New Generation Pipeline Analysis Software

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Abstract

Modelling pipelines using general purpose finite element software packages is not always straightforward. In order to model more rapidly and efficiently an offshore pipeline being laid onto a seabed and its interaction with the soil, new generation pipeline analysis software has been developed. This software, SAGE Profile 3D (SP3D), which uses a transient dynamic explicit integration kernel, SimPipe, is described in this paper.

The mandatory initial stage of any pipeline analysis consists of laying the pipeline on the seabed. A realistic and computationally efficient approach was adopted to model this laying process onto a 3D seabed with the assistance of Digital Terrain Modelling (DTM) techniques. Advanced tools (e.g. a customised graphical display) have been developed to rapidly locate problem areas and re-route the pipeline.

Once the pipeline is laid, the new computational engine (SimPipe) performs full 3D pipeline analyses. The pipeline-soil interaction is modelled by the use of advanced soil springs and the DTM. Loads are automatically generated for commonly encountered conditions.

Keywords

Submarine pipeline, finite element analysis, pipe-soil interaction, out-of-straightness analysis (OOS), pipeline walking, pipeline buckling.

1. INTRODUCTION

Setting up a pipeline-soil interaction model in a general purpose finite element (FE) package (e.g. ABAQUS, ANSYS) is not always straightforward. For example, defining the seabed grid and pipeline geometry requires advanced scripting techniques. Writing and validating script files and input decks consume a considerable amount of time and resources. In order to assist the offshore pipeline engineer, Fugro have developed a new dedicated FE software package that allows users to define and analyse pipeline models much more quickly without compromising on realism provided by advanced general purpose packages.

In the 1980s, SAGE Engineering (now Fugro Engineers SA/NV) developed in co-operation with EMC (now Saipem UK) FE software for pipeline out-of-straightness (OOS) analyses. The software implemented a static implicit finite element engine, able to compute the OOS profile of a pipeline given a seabed profile, pipe properties, soil conditions, internal and external loads (water pressure, operating pressure and temperature, etc). This software was based on some assumptions in order to provide fast and reliable solutions using the computer power available at that time. Its main limitations were the use of an implicit equation solver and that the laydown phase was performed in 2D.

In 2005, Fugro Engineers started to develop a brand new 3D FE engine for pipeline analysis: SAGE Profile 3D (SP3D). The goal was to provide a full 3D software package for on-bottom pipeline analysis which could also efficiently model pipeline lay down onto a DTM.

This paper will first describe the theory behind the SP3D FE engine SimPipe. The functionality of the engine is then illustrated by some application and validation examples.

2. THEORY

2.1 SIMULATION ASSUMPTIONS

SimPipe/SP3D simulates a pipeline by discretising it into sections of finite length. These sections are called elements and are bounded at either end by nodes. The continuously distributed mass of the pipe is concentrated at these nodes. The pipe is therefore represented by a chain of point masses (the nodes) linked by massless elements. To ensure similar structural behaviour, each node is assumed to have a cross section similar to the cross section of the pipeline. If present, soil support is also lumped at these nodes.

SimPipe analyses the pipe-soil system using a transient dynamic explicit integration kernel. It therefore does not use matrix assembly or matrix solution methods. This means that SimPipe calculates node movements over time.

By introducing the concept of damping, this explicit dynamic approach can also be used to obtain solutions to quasi-static problems. To compute the pipe deformations (and stresses) under a given static loading, SimPipe gradually applies the loading over a period of time and traces the motion of the pipe as it adapts to the changed circumstances. Provided that enough elements are used, the time steps are small enough and damping is applied to eliminate vibration, the pipe static equilibrium shape is obtained.

2.2 DEGREES OF FREEDOM

The SimPipe model is inherently three-dimensional: each node has three degrees of freedom associated with its three co-ordinates that define its position in a 3D space. Additionally, pipe cross-sections in each node can rotate under applied loads. To describe the orientation of the cross section, three rotational degrees-of-freedom are introduced. Each node is therefore has six degrees of freedom: three translational and three rotational.

2.3 TIME STEP SELECTION

The selection of a suitable time step is critical for the computation of the model. Selecting a time step that is too small will result in a simulation that is computationally very expensive and requires a long time to complete. Taking a time step that is too large will result in instabilities and possible divergence of the solution.

The central difference integration scheme used is conditionally stable provided the time step is kept sufficiently small (Cook, 1989). For the axial deformation mode, the critical time step can be computed as:

$$\Delta t_{crit,axial} = L_0 \sqrt{\frac{\rho_s}{E}} \left(\sqrt{1+\xi^2} - \xi \right)$$

with

$\Delta t_{crit,axial}$	Critical time step for axial elongation (sec)
L_0	Pipe element initial length (m)
ρ_s	Steel density (kg/m^3)
E	Pipe steel elastic modulus (Pa)
ξ	Fraction of critical damping at the highest undamped natural frequency (-)

The physical interpretation of this condition is that the time step must be small enough that information does not propagate across more than one element per time step (Cook, 1989).

3. LAYDOWN

3.1 GENERAL DESCRIPTION

Other software packages dedicated to modelling pipe laydown contain a full suite of advanced features to model pipe – lay barge – water interaction. The goal of SimPipe is not to model the pipe lay process, but to analyse pipe-soil interaction and on-bottom stability once the pipeline has been laid on the seabed. Such SimPipe analyses include on-bottom roughness analysis, span prediction, expansion analysis, buckling etc.

When modelling on-bottom stability using FE software, laydown is the most challenging case to model. For these types of analyses, the as-laid position of the pipeline is used as the starting point for further simulations. Starting from a correct position is therefore of the utmost importance. In general, FE software should produce in a short computational time the as-laid profile. One of the key issues during SimPipe development was how to rapidly and accurately lay a pipeline on a 3D surface.

The answer came from how pipelines are installed in reality: they are laid onto the seabed from a lay barge in an S or J form. On the lay barge, pipe elements are welded together and fed out as the lay barge moves forward. To reduce the complexity of the lay process in the model, the lay barge was fully left out. In addition, the largest upper part of the S or J lay shape was removed from the model by cutting the pipeline as close as possible to the seabed. Both the lay barge and most of the free hanging pipeline could then be replaced by a single pipeline feeding point in the water column moving close to the seabed (see Figure 3-1). In the same way as on a lay barge, the SimPipe feeding point generates new pipe as it moves forward. The bottom tension is applied at the feeding point, generating a residual lay tension in the laid pipe section.

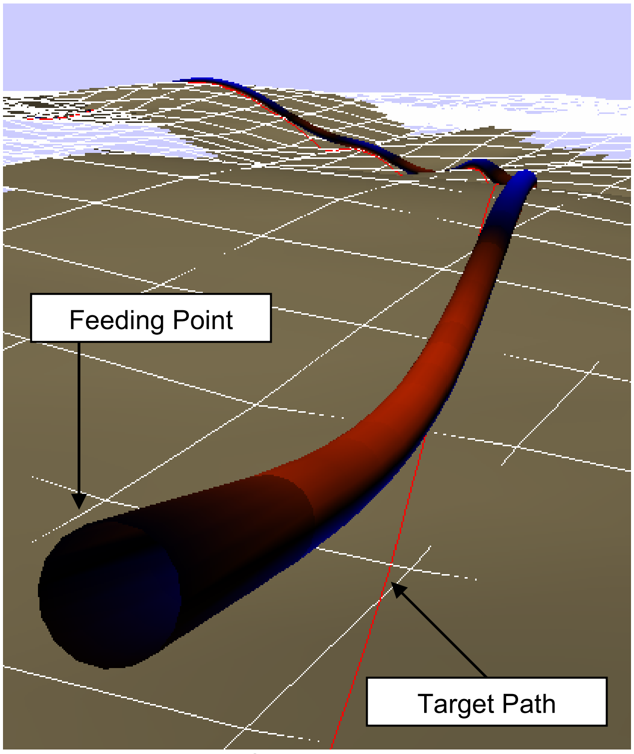

Figure 3-1: SimPipe pipelay process

3.2 FEEDING POINT STEERING

Given the inherent complexity of pipeline laying, an accurate and robust steering mechanism of the feeding point is fundamental in order not to increase the computational requirements. The SimPipe steering mechanism provides a smooth movement of the feeding point in such a way that the pipeline is laid as close as possible to the user-defined pipeline target path. More information on this is in the SimPipe/SP3D manual (Fugro, 2006).

Currently, two laydown modes have been implemented:

- Fixed height: the feeding point height is fixed by the user.
- Fixed angle : the angle between the last element (i.e. at the feeding point) and the horizontal is fixed. In this case, the feeding height used in the steering mechanism is automatically computed.

3.3 ELEMENT KILLING

As the feeding point moves over the seabed, more and more elements are introduced into the model. For all nodes in the model, the co-ordinates need to be computed at each time step. It would be computationally too expensive to continue modelling the entire pipeline length (e.g. for a 50 km pipeline with one node every 4m 12,500 nodes need to be updated at each time step). In order to reduce the amount of computation time, elements already on the seabed and no longer moving are removed from the simulation. This process of element removal is called element killing. This procedure removes all nodes whose velocity is below a user-defined threshold for a specified amount of time.

Pipe laydown only ends when all elements have been killed. This ensures that all nodes have reached a stable static solution before laydown ends and on-bottom stress analysis starts.

4. PIPE-SOIL INTERACTION

4.1 GENERAL CONSIDERATIONS

Pipe-soil interaction is a key issue when assessing pipe out-of-straightness profiles, both axial and laterally. Using low estimate soil strength and stiffness parameters can be conservative in some cases and unconservative in others. For example: using a low axial resistance will underestimate upheaval buckling issues. Similarly, low vertical resistance will overpredict pipe penetration and thus overestimate lateral resistance, leading to a higher resistance for lateral buckling.

Good pipe-soil interaction modelling starts with an appropriate geotechnical site investigation, the importance of which is still underestimated by some pipeline operators. Recommended best investigation practice has been provided by an international working group incorporating geotechnical engineers from operators, installation contractors, engineering contractors and survey companies (OSIG, 2004).

4.2 PIPE-SOIL MODEL

The seabed soils (clay, sand, rock) provide an almost continuous support for the pipeline. In FE software, this support is modelled by discrete springs at each node.

To simplify the computational complexity of seabed contact detection, SimPipe only checks for seabed contact along the absolute vertical below each pipe node and not along the perpendicular direction to the seabed. Nodes in contact are assigned a soil response based on the pipe penetration into the seabed. Computed penetrations are converted to a soil response (a force) using pre-defined force-penetration curves. These curves are automatically generated by SP3D interface using the soil properties input by the user or manually defined. Multiple zones with different soil properties are possible and the soil response will depend on the location of the node along the pipeline. If a node lifts up, the springs are reset and removed from the model.

Vertical springs in SimPipe are modelled by a piecewise linear curve. Axial and lateral springs are modelled by an elastic-perfectly plastic curve with a memory component. The residual plastic resistance consists of a frictional part and adhesion. The frictional part links the axial and lateral characteristics to pipeline penetration. Therefore, both axial and lateral resistances increase as the pipeline penetrates into the soil. The memory component ensures that, when pipeline movement reverses, soil reactions also reverse. Subsequent loading and unloading cycles will, as a consequence, result in a permanent deflection.

More details on pipe-soil interaction models developed for vertical, axial and lateral resistance can be found in the recent state-of-the-art paper written by Cathie et al. (2005).

Figure 4-1 shows SimPipe interface and pipe-soil models. The pipe rendering shows the soil reaction force. Higher reactions can be seen (green shading) at the span shoulders.

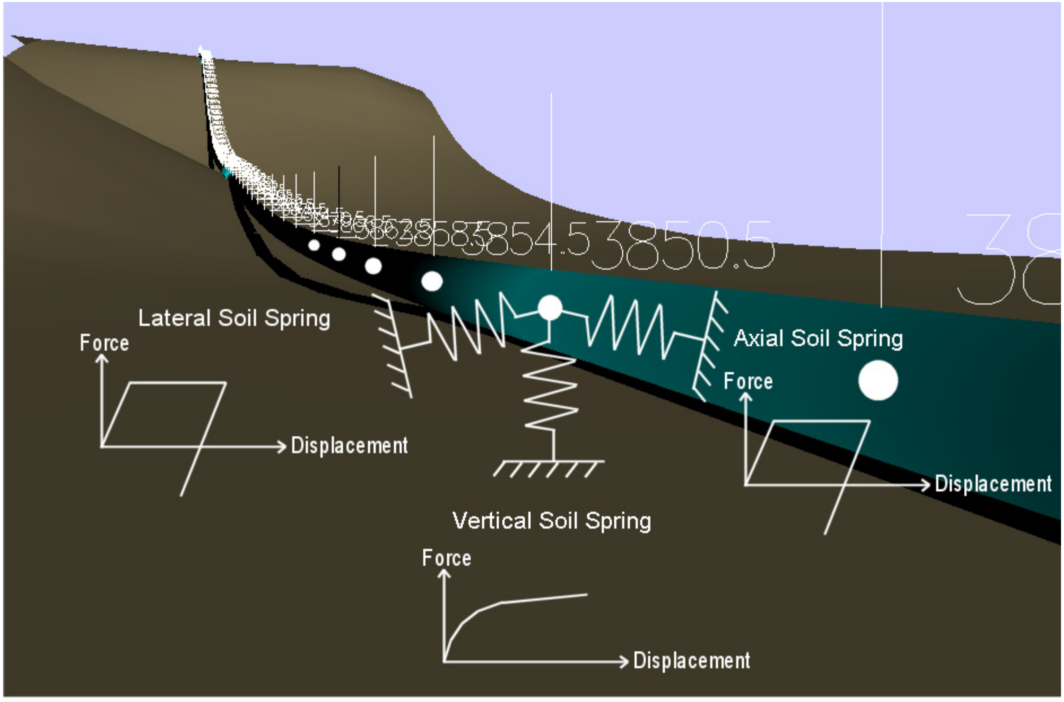

Figure 4-1: Pipe-soil interaction model

5. PIPE MATERIALS AND LOADING

5.1 GENERAL CONSIDERATIONS

Realistic pipe material models, which correctly depict non-linear and plastic behaviours, are fundamental for accurately assessing pipeline profiles. In large displacement analyses, such as lateral buckling or thermal expansion, material non-linearity greatly influences pipe behaviour. Adopting a linear elastic approach significantly increases pipeline rigidity and consequently overpredicts the load level and underestimates displacements. A too soft non-linear material would, on the other hand, substantially increase displacements and reduce load levels.

In addition to an accurate material model, a realistic representation of the different loads acting on a pipeline is essential (see Figure 5-1). The actual loads on a pipeline are very diverse ranging from environmental (currents, waves, external pressure etc.) to operational (internal pressure, temperature) and installation linked (lay tension, trenching etc.). In addition to a comprehensive modelling of the acting loads, the load history is crucial. Indeed, given the high non-linearity of the different parameters in a pipeline problem (pipe-soil interaction, material), the loading history greatly influences the analyses results (i.e. pipeline shape, loads, displacements).

5.2 PIPE MATERIALS

As already mentioned, SimPipe models the pipe as a chain of point masses (the nodes). At each time step, the new node positions are computed based on Newton's equations of motion. By comparing the new positions at time t+1 with the positions obtained at time t, the deformation of each element can be computed. The obtained strains and curvatures are computed and, in accordance with the chosen material model, converted to forces and moments.

Both linear elastic and non-linear material models have been implemented in SimPipe. All non-linear model curves are described by a Ramberg-Osgood curve fit (Ramberg and Osgood, 1943; Murphey and Langer, 1985). By using appropriate curve fit parameters, different non-linear bending effects can be taken into account.

5.3 PIPE LOADING

The loads acting on the pipeline can be either defined specifically (lay tension, internal and external pressures and temperature) or modelled using either uniformly distributed loads (e.g. to model buried pipe sections), point loads or prescribed displacements (e.g. pipeline being lifted by the plough grabs during trenching operations).

External and internal pipeline pressures are modelled by taking into account the water depth at each node. Linear and piecewise temperature profiles can be input. Pressures and temperature variations (as well as the bottom tension defined during lay down) contribute to the nodal forces.

Finally, the pipeline loading history, fundamental in any realistic case, can also be very accurately depicted by defining different successive load cases. Loading sequences, such as shut-down cycles, can be easily modelled using the SimPipe restart capability. This allows a load case to start from the end configuration of a previous one.

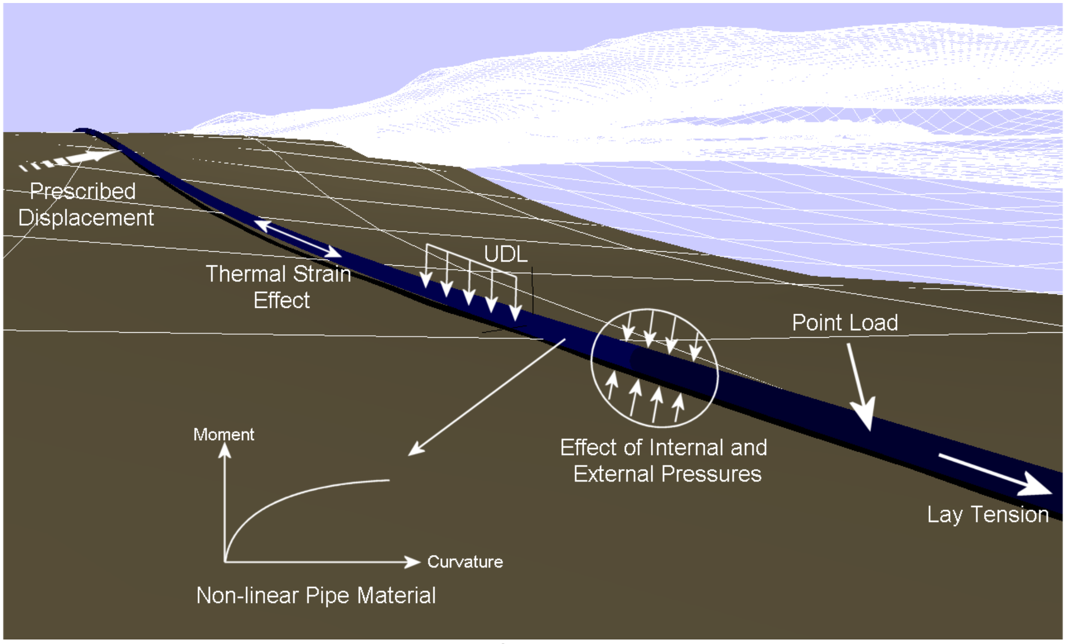

Figure 5-1: SimPipe 3D model

6. EXAMPLES OF APPLICATION

6.1 3D PIPE ANALYSIS

This section illustrates the use of SimPipe/SP3D to model pipelines in 3D. Both empty laydown and operational loading cases were compared for a gas pipeline. Figure 6-1 shows a span just after laydown and Figure 6-2 shows the same span during operational loading. It can be clearly seen that, due to the feeding of the pipe in the trough, the span length has reduced and that bending stresses (plotted in red for compressive stress and in blue for tension stress) have increased due to the operational loads.

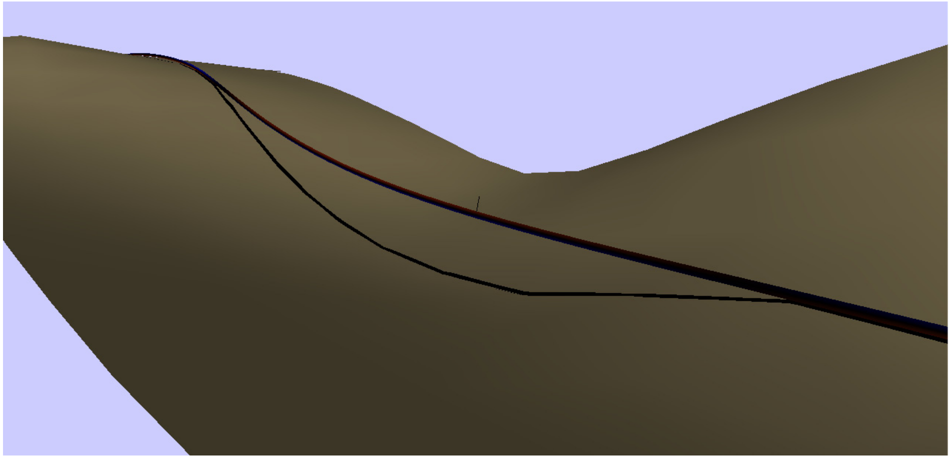

Figure 6-1: Span after laydown - Empty case

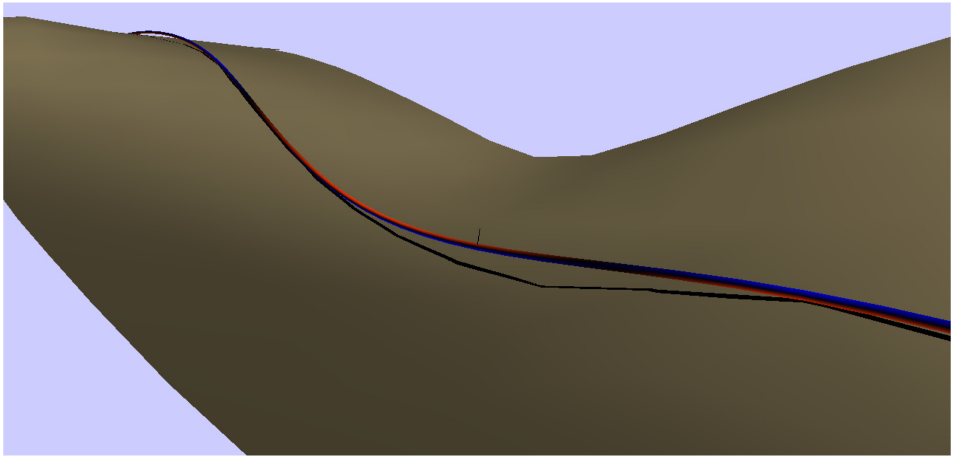

Figure 6-2: Span - Operational load conditions

Figures 6-3 and 6-4 show lateral pipeline movement due to operational loading conditions. On both figures, the bottom window shows the lateral deviation of the pipeline from the target path. The lateral deviation is expressed in pipeline diameters. The area marked in red is visible in the top screenshot. On Figure 6-3 it is observed that the pipe has been laid on the target path to within half the pipeline diameter.

Due to the operational load, the pipeline moved sideways at various locations (see bottom of Figure 6-4). Lateral movement up to 4 pipe diameters is seen. The lateral movement in the areas depicted on the screenshots is limited to 1 pipe diameter. Figure 6-4 also illustrates the 3D bending stress state in the pipeline. The neutral bending axis rotates clearly when the pipeline moves from the lateral buckle into the seabed depression.

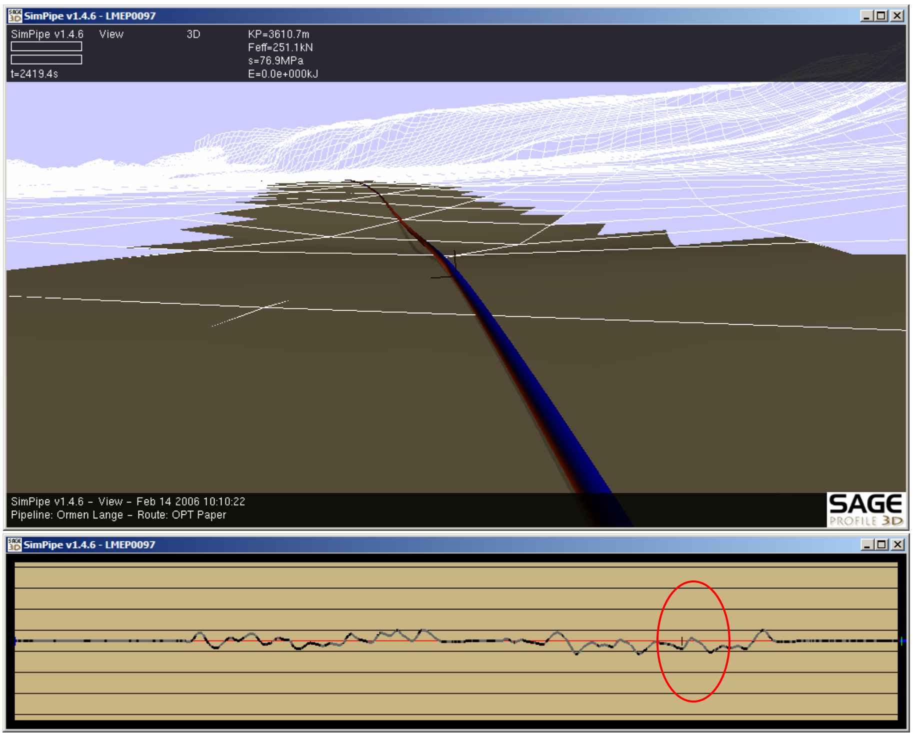

Figure 6-3: Bending stresses - Empty case

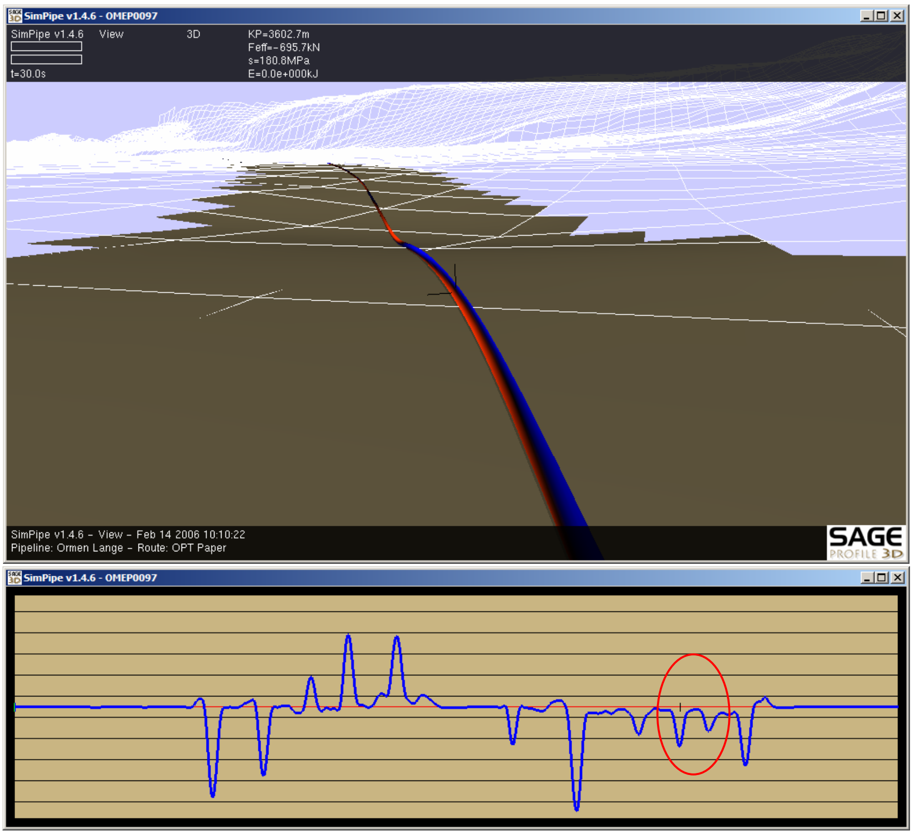

Figure 6-4: Bending stresses – Operational loading conditions

6.2 PIPE WALKING

6.2.1 Introduction

Observations and analysis have shown that pipelines can walk or creep axially (Tornes et al., 2000; Carr et al., 2003). The driving mechanism is expansion and contraction due to internal heating and cooling of the pipeline and whether or not there is an effective anchor point at which no movement occurs. The rate of movement depends not only on the temperature profiles but also on the magnitude of the axial resistance, the mobilization distance and the rate of degradation to residual conditions. Some combinations of seabed topography, low seabed friction, pipeline layouts and lengths can also lead to pipe walking.

This well known phenomenon can lead to large displacements along the pipeline, which in turn, can cause the pipeline to deviate from its original lay configuration and/or overstress in-line structures, such as termination units or expansion spools.

In this section, pipeline walking due to seabed slope is illustrated through SimPipe FE examples (Figure 6-5).

6.2.2 Theoretical background

Walking due to seabed slope can occur in unrestrained pipelines under repeated cycles of temperature and/or pressure and takes the form of a rigid body movement, i.e. only the pipeline position changes, not its total length. Migration is caused by asymmetry of frictional forces acting on the pipeline caused by the seabed slope (see the effective axial force profiles in Figure 6-6).

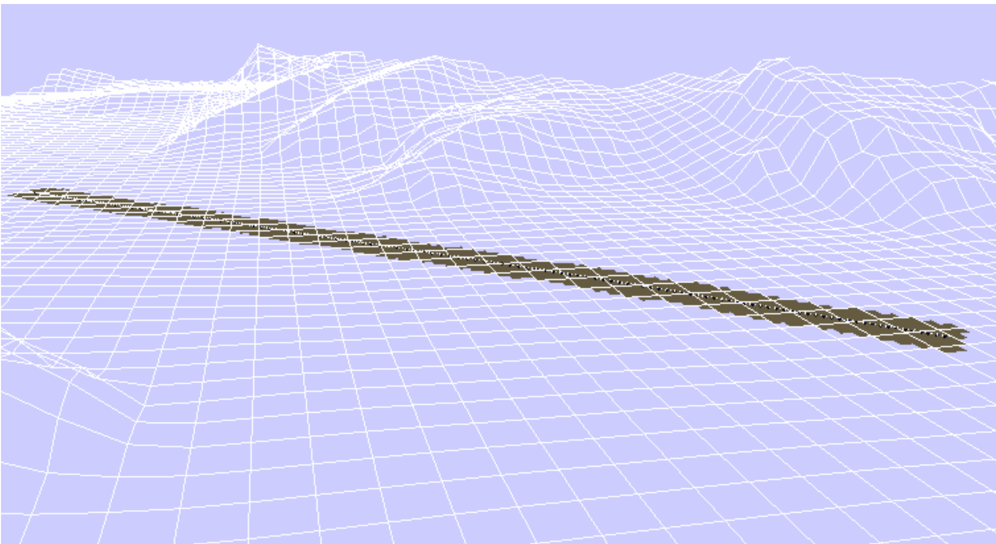

Figure 6-5: Pipeline on an inclined seabed

For movement to take place, the effective axial force over the entire pipeline length has to remain below the fully restrained conditions during all the steps of the cycles (Gaillard and Williams, 2005). Any section of the pipeline where the effective axial force reaches fully restrained conditions will become anchored and prevent the pipeline from walking.

From simple geometrical considerations, it is easy to determine that, for a straight pipeline on an inclined seabed with uniform temperature and/or pressure profiles, pipeline walking will take place if the following inequality is true (Gaillard and Williams, 2005):

$$f < \frac{\Delta \mathrm{ESF} + \mathrm{L} \cdot \mathrm{w} \cdot \sin\alpha}{\mathrm{L}}$$

with:

$$f = \mu \cdot \mathrm{w} \cdot \cos\alpha$$

where:
α the slope angle
w the pipeline unit weight
μ the axial soil friction factor
L the pipeline length
ΔESF the variation of the fully restrained effective axial force over the pipeline length L between heat-up and cool-down

6.2.3 Model

The axial and lateral soil responses are modelled in SimPipe using uncoupled axial and lateral elastic-perfectly plastic memory springs. The memory component of the frictional springs, which allows for plastic deformations, is fundamental to accurately model walking.

In order to analyse the walking response of the pipeline, the model was subjected to temperature cycles. Three cases were considered. In all cases, the temperature cycles went from 0°C (no temperature variation) to 20°C. The seabed slope is 15 degrees Only the seabed friction and the pipe total length was varied:

- Case 1: L = 1000 m and μ = 0.4
- Case 2: L = 5000 m and μ = 0.4
- Case 3: L = 5000 m and μ = 0.7

In the results presented in the next section, compressive effective forces are negative. KP 0 is located near the top of the slope and KP 1000 or 5000 are located near the bottom of the slope.

6.2.4 Results

6.2.4.1 Case 1

As it can be observed in Figure 6-6, the axial friction is not enough for the pipeline to reach fully restrained conditions neither during heat-up nor cool-down. During heat-up, the pipeline has a virtual anchor point near the top of the slope while, during cool-down, the virtual anchor point (relative to the heat-up) is located near the bottom of the slope. Since no point is anchored during both stages (see Figure 6-7), the pipeline walks downslope as shown in Figure 6-8. This figure also shows the rigid body nature of this walking type: both pipeline ends move the same amount at the end of each cycle.

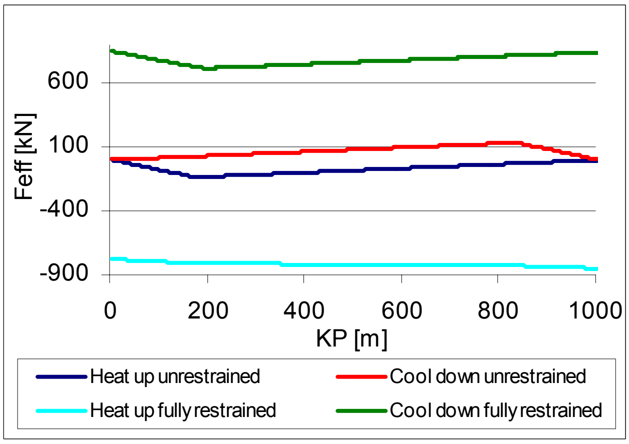

Figure 6-6: Effective axial force - Case 1

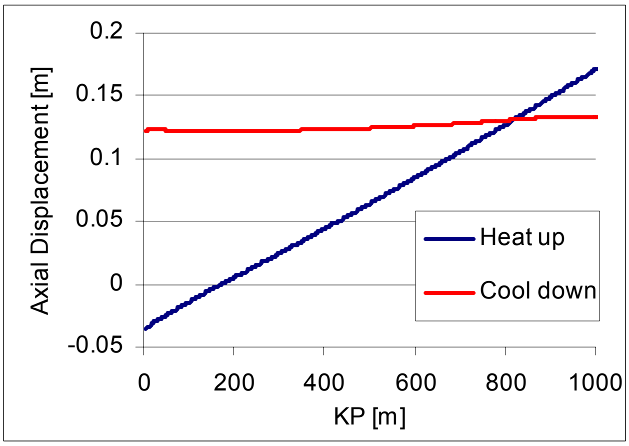

Figure 6-7: Axial displacement along the pipeline - Case 1

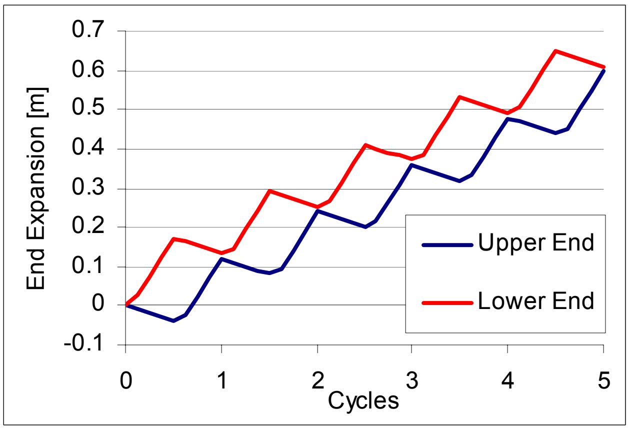

Figure 6-8: Pipeline walking

6.2.4.2 Case 2

As can be seen in Figure 6-9, the axial friction is not enough for the pipeline to reach fully restrained conditions during heat-up. Like Case 1, the pipeline has simply a virtual anchor point near the top of the slope. On cool-down, however, axial friction is enough for a certain part of the pipeline to reach fully restrained conditions (between KP 1000 and 4000 approximately). Over this length, the pipeline remains anchored and, thus, cannot move during cool-down (see Figure 6-10). In addition, since the virtual anchor point of the heat-up stage is located within the cool-down anchored length, the pipeline becomes anchored at that location (during both heat-up and cool-down) which prevents walking.

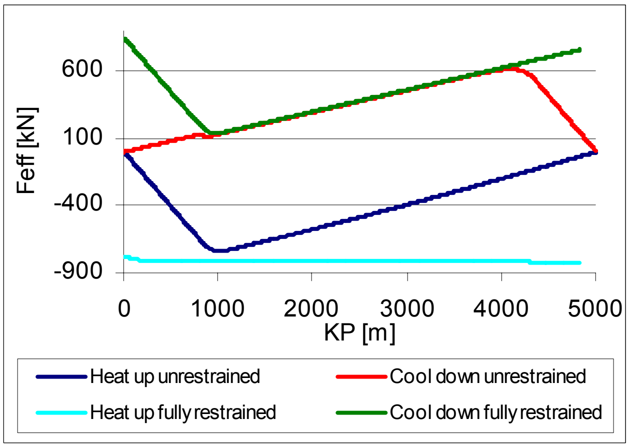

Figure 6-9: Effective axial force - Case 2

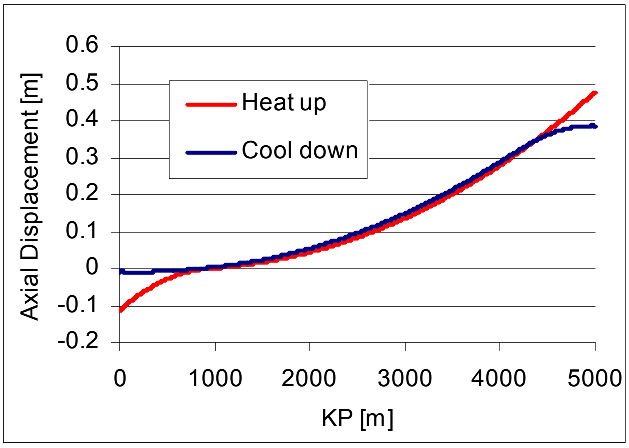

Figure 6-10: Axial displacement along the pipeline – Case 2

6.2.4.3 Case 3

As it can be observed in Figure 6-11, in this case, axial friction is sufficient for the pipeline to reach fully restrained conditions over a certain length during both heat-up and cool-down. Hence, the pipeline is anchored over that length and cannot move during heat-up or cool-down (see Figure 6-12). Since the anchored lengths during both phases overlap, the pipeline cannot walk.

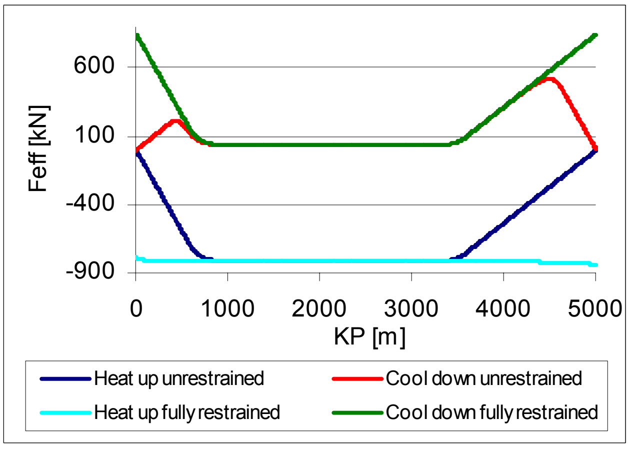

Figure 6-11: Effective axial force - Case 3

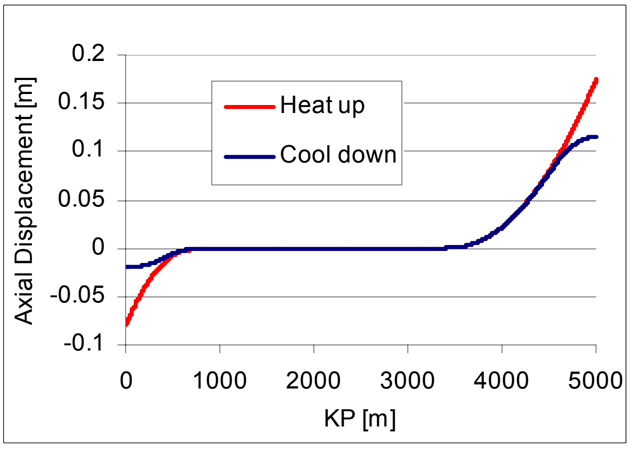

Figure 6-12: Axial displacement along the pipeline – Case 3

6.2.5 Summary

Pipeline walking due to seabed slope has been modelled and the results showed perfect agreement with theory: migration occurs only when the effective axial forces along the entire pipeline remain below the fully restrained conditions during both heat-up and cool-down.

Accurate pipeline walking modelling is very important to closely simulate both pipeline behaviour and the actions it imposes on other in-line structures or termination units. Including such considerations in the design phase, especially with significant slopes and reduced friction factors, is essential.

Compared to the existing 2D FE engine, SimPipe allows rigid body movement. One of the main improvements is that pipeline nodes are not linked with seabed nodes, allowing essentially unlimited pipeline displacement and modelling more accurately pipe expansion. Due to the memory component of the axial springs, modelling pipe walking is feasible. In the above examples, the pipeline was aligned with the maximum slope gradient. More complex situations can be modelled in the same way (e.g. pipeline installed at 45° across the slope).

6.3 BUCKLING

6.3.1 Introduction

Subsea pipelines are increasingly being required to operate at High Temperatures (HT) and High Pressures (HP) as more and more HP / HT fields are being developed. Under such conditions, very high compressive forces can build up in a pipeline (because of restraints such as soil friction, burial, connections with other structures, etc.). In the presence of initial imperfections, always existent in a pipeline (because of seabed irregularities, barge motion during laydown, fishing gear interaction), these forces can cause buckling which may have serious consequences on pipeline integrity.

Two major buckling groups exist:

- Upheaval buckling (UHB)
- Lateral buckling.

In the following sections, both types are briefly explained and illustrated through FE examples modelled using SimPipe.

6.3.2 Theoretical background

The basics of buckling were developed by Euler who first established the critical load for a perfect elastic strut with pin bearings.

In pipeline engineering, Hobbs (Hobbs, 1981) was among the pioneers who developed an empirical method for computing buckling. His approach was based on solving the linear differential equation for the deflected shape of a spring-supported beam-column under axial load. The most important limitations of this method are the assumption of linear elastic material and small rotations as well as the idealised straight pipeline.

It is however well established that lateral buckling modes are possible at lower compressive forces than the vertical mode. Thus, unless horizontal displacements are restrained (typically a buried pipeline), or a dominant vertical imperfection is present, pipelines tend to buckle laterally.

In post-buckling behaviour, the effective axial force in the buckle zone (which reached a critical value to trigger instability) drops because of the extra length that feeds into the buckle. The length of the buckle, its maximum amplitude and the effective axial force inside mainly depend on the material mechanical properties, pipeline geometry and weight and pipe-soil friction.

6.3.3 Model

Two simplified examples have been considered; one dealing with UHB and the other one with lateral buckling. A linear elastic pipe material has been adopted and the compressive axial force is due to temperature increase. As a comparison, both models have been run using the general purpose FE software ABAQUS Standard V6.5 (Abaqus, 2004).

It is very important to note that the initial imperfections considered in these examples are fundamental for buckling to occur. Perfectly straight pipelines (with linear elastic materials) will never buckle, whatever compressive force they are subjected to.

6.3.4 Upheaval buckling

During SimPipe validation, Hobbs UHB theory has been taken as reference for setting up an example. Simplified artificial cases have been considered with the following main characteristics:

- Rigid frictionless soil
- 100 m long pipeline pinned at both ends
- 30 cm initial vertical imperfection at mid-length.

Results are presented on Figure 6-13 through Figure 6-16 The model showed excellent agreement with both ABAQUS and Hobbs theory. Note that Hobbs' method, since it does not consider any initial imperfection, cannot be used to predict the exact onset of buckling. Nevertheless, the method has been used in the post-buckling phase to predict both the effective axial force and buckle maximum amplitude based on the buckle length.

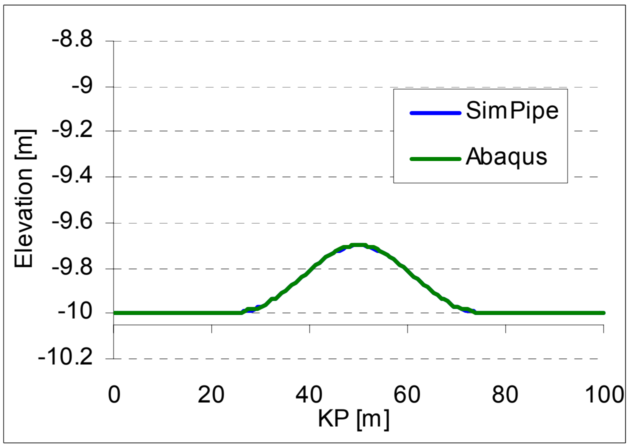

Figure 6-13: Pipe profile – UHB – Onset of buckling

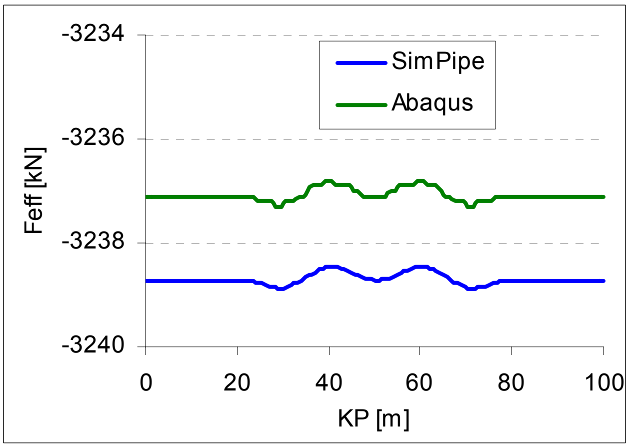

Figure 6-14: Effective axial force – UHB – Onset of buckling

The drop in the effective axial force discussed in Section 6.3.2 can clearly be observed in Figure 6-16 (also by comparison with Figure 6-14). But, in this case, given no soil friction and a very short pipeline, the force drop occurs over the whole length and is not limited solely to the buckle region.

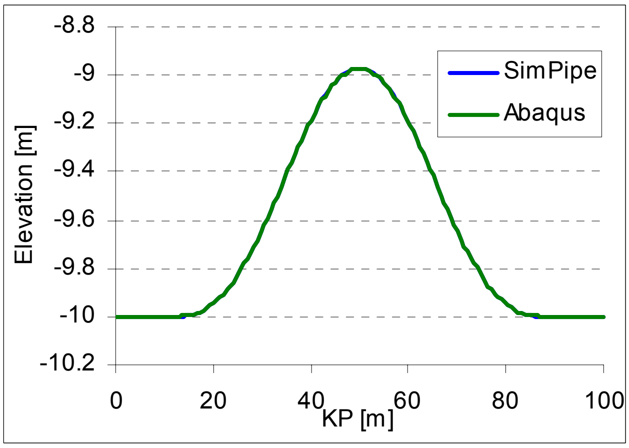

Figure 6-15: Pipe profile – UHB – Post-buckling

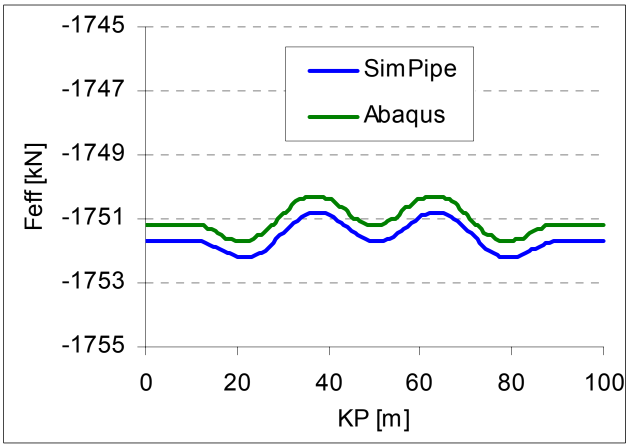

Figure 6-16: Effective axial force - UHB – Post-buckling

6.3.5 Lateral buckling

A SimPipe lateral buckling validation example has also been made. As a target solution, a similar model run using ABAQUS has been considered. In this case, the model characteristics are:

- 200 m long pipeline pinned at both ends
- Lateral and axial friction factors equal to 0.7
- Initial imperfection created by a lateral force at mid-length.

Results are presented on Figure 6-17 through Figure 6-20. In this case, the agreement between both software remains very good (maximum differences within 5%) but differences can still be observed. The main reason for such discrepancies is the different soil friction models in SimPipe and ABAQUS.

The SimPipe soil interaction is modelled by two uncoupled springs linked to the local coordinate system; i.e. the lateral soil resistance remains perpendicular to the pipe section whatever the displacement direction. In ABAQUS, a simple Coulomb friction model was used (Abaqus, 2004). This difference in friction explains the deviation between the displacement and the effective axial force values.

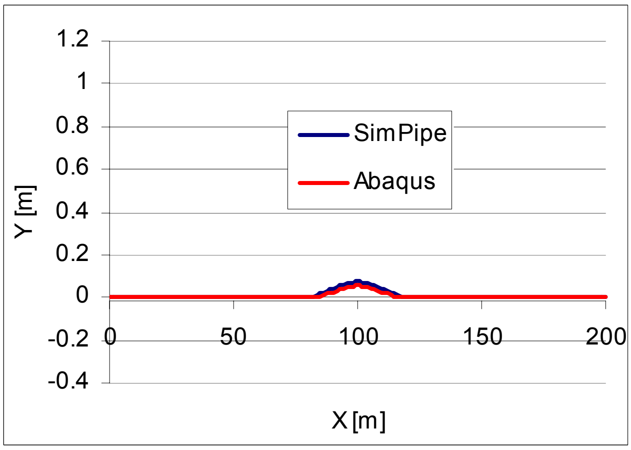

Figure 6-17: Pipe profile – Lateral buckling – Onset of buckling

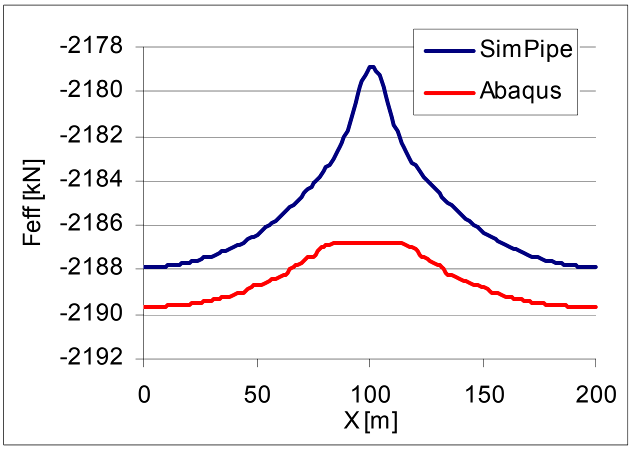

Figure 6-18: Effective axial force – Lateral buckling – Onset of buckling

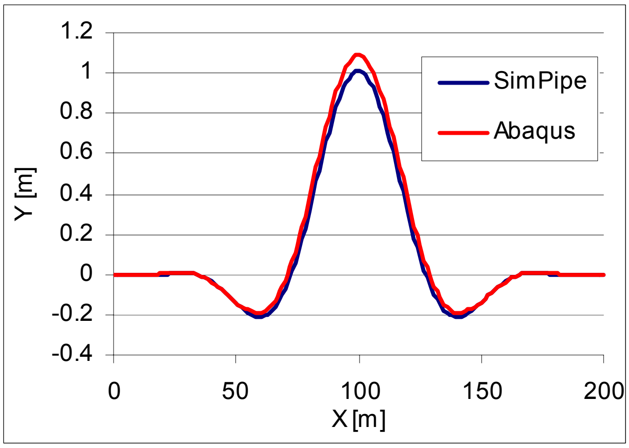

Figure 6-19: Pipe shape – Lateral buckling – Post-buckling

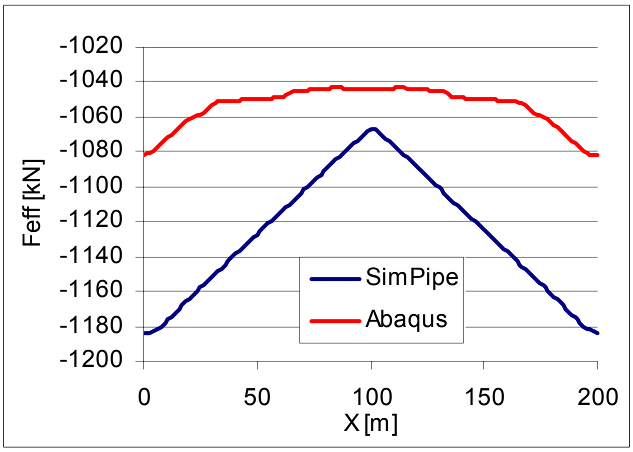

Figure 6-20: Effective axial force – Lateral buckling – Post-buckling

6.3.6 Summary

Validation examples have proved that SimPipe is suited to model both lateral and upheaval buckling. When modelling an unburied pipe in 3D with SimPipe, lateral buckling will occur first allowing axial force redistribution. Upheaval buckling is likely to occur if vertical imperfections are predominant.

7. ON-GOING DEVELOPMENTS

Modelling pipe-soil interaction properly is essential. Examples given in this paper have demonstrated that advanced analyses can be made in SimPipe. However, lateral and upheaval buckling and pipeline walking are highly dependant on the soil model used.

In order to model such problems more accurately, a new pipe-soil model will be implemented in SimPipe. It will mainly concentrate on the lateral soil resistance and allow improved lateral buckling simulation. This pipe-soil model is based on the yield envelope approach (e.g. Zhang, 1999 and Cassidy, 2004).

8. CONCLUSIONS

A new FE engine for subsea pipeline modelling has been developed. SP3D uses a transient dynamic explicit integration kernel (SimPipe) that makes full 3D analyses possible. The seabed is modelled using a 3D digital terrain model.

The main purpose of the software is to analyse pipeline out-of-straightness by modelling accurately the pipe soil interaction. Hence, laydown is performed in a realistic but simplified way in order to efficiently and rapidly find the corresponding as-laid pipe profile. Once the pipeline has been laid, SimPipe allows to perform full 3D pipeline stress analysis. Thanks to its user-friendly interface and powerful FE engine, complex 3D models can be easily setup and efficiently solved in SP3D.

The SimPipe/SP3D software has been validated with more than 50 examples and will be soon certified by a third party.

Capabilities include lateral and upheaval buckling as well as pipeline walking. These capabilities will be further improved by the introduction of new pile-soil interaction models and more refined beam elements.

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