OIL AND GAS

MARINTEK
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REVIEW

Wave impact on columns, platforms and FPSOs

›› Research Scientist Csaba Pákozdi
›› Chief Scientist Carl Trygve Stansberg

MARINTEK is experiencing a rising level of activity on the estimation of hydrodynamic loads from wave impacts in high sea states. This includes problems such as steep and breaking waves on columns, green water and loads on FPSOs, and platform negative air-gap/ wave-in-deck events. A recent key project on this topic was the MARINTEK Wave Impact Loads JIP (2007-2010), where these topics were addressed and engineering tools with recommendations, together with better knowledge and understanding, were developed.

The work also benefited from the earlier WaveLand JIP (2000-2004). Several follow-up studies and applications have recently performed, and further research studies will also be proposed. Model testing still plays an essential role in this work, due to the very complex and highly nonlinear hydrodynamics involved, and various challenges, for example in the proper measurement of slamming loads, are currently being addressed. Improved engineering tools and the use of CFD are also under development. Some recent examples are discussed below.

The impact of steep and breaking waves on vertical structures in storms is a key issue in the design of wind-turbine foundations and column-based offshore platforms. A study has been performed on the experimental and numerical modelling of nonlinear and breaking waves in finite and shallow water, using engineering-type second-order random wave modelling as well as CFD tools. An example of CFD (VOF) modelling on a mildly sloping bottom is shown in Figure 1. Comparisons with experimental results showed good agreement on the breaking event in this case; see OMAE2012 paper # 83796 for more details.

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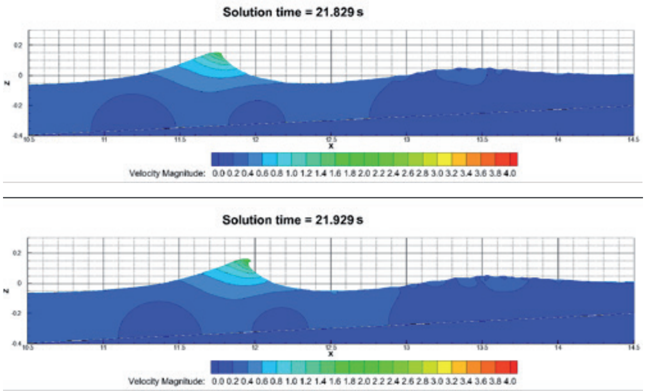

Figure 1. VOF reproduction of breaking wave in shallow water. (Model scale).

The laboratory measurement of wave slamming on vertical columns is a challenging topic. Usually, the average pressure over a defined area (typically 5-10 m^2 full-scale) is measured by a force panel connected to a displacement sensor. There may be significant local variations within the integration area, as shown in Figure 2, which illustrates a wave-slamming measurement using a matrix of 49 local pressure sensors. In this particular experiment, the pressure matrix was mounted on a traditional force panel, and the integrated force from pressure records was compared with the panel force. The fairly good agreement between the two measures can be seen in Figure 3. The basic nature of force panel sensors results in some dynamic characteristics that can lead to significant artificial amplification if the sensors' own natural periods are close to the excitation period. We usually try to reduce this by designing the panels to have high natural frequencies. A moderate effect of this sort is shown in this example, although it can be more pronounced. Techniques aimed at improving instrumentation and the interpretation of such measurements are under continuous development. Further details can be found in OMAE2012 paper # 83929.

Green water loads on FPSO's has been a research topic at MARINTEK for more than a decade, and tools, procedures

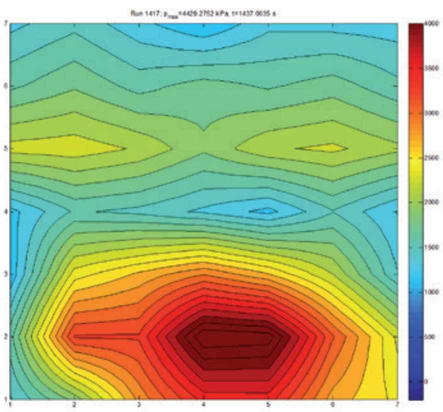

Figure 2. Wave impact on 4.4 x 4.4 m area (full scale) measured by 7x7 point pressure matrix. The peak pressure is 4010 kPa, while the average is 2200 kPa.

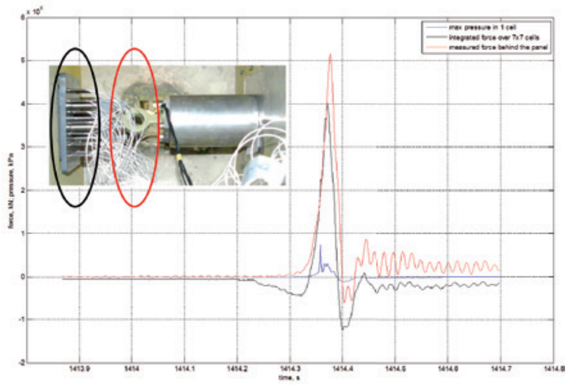

Figure 3. Impact force signal from force panel (red) vs. integrated results from 49 pressure sensors (black). The mounting of the pressure sensors on the force transducer is also shown.

and better knowledge of the physics involved have been developed. One such tool for engineering use is the recently updated Kinema3 package, which offers fast and efficient nonlinear analysis of green water and loads in random waves for early design stages. Recently, studies of the use of CFD in this problem have also begun in a current project for Petrobras, in which MARINTEK is participating in a benchmarking trial against various VOF models as well as against systematic model tests. Some initial results are shown in Figures 4 and 5. A particular challenge in Brazilian waters is the use of spread mooring systems, which mean that large oblique angles and beam seas become important. This needs particular attention in the studies, since many earlier studies have been done on weather-vaning turret-moored ships where smaller wave heading angles are relevant.

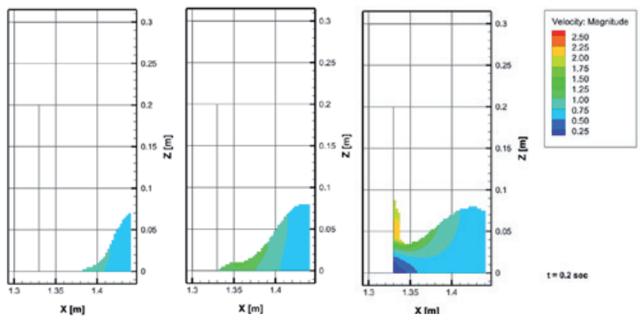

Figure 4. Centre-axis cross-section of water propagation on deck from StarCCM+ 3-D VOF simulation, using prescribed input conditions (relative wave kinematics) from Kinema3, at t=0.10s, 0.15s and 0.20s. (Model scale).

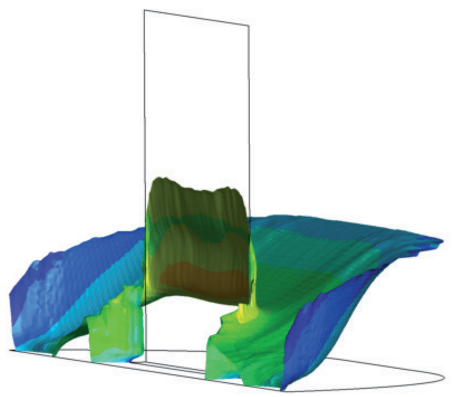

Figure 5. Snapshot of 3-D visualization of VOF simulation in Fig. 4, t=0.20s.

SPH - Smoothed Particle Hydrodynamics applied to violent flow problems

›› Research Scientist Csaba Pákozdi

Violent flows and violent fluid-structure interaction problems such as wave breaking, sloshing, green water and water impact cannot be consistently analysed by traditional hydrodynamic analysis tools. For this purpose, a combination of model testing and semi-empirical engineering methods is normally used.

Euler methods with fully nonlinear descriptions of the hydrodynamics, such as Boundary Element Methods (potential theory), Reynolds-Averaged Navier-Stokes Equations (RANSE) and Volume Of Fluid (VOF) methods are able to handle complex geometry, but they are not fast and robust enough.

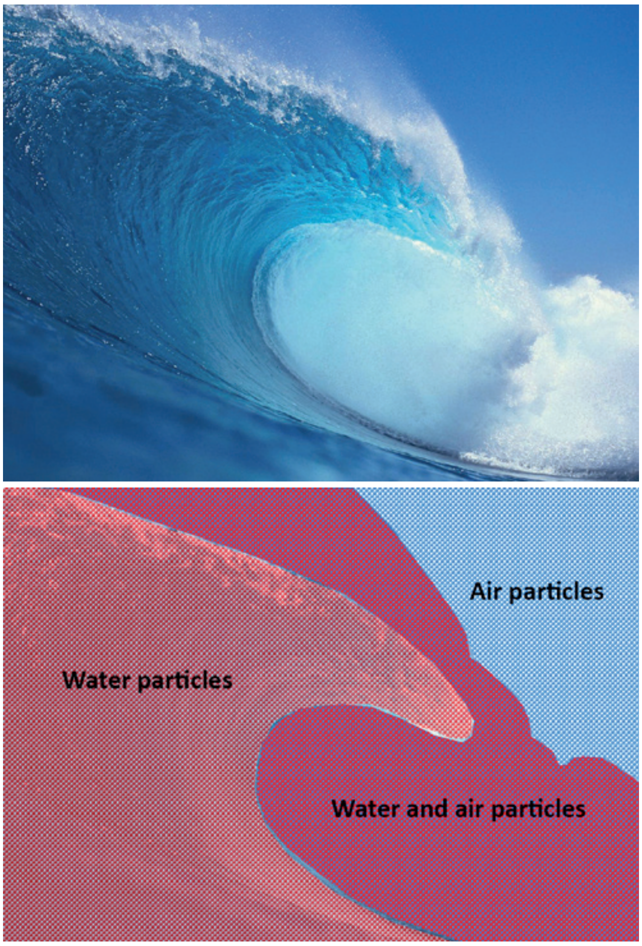

Figure 1. Breaking waves (source: SINTEF SCORE team)

An alternative approach to the analysis of such problems is the Smoothed Particle Hydrodynamics (SPH) method. Unlike the Euler-based methods mentioned above, this is treated as a Lagrangian method and in principle it is capable of significantly reducing processing requirements and thus increasing simulation speed, at least for the complex flow description. The method is still in the development stage for these applications, but is a promising path for future solvers.

Smoothed particle hydrodynamics (SPH) is defined as a method for obtaining approximate numerical solutions of fluid dynamics equations by replacing the fluid with a set of particles. In other words, the fluid domain is represented by a set of calculation points.

The physical properties, for example the time derivatives of mass and velocity on each point, are obtained summing weighted contributions from the surrounding points. The weighting function is often called a "smoothing kernel". These points, also called particles, then move with the fluid. SPH is treated as a Lagrangian method by many physicists and is frequently used to model free-surface flows.

MARINTEK is currently a member of the SINTEF SCORE project team (2011-2013), which was set up in order to develop a generic professional code and environment for a variety of SPH applications.

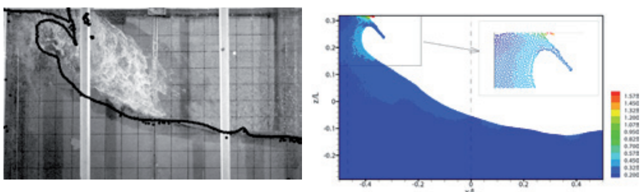

Figure 2. Sloshing. Left: sloshing tank test. Right: SPH model.

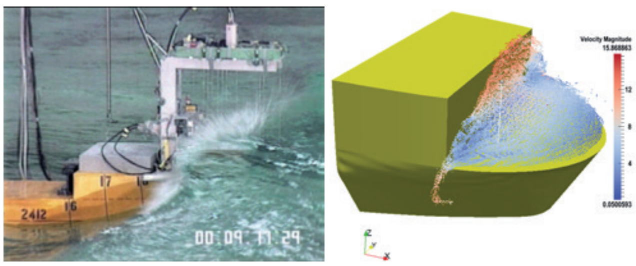

Figure 3. Green water on FPSO. Left: model basin test. Right: SPH model (from Pakozdi et al., OMAE2012-83847).

Wave forces and mooring integrity in high seas

›› Chief Scientist Carl Trygve Stansberg

In recent years, a number of line breakages have been reported on drilling rigs and other floating units in the Norwegian and UK offshore sectors. Among the cases in the Norwegian sector can be mentioned in particular several drilling rigs (Statoil/Tekna Mooring Seminar February 2013 in Trondheim), while the UK sector has experienced several FPSO mooring failures. Most incidents are related to heavy sea states, typically corresponding to one-year storms, and in some cases, a major direct cause is believed to be overload from extreme and steep waves or wave groups.

There is probably also a combination with other unfavourable circumstances. Two particular rig incidents took place during a storm in January 2012 (Figure 1). Figure 2 shows the actual measured line tension compared to a simulated tension for one of the cases. Preliminary studies initiated by Statoil have been made by MARINTEK, DNV and other parties. MARINTEK and DNV are currently investigating needs for improvements in state-of-the-art tools and procedures for determining wave loads in high seas, and a follow-up implementation phase is planned as a Joint Industry Project (JIP). Slowly varying wave drift forces in energetic wave groups where also the effects of currents is included, have been identified as one key issue that needs to be investigated, in order to find out to what extent this might have led to larger forces and vessel offsets than expected.

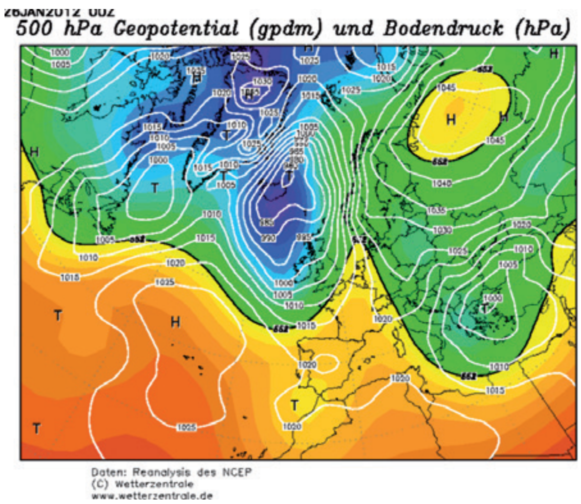

Figure 1. Weather map of Europe and the North Atlantic, 26 January 2012. (Source: Statoil)

The offshore industry is generally aware that slowly varying drift forces from wave groups can be very important in the prediction of vessel motions and resulting mooring forces, and reasonable estimates can be obtained using state-of-the-art analysis tools. However, experience derived from earlier studies suggests that the effects of high waves and currents can contribute significantly to the drift forces, and such effects are not easily taken into account. The effects of currents on drift forces have traditionally been either ignored, estimated by simple engineering formulae, or empirically found from model tests. MARINTEK's recently developed hydrodynamic industry tool, MULDIF-2 (see next page), does in fact consistently include such effects and will be useful in future studies. The effects of high waves may be two-fold: in general, large wave-frequency vessel motions may influence the drift forces, while for column-based rigs there are also viscous drift contributions. Model tests are essential in pre-

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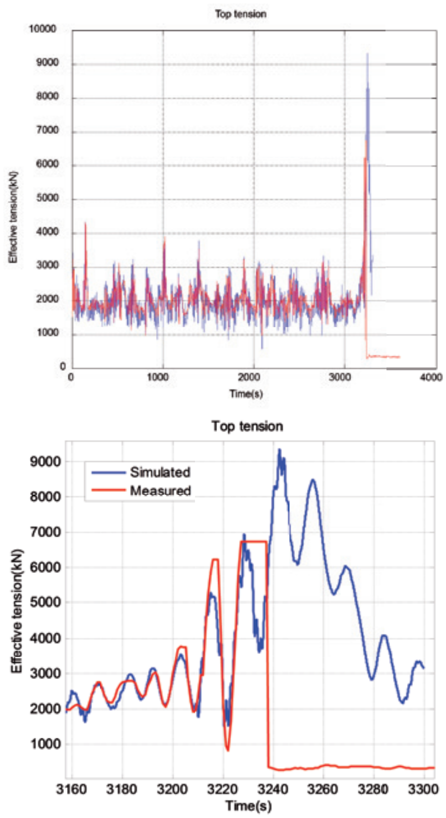

Figure 2. Measured (red) and simulated (blue) line tension from rig incident. Simulations are made by MARINTEK with RIFLEX based on measured fairlead motions. The lower plot is zooming in on the event.

MULDIF-2: multipurpose hydrodynamic analysis tool

›› Chief Scientist Carl Trygve Stansberg
›› Senior Research Scientist Jan Roger Hoff
›› Research Scientist Elin Marita Hermundstad

MARINTEK's new numerical hydrodynamic analysis tool MULDIF-2, which includes a consistent implementation of wave-current interaction in addition to standard offshore-industry functions, is now being released. This industry code development has been carried out since 2011 as part of a JIP, and is based upon basic research at MARINTEK and NTNU that has continued for several decades.

The wave-current interaction in particular is important for wave drift forces, for which it can lead to typically 50% increases. Until now, however, most industry tools and procedures have not included such a consistent wave-current function, and model tests with empirical adjustments and/or simplified engineering procedures have been used.

At present, features of MULDIF-2 include:

- 1st-order general potential-flow hydrodynamic analysis in waves, with drift forces computed by Newman's approximation
- wave-current interaction with arbitrary angles between wave direction, current direction and vessel heading, using a specific wave-current Green function formulation based on a forward-speed approach
- single- and multibody hydrodynamic analysis, with drift forces from a control-surface (middle-field) formulation
- Graphical User Interface (GUI) through integration into the MARINTEK SIMA work bench, linking it smoothly with other MARINTEK software (SIMO, RIFLEX, MIMOSA etc.)

An extension of MULDIF-2 to include various practical nonlinear corrections, e.g. for higher sea states, is planned for a Phase 2 of the JIP, in addition to further validation and optimization work. Such nonlinear functions will include semi-empirical adjustments of viscous effects as well as relative wave-structure water elevation incorporating experience gained from previous developments (such as WaveLand & Wave Impact Loads JIPs).

More details regarding the significance of wave-current influence on drift forces, and the MULDIF-2 numerical implementation, will be presented at OMAE2013 – paper #11407, in June 2013.

Wave forces and ...

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dictions for design, and empirical procedures have also been suggested, while there is clearly work to be done to improve the industry's knowledge within this field. This work requires an evaluation of state-of-the-art analytical tools in relation to actual incidents, as well as better insight into underlying metocean conditions, including the physics of steep waves.

An example from a model test with a moored FPSO is shown in Figure 3, where the effects of large wave groups can be seen in the form of very high-tension responses with a significant slow-drift component, together with a clear amplification of the wave-frequency component. We also observe a large increase from 3200kN to 4400kN due to current; this increase is largely due to wave-current effects on drift forces, since in the case, the line load contribution from current forces alone accounts for only 300kN.

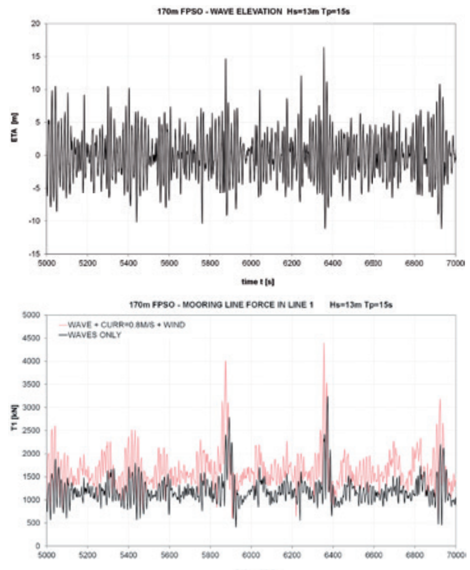

Figure 3. Example of FPSO model tests: Wave elevation (upper) and line tension (lower), with and without current.

Local analysis of a gas flowline subjected to upheaval buckling

›› Research Manager Frank Klæbo

In October 2010, a subsea inspection of flowlines on the MacCulloch field in the North Sea was performed. Several points of upheaval buckling on a flexible flowline were recorded. These observations required evaluation and possibly remedial action. A detailed study showed that only one of the upheaval buckling locations was critical, since the radius of curvature was less than the minimum bending radius (MBR) specified for the flowline by the manufacturer. MARINTEK was requested to perform a detailed analysis of the 4 inch gas-lift flowline, using the estimated bending radius and the current operating conditions. The objective of the study was to investigate the effect of extreme bending beyond the minimum bending radius.

The MacCulloch oil field lies 250 km north-east of Aberdeen on the United Kingdom continental shelf (UKCS) block 15/24b. The field was discovered in 1990 and came on-stream in 1997 using the North Sea Producer FPSO. The field has five active wells. MacCulloch was operated by ConocoPhillips when the subsea inspection was performed.

Many offshore pipelines are required to operate at high temperatures and pressures. A temperature rise results in thermal expansion of the pipeline. Friction forces between the pipe and the seabed restrains the pipeline along its route, which in turn increase axial stress, with the result that buckling may occur. Buckling may have serious consequences for the integrity of the pipeline if not properly taken into account.

A pipeline will tend to buckle in the direction of smallest resistance. The direction of the buckle therefore depends upon the installation and pipe configuration:

- In a free span the pipe will buckle downwards
- If it has been installed on the seabed, the pipe will buckle sideways
- A buried pipe will tend to buckle upwards

Vertical buckling of a pipeline is called upheaval buckling, see Figure 1.

Offshore pipelines are buried for various reasons; for example, in order to:

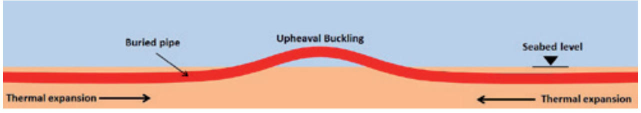

Figure 1. Upheaval buckling of a buried pipeline.

- eliminate the risk of trawl gear snagging the pipeline and pulling it out of position.
- avoid anchor snagging
- protect the pipeline from dropped objects near installations
- protect it from iceberg scouring
- stabilize pipelines with low submerged weight.

The flowline at the MacCulloch field was buried. Upheaval buckling was observed during a subsea inspection in 2010.


Figure 2. Upheaval buckling observed during the subsea inspection.

The calculated radius of curvature based on the data provided by the ROV was estimated to approximately half of the minimum bend radius (MBR) allowed for storage defined by the manufacturer of the pipeline, i.e. the bend was more severe than the pipeline design allowed.

In order to evaluate its operability, the operator requested a detailed study of the flowline. The study had two objectives:

- **Global analysis**: to understand the mechanism of the observed upheaval buckling and suggest potential remedies to stabilize the flowline
- **Local analysis**: Detailed analysis of the cross section to investigate the possible effect of extreme bending beyond minimum bending radius.

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Local analysis of a gas ....

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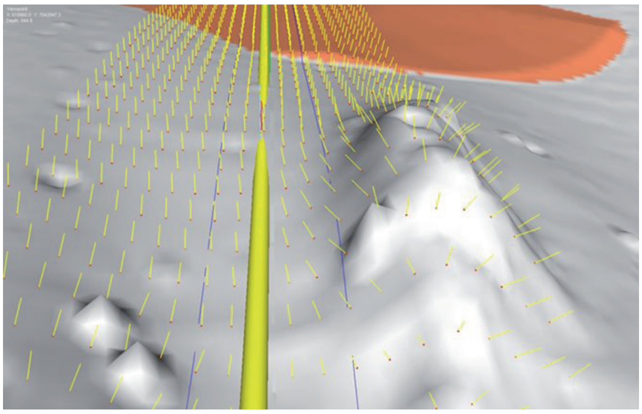


Figure 3. Section of the global model.

The global analysis was performed in SIMLA, which is MARINTEK's modelling software package for numerical analysis for offshore pipelines in deep waters and hostile environments.

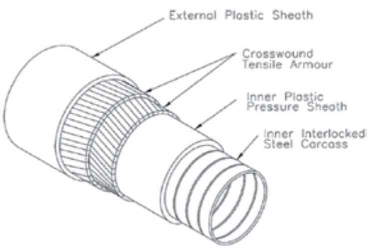
The local model was analysed in MSC.Marc, which is a powerful, general-purpose, nonlinear finite element analysis software package that accurately simulates the response under static, dynamic and multi-physics loading scenarios.

A flexible pipe or flowline usually consist of several layers. The most usual layers, and their roles, are:

- Carcass: Provides the pipe with radial support to resist external loads (crushing and hydrostatic pressure)
- Pressure sheath: Leak-tight barrier
- Pressure armour: Provides the required radial strength to resist internal pressure
- Tensile armour: Provides the required axial tensile strength capacity
- External plastic sheath/Outer sheath: Prevents the steel wires from coming into direct contact with seawater and provides mechanical protection for the outer tensile armour wire layer.

The local model of the MacCulloch flowline was built according to the specification of the flowline cross-section.

The integrity of the flowline was assumed to be critical with respect to the condition of the carcass. For this reason, the carcass was modelled in detail(Figures 6 and 7).



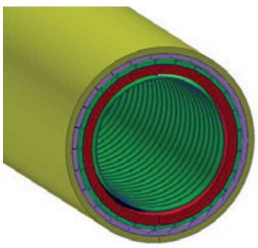


Figure 4 (left). Typical cross-section of a flexible flowline.

Figure 5 (right). Local finite element model

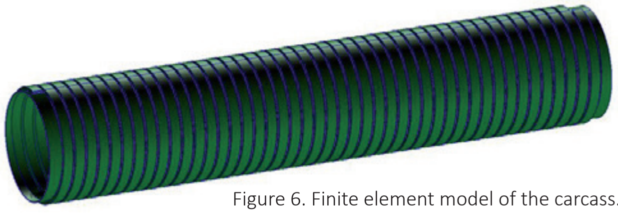


Figure 6. Finite element model of the carcass.

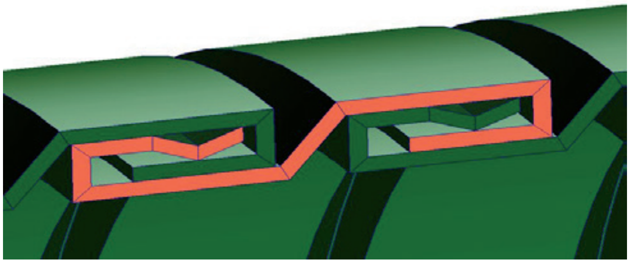


Figure 7. Zoomed plot of the carcass geometry.

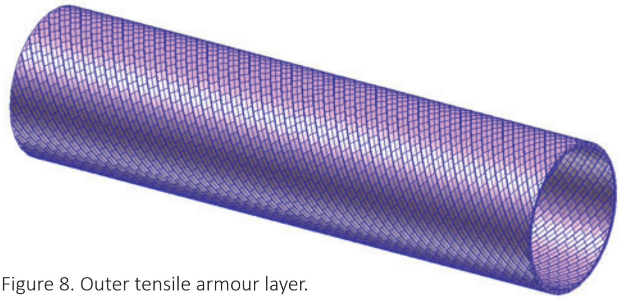


Figure 8. Outer tensile armour layer.

The flowline consists of two helically wound layers of tensile armour wires. Both layers are critical and were also modelled in detail in the FE-model (Figure 8).

The finite element model was built on the basis of methods developed by 4Subsea AS.

The results of the FM analysis showed that the carcass did not collapse at the observed radius of curvature (Figure 9). However, the analysis indicated that the carcass would collapse at a radius of curvature slightly lower (i.e. slightly tighter bending) than the observed radius of curvature, (Figure 10).

The analysis showed that the stresses in the carcass and tensile armour layers were high at the observed radius of curvature. The margin to failure was small; the carcass material was in the plastic region, i.e. stresses beyond the yield limit, the strain in the pressure and outer sheaths was significant, there was high stress in the tensile armour wires, etc. If a probabilistic analysis had been applied to this model, the probability of failure would therefore have been high.

The analysis of the local model employed a one-off loading, and cycling loads were not used. The integrity of the pipe would probably have deteriorated in the course of time due to repeated start-up and shutdowns.

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An Active Hybrid Decomposed Mooring System (HydeMoor) for Model Testing of Offshore Platforms

›› Research Manager Yusong Cao

Since 2010, MARINTEK's Houston office has been conducting a theoretical and numerical study on the feasibility of a proposed active hybrid decomposed mooring system (HydeMoor) for model testing of offshore platforms in wave basin.

Due to the dimensional limits of existing ocean wave basins and the limits on the model scales, it is not practical to put a scaled model of the complete mooring system of an offshore floating structure in deepwater (>1000m) in an ocean basin. Truncated mooring systems have been used. Various types of truncated mooring systems have been proposed and used. Almost all the truncated systems currently in use are of passive types. In a passive system, the portion beyond the ocean basin bottom is truncated and excluded in the model testing. The truncated system must be carefully designed so that it has some "equivalent" behavior close to that of the full system. Depending on the objectives of a model testing, there are criteria of "equivalence" between the truncated system and the full depth system including (but not limited to) the mooring system's 1) static stiffness, 2) dynamic responses, 3) couplings of the mooring system with the

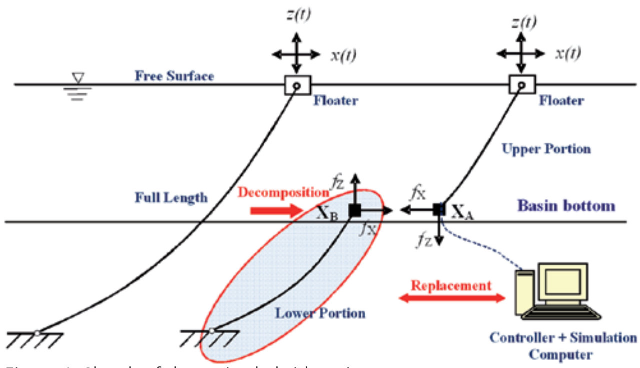

Figure 1. Sketch of the active hybrid testing system.

floater and environmental conditions, etc. Unfortunately, only a very small number of criteria can be met with a passive system. Most of existing passive systems can only have the equivalence in the static stiffness (not even in all the 6 motion modes). In many cases, in order to match the overall global restoring force/moment characteristics, it may not be possible to maintain the similarity in geometry of the individual mooring lines and risers, not to mention the dynamic similarity. Loss of the geometry and dynamic similarity can

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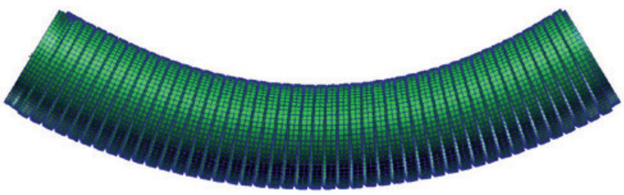

Figure 9. Carcass at the observed radius of curvature.

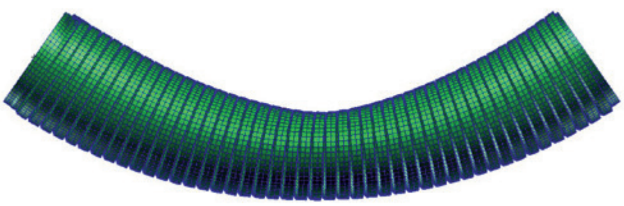

Figure 10. Carcass at a slightly smaller radius of curvature.

On the basis of the survey data provided by the ROV, the results of the analysis and the probability of failure, MARINTEK recommended replacing the flowline, although it was made clear that any changes to the survey data would affect the results and the conclusions drawn.

Because of the importance of the observed radius of curvature, in early 2012, a more detailed and accurate survey was performed on behalf of ConocoPhillips. The primary objective of this inspection was to accurately determine the radius of curvature of the flow line at the site of the anomaly. The new survey showed that the radius of curvature was much larger than estimated in the first survey (i.e. less critical). It was even above the defined MBR for this flowline. The new observations showed that the requirements specified by the flowline manufacturer were not violated, and replacement of the flowline was not necessary. The anomaly will be closely monitored for any developments in the future.

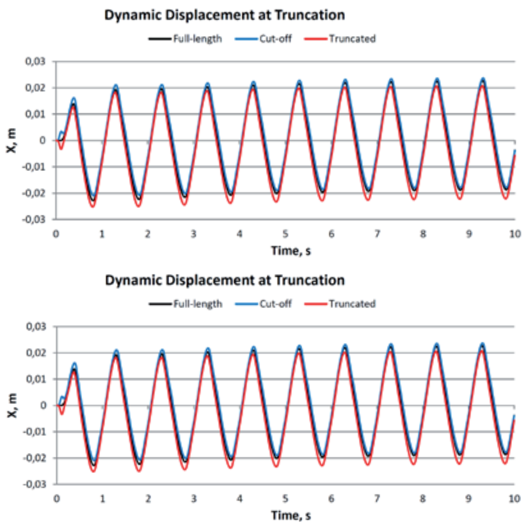

Figure 2. Synchronization of $\mathbf{X}_A$ and $\mathbf{X}_B$.

impose a serious concern in scaling the results from the model tests to the full scale prototype.

It is possible to maintain the system geometry similarity (and thus better dynamic similarity) with use of an active type truncated system. In an active truncated system, such as the active HydeMoor depicted in Figure 1, the effect of the cut-off portion of a mooring line (simulated by a computer/numerical simulation) on the portion physically tested in the ocean basin is applied through an actuator attached to the physical line at the truncation. The actuator is controlled by a controller with proper control algorithm which uses the numerical simulation of the cut-off portion and the physical measurement of the physical portion to generate proper control commands. The interaction between the two portions of the line is correctly simulated by the right action of the actuator, thus simulating the full line correctly (maintaining the geometry and dynamic similarities) simultaneously as the physical test goes on.

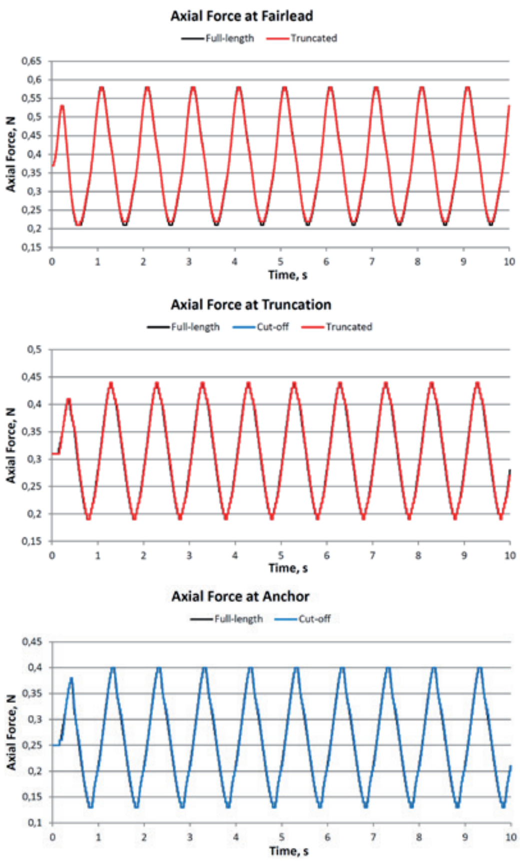

Figure 3. Tension in the decomposed lines and the full line.

HydeMoor adapts the domain decomposition principle used in finite element methods. In HydeMoor, the full line is decomposed into two portions (subdomains). The top of the upper portion is connected to the same floater as the full line would be (same boundary conditions at the top of the full line). The connection of the full line to the sea floor is properly modeled in the numerical model for the lower portion of the line (same boundary conditions at the bottom of the full line). The same environment conditions the full line is subject to is modeled, the upper region in the physical wave basin and lower region in the numerical model. If the motions of the truncation points X_A and X_B (X_A being the lower end of the portion in the wave basin and X_B the upper end of the portion in the numerical model) is synchronized (i.e. $X_A = X_B$) through the actuator applying a load F_A on X_A. The reaction load F_B ($=-F_A$) is applied at X_B in the numerical simulation. The synchronization ensures that the solution of the decomposed system is the same as the solution of the full-length line based on the principle of the domain decomposition. In our study, a scheme to determine F_A was developed and a PID controller was used and tuned to achieve the synchronization.

The basic concept and working principle of HydeMoor were proven and demonstrated through numerical simulations using Riflex. The results of the simulations indicated that as long as synchronization at the truncation is achieved within a reasonable accuracy, the decomposed solution agrees very well with the full-length solution, which is illustrated here with a study case. Figure 2 shows the synchronization of the truncation points X_A and X_B. Figure 3 shows the tension in the decomposed lines at the fairlead, the truncation points X_A and X_B, and the anchor point, as well as the tension in the full length line at the corresponding locations. As seen, the agreement in the tension in the lines between the decomposed solution and the full length solution is excellent.

Study on the effects of actuator's electro-mechanical inertia, measurement sampling rate, the computer simulation timestep size, communication delay between the physical instruments and the simulation computer on the performance of HydeMoor have started. Effort to prove the concept with hardware implementation was also attempted at MARINTEK (Trondheim) and more effort is being planned.

Researchers actively involved in this study include Galin Tahchiev, Liqing Huang (now with Aker Solutions), and Thomas Sauder.

PVC3D – Potential Viscous Code

›› Research Scientist Trygve Kristiansen, PhD

PVC3D is a special-purpose code for marine resonance problems. Examples are moonpool resonance problem, ship-by-ship configurations, LNG carriers moored at a terminal and vessel roll. For engineers dealing with such problems, the code represents a significant step forward.

Results from a recent proof-of-concept study with application to 3D moonpool are given in Figure 1. From the figure, it is clear that pure potential theory, on which state-of-the-art industry codes are based upon, greatly over predicts the piston-mode amplitude of the water inside the moonpool. The results demonstrate that PVC3D yields good results.

Beyond state-of-the-art

PVC3D was developed by MARINTEK in 2011. The code implements recently developed theory from CeSOS (Centre for Ships and Ocean Structures), NTNU. A new method to directly combine linear potential flow theory and Naviér-Stokes solvers was invented. The method is attractive in that it has the ability to calculate for both waves and vortices in combination, at low computational cost. In problems with structures floating in waves, vortex shedding may be important in providing damping at resonance. This is commonly referred to as viscous damping.

Viscous model without empirical input

In present industry codes, viscous damping has to be included by empirical coefficients. PVC3D requires no empirical input; the wave field and the vortex shedding that causes viscous damping are solved for simultaneously. Examples of strong vortex shedding at the inlet of a moonpool as calculated by PVC3D are illustrated in Figure 2. A moonpool is a vertical opening inside an offshore vessel, used for lowering equipment into the sea.

Low computational effort

The proof-of-concept study revealed that the computational times involved were several orders of magnitude shorter than needed by conventional CFD codes. Furthermore, PVC3D is robust and accurate. Short computational times enable parameter studies, supporting for instance moonpool design and providing decision support for complex marine operations. In the example presented in Figure 1, 100- 200 simulations were performed on a typical work-station during one day, which is fast enough for parameter studies to be performed. Such studies of marine resonance problems have not been possible earlier.

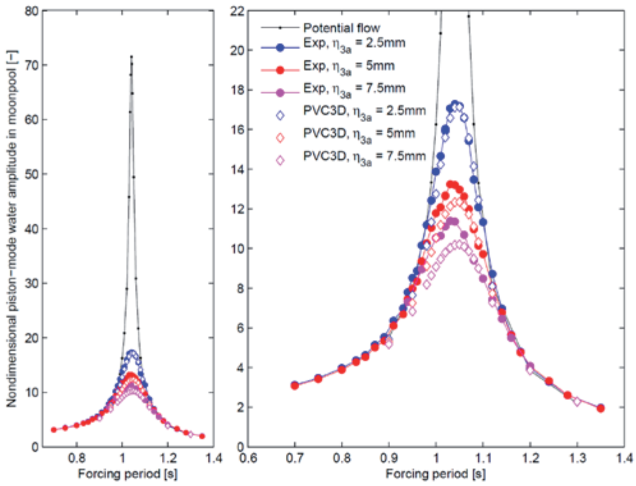

Figure 1. Pure potential flow theory highly over predicts the piston-mode amplitude of the water inside the moonpool at moonpool resonance, while the PVC3D results compare well with moonpool resonance experiments. These results are part of a proof-of-concept study for PVC3D. The right figure is a zoom-in of the left figure.

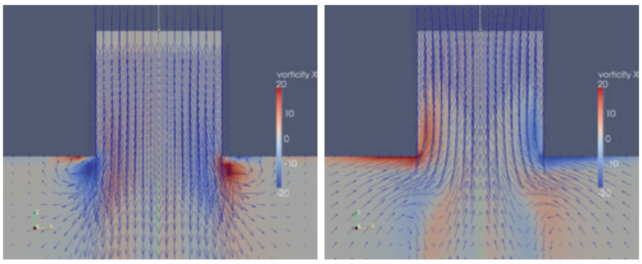

Figure 2. Snapshots of flow field taken from simulations with PVC3D illustrating the strong vortex shedding at the moonpool inlet that causes important viscous damping.

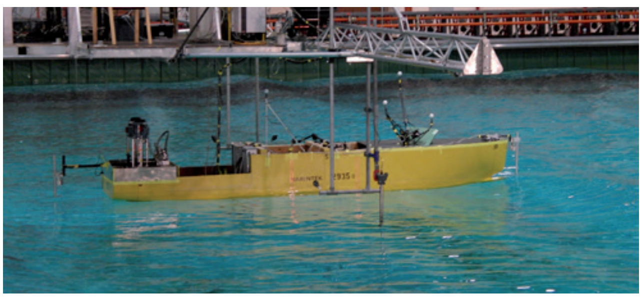

Figure 3. Recent experiments of a ship with a moonpool exposed to a low sea-state, carried out in the Ocean Basin at MARINTEK. Even in low sea-states, operations in the moonpool may become impossible when massive resonant piston-mode motion occurs.

Implementation of condition monitoring

›› Research Scientist Per Kristian Norddal

Onshore technical support has been an important area of interest for the IO Centre. One of the enablers for onshore technical support is the use of condition monitoring (CM) for technical systems. The success rate CM is difficult to measure, as such information tends to be classified. However, through the IO Centre, GDF SUEZ has been willing to share the company's experience of implementing CM systems on the Gjøa platform.

The Gjøa field lies offshore Florø and is operated by GDF SUEZ. The field contains five subsea installations and a semi-submersible platform. Production started in late 2010. The platform design emphasied the importance of utilizing CM systems during the operational phase.

GDF SUEZ provided operational experience for the study, with the implementation of systems for monitoring and follow-up on the Gjøa platform. The study was carried out in the form of a questionnaire and in-depth interviews of personnel responsible for the day-to-day use of the systems. The questionnaire and the interviews focussed on the use of each system, and the initial analysis was therefore related to experience of the use of each of the monitoring systems. From the perspective of learning and improvement, the general experience obtained from the study is just as important. The main experiences are:

1. Sharing of information – CM solutions are to a various degree adapted to the IT infrastructure that permits sharing of information across the organization. CM solutions that require on-site logon, or where the communication is not based on a standard interface (e.g. OPC), tend to be less successful in an IO perspective.

2. Flexibility – Users require flexible solutions for grouping of data streams and displaying results. However, there is also a need for a set of standardized data set-ups for specific personnel categories and disciplines.

Figure 1. The Gjøa platform (Courtesy of GDF SUEZ)

3. Make decisions – Many of the CM systems generate large quantities of data, which do not necessarily support the decision-making. When CM systems are being acquired, more emphasis needs to be placed on how the data should be processed to support the decision-making process.

The challenges of implementing CM systems concern both technological and organisational issues. An important area concerns the activities and analysis processes utilised in the process of deciding on which type of CM systems to adopt. The condition monitoring and diagnostics cycle [ref. ISO 13379-1:2012] can be used as guidance for this process.

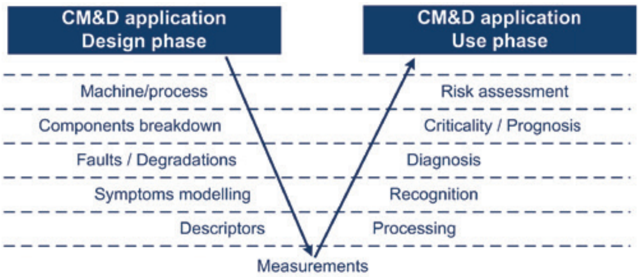

Figure 2. Condition monitoring and diagnostics cycle [ref. ISO 13379-1:2012]

As the condition monitoring and diagnostics cycle shows, there are two distinct phases related to the implementation of a CM system:

1. The design phase: The analysis processes employed to define the measurements that need to be made for the condition monitoring program.

2. The operational phase – The data processing and analyses that must be performed to utilise the measurements or data streams for proactive purposes in the operational phase.

A structured approach to defining the type of measurements and the data processing is important if the CM system is to support the decision-making process. As the study has shown, these processes, or their documentation, may be somewhat overlooked. In order to enable decision-making from the CM systems, these aspects need attention both in the design and operational phase.

Authors

Carl Trygve Stansberg
Chief scientist

Phone: +47 932 68 363
E-mail: CarlTrygve.Stansberg@marintek.sintef.no

Csaba Pákozdi
Research scientist

Phone: +47 454 27 783
E-mail: Csaba.Pakozdi@marintek.sintef.no

Jan Roger Hoff
Senior research scientist

Phone: +47 416 26 120
E-mail: Jan.Hoff@marintek.sintef.no

Elin Marita Hermundstad
Principal research engineer

Phone: +47 478 66 109
E-mail: Elin.Hermundstad@marintek.sintef.no

Frank Klæbo
Research manager

Phone: +47 473 78 649
E-mail: Frank.Klaebo@marintek.sintef.no

Yusong Cao
Research manager

Phone: +1 281 935 9914
E-mail: Yusong.Cao@marintekusa.com

Trygve Kristiansen
Research scientist

Phone: +47 917 02 628
E-mail: Trygve.Kristiansen@marintek.sintef.no

Per Kristian Norddal
Research scientist

Phone: +47 416 41 842
E-mail: PerKristian.Norddal@marintek.sintef.no

MARINTEK
Norwegian Marine Technology Research Institute

Otto Nielsens veg 10, P.O.Box 4125 Valentinlyst
NO-7450 Trondheim, Norway

Phone: +47 464 15 000 Fax: +47 7359 5776
E-mail: marintek@marintek.sintef.no
www.marintek.no

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