design of subsea pipelines is on the verge of significant changes to the approach the industry currently employs. The work being performed in Australia continues to increase in momentum and has already led to the development of a state-of-the-art hydraulic facility at the University of Western Australia known as the O-Tube. The O-Tube promises to provide invaluable insight into the design of subsea pipelines in Australia and throughout the world.

Atteris Pty Ltd provides the pipeline stability expertise, and is a key player in pushing the boundaries in the development of the new pipeline stability design methodology. Atteris is a subsea pipeline design engineering company, and has been involved with the design of offshore pipelines around Australia, Asia and North America. In particular, the company has significant expertise in the field of pipeline stability design in the Northwest Shelf of Western Australia, where pipeline stability has proven particularly challenging for medium and large diameter pipelines. This is due in part to the tropical cyclones which affect this part of the world on a seasonal basis in combination with the unique geotechnical conditions of the Northwest Shelf. WP

References

1. Det Norske Veritas, DNV-RP-F109 - On-Bottom Stability Design of Submarine Pipelines, October 2007.
2. Palmer, A.C. A Flaw in the Conventional Approach to Stability Design of Pipelines. Proceedings. Offshore Pipeline Technology Conference, Amsterdam 1996.