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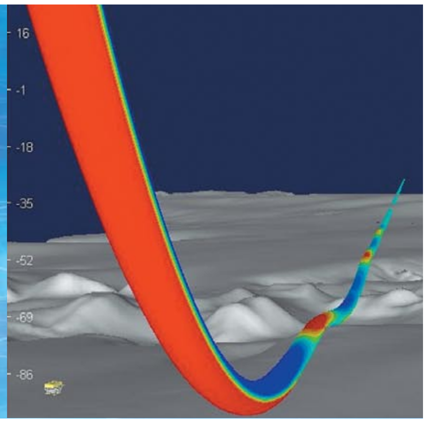
SIMLA

- a special purpose computer tool for engineering analysis of offshore pipelines during design, installation and operation



SIMLA - Simulation of Pipelaying

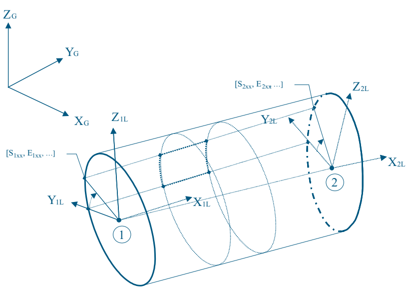
In recent years, more and more pipelines have been installed on uneven seabed, both in deepwater fields and in the inshore zone, while production temperatures in the reservoirs have also been increasing. This trend is continuing in new field developments.

SIMLA is MARINTEK's newly developed computer tool for analysis of offshore pipelines in deep waters and rough environments. Currently available functionality includes pipelaying and inspection of free spans. The initial version of SIMLA was developed by MARINTEK for Norsk Hydro ASA, with Ceetron GLview AS and Systems in Motion as sub-contractors on 3D visualization.

The objective for SIMLA was to develop a software tool capable of simulating the structural response of a pipe during laying, and to allow inspection of the result of this operation by 3D graphical visualization of the pipe on the seabed, including pipe details with results from the analysis. The simulator, including its visualization functions, can be run on desktop computers.

Analytical engine for calculation of pipeline response

A special-purpose finite element solver has been developed to calculate the structural response of the pipe being laid.



12 degrees of freedom 3D beam element.

The special purpose numerical engine is based on integrating several levels of response resolution into one finite element solver, including the following features:

- Catenary solution
- Stiffened catenary solution
- 2D FEM solution with both four and six degrees of freedom per element, in a linear and elastoplastic material model
- 3D FEM solution with both eight and twelve degrees of freedom per element, in a linear and elastoplastic material model

The multi-level solver approach has been chosen to allow for different levels of detail in the analysis, including efficient generation of initial pipe configuration.

The active number of degrees of freedom is configurable to allow for optimisation of computer time if necessary in order to obtain the computation speed desired.

The input to the numerical module is based on engineering terms for pipelaying, as used for example in alignment sheets.

The principle of the analysis module is to only handle the pipe from the touchdown point to the vessel, including the necessary (affected) part of the pipe resting on the seabed. The structural response for the pipe already laid but not affected

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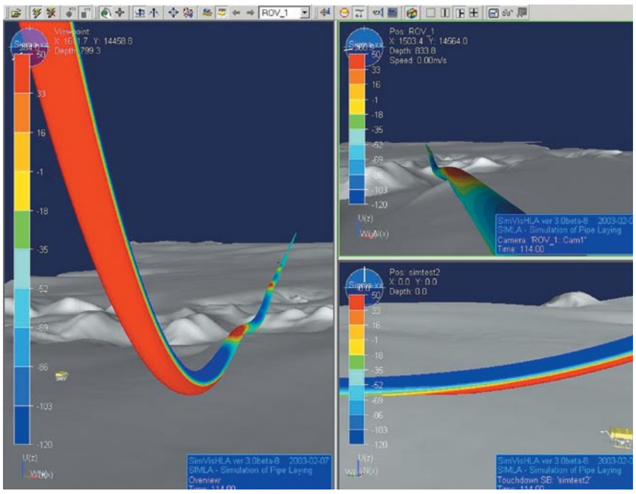
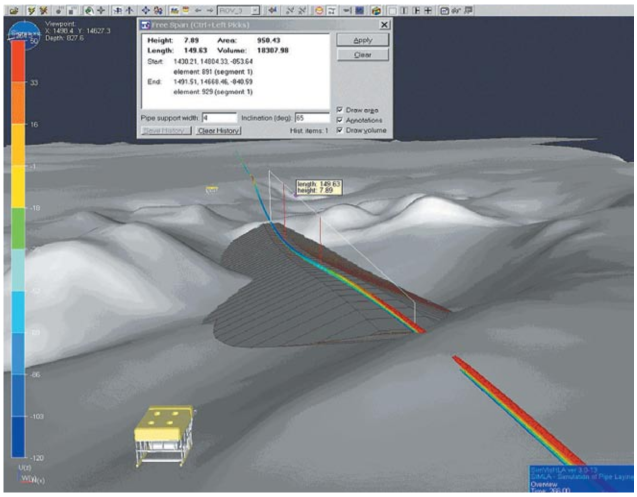
- **Nonlinear 3D FEM static and dynamic analysis**
- **Simulation of pipe laying**
- **Evaluation of laying stability**
- **Upheaval buckling and snaking analysis**
- **Inspection and evaluation of free spans**
- **Training and familiarization**
- **Route planning and optimalization**
- **Seabed interventions**
- **Prediction of vessel position**
- **Operator guidance**





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by the current configuration is therefore stored in a result database for later use (result plots, restart analyses, etc).

Visualization

The SIMLA visualization module automatically adjusts the graphical resolution of both the pipe and the seabed, depending on viewpoint. Thus, when a laying scenario is being inspected from some distance the actual pipe will be rendered as a line (coloured if analysis results are included). However, when closing up, for example to the touchdown point, the pipe will be rendered with polygons (again, coloured if analysis results are included) representing the outer surface of the pipe, and the resolution of the 3D seabed will increase.

The visualization module is built as a Windows application with pull-down menus, toolbars and 3D graphics. The main objective of this module is to allow large terrain models and the actual pipe laying process, including vessel and pipe with structural response, to be visualised simultaneously during the analysis.

The user can move freely around in the selected project scenario, e.g. by utilizing a joystick-controlled ROV.

At any time the pipeline as laid may be inspected visually, and free span details, such as length, height, pipe support volume, etc, may be inquired by a single point-and-click operation.

Lateral buckling analysis of offshore pipelines using SIMLA

Offshore pipelines are required to operate at ever higher temperatures and pressures. The resulting high axial compressive force may lead to unexpected buckling, which may have serious consequences for the integrity of the pipeline if this is not taken into account during the design phase.

Unexpected lateral buckling has been observed in several operating pipeline systems. The offshore industry lacks a complete understanding of lateral buckling, and efficient tools for simulating buckling behaviour early in the design phase would make a valuable contribution to our knowledge.

The computer analysis tool, SIMLA, which has been developed by MARINTEK for Norsk Hydro, can accurately predict and simulate buckling effects. SIMLA includes special-purpose tailor-made nonlinear finite elements, contact algorithms, material models and numerical procedures for advanced structural analyses of offshore pipelines. Furthermore, the full 3D representation of the seabed can be taken into account, a necessity in areas with very irregular seabed topography.

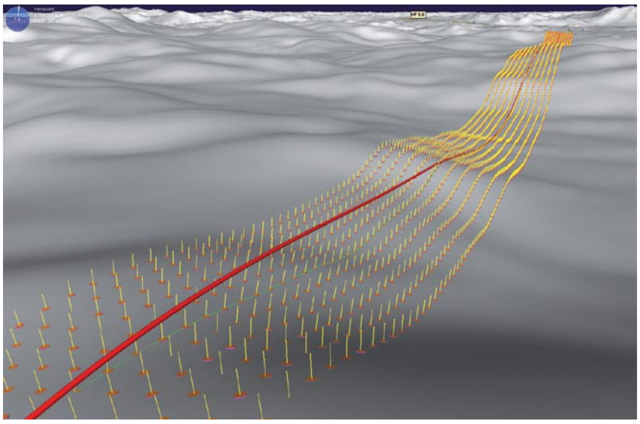

Figure 1. 3D seabed with pipeline and route corridor.

Buckling is very sensitive to the initial configuration. In order to obtain accurate results, the various phases in the life-cycle of the pipeline need to be taken into account in the analysis. SIMLA does this in sequential steps:

- In the first step, the pipeline is automatically placed along the predefined route. This is handled automatically by the AUTOSTART feature in SIMLA. The correct stresses

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resulting from the route description, seabed, hydrostatic loads and gravity effects are calculated with minimum input from the user.

- Water filling and pressure test are usually then carried out. After full pressure has been obtained, the pipe is de-pressurised and the water is removed. In SIMLA this is performed by raising and lowering the internal pressure and submerged weight of the pipe.
- Operating or design pressure and the corresponding updated submerged weight are then applied.
- In the final step, the thermal load is applied.

When buckling takes place, the problem is unstable, and a transient dynamic analysis is normally performed to apply the thermal load. SIMLA is able to switch from a static to a dynamic approach within the same analysis. This way, the water filling, pressure test and operating loads may be applied statically for the sake of efficiency, leaving the thermal load to be applied dynamically, thus increasing the numerical robustness.

In a lateral buckling and stability analysis, interaction between the seabed and the pipeline are very important. The 3D representation of the seabed ensures accurate results on the basis of geometric effects. Figure 1 visualises an example of a 3D seabed. The green line defines the route centreline and the yellow pins define the surface normals at discrete points. The route corridor grid resolution in both the axial and longitudinal directions is defined by the user.

In addition to the 3D route corridor, the numerical representation of the interaction between the pipe and the soil is also very important. SIMLA makes several numerical pipe/soil interaction models available. The soil stiffness and friction coefficients may individually be defined as functions of displacements in the lateral, axial and vertical directions. Both hyperelastic and elastoplastic material behaviour may be applied.

In order to verify the buckling analysis capabilities of SIMLA, a 4.5 km section of the Ormen Lange PL-A import line

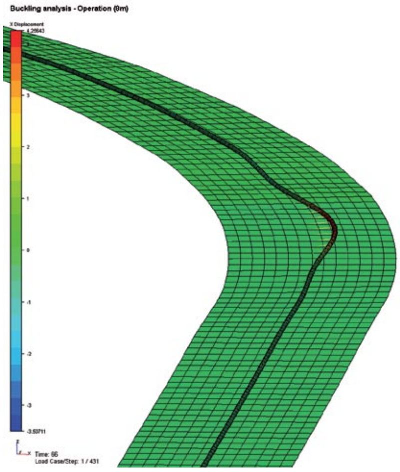

Figure 2. Displacement pattern at 100% load.

was analysed, using a snake lay route according to the original design produced by Reinertsen Engineering.

The route is relatively flat in this area, with a vertical difference between the start and end of the route section of approximately 22 m.

The seabed was defined with a resolution of 2 m in both axial and lateral directions; see Figure 1 for illustration.

During the pressure test, a pressure of 27.3 MPa was applied. The design pressure was 24.2 MPa, and the design temperature increase was 31.7^{o} C.

The analysis was defined and run in SIMLA. The results indicate that the pipeline would buckle at two sections, and that the maximum lateral displacement is estimated to be 4.6 m, with a maximum axial strain of 0.24%; see Figures 2 and 3.

The SIMLA results were compared with existing results from an ANSYS analysis performed by Reinertsen Engineering as part of the detailed design process. The buckling shapes, moment and distributions of force are virtually identical. The maximum lateral displacements differed somewhat, being about 9% lower in ANSYS than indicated by SIMLA results; see Figure 3.

In order to enable the ANSYS analysis to be completed within a reasonable time, 8 m elements were used in the ANSYS model. The time required for analysis of an 8 m element model in SIMLA is less than 5 minutes on a 1.8 GHz AMD Opteron PC. In order to obtain more accurate results, an element length of 2 m was also utilised in SIMLA, requiring an elapsed time of 18 minutes. The short analysis time indicates that significantly larger sections of the pipe can be analysed in one go with SIMLA without problems.

The existing analysis capabilities of SIMLA enable us to accurately predict and evaluate lateral buckling in subsea pipelines. Automatic algorithms and an engineering-friendly input format significantly simplify the pre-processing and model set-up stages. Efficient numerical routines make it possible to analyse long pipeline section with a high degree of accuracy in a matter of minutes.

Figure 3. Lateral displacement vs. route position at 100% load in SIMLA and ANSYS.

Applying SIMLA for evaluation of pipeline stability during installation

Due to the rough seabed terrain in the deepwater area of the Ormen Lange field (Figure 1) stability during installation is an important issue.

Simplified 2D evaluation methods do not take the contribution from bending stiffness of the pipe into account. In large-diameter pipes, bending stiffness will distribute the lateral reaction force from the seabed over a significant length in the touchdown area, and this therefore needs to be taken into account when evaluating stability during installation.

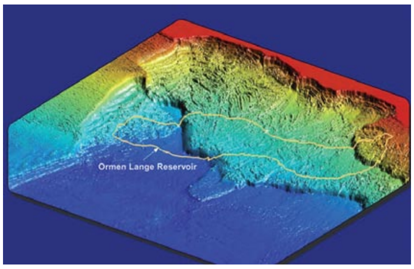

Figure 1. The Ormen Lange deepwater area.

By utilising SIMLA, which has been developed by MARINTEK for Norsk Hydro, the contribution from bending stiffness of the pipe can be included, and the constraints of the pipe aft of the touchdown will be simulated in a realistic way, as the software makes use of a proper 3D terrain model. Furthermore, instability at specific locations is not necessarily regarded as critical if it can be shown that the pipe slides into a stable configuration. Utilizing recently developed functionality in SIMLA (the FEED approach), sliding of the pipe can be studied numerically.

Recommended analysis procedure

When SIMLA is applied for the evaluation of laying stability the recommended analysis and evaluation procedure is as follows:

I. Agree on geotechnical input to be used in the analysis
II. Convert geotechnical input to pipe/soil interaction models
III. Screening analysis
    A. Identify possible challenging areas
IV. Evaluation of challenging areas in view of:
    A. Contact force build-up
    B. Soil type
    C. Seabed topography
V. Apply the FEED analysis approach for the remaining challenging areas
    A. Determine whether sliding might be a problem

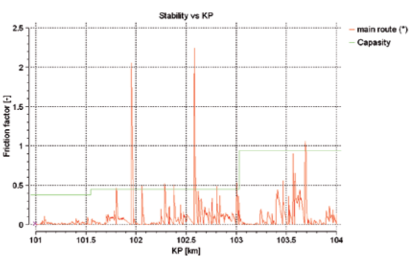

Figure 2. Results from a SIMLA screening analysis – Stability vs KP.

Screening analysis

This approach is used to screen potentially critical locations with respect to stability. The SIMLA screening approach can be regarded as a repeated sequence of static solutions in which the pipe configuration is stepped along a planned numerical route. The correct pipe properties and soil stiffness parameters are mapped to the model as a function of the kilometre point (KP) for the current location.

The result of a screening analysis is illustrated in Figure 2. As the plot shows, the capacity curve indicating the available friction factor will vary depending on location.

As can also be seen from Figure 2, at some areas along the route the calculated necessary friction factor (red curve) crosses the available capacity curve. Such locations need to be examined in more detail.

FEED analysis

The FEED approach has been developed for detailed study of particularly challenging areas. In this model the lay vessel is moved and new elements are introduced from the vessel. This approach thus provides a more physically correct analysis where the history of a node in the finite element model is known. In this case axial friction, as well as on-bottom sliding and possible yielding of pipe material, can be modelled.

As mentioned above, this approach allows the pipe to slide relative to the pipe route. In such cases it is important to note that even if the pipe has been evaluated as unstable relative to the centre-line of the pipe route, it may still be stable within the route corridor.

Figure 3 shows a close-up of a specific pipe route location with a 10 m wide route corri-dor and with the pipe configuration being a result of a FEED analysis. Initial contact has been established to the left of the centre-line.

However, since the route enters a right-hand curve at this location, and since the FEED analysis approach allows for lateral sliding of the pipe, the as-laid pipe configuration ends up to the right of the route centre-line.

The FEED approach makes it possible to evaluate lateral stability within the route corridor, which offers more flexibility in particularly challenging areas. If this approach is used for screening purposes, the result will typically be that some of the peaks in the calculated necessary lateral friction factor are removed.

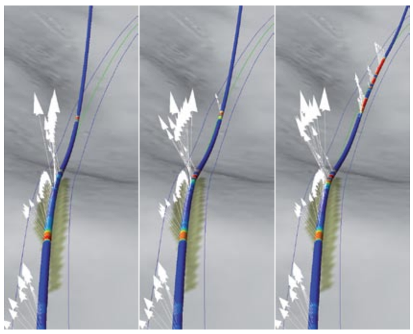

Figure 3. Pipe sliding within route corridor.

MARINTEK
Norwegian Marine Technology Research Institute
P.O.Box 4125 Valentinlyst
NO-7450 Trondheim, Norway
Tel: +47 73 59 55 00 Fax: +47 73 59 57 76
marintek@marintek.sintef.no

Website: http://www.marintek.sintef.no
Contact:
Egil Giertsen, Research Manager
Egil.Giertsen@marintek.sintef.no