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Numerical simulation of broken ice interaction with offshore structures: validation exercises

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ABSTRACT

The Equinor software SIBIS for simulation of broken ice interaction with offshore structures has been further developed in 2018/2019. An overview of the software capabilities is presented and illustrated by showing benchmark tests simulation results and post simulation exercise of two interaction events recorded during full scale Station Keeping Trials with a moored vessel in drifting ice cover.

KEY WORDS: Broken ice; Numerical simulation; Benchmark tests; post simulation

BACKGROUND

Estimation of sea ice action on stationary floating structures

Retreating ice associated with expectation for large oil and gas reserves have led to increasing activities in the Arctic region. In the case of oil and gas activities, ISO 19906 (2010) requires that the offshore structures design takes into account sea ice action effects associated to a return period of up to 10 000 years. Consequently, even if the structure is meant to operate in an area where no sea ice presence has ever been documented, the effects from the sea ice on the structure will have to be assessed as long as the yearly possibility that the floater encounters sea ice is above 10^{-4}.

Ability to predict ice actions and action effects on stationary floating structures is thus critical for safe and cost-efficient design and operations. ISO 19906 (2010) states: "*Methods based on full-scale action and response data from measurements on instrumented structures shall be used for the determination of representative ice actions on offshore structures. Physical models and mathematical models can also be used to complement the full-scale data, with due account for uncertainties in their application*".

Mathematical models include analytical models and numerical models. The latter often include analytical and empirical formulations for parts of the problem solved. Numerical models have many advantages and are often the only opportunity to estimate response of complex systems to complex interactions. However, numerical models are of limited use until they are tested and validated. A typical approach for developing and validating numerical models for interaction between ice and stationary floating structures consists of looping through the following steps:

- Identification of the physical mechanisms involved in the interaction and appropriate solutions.
- Implementation into numerical models.
- Model verification, including verification of separate components.
- Model validation, which involves comparison with (typically) model scale experiments.
- Revision of the theoretical understanding, initiation of a second loop iteration.

Development of a numerical tool for computation of ice action

This approach is used for the development of the simulation tool SIBIS, originally developed for the time domain simulation of interaction between broken ice and stationary structures (Metrikin et al., 2015).

SIBIS is designed to simulate the actions and action effects from drifting intact and broken ice on a moored offshore structure. The simulation comprises a system of bodies (offshore structure and ice floes) interacting with each other. SIBIS software is composed of:

- Computation of the forces acting on the bodies, such as buoyancy, drag, added mass, wind, and mooring forces
- A collision detection engine for detection of all the contacts between the bodies.
- A physics engine for solving the dynamic equations of the system:
    - Computation of the contact forces, limited by the ice resistance
    - Update of the body positions
- A mesh engine for update of the geometry of broken ice floes

In Serre et al. (2018) the SIBIS software was used to post-simulate full scale Station Keeping Trials (SKT 2017) performed in the Baltic Sea in 2017 (Liferov et al., 2018). Some of the gaps which were identified served as basis for further software development in the second half of 2018. The present paper describes a set of benchmark tests which were conducted to validate these developments.

TEST OF ICE RESISTANCE MODELS

The large complexity of the software requires that its simulation results can be tested and validated on simple cases for which ones the ice action can be easily computed. In the present section it is verified that the SIBIS software is able to compute the ice loads according to the guidelines given in the ISO19906 (2010) standards, where ice breaking models are given for continuous ice sheet interacting with inclined and vertical structures.

In addition, the software was tested against the RITAS model ice tank experiment (Serre et al., 2012) where the effect from rubble accumulation on the ice action on inclined hull was studied.

Finally, a simple post simulation of two interaction events during the SKT 2017 allowed assessment of the usability and effects of the new implementations.

Ice crushing tests

Two tests are conducted, a fixed vertical 30-m diameter cylinder and a fixed 49.2 m wide flat indentor interacting with continuous level ice. This test configuration activates failure of the ice sheet in crushing mode, and the ice resistance is then limited by the crushing pressure model defined in ISO19906 (2010). This crushing pressure model allows estimation of the global crushing load on the structure. This global crushing load is here distributed along the ice - structure contact zone according to the pressure distributions monitored on the Norströmsgrund lighthouse (Ervik, 2019).

The tests illustrated in Figure 1 and Figure 2 show that the SIBIS software is able to compute the ice load on the structure according to the ISO 19906 model, for varying contact widths and number of contact zones.

a) b)

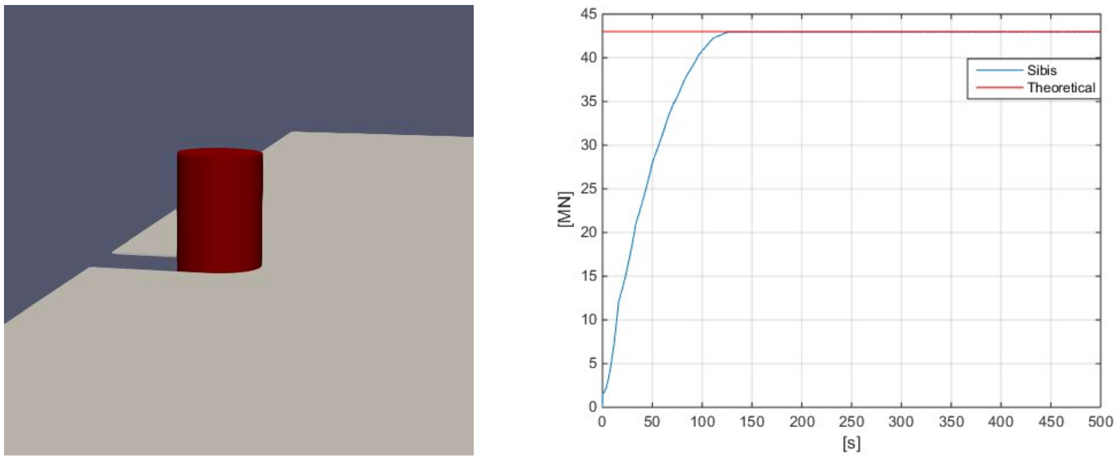


Figure 1. In a) simulation of vertical cylinder interacting with level ice; in b) simulated ice load (blue curve) and computed theoretical load level.

a) b)

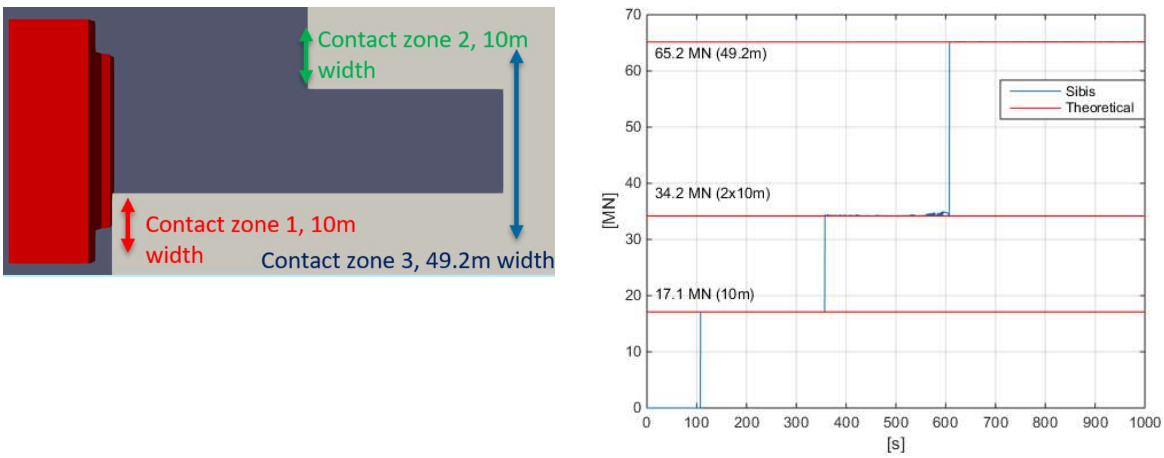


Figure 2. In a) top-down view of simulation of flat vertical surface interacting with ice; the structure interacts first with one contact zone of 10 m width, then with 2 separate contact zones of 10 m width each, then with one continuous contact zone of 49.2 m width; in b) simulated ice load (blue curve) and computed theoretical load level.

Ice bending tests

Two tests are conducted, a fixed 30-m cylinder inclined downward with 45^{o} and the fixed RITAS structure where ice sheet interacts with a 54-m wide plate inclined downward with 45^{o}. The ice resistance model tested in this configuration is the Croasdale ice bending model described in ISO19906 (2010).

The simulation of the cylinder interaction with the level ice is shown in Figure 3. The simulated load time series show a large variation related to the broken ice motion along the hull and the numerous bending failure of the ice sheet against the structure. The simulated load mostly ranges from 0.5 to 1.7 MN, with peaks extending from 0.3 to 3.5 MN. This load can be compared to the computed theoretical load ranging from 0.8 MN (when removing the ice breaking and submerging component from the Croasdale load model) to 1.8 MN (when assuming simultaneous failure of the ice sheet along the hull).

a) b)

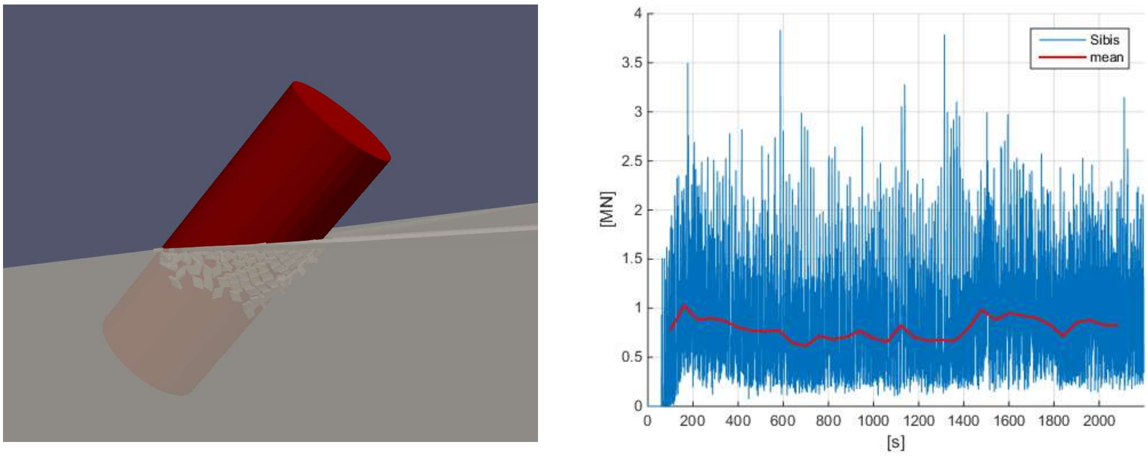
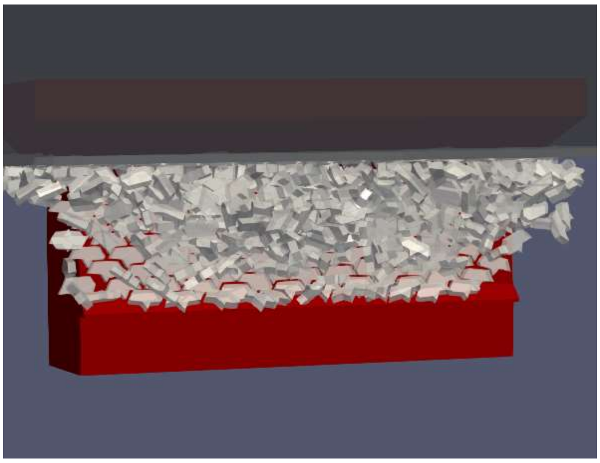


Figure 3. In a) simulation of 45º inclined cylinder interacting with level ice; in b) simulated ice load (blue curve) and simulated mean load level (red line).

The simulation of the RITAS structure interaction with the level ice is shown in Figure 4. The simulated load time series reach a steady state after 1500 s of simulation, where the load ranges from 2.5 to 5 MN, with few peaks extending above 7 MN. The simulated loads can be compared to the computed theoretical load ranging from 2.8 MN (when removing the ice breaking and submerging component from the Croasdale load model) to 7.7 MN (when assuming simultaneous failure of the ice sheet along the hull).

The behavior and magnitude of the simulated load time series are also compared to experimental time series, where a mean steady state load of 3.7 MN was reached after 500 s of interaction (measured load and time converted from model scale to full scale with a 1:20 scaling ratio). The comparison shows that the correct load level is simulated, however the steady state load appears to be reached 3 times faster experimentally than numerically.

a)



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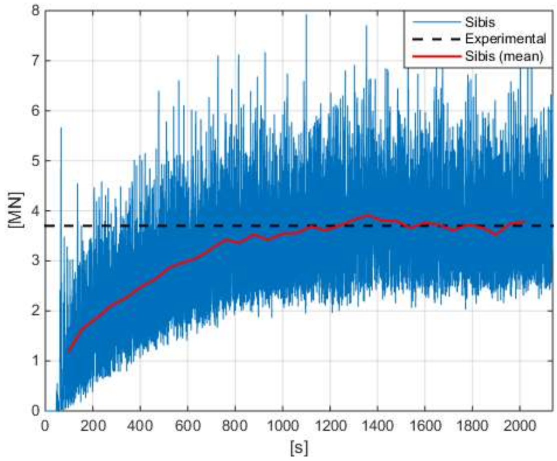


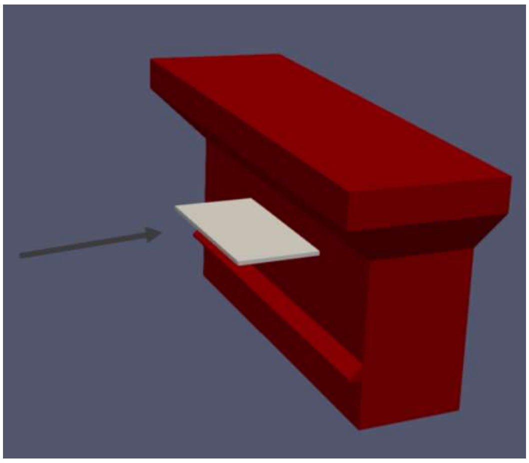
Figure 4. In a) simulation of RITAS structure with 45º inclined panels interacting with the level ice; in b) simulated ice load (blue curve), simulated mean load level (red curve) and measured experimental steady state load level.

Brash ice action test

Brash ice is an essential feature of managed ice fields. Modelling it as an ensemble of particles with specific frictional, cohesive, and compressive properties is not practically feasible per today due to the large computation time that would be required. The effects from the brash ice on the broken ice cover are nevertheless necessary to capture in the simulation, in order to represent its constraining effects on the ice floe motion, and consequently its effect on the broken ice field action on the floater.

A simple model of brash ice resistance was derived based on available literature on ship resistance in brash ice. The model is then used in SIBIS for computation of the brash ice forces on ice floes. One test set up of this model is represented in Figure 5 where a vertical structure pushes an ice floe on which one brash ice forces are computed, based on floe geometry, motion, and brash ice parameters. The conducted tests show that the brash ice forces are applied to the ice cover according to the specifications of the derived brash ice model.

a)



b)

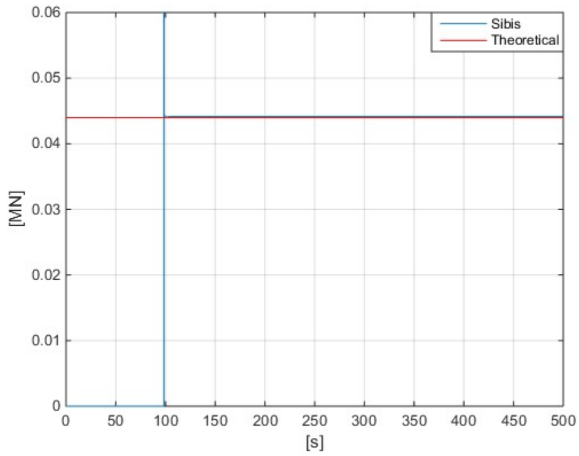


Figure 5. In a) simulation of vertical structure pushing an isolated ice floe against brash ice (no graphical representation of the brash ice, only represented as an external force in the simulation); in b) simulated ice load (blue curve) and computed theoretical load according to derived model (red curve).

POST SIMULATION OF SKT 2017

Simulation of selected full scale interaction events from the SKT 2017 can be used to assess the performance of the software. Two events are selected, described in Serre et al. (2018): interaction with a continuous level ice sheet the 12/03/2017 (Figure 6) and interaction with a broken ice field the 08/03/2017 (Figure 7).

Figure 6 shows that the simulated load level is in the same range as the experimental measurements. A close up view on the simulated time series is given in Figure 6 c) and shows that the dynamicity of the load signal is now better captured with the current version of SIBIS (2019) than the one previously used in 2018 for post-simulation of the SKT. Qualitive analyses of the output videos also showed the simulated motion of ice floes around the vessel was diminished and more comparable to full scale observations.

Figure 7 shows that including the brash ice effects on the ice floes in the simulations allows for a better match of the experimental load time series both in load level and dynamic behavior.

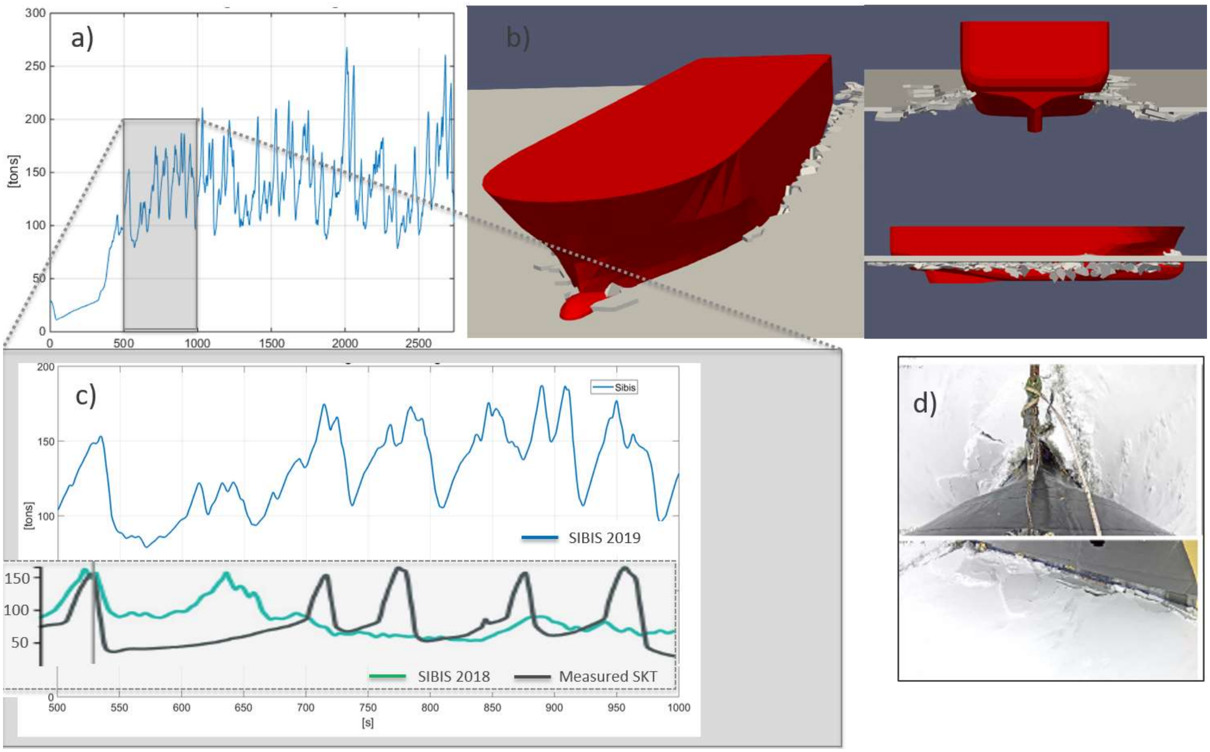


Figure 6. In a) and b) simulation of AHTS Magne Viking in intact level ice, interaction event 12/03/2017 described in Serre et al. (2018); in c) comparison of simulated horizontal mooring load with SIBIS 2019 (blue curve), SIBIS 2018 (green curve) and experiment (black curve); in d) observed ice failure mode on bulb and bow side.

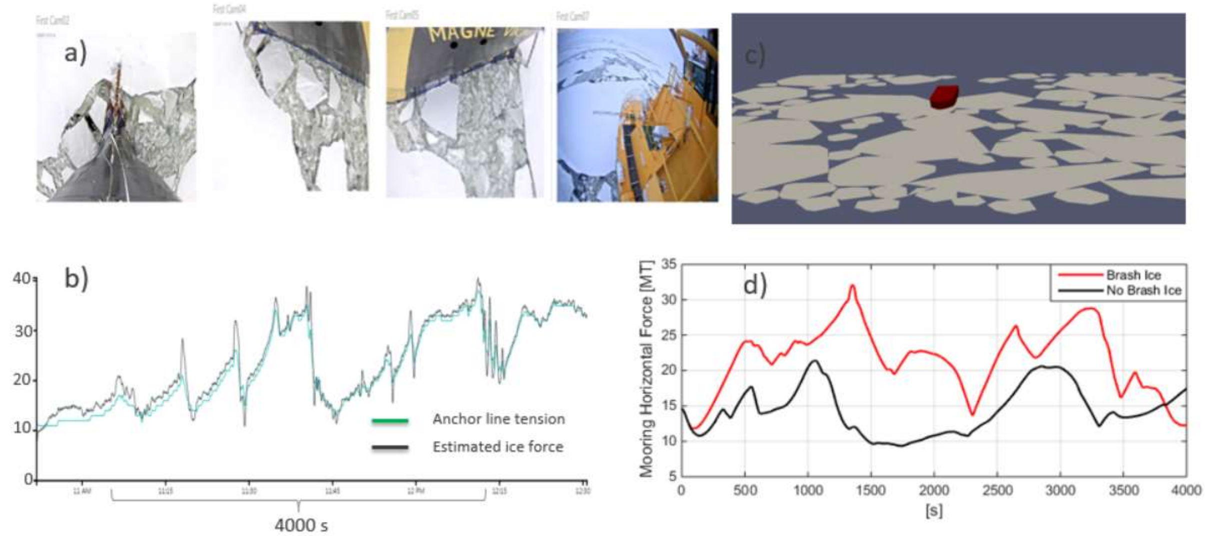


Figure 7. In a and b) observations and measurements from AHTS Magne Viking moored in drifting broken ice, event 08/03/2017 described in Serre et al. (2018); in c) numerical simulation; in d) time series of simulated horizontal mooring load.

DISCUSSION

The SIBIS software is a complex tool, which requires that a sound engineering approach is used in order to make sure that it can serve engineering needs of industrial projects. As for previously developed ice load computation softwares, focus is put on modelling the steering processes, and the validity of the simulation outcome needs to be assessed by comparison to measurements (Bonnemaire et al., 2014).

Complexity of the computational methods and lack of complete theory covering the entire range of ice action mechanisms present in a drifting broken ice field can be to a large extent alleviated by post simulating physical (model) tests and then calibrating parameters of the numerical model to match the main loading behavior from the ice field and the associated floater response.

The study described in the present article shows that SIBIS is capable to post simulate the global action and floater response from drifting ice cover on a moored offshore structure. The ice action levels are limited in upper bound by the failure of the ice sheet on the structure. The load levels associated to this action mechanism can be computed according to the ISO19906 recommendations, and the simulation of simple interaction cases with intact level ice have shown that the simulated results match the analytical loads computed with ISO 19906 models.

It is then possible to achieve a numerical set up which both satisfies standard requirements and observation from ice test campaign, thus providing the engineer with a numerical tool able to supplement ice tank tests for the design of arctic offshore structures. For instance by simulating interaction cases not possible to reproduce in a model ice tank, or to generate additional ice action estimations associated to a large number of ice conditions.

CONCLUSION

The Equinor software SIBIS has been further developed in 2018/2019 in order to improve simulation capabilities of broken ice interaction with offshore structures and close some of the gaps identified during previous post simulation of full scale Station Keeping Trials in drifting ice (SKT 2017).

An overview of the software capabilities has been presented and illustrated by showing benchmark tests simulation results and post simulation exercise of two interaction events recorded during the SKT.

The study described in the present article shows that SIBIS conforms to the ice load models given in ISO 19906 and is able to simulate the measured full scale ice loads on a moored vessel. The latest software improvements allow for a better representation of the brash ice effects on the ice floes and the dynamicity of the load signal.

Combination of the numerical tool with (model) tests experiments and identification of the main ice action mechanisms can thus provide an engineering solution to estimate the global ice action and action effects involved in the design of arctic offshore structures exposed to drifting sea ice.

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REFERENCES

B. Bonnemaire, N. Serré, T. Lundamo, A. Fredriksen and A. Jensen, Multiconsult, A. Gürtner and S. Teigen, Statoil ASA , 2014. Ice breaking and accumulation around a moored structure: ice basin tests and numerical simulations. In proceedings of the Arctic Technology Conference held in Houston, Texas, USA, 10-12 February 2014.

Ervik, Å., Serre, N. High force ice interactions at Norströmsgrund lighthouse. *To be published in proceedings of the 25th International Conference on Port and Ocean Engineering under Arctic Conditions,* 2019.

ISO/FIS 19906:2010, Petroleum and natural gas industries - Arctic Offshore Structures.

Liferov, P., McKeever, T., Scibilia, F., Teigen, S.H., Kjøl, A., Almkvist, E. and Lindvall, J.K. Station-keeping Trials in Ice: Project overview. *Proceedings of the 37th International Conference on Ocean, Offshore & Arctic Engineering,OMAE2018,* June 17-22, 2018, Madrid, Spain.

Metrikin, I., Gürtner, A. Bonnemaire, B., Tan., X., Fredriksen, A. and Sapelnikov., D. SIBIS: a numerical environment for simulating offshore operations in discontinuous ice. *In proceedings of the 23rd International Conference on Port and Ocean Engineering under Arctic Conditions,* 2015.

Serre, N., Kerkeni, S., Sapelnikov, D., Akuetevi, C., Sukhorukov, S., Guo, F., Metrikin, I., Liferov, P. Station-keeping trials in ice: Numerical modelling. *Proceedings of the 37th International Conference on Ocean, Offshore & Arctic Engineering,OMAE2018,* June 17-22, 2018, Madrid, Spain.

Serre, N., Høyland, K., Lundamo, T., Bonnemaire, B., Evers, K-U., Gürtner, A., Rubble Ice Transport on Arctic offshore Structures (RITAS), part I: scale model investigations of level ice action mechanisms. *In proceedings of the 22nd International Conference on Port and Ocean Engineering under Arctic Conditions,* 2013.