TAMING THE SUBSEA PIPELINE

Advanced analyses can improve subsea pipeline lateral buckling predictions. Alastair Walker and Kin Yin Chee, INTECSEA, Australia, explain.

During operation, many subsea pipelines are subjected to high internal pressures and temperatures from the oil or gas that they are transporting. Since these temperatures and pressures are much higher than those experienced by the pipeline during installation, the natural response of the pipeline is to expand axially as production initiates. However, the embedment of the pipe in the seabed and the frictional interaction between the pipeline and the soil provides a resistance to expansion, resulting in axial compressive forces generated along the length of the pipeline, the effects of which have to be considered in pipeline design.

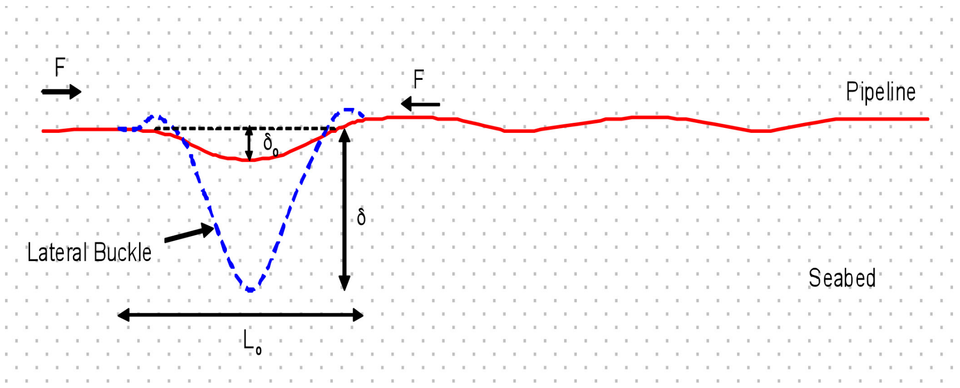

Figure 1. Installed pipeline out-of-straightness.

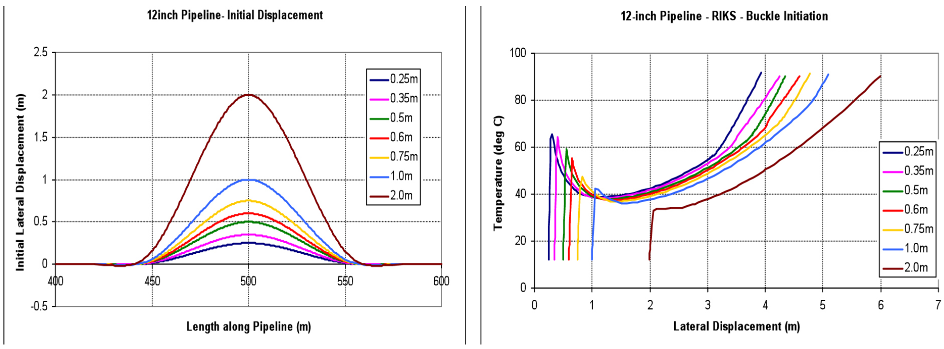

Figure 2. Initial assumed out-of-straightness values, and resulting lateral displacements.

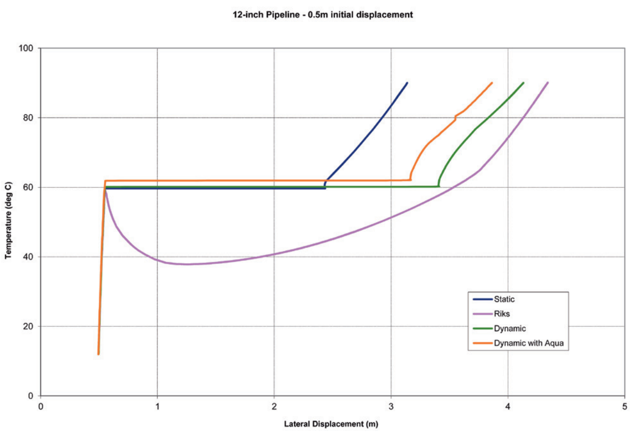

Figure 3. Lateral displacement comparisons.

Commonly, an installed pipeline has a shape along the seabed that varies continuously from the intended straight condition, as shown in Figure 1.

The installed shape can be described by the variations of the initial as-laid out-of-straightness (o-o-s), δ_o, and the related wavelengths, L_o. Because the as-laid o-o-s of the pipeline is not known at the time of design, o-o-s assumptions must be made based on experience and knowledge of past pipeline project as-laid conditions. These assumptions are further challenged by recent improvements in installation capabilities. Dynamically positioned (DP) vessels are becoming more common (allowing for more stable vessel motions), and higher tensioner capabilities on newer installation vessels increase the tensile forces applied to the pipe during installation. These two factors combine to decrease the o-o-s of the installed pipeline, and traditional assumptions regarding o-o-s may lead to a design that is not conservative.

A new study in lateral buckling

Since the noted installation improvements are recent, there are few published results from surveys in which reliable up-to-date levels of o-o-s can be used to provide a safe basis for design of pipelines in new projects. As part of INTECSEA's design assurance procedures, a study has been carried out to assess the effects that decreased levels of o-o-s and increased levels of as-installed tensions would have on the design of pipelines subjected to high temperatures and internal pressures. The following is a brief summary of results from part of that study.

As pipeline production initiates during start-up, the effect of the generated axial force is to increase the amplitude of the o-o-s, marked by the change from δ_o to δ in Figure 1. The lateral resistance generated by the soil is a function of the pipe submerged weight and an equivalent friction factor, which is composed of Coulomb friction and the force required to displace the seabed soil. The relationship between the equivalent friction factor and the lateral movement of the pipe is nonlinear and varies considerably, and the lateral force that drives the pipe movement also varies due to the assumed o-o-s amplitudes and wavelengths. This variability results in quite complex nonlinear relationships between the temperature and pressure loading, the lateral movements of the pipeline, and the local strains generated by the movements. To account for these complex interactions, analyses have been carried out using nonlinear finite element modelling of the soil properties, pipe material properties, and assumed initial o-o-s.

As a preliminary step to analysing a complete pipeline route, representative lengths of pipe were initially modelled. Figure 2(a) shows examples of the assumed as-laid o-o-s of a 1 km length of pipe on a seabed, and Figure 2(b) shows the resulting highly accurate nonlinear modelling solutions for the initially assumed o-o-s of the as-laid pipeline.

As the temperature gradually and continuously increases during start-up, the force reaches a maximum and, at the point of instability, the lateral displacement suddenly increases considerably as the temperature continuously increases. This significant increase in the lateral displacement at the same temperature is termed 'snap-through buckling' in general stability theory or, in the case of a pipeline, it is called 'lateral buckling' or 'global buckling'.

It is generally assumed in project-based lateral buckling design that the level of o-o-s in practical pipelines would be such that no lateral buckling would occur and the development of lateral movements would be a quasi-static increase of displacements as the temperature is gradually increased during start-up. In fact, this would be the case in the preliminary analysis results shown in Figure 2 if the initial lateral displacement was 2 m or greater. However, with the previously noted changes in pipeline installation capabilities (resulting in straighter as-laid pipelines), snap-through buckling may occur and the assumption of a gradual lateral movement may not be valid. A more accurate solution of the nonlinear modelling is required.

The realisation that straighter as-laid pipelines may result in a sudden lateral movement also gives rise to the need to consider dynamic effects, and further analyses were performed. Figure 3 shows example results based on the incorporation of dynamic factors, such as inertia, hydrodynamic forces and damping in the solution method.

It is seen in Figure 3 that ignoring the dynamic factors and using a static method of solution can underestimate the lateral displacements that occur during buckling. Including the hydrodynamic factors using a subroutine in ABAQUS called AQUA is seen to modify slightly the results from the purely dynamic solution routine. Carrying out a range of calculations corresponding to the example o-o-s in Figure 2 shows that using the static solution method, which is assumed in most project-based analyses, can underestimate the maximum strains generated during lateral buckling by up to 50% for small levels of initial o-o-s. The various methods of solution calculate the same levels of strain for large levels of o-o-s, thus emphasising the importance of supplementing the commonly used static method of solution with the more complex dynamic method for cases where installation vessels with DP and high levels of installation tension are to be used.

Conclusion

Results from the dynamic method described above show that, for small initial levels of o-o-s, lateral buckling is a very rapid occurrence and the pipe speed across the seabed can exceed 10 m/sec. This indicates the need for additional modelling requirements that have been not been included in the analyses described above, as the speed of the pipe during lateral buckling affects the assumed levels of the equivalent friction factor. Work is continuing at INTECSEA to include this phenomenon in the finite element dynamic modelling to ensure that simplified methods do not underestimate the maximum pipe strains, and ensuring high levels of pipeline reliability are maintained at the design stage.