Ship Collisions during Offshore Operations

A collision or impact event may be catastrophic for a platform or a FPSO. Depending on the size and speed of the impacting ship, anything from cosmetic damage to hull rupture, oil pollution, flooding, loss of buoyancy, capsizing and sinking may occur.

MARINTEK has been involved in several projects that have studied the effect of impacts between ships, platforms, FPSOs and other installations.

Both bow, side and stern corner impacts have been analysed. Detailed nonlinear finite element analysis has been found to be a valuable tool for analysing and assessing collision events.

A recent project for StatoilHydro included the analysis of a bow impact between a supply vessel and a platform column in the Gjøa field. The most critical collision events for the Gjøa platform were considered to be stern corner collisions of the supply vessel when operating close to the platform and bulbous bow collisions when a supply vessel or other vessel collides with the platform at high speed. These are considered most critical because the stern corner and the bulb are relatively strong and the contact area is small. In addition the bulb is likely to hit the platform below the mean draft level, yielding higher risks of flooding due to shell puncture.

Bow collision accidents with supply vessels have occurred recently, as illustrated by the West Venture – Far Symphony collision in 2004 in Figure 1.

Current trends in supply vessel design include greater size and bulbous bows. The NORSOK Standard - Appendix A is based upon a vessel of 5000 tonnes displacement without bulbous bows, whereas new vessels may displace 7500 tonnes

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or more. No guidance is available for estimating the damage caused by bulbous bows.

In the Gjøa collision project, a detailed finite element model of a bulbous bow of a 7500 ton supply vessel was established (Figure 2). The bow was assumed to be representative of passing vessels which might collide with the Gjøa platform.

The Gjøa semi-submersible columns use a special design which exceeds the requirements of the Norwegian Maritime Directorate. In the finite element model, a part of one column was modelled using 158,000 shell elements (Figure 3). Both the bow and column model included frames, bulkheads, stiffeners etc., for an accurate representation of the structural stiffness.

Determining the point of rupture in structural members is very important in collision and grounding analysis. The effect of a fracture may weaken the structure to and beyond the point of collapse. Most explicit nonlinear finite element codes allow fracture initiation and propagation to be modelled in some way or another. So far, fracture by element removal with an effective strain criterion has been preferred in most codes. The method has earned its popularity due to its simplicity, but unfortunately it is not accurate enough. MARINTEK uses an approach based on continuum damage theory, called the RTCL criterion. The material model was implemented by NTNU and has been verified by a range of simulations and tests carried out at DTU and NTNU.

Four different impact locations were analysed to evaluate the different effects when the bulb and superstructure collide directly with or between decks, bulkheads and ring frames. The analyses were performed by enforcing a 5m displacement of the bow in the longitudinal direction. This displacement allows for sufficient energy dissipation to represent a typical collision. Contact forces, stresses, strains and dissipated energies are key parameters when the results from a collision analysis are being analysed.

The results presented below are for the impact location where the bulb hits the column midway between two ring frames in the vertical direction and midway between two bulkheads in the horizontal direction. The stresses and displacements at 4m bow displacement are shown in Figure 4. The structural damage to the bow is considerable.

In Figure 5, the column has been removed in order to better visualize the damage in the bow. This figure clearly shows that the bow is crushed against the column.

The column is relatively intact after the impact. The stresses and displacements inside the column at the location of bulb impact are shown in Figure 6. The results confirm that the column is strong enough to crush the bulb at this impact location. The stresses and strains are below the fracture failure limit, and the risk of rupture in the column hull is regarded as low. The damage at the site of impact of the superstructure is less.

Figure 7 shows the contact forces between the bulb and column (green), superstructure and column (blue) and total force (red). The superstructure hits the column first, and the contact force between the superstructure and column gradually increases as the bow moves forward. This is expected as larger areas of the superstructure are involved in the impact because of the growing beam of the ship. The figure also shows that the bulb impacts the column after 1.2 m bow displacement. The contact force increases rap-

Figure 6: Stresses and displacements – Inside column (location of bulb impact).

Figure 7. Contact force vs. bow displacement.

Figure 8. Energy dissipation in the bow and the column.

Figure 2. Bow model.
Figure 3. Column model.
Figure 4. Stresses and displacements.
Figure 5: Stresses and displacements (bow only).
The Twin Marine Lifter system (TML) is a new offshore heavy lift system developed by SeaMetric International (SMI) to manage heavy lifts up to 20,000 tonnes. The lifts are performed by two TML vessels positioned on either side of the object to be lifted. Each TML vessel is equipped with four lifting arms, each of which is designed for a lifting capacity of 2500 tonnes.

The lifting arms have ballast tanks on their outer side and buoyancy tanks on the inner side nearer the object to be lifted. By changing the ballast in the ballast and buoyancy tanks, the force of the lifting arms is changed, thereby facilitating the lift. The lifting points of the arms fit into prepared docking stations on the object. The system can be used for either installations or removals. For removals the vessels will float the lifted object over to a heavy transportation vessel.

The system is illustrated in Figure 1.

Figure 1. TML system for platform deck removal.

The system poses challenges to the design and operation. Careful analyses and testing of both stability properties and dynamic responses are necessary in order to establish procedures and limitations that are required for safe operations.

Numerical simulations using the SIMO computer program have been performed, both for steady-state load conditions, before and after lift-off, and for mating operations. The complexity can be illustrated by the number of components involved in a simulation: 3 vessels, 8 lifting arms, 8 buoyancy tanks, 1 object to be lifted, altogether 20 bodies. These are interconnected by hinges, guides, fenders and bumpers, guide pins, etc.

Model testing is a vital tool for verification of a system like this. During the development of the TML system it has been extensively tested in MARINTEK's Ocean Basin. Marine lift operation model tests of platform decks and jackets of various weights have been carried out in various sea states. The tests reveal that lifts are possible in wave heights of up to 2 m. The tests show that the dynamic force variations in the system are acceptable.

Figure 2 shows a picture of the model tests.

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column (red) and bow (blue). After 2m bow displacement, the dissipated energy in the column no longer increases and is almost constant for the remaining part of the crash. This shows that almost all the energy of impact is dissipated by the bow after the point where the bulb starts to crush.

The enforced motion approach is valid for various vessel speeds. The dissipated energy may be used together with the mass of the ship (including added hydrodynamic mass) to determine the speed of the vessel.

The analyses for this impact location show that the column is likely to crush the superstructure of the ship with very small deformations in the column. This is in agreement with experience with the Far Symphony/

West Venture collision shown in Figure 1.

The results indicate that the bulb will normally be the softer structure and undergo by far the largest deformations, but that the deformation of the column at the level of bulb impact is larger than at the level of the bow superstructure.

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The development of methods and procedures to overcome this problem has been addressed through extensive research programmes at MARINTEK (VERIDEEP, VERIDEEP Extension, NDP, DEMO2000) that have led to a hybrid verification methodology based on reasonable truncation principles, model tests of the truncated system, and numerical simulations, to estimate the system’s response at full depth.

A key assumption underlying the procedure is that the important hydrodynamic properties of the vessel can in theory be represented in the coefficients of the numerical model, independent of depth. The numerical vessel model can then be calibrated against the model test results from the truncated system and then used in equivalent simulations with a full-depth mooring and riser system. The difference between the full-depth and the truncated results then becomes purely the influence of the changing mooring line dynamics on the system (assuming that the mooring line quasi-statics are similar at the two depths), which can be reasonably represented in the numerical model by the use of a generalised Morrison’s approach, subject to a suitable choice of coefficients.

In spite of previous successful validations of the procedure, there is still a need to provide further validation in order to access the influence of the truncation procedure and the integration with simulations on the final extrapolated full-depth results. This need recently motivated a joint project between MARINTEK, Petrobras and LabOceano, in which model tests on a moored semisubmersible in irregular waves (scale 1:100) were performed for both a full-depth (water depth 1250m) and a truncated mooring and riser system (water depth 500m) at the ocean basin facilities of LabOceano and MARINTEK respectively. Blind comparisons were then made between the numerically extrapolated and model tests results at full depth.

The truncated system was designed using MARINTEK’s computer code MOOROPT-TRUNC, with the objective of minimising the mooring line quasi-statics at the two depths in the specified environmental directions. The time domain simulations were then carried out using MARINTEK’s coupled analysis program RIFLEX-C, which combines the general vessel response code SIMO with the slender element code RIFLEX.

Line tension and vessel response were compared at full depth, and these confirmed the results of previous studies that the numerically extrapolated results appear to be capable of capturing the change in the systems response from truncated to full depth due to the increased line dynamics. However, the hybrid verification process relies heavily on the tuned model of the vessel being meaningful at both depths; and some automation of the tuning procedure is currently under way in order to help advance the implementation of the procedure.

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MARINTEK, Petrobras and LabOceano Collaborate to Validate Hybrid Verification Methodology for Ultra-Deepwater Model Testing

Model test verification of floater systems in ultra-deep water meets limitations when it comes to available laboratory sizes. Systems designed for depths beyond 1000-1500 m cannot be tested at reasonable scales without the truncation of the mooring and riser system.
The Troll Project

Ringing loads and their associated non-linear responses may be important in connection with the design of fixed installations. In 2007, MARINTEK carried out a comprehensive series of tests to determine the extent of ringing on the Troll A platform in connection with plans to increase its deck load. Tests of this kind require an elastic model with appropriately scaled stiffness and mass. The soil stiffness under the foundation of the platform is also of great importance for the platform’s dynamic response, and the model must therefore be set up on an elastic foundation.

Troll A has four concrete shafts that are linked by a concrete “riegel” about half-way between their base and the still-water level. This connection makes the load-bearing characteristics of the structure rather complex, and for the connection itself torsional stiffness, bending stiffness and shear stiffness must be scaled correctly if the load-bearing characteristics are to be correctly represented. The point of departure for the design of the physical model was a numerical finite element model that best represents the platform as it exists today. Based on studies of the dynamic properties of the numerical model, a scale test model with equivalent properties was designed. With support provided by a detailed ABAQUS model, the properties of the individual components were identified and a complete model built.

The physical model was instrumented to measure moment- and shear force distributions for all four shafts. Axial forces in the shafts under the riegel and where the shafts meet the deck, accelerations at various levels and wave elevation in the area around the deck were also measured. The total number of channels measured was about 200.

In order to validate the stiffness, dynamic properties and instrumentation of the physical model, the individual components and the complete model were tested both numerically and in the laboratory, using static and dynamic tests.

A comprehensive programme of tests of various combinations of deck loads and foundation soil stiffness was carried out, including a total of 290 three-hour wave tests and more than one hundred validation tests. A great deal of effort has since been put into analysing the test data and models in order to establish design loads for the structure.

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Figure 1. From real structure to model test.

Figure 2. Instrumentation of shafts.

Figure 3. Component tests during fabrication of test model.

Figure 4. Testing in model basin and post-calculations/assessment of test results.

Figure 5.
Offshore Supply Logistics and Integrated Operations

The offshore supply chain and related logistics support make up an important lifeline for offshore drilling and production. Although the offshore supply chain plays an important role, it is also a costly operation that needs to be cost-effective.

Some of the most costly resources used in the offshore supply chain are offshore supply vessels. Establishing a customer-focused and cost-effective supply service requires planning and operation of supply vessel routes and schedules to be planned, optimized and operated conscientiously. In MARINTEK we have addressed route and fleet optimization in a wide range of shipping segments, including the offshore supply segment. This article describes an approach to service-oriented resource management of vessel resources in offshore supply chains. The approach focuses on good demand management, tactical fleet planning and optimization, operational fleet management, as well as taking the requirement for solution robustness and flexibility into account.

Demand management
The starting point for the offshore supply chain is a specific and aggregated set-up of the periodic demand for supplies and therefore logistics supply services from offshore installations. Given the focus on integrated operations, IO, in the petroleum industry, specifically in the North Sea basin, the logistics support function, as a real node for all supply requirements in the operation, is attracting greater attention as a constructive approach for integrated planning, balancing demands, requirements and supply resources.

The demand for supplies varies in the course of the year, and even over the week. Such variations in demand over time are due to several reasons, ranging from periodic maintenance campaigns and drilling operations, storage build-up and back-load to prepare for periods of bad weather, as well as better insight into the demand picture over a week, but also due as much to old habits and practice. The position on the life cycle for individual installations will also contribute to changes in demand characteristics, e.g. the balance between deck load and bulk load.

Fleet planning and optimization
To perform logistics supply operations, a fleet of supply vessels is required to bring the cargo from the supply base to the offshore installations. These vessels are among the most costly elements of the offshore supply chain, and as such a set of resources that should be planned and committed so that the number and type of vessels matches the demand for supply services over the period. This task involves fleet planning and optimization.

There are also several physical and regulatory requirements that must be observed in order to plan and optimize supply vessel usage and to meet demand. These requirements may involve service hours on supply bases and offshore installations, e.g. some offshore installations are closed for crane operations to load supplies during night shifts, wind and wave height limitations, storage capacities setting requirements regarding supply frequency, etc.

The fleet planning and optimization task requires an optimization model meeting the different aspects of the fleet and supply structure context to be developed and built, and the necessary analyses to be performed using this model.

The result of fleet planning and optimization is a decision-support basis that outlines a set of supply vessel portfolios, with related supply schedules, that will meet the demand for supply services over a given period of time. This decision basis may also be used as a basis for contracting supply vessels.

Fleet management
Having established and optimized the periodic plan for the supply vessel fleet and the corresponding contract portfolio of supply vessels, we turn to the short-term operation of the supply vessels. The short-term operation of a supply vessel pool covering a set of supply schedules requires the ability to make qualified decisions in change situations that emerge. Establishing a sound decision basis for making such qualified decisions rapidly requires a fleet scheduling and management decision-support tool. In MARINTEK we use our own fleet management tool, TurboRouter® for such purposes.

Robust planning and operation
As logistics supply operations use costly resources, and resources that we wish from a cost-effectiveness point of view to reduce or optimize the use of, we must never forget the need for robustness and flexibility to cope with uncertainty in demand and supply operations. Robustness and flexibility are built into supply vessel management at both the planning and optimization stages, through analyses of different fleet and schedule structures, as well as operationally in the ability of logistics professionals to handle changes in requirements. As we see it, this

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Modelling and Characterization of Artificial Marine Growth

The Riser and Mooring project of the Norwegian Deepwater Programme (NDP) and MARINTEK have made a parametric study of marine growth on circular cylinders fitted with helical strakes. The aim has been to provide guidance regarding the effects of marine growth on the dynamic response of the riser. The tests were conducted in a controlled laboratory condition where organic material is not allowed. Hence artificial marine growth had to be modelled and manufactured. Both hard and soft marine growth have been modelled.

Helical strakes are first-generation technology for mitigation of vortex-induced vibrations (VIV) on risers and pipelines. They are screw-like protrusions that are wrapped around the pipes to suppress the flow vortices by shortening their correlation lengths. This causes the vortices to be shed in finite cells and thus to be weakened. In a previous NDP/MARINTEK study the efficiency of various helical strake configurations was examined by means of model tests.

In some cases, however, marine growths on offshore structures can be of vital importance to their hydrodynamic behaviour. The effect of marine growth on bare marine risers will increase the riser drag. This may be critical for the extreme off-set of floating production units and for the probability of riser clashing in riser arrays. Another example is the dynamic behaviour of marine risers fitted with helical strakes covered in marine growth. In areas like the North Sea and the Gulf of Mexico, marine growth on risers is a concern for the operation of production facilities. Our understanding of the effects of marine growth on the dynamic behaviour of straked risers is limited. Improved knowledge of how marine growth affects the ability of strakes to suppress VIV could be helpful when strategies for riser cleaning are being designed.

A test programme was performed to study the effect of marine growth on the ability of strakes to suppress VIV. A distinction was made between hard and soft marine growth. The first group represents shells, barnacles and the like, while the latter corresponds e.g. seaweeds and marine grasses. Both the size of the growth relative to the height of the strakes and total coverage of the growths were varied during the series of tests.

A vital part of the project was to produce reliable models of the growths. Another important issue was to document the characteristics of the riser models with marine growth for further reference.

One objective of the project was to reliably model artificial marine growth for use in a laboratory where organic material is not allowed. Figure 1 shows various riser models with hard marine growth. In order to measure and characterize the roughness parameters of the growths, a method based on 3D scanning was used; the method of structured light. This is a flexible optical method for measuring the three-dimensional shape of objects and surfaces. These measurements were performed by SINTEF ICT.

The tests demonstrated that both hard and soft marine growths can significantly reduce the ability of helical strakes to suppress VIV.

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Figure 1

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will become an important part of the supply logistics management role in the IO context.

The result of such an approach is a thoroughly analysed basis for a customer-service oriented and cost-effective supply vessel operation. The approach meets the requirement to balance the need for supply vessel support, while seeking to cost-optimize supply vessel usage. This is achieved by establishing a good portfolio of available supply vessels capable of covering a defined set of supply routes and schedules, offering the ability to cope with operational uncertainty through robustness and flexibility built into the routes and schedules, and having systems and competence to address this challenge under operational requirements.

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Figure 2

Figure 4. The fleet management software TurboRouter.

The use of structured light to document the shape of the barnacled riser models was successful. Figure 2 shows an example of a numerical representation of the riser surface geometry obtained from the measurements. From this numerical representation of the surface simple procedures to evaluate various degrees of roughness could be implemented.

The tests demonstrated that both hard and soft marine growths can significantly reduce the ability of helical strakes to suppress VIV.

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Condition Monitoring of Subsea Oil and Gas Installations

Subsea hydrocarbon production has been increasing in recent years. Thanks to subsea installation, marginal satellite fields can be developed around existing field developments, or fields can be completely developed without any surface infrastructure. The best-known subsea fields in the Norwegian sector are Snøhvit and Ormen Lange.

Traditional platforms have all their technical equipment accessible for inspection, maintenance and repair. Equipment standing on the seabed is not accessible in the same way. Subsea installations have traditionally been designed to be maintenance-free for 20 – 30 years, but damage and deviations can also occur on the seabed. On the basis of this experience, and given that components and systems are becoming increasingly standardised, systems for monitoring the technical condition of subsea installations are becoming more and more important. Subsea interventions are expensive for operators, as they may require partial or full production shutdown, as well as time spent waiting for the delivery of spare parts and for bad weather to improve.

MARINTEK has performed a pilot study for NCE Subsea, where the challenges we face in condition monitoring of subsea installations are surveyed.

Sensor technology today measure process parameters (temperature, pressure, sand production, flow-rate, etc.) enabling the operator to monitor changes in the production process over time. Such process parameters can also tell us something about the condition of the installation, but at present no systems exist that are capable of utilising these data to pick up faults, wear and tear or the development of mechanical or material weaknesses. With the help of the process parameters, experienced operators can suggest that a component, (e.g. a choke) should be replaced, but it is difficult to quantify the degree of damage and estimate the remaining life-time of the component. A monitoring system that offers a warning about the seriousness of damage and thus gives the operator an indication of when a component will need to be replaced would make the production process more predictable. In the context of maintenance, such a system could mean major savings, since a number of repairs and replacements on the same or neighbouring fields could be combined, using the same intervention vessel. Robust, reliable data transfer from a monitoring system is a prerequisite for being able to predict the technical condition of subsea oil and gas installations. Such a system would also be capable of preventing major oil or gas leakages, with the serious environmental consequences that these can have.

MARINTEK is currently collaborating with NCE Subsea and its partners in the supply industry, research and the oil companies, on identifying requirements and R&D challenges for condition monitoring of subsea installations.

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Maintenance Practice in the Gassled Transport System

In 2007, MARINTEK completed an analysis project for Gassco, - operator of the Norwegian gas transportation and processing system, - Gassled. Gassco wished to place greater focus on availability and the contribution of maintenance to potential increase in delivery capacity. There is an ambition to increase the delivery capacity of the system. In this respect, the gas processing plants are of special interest.

This project addressed the following aspects:

- Proposed activities to realise potential availability
  It was anticipated that changes to the turnaround intervals for the gas processing plants could perhaps quickly yield the targeted improvements in system availability. A model was developed to include all the necessary elements of a maintenance management system, as well as techniques and tools for the execution of maintenance. A Gassled processing plant and a best-in-class facility outside Norway were benchmarked against this model.

The report identified recommendations for improvement in key maintenance management elements and execution techniques, and assessed their potential. It was demonstrated that improvements to 3 areas of the maintenance management system itself would have quicker and/or greater effect on system availability than would the anticipated changes to plant turnaround interval.

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