

MARINTEK

Address:

Otto Nielsens veg 10
P.O.Box 4125 Valentinst
NO-7450 Trondheim, Norway
Phone: +47 7359 5500
Fax: +47 7359 5776
E-mail: marintek@marintek.sintef.no
Internet: www.marintek.sintef.no



REVIEW

NORWEGIAN MARINE TECHNOLOGY RESEARCH INSTITUTE

Harsh Environment and Ultra Deep-Water

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New oil fields worldwide are very often characterized by harsh environments with steep and high waves combined with strong currents and wind, and ultra deep waters whose depths may exceed 1000 – 1500 meters, or a combination of both. These conditions present severe challenges to offshore installations. MARINTEK is heavily involved in the analysis and verification of design loads and responses for such installations. Activities include model testing as well as the development and use of advanced numerical analysis tools. Three recent 2009 project examples are presented below:

North Atlantic FPSO model tests

Model tests in scale 1:80 were carried out for BP on the verification of a new FPSO for installation in 395 m water depth west of Shetland (the Schiehallion field), representing an area with particularly strong wind-driven seas combined with strong currents and swell. The hull characteristics, main topside details as well as individual mooring lines and risers were modelled (except from some riser details) in extreme weather conditions. The primary objectives of the tests were to verify the motion characteristics of the FPSO system, assess extreme wave interactions with the hull, calibrate the results of the analytical studies of the mooring, and calibrate the global mooring fatigue analytical model. In addition, focus was also addressed on assessment of riser loads, motions and interactions, and on loads and motions at heli-deck and topside modules.



FPSO model in the Ocean Basin, 100-year storm.

Deep-water GoM semisubmersible model tests

The project included 1:60 scaled model test verification of a large new production semi-submersible platform to be installed in the Jack-St. Malo field (in the Gulf of Mexico) operated by Chevron, at a depth more than 2000 m and with hurricanes and strong loop currents challenging the design. As for the FPSO tests above, among the primary objectives were the evaluation of the global motion and mooring line responses (wave frequency and low frequency). The extreme depth was modelled by a careful truncation of mooring lines and risers. Furthermore, the tests included a verification of extreme motions with particular focus on Steel Catenary Riser (SCR) design; on the deck clearance (air-gap and run-up) in extreme hurricanes;



Semi model in the Ocean Basin, 100-year storm.

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Improvements in VIVANA

- Prediction of Stochastic Vortex-Induced Vibrations in Deepwater Risers

A new model for prediction of fatigue damage caused by vortex-induced vibrations (VIV) in risers has been developed and implemented in VIVANA. It overcomes some of the shortcomings of previous methods. A fully 3D model has been implemented, “cross-flow” (CF) and “in-line” (IL) responses are predicted, responses at higher-order harmonic components will be added, and the stochastic nature of the response has been taken into account by introducing a time-varying envelope function of the response combined with “time sharing” between domi-

nant response frequencies. A model that reflects this behaviour is regarded as being more realistic, and is more likely to predict lower fatigue damage than the traditional discrete-frequency models. The model will predict a response that will appear as a combination of standing and travelling waves depending on boundary conditions, damping and load distribution. Fatigue damage will thus become more evenly distributed along the riser, and less concentrated at anti-nodes (of dominant modes) than seen using traditional discrete-frequency models.

VIVANA

VIVANA is a computer tool for calculation of VIV in slender marine structures such as risers, free-span pipelines and cables subjected to ocean currents. The hydrodynamic model in VIVANA is based on empirical coefficients, while the structural model employs a non-linear three-dimensional finite element formulation. The program is capable of working with arbitrary distributions of tension, mass, stiffness, buoyancy and diameter. Response frequencies are identified while taking frequency-dependent hydrodynamic mass along the structure into account. Response amplitudes are calculated at the discrete frequencies by the frequency-response method. The excitation force model includes a lift coefficient that is a function of the response amplitude and the response frequency. Damping outside the excitation zone is introduced by high- and low-velocity damping terms.

Background

In the course of the past 10-20 years, a number of model test programmes have been

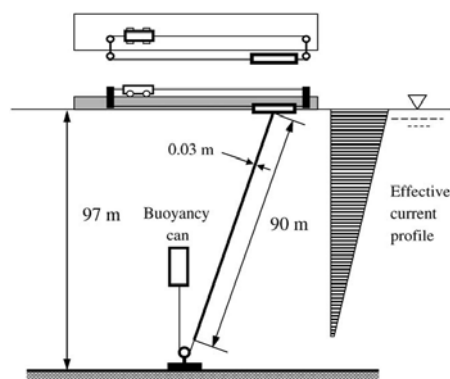


Figure 1. Test set-up at Hanøytangen.

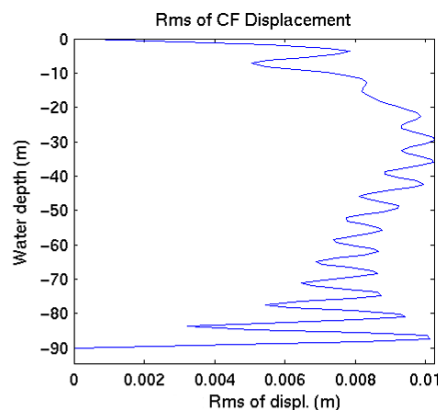


Figure 2. Rms of displacement along the riser, from Hanøytangen VIV experimental programme, Test 39.

performed on long elastic cylinders, in order to study VIV behaviour in uniform and shear flows. Analysis of these results has been crucial to the further improvement of the semi-empirical VIV prediction tools, such as VIVANA, which are used by the industry in the analysis and design of riser VIV. One key finding is that a stochastic response type seems to occur if the dominant modes are higher than about the 10th mode in both shear and uniform flow.

In the Hanøytangen experimental programme, bending moments were measured on a 90 m long vertical steel pipe with a diameter of 30

mm, when the pipe was subjected to linear shear current flow. Figure 1 is a sketch of the test set-up. A time series of the measured response shows that the cross-flow response oscillates at a frequency close to the Strouhal frequency, given by $f_s = \frac{St U_n}{D}$, where St is the Strouhal number (typically around 0.2), U_n is close to the highest current velocity along the riser (normal component to the riser axis) and D is riser diameter. One typical observation is that the response amplitude varies over time and the response seems to be irregular. Figure 2 shows the CF rms displacement along the riser model for such a case. The figure indicates that modes around 13 seem to dominate since there are about 13 peaks along the curve. But since there are no clear anti-nodes (where the displacement will be zero) several modes must be active. More extensive analyses show that the response typically changes between various modes, where one mode dominates for a period, and later another mode takes over and dominates. In this case modes 13 and 14 were found to be the largest modal responses. Time-varying modal weight factors from these two modes are shown in Figure 3. Note that the amplitudes vary, but the time series are found to be

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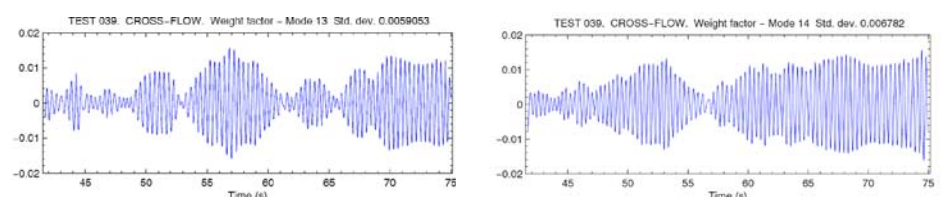


Figure 3. Time series of the two dominant modal weight factors taken from the Hanøytangen VIV experimental programme, Test 39.

Wave-in-Deck Impact: Insight through CFD

The problem of wave impact loading involves very complex physical mechanisms which require special attention, and experimental validation is essential. This led MARINTEK in 2007 to start a Joint Industry Project (JIP) on Wave Impact Loads. For a brief general info on the JIP, we refer to a notice elsewhere in this Review issue (on “Ultra Deepwater and Harsh Environment”).

While Phase 1 of the JIP focused on practical engineering tools and procedures for the industry, in order to improve tools further a greater insight into the physics is still desirable. In Phase 2 of the JIP, an assessment of the application of CFD on the wave-in-deck impact problem is therefore made.

Whilst, with the advent of Particle Image Velocimetry, model tests are increasingly able to provide a spatial picture of the flow field during wave impact events, the procedure is still non-trivial and so model test results are still largely restricted to time histories at specific locations, global integral loads and video snapshots. In this respect, numerical modelling using CFD is a valuable tool to provide qualitative insight into the wave impact

physics simultaneously in space and time.

Thus, one of the sub-tasks of the Wave Impact Loads JIP focuses towards an idealised model test setup of a rectangular block without substructure in regular waves. The block is fixed at a distance h above the calm water line. Both 2D and 3D model test experiments of the block in regular waves were carried out and comparisons were made with the CFD tool Star-CCM+ (CDadapco). Some results from the comparisons are being published in OMAE2010-20860. The results demonstrate that a second impact event closely following a first impact event can have a much flatter free-surface profile (and stronger water entry force) as a result of its interaction with the (deck) diffracted wave from the first impact event. The

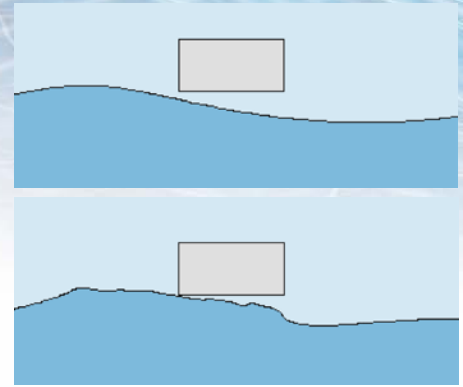


Figure 1. CFD snapshots of the free surface profile (isosurface of VOF=0.5) a) before 1st impact, b) before 2nd impact.

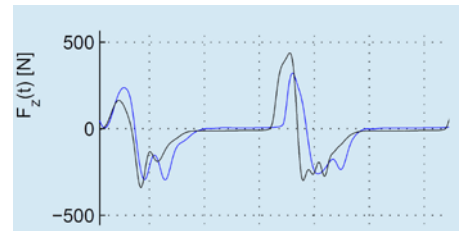


Figure 2. Vertical loading over first and second impact. Blue line (CFD), black line (measurement).

importance of resolving this diffracted wave in the CFD analysis is demonstrated.

MARINTEK contacts:
CarlTrygve.Stansberg@marintek.sintef.no
TimothyEdward.Kendon@marintek.sintef.no

Improvements in VIVANA ...

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narrow-banded with regard to frequency. Also observe the “time-sharing” that takes place between the two largest responding modes; when mode 13 has large amplitudes, mode 14 has a low response and vice versa. These observations led us to introduce a new option for how to combine responding frequencies to VIVANA as a part of the stochastic model. The original VIVANA version applied a ranking procedure for identifying load frequencies and how frequencies grab their excitation zones without overlaps. These loads were acting on the riser model simultaneously. For risers responding in low and moderate modes (say less than 10) this was regarded as a reason-

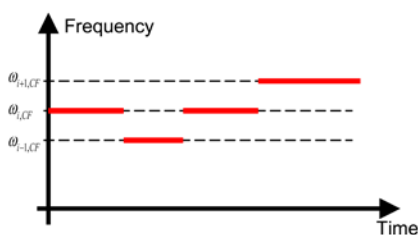


Figure 4. Illustration of the time-sharing process.

able approach. For higher modal responses the new time-sharing approach would appear to be more relevant. The excitation zones are allowed to overlap, but they are not simultaneously active. Within the time period a specific frequency keeps control, and this frequency will occupy the entire excitation zone. Time-sharing means that the response frequency will shift from one of the identified CF response frequencies to another. This process is illustrated in Figure 4.

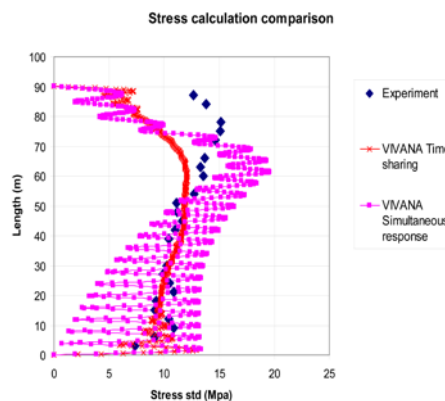


Figure 5. Stress standard deviation calculated from VIVANA and compared with experiment measurements (Hanøytangen test 0051).

One other key result from the analysis of the long elastic cylinder VIV experiments is that fatigue from in-line response is often of the same magnitude as the cross-flow fatigue. However, until now the IL response has normally not been predicted and has thus been neglected in the design process. This is regarded as a major gap in the VIV design procedure and the new VIV prediction model therefore also includes calculation of the IL response.

Examples of predicted results

An example of predicted response from the Hanøytangen experiment is shown in Figure 5. Here bending strain, which is a direct input to fatigue calculations, is presented as standard deviation along riser length. Both the time-sharing option and simultaneously acting load frequencies option are used in VIVANA. The results of the experiment are also shown for comparison. As expected the time-sharing option will provide a more uniform response along the riser than the alternative option. In the case presented here, where we have a response whose dominant mode is about 23, the time-share option gives results that are reasonably close to the experimental results.

MARINTEK contact: Halvor.Lie@marintek.sintef.no

Renewable Energy – Offshore Wind Technology

Steadily rising energy consumption, rising fuel costs and concern about global climate change have led governments all over the world to focus on new, sustainable sources of energy. Offshore wind is among the promising alternative energy sources that have recently been attracted more and more attention. The potential for wind farms in deeper waters is huge, provided that costs can be reduced to a competitive level.

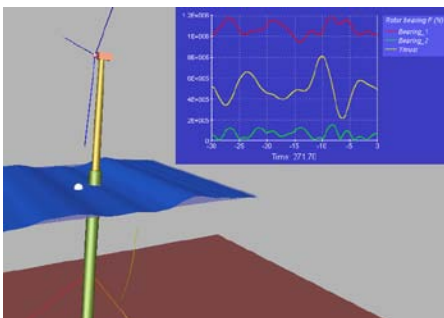
MARINTEK is extending its wide range of competence gained from offshore technology to cover offshore wind technology.

KMB project – Deep Sea Offshore Wind Turbine Technology

As a part of the joint competence development (KMB) project Deep Sea Offshore Wind Technology, which is coordinated by SINTEF Energy Research, MARINTEK has developed a tool for the analysis of floating wind turbine design. This has been developed as an extension* to SIMO, our well-proven tool for simulating complex marine operations, and incorporates resources and experience from the offshore industry, together with state-of-the-art aerodynamic simulation models. The tool has been successfully used in the IEA Annex 23 Benchmarking test programme. The wind-turbine model is currently being implemented in the finite element analysis program RIFLEX.

In collaboration with SINTEF Energy Research, MARINTEK has written a report on the state-of-the-art of condition-monitoring technologies for wind turbines. The report also addresses accessibility issues, i.e. how to bring personnel safely on and off installations at sea. Part of the report focused on logistics aspects of the operation and maintenance of offshore wind farms, drawing on MARINTEK's expertise from the offshore petroleum industry and shipping.

*) http://www.eow2009proceedings.info/programme_test/info2.php?id=34&id2=232&ordre=126#top



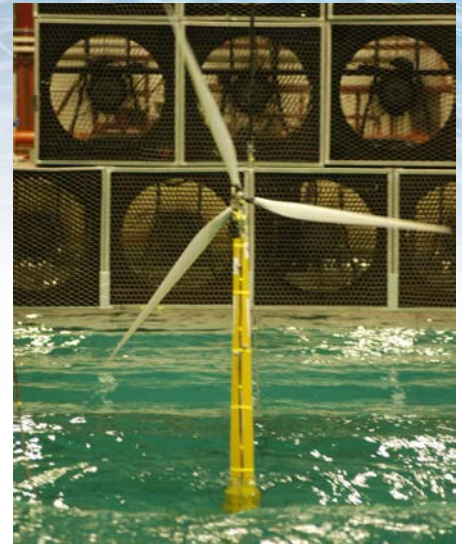
Snapshot of SIMO simulation, with time traces of rotor bearing forces.

The research programme was performed by SINTEF Energy Research, Institute for Energy Technology (IFE), Norwegian University of Science and Technology (NTNU) and MARINTEK, and was funded by the Research Council of Norway and several industry partners. The KMB project came to an end in 2009 and is a good basis for the smooth launch of the Centre for Environment-friendly Energy Research (CEER): NOWITECH.

NOWITECH – Norwegian Research Centre for Offshore Wind Technology

NOWITECH is part of the Centre for Environment-friendly Energy Research (CEER) scheme co-funded by the Research Council of Norway, leading industrial companies and research organisations. The centre was set up in mid-2009 and will operate for eight years. MARINTEK, together with its research partners SINTEF Energy Research, SINTEF Materials and Chemistry, SINTEF Information and Communication Technology, NTNU and IFE, aims to provide new knowledge, tools and technologies as a basis for the industrial development of cost-effective offshore wind farms at deep sea. The research will mainly be pre-competitive.

MARINTEK is involved in the development of integrated numerical tools. This work is a continuation of the KMB project which involves extending MARINTEK's well-proven simulation tools to include loads on and responses of an operating wind turbine. Ongoing activities include the implementation of a non-uniform wind model with more realistic coherence over the rotor blades, and the development of a frequency-domain analysis toolbox to provide a tool for minimum-cost design of supporting structures and mooring lines. There are also plans to develop a wind turbine module for the simulation tool NIRWANA, a finite-element code for bottom-fixed jacket structures. Individual



Statoil's wind turbine Hywind is the very first full scale floating wind turbine installed offshore. A scale model of the turbine was tested in the MARINTEK Ocean Basin for proof of concept in 2005.

blade pitch control is also planned to be implemented in the time-domain simulation tools.

A scientific basis for cost-effective operation and maintenance strategies and technologies is being developed by MARINTEK in close cooperation with the NOWITECH research partners. This involves the development of maintenance strategies that focus on availability in a life-cycle cost perspective. Condition-monitoring methods and tools for predictive maintenance strategies will be adapted and developed. The development of safe and efficient concepts for installation, hook-up, commissioning, intervention and replacement logistics, including marine operations, is among the research topics to be addressed.

MARINTEK is participating in the assessment of novel substructures for fixed and floating concepts. A particular challenge is to assess the overall behaviour of wind turbines in wave and wind loads, in order to determine their motions, structural and power-train responses. This is basically done by means of numerical studies using the tools developed at MARINTEK, but will also be supported by scale-model tests in the Ocean Basin. Model testing is important for validation of numerical tools. However, the proper scaling of models with respect to wave, current and wind-induced loads, machinery and automatic control systems offers significant challenges. As part of the research programme, therefore, we are developing new experimental techniques for model testing of offshore wind turbines.

MARINTEK contacts:
PetterAndreas.Berthelsen@marintek.sintef.no
Anders.Valland@marintek.sintef.no
Gro.Baarholm@marintek.sintef.no

SIMLA. Installation - Online System for Monitoring of Pipe-lay Operations

For pipe-lay operations, parameters such as the heading and position of the lay vessel are available from the GPS system on board the vessel. In some cases the current profile is also monitored, particularly in the case of small-diameter pipes, when current is important for the configuration of the pipe catenary. Provided that a fast and robust numerical tool is available and can be integrated with the on-board monitoring system, the above parameters and a measure of tension in the system are sufficient to simulate the static configuration of the catenary and visualize it online during the lay operation. This provides valuable additional information, such as catenary shape including stresses in the pipe, lay tension, sag-bend utilization, development of free spans, and lateral stability of the pipe during the installation.

Important features of the numerical solution include 3D terrain description, models for pipe/seabed interaction, modelling of pipe contact with rigid elements, control algorithms for feeding of pipe joints, 3D load model for current, and nonlinear material model of the pipe in cases where there is significant plastic strain. In recent years, MARINTEK has developed a new generation of numerical tools for pipeline analysis, in which all these issues are addressed.

A data communication channel through which the vessel monitoring system, the numerical engine and a 3D visualization module can exchange data enables an efficient online system to be established.

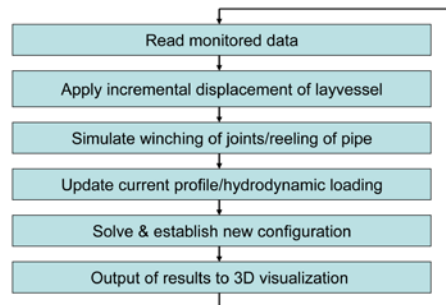


Figure 1. Analysis loop of the online system.

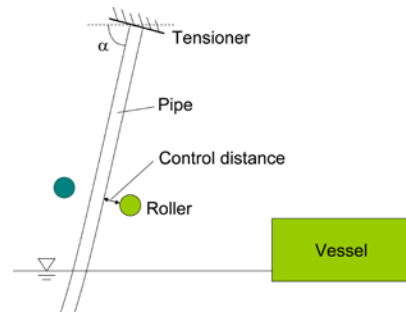


Figure 2. Illustration of tension measure for analysis.

Main components of the numerical analysis

The numerical tool used in the online system is based on the SIMLA Program System. The starting point for an online lay analysis is to obtain the static configuration corresponding to the location of the vessel at startup. The most important factors for the static configuration are lay-tension, sz-seabed profile (and curves for the design route in 3D-case) in addition to the geometry of a possible stinger. The new tool obtains an initial static configuration in a single step by assuming a start configuration for the pipe, based on 3D route information, stinger geometry, departure point/angle and classic catenary theory. When the true static configuration has been established, incremental displacements corresponding to the actual monitored displacement of the lay vessel can be applied. The analysis loop of the online system is illustrated in Figure 1.

The tension in the system depends on the ratio between vessel displacement and how fast new pipe lengths are fed through the tensioner system on the vessel. A measure of tension is thus needed to control the feed

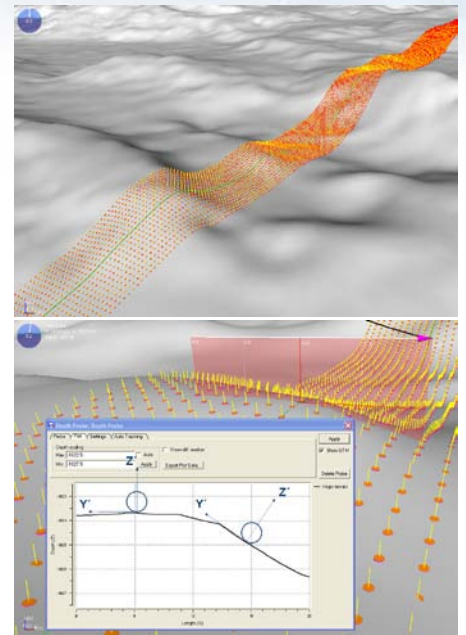


Figure 4. Online visualization of 3D terrain model.

rate in the analysis. A reliable and practical measure of tension in the system depends on the installation setup/vessel. For S-lay, the distance to a given roller close to the stinger tip will be a good measure. If a tower with fixed lay angle (J-lay) is employed, the position in a roller box located after the last tensioner is normally used, see Figure 2.

Online system

An illustration of the Online System is given in Figure 3. As indicated, both the Online FE Analysis and the 3D Visualization module are linked to an I/O channel that keeps track of the most recent set of updated common data for the system. The link to the vessel monitoring system is handled by a Data Exchange module that provides data from the vessel

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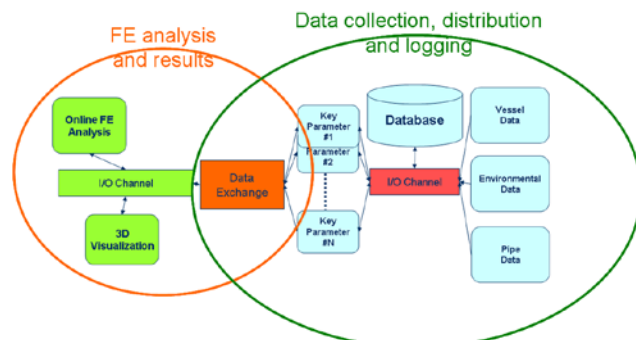


Figure 3. Components in the Online System.

SIMLA.Installation ...

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monitoring system to the I/O Channel, and also collects and sends data and results to be logged back to the vessel.

The I/O Channel is based on a time-synchronized principle, utilizing the Pitch pRTI™ implementation of the IEEE 1516 standard for modelling and simulation.

The Data Exchange module is based on exchange of ASCII-based XML (EXtensible Markup Language) telegrams, typically exchanged through protocols that utilise the standard computer network, e.g. through TCP/IP (Transmission Control Protocol/Internet Protocol)-based UDP (User Datagram Protocol) packages.

The prototype of the monitoring system focuses on static analysis of the catenary. The system as such is fully capable of handling dynamic analysis, but the requirements with respect to calculation speed will be more challenging.

Output from Online System

The main output from the online tool is:

- 3D visualization of the seabed with possible intervention work (dredging, rock supports, gravel carpets etc.). Target route and route corridor with specified width can be added to the visualization of the seabed, as illustrated in Figures 4 and 6.
- Visualization of lay vessel with online position and corresponding numerical configuration of the catenary. Calculated contact forces acting on the pipe from seabed, rollers on the stinger, counteracts or other objects can be visualized as vectors, and results and prospective online current profile acting on the catenary can be shown. Element results such as pipe tension and detailed results like strains and stresses for the pipe cross section can be shown as scalar results mapped to the 3D model of the pipe. Typical snapshots from the visualization module are shown in Figures 5 and 6.
- A set of online key parameters can be made available as curve plots in the visualization module. Typical key parameters are calculated top- and lay-tension, lay-back, maximum curvature/sag-bend utilization for the pipe, predicted deviation from target route, utilized lateral capacity, etc. These results are configured up front in the online tool and exported online to

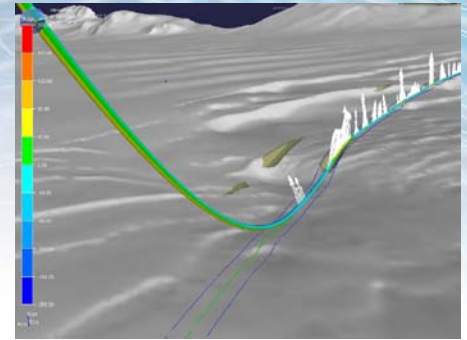
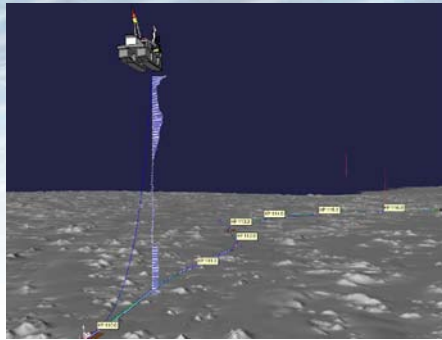


Figure 5. Online visualization of pipe lay. Overview and zoomed view of the touch-down area.

the visualization module. Results derived from the online FE analysis can also be sent back to the vessel for decision support and logging purposes.

- Visualization of existing infrastructure on the seabed (installed/crossing pipelines, PLETs, counteracts, etc). Full 3D models of installed objects with specified locations can be imported in the visualization module.
- Online 3D visualization of other objects, e.g. supporting ROVs. In combination with the results of the FE analysis, the visualisation module can also display online updated positions of other objects that form part of the marine operation, e.g. supporting ROVs.

Remote use of the Online System

Since the amount of data required as input to the system is limited, the online system can also easily be linked up with any location such as an onshore control room. By sending the required input data for the FE analysis to a server onshore, the data may be shared with others and accessed via an internet address.

Conclusions

By combining recent advances in numerical tools, 3D visualization with key parameters from the monitoring system of a lay vessel an online tool for FE calculation and visualization has been developed as part of the SIMLA-Installation DEMO2000 JIP. The system has

been tested on realistic data from previous installations on the Ormen Lange field, and the numerical testing shows that:

- Stability and robustness of the solution are good
- Calculation speed is satisfactory for static analysis
- Data exchange using XML and UDP has been tested and works well

The first version of the Online System was field-tested in the summer of 2009 during two different installation campaigns related to the Ormen Lange Southern Field Development project.

This technology will help to ensure safe and cost-effective deepwater pipe-lay installation operations in the future, not only because of the onboard system itself, but also because putting this technology in place will allow high-quality training and familiarization to be carried out in advance prior to offshore construction.

Acknowledgements

The SIMLA.Installation DEMO2000 JIP has been performed in close cooperation with Statoil, Shell and Acergy, and with financial contribution also from the Research Council of Norway through the DEMO2000 Programme.

MARINTEK contact:
Egil.Giertsen@marintek.sintef.no

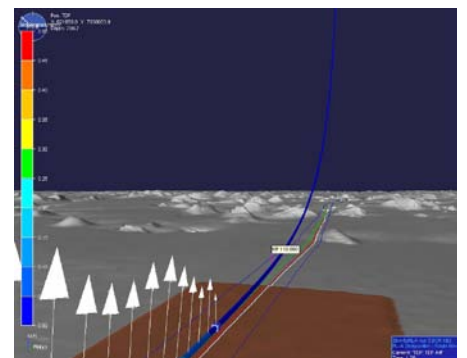
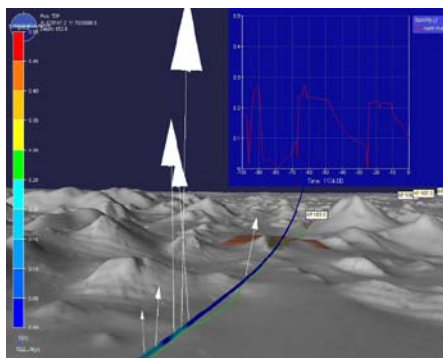


Figure 6. Online visualization of pipe-lay with time series results, and view following TDP.

Experimental Validation of a Three-Dimensional Umbilical Cross-Section Model

Through a Joint Industry Project on Stress and Fatigue Analysis of Umbilicals, sponsored by BP, Nexans, Petrobras, Shell and Statoil, MARINTEK has developed a three-dimensional finite element formulation for complex umbilical cross-sections. Two full-scale umbilical specimens have been used to validate the model.

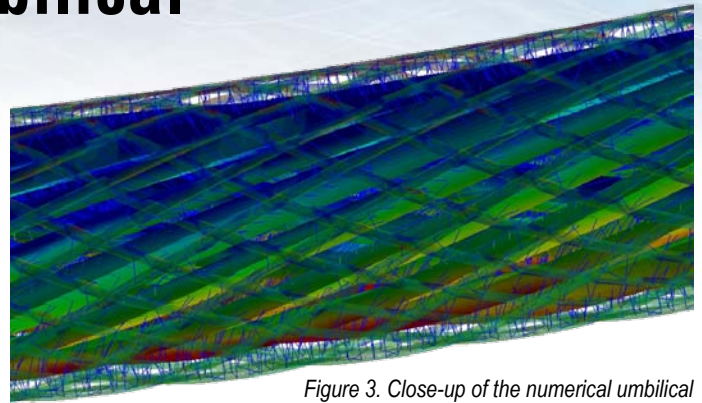


Figure 3. Close-up of the numerical umbilical model. In order to minimize model size, only four points were employed around the circumference of the tube for each of the elements.

FEM model

The 3D finite element formulation has been tailored to predict the behaviour of complex umbilical cross-sections. The effects of different load patterns such as tension, torque, internal and external pressure and bending are taken into account. Helically wound armours and tubes are treated as thin and slender beams and are formulated within the framework of small strains but large displacements. Interactions between structural elements are handled by 2- and 3-noded contact elements, and based on penalty parameter formulations. The model includes a number of features such as material non-linearity, gap and friction between individual bodies, as well as contact with external structures.

Testing

Two different umbilical cross-section designs have been tested in MARINTEK's structural laboratory in order to obtain data for validation of the numerical model. The first specimen was a steel tube umbilical without armour,

while the second had PE-coated tubes and two layers of armour. Combinations of bending and tension loads were applied to the 16 m long specimens. A bellmouth with two sections of different curvatures was employed to control the curvature of the umbilical; see Figure 1. Strain measures were obtained for selected tubes at three stations along the umbilical. At each station the strains were obtained by fibre optic sensors at four points close to the tube inner walls and with 90 degree spacing. Such measurements enable the bending-induced

effects to be separated from the axial effects.

Numerical model

A numerical model was built to perform numerical analysis of the full-scale tests. An effort was made to make the numerical model as accurate as possible relative to the tests. The longitudinal and cross-sectional positions of the measuring stations were identified from the full-scale tests. The arrangement of the components in the model was organized so as

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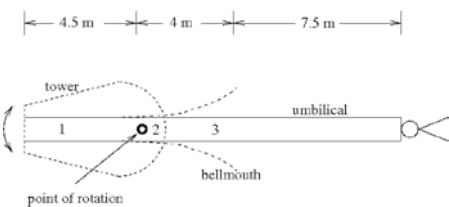


Figure 1. Test set-up, viewed from the side. The numbers printed on the umbilical refer to the measuring system stations.



Figure 2. Numerical model of the full-scale tests. The tower to which the green bellmouth is attached is the red section on the left side. Rotation is applied on the right-hand side of the tower.

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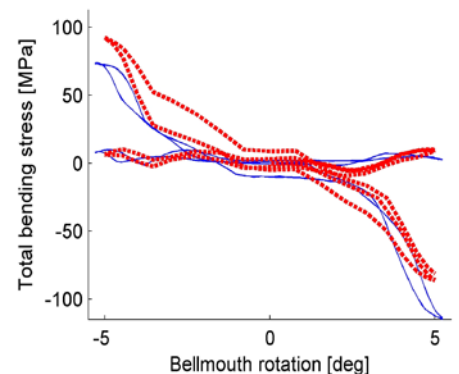
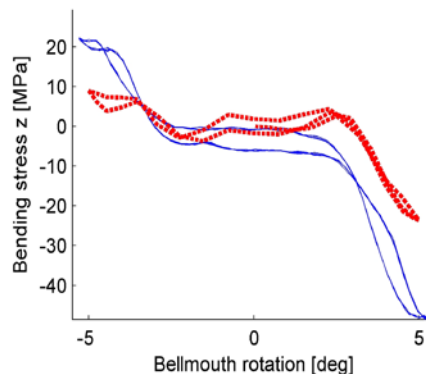
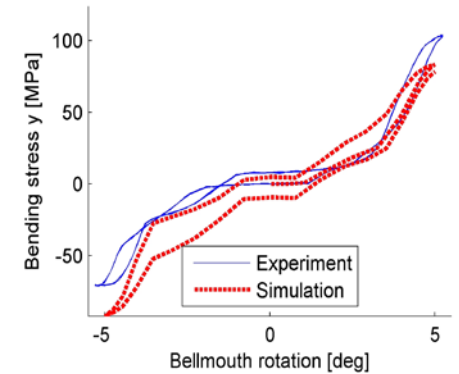
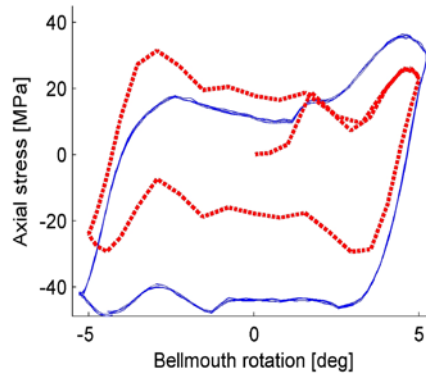


Figure 4. Specimen 2. Curvature 0.05 m-1. Tension 600 kN. Inner helix layer.

Experimental validation ...

Cont. from page 7

to have numerical measuring stations at the same locations.

Figures 2 and 3 illustrate the numerical model. An example of results from the comparison of the test and the analyses is shown in Figure 4. The results are taken from one tube and for one combination of tension and rig rotation. The figure contains four plots, each of which includes a red curve for the numerical results and blue curves for the experimental data. The axial stress plot displays the axial stress range adjusted for mean stress level. The amount of hysteresis in this signal would usually be interpreted as friction effects. Both bending-stress components are displayed, and finally a plot of the total bending stress.

We have focused on the results from the station with the sharpest bellmouth curvature, as inaccuracies in the measuring system of a constant nature will be less significant for

this location. For these measurements, the numerical model predicts between 80-110% of the experimental bending stress ranges, with a coefficient of variation (COV) of 0.2.

For the axial stress range, the numerical model predicts 80-100% of the experimental results with a COV of 0.2. These numbers are for specimen number one. For the second specimen the performance is much poorer, with numerical results about 60% of the experimental stress ranges.

The numerical model shows good performance with regard to bending stress ranges. For the axial stress ranges the results are rather less conclusive. For specimen one the performance is good, but for specimen two there was a pronounced underprediction .

The axial stress ranges are expected to be the result from frictional forces acting on the tube walls. The magnitudes of these forces will depend on the contact pressure and the friction coefficients, and for an umbilical with perfect helical-wound components, the contact

pressure increases linearly with increasing tension. With no tension, their contributions will be very small.

With respect to the experimental results for specimen two, and extrapolating to the no-tension level, there should be axial stress ranges also under conditions of bending at zero tension. However, this has not been picked up by the numerical model. Various explanations have been considered for the effect, but so far no conclusions have been drawn. Further full-scale testing may help to shed light on these observations.

The complexity of the model requires a large number of elements to be employed, which makes the calculations computationally intensive. One task that we will need to consider in future work is the efficiency of the solution algorithm.

MARINTEK contact:
Janne.K.Gjosteen@marintek.sintef.no

Harsh environment

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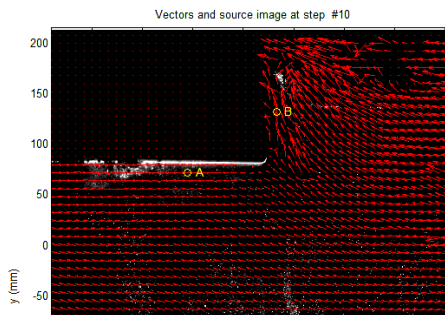
and on the estimation of wave-induced slamming loads.

The MARINTEK Wave Impact Loads JIP, Phase 2

A four-year international Joint Industry Project (JIP) is being completed in 2010, with the aim of improving the design against the impact of energetic and extreme waves on ships and platforms in harsh conditions. The wave impact problem is theoretically very complex and challenging, and the JIP has included various model test studies combined with robust numerical tool development for engineering

use, as well as an assessment of Computer Fluid Dynamics (CFD) applications for wave impact.

Phase 1 of the JIP, focusing on the establishment of simplified and robust engineering pro-

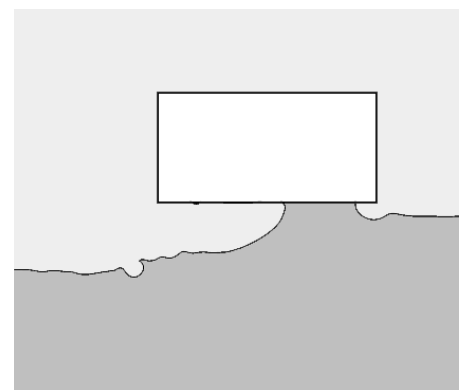
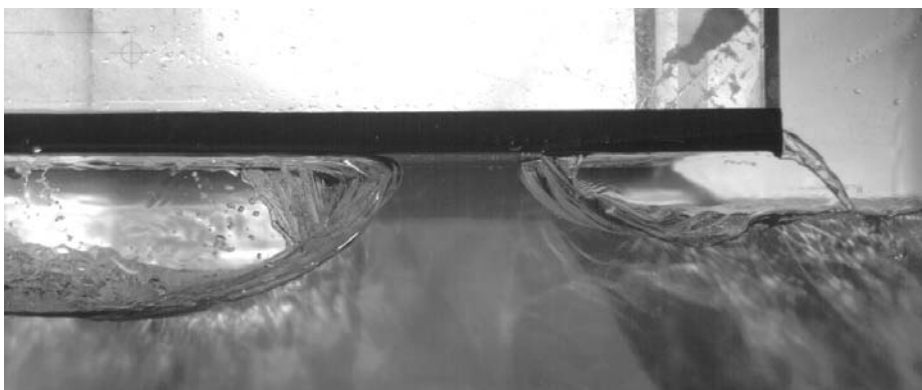


Water particle velocity vectors during interaction between wave and deck; water-entry phase. From PIV experiment. Wave is going from right to left.

cedures and tools, was previously completed in 2008. This topic is presently being followed up in Phase 2, which also includes particular research on: A) The use of advanced numerical (CFD) and experimental (Particle Imaging Velocimetry – PIV) tools, and B) Slamming from steep waves on columns. Learnings and recommendations are included in final guidance reports. More details on the CFD activity are presented elsewhere in this MARINTEK Review issue.

Phase 2 participants include ABS, Aker Solutions, ConocoPhillips, MARINTEK, Petrobras, and Statoil.

MARINTEK contacts:
CarlTrygve.Stansberg@marintek.sintef.no
Ivar.Nygaard@marintek.sintef.no



Wave-structure interaction in wave-in-deck event. Left: Model test high-speed photo. Right: CFD model.