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INFLUENCE OF MODELING FULL SCALE BASED MANAGED ICE CONDITIONS IN DP ICE MODEL TESTS

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ABSTRACT

Recently there have been significant steps taken regarding the development of ice model testing capabilities for dynamic positioning (DP) operations in ice. Such developments have stemmed from the knowledge gained through involvement in real life DP operations in ice, namely the subsea construction operation with the CSO Constructor in the Sakhalin offshore in 1999, and the Arctic Coring Expedition with the icebreaker Vidar Viking near the North Pole in 2004. Lessons learned from these operations have lead to the conclusion that ice model testing for DP vessels in ice may require the need for a new approach to modeling ice conditions in order to achieve results that would start to approach real life experience.

Two big steps have been taken that attempt to narrow the gap between model scale results and full scale expectations. First, a novel approach of starting to model ice such that the ice more closely resembles managed ice conditions that a DP vessel would be expected to operate in full scale was developed and applied in actual ice model tests. This will be the focus of this paper. Second, an actual DP system was installed on a model and tested in an ice model basin, to achieve a realistic level of behaviour of the model to match the real life operation as close as possible. Additional information on this topic can be found in Hals and Efraimsson (2011). These two developments constitute a major advancement in the development of dynamic positioning vessels and their DP systems in ice, and provide an approach to evaluate their operational capabilities.

INTRODUCTION

A key lesson from previous full scale DP in ice operations is that ice management plays a central role in the loads experienced by the platform. For this reason, it is generally accepted that any station keeping operations performed in significant pack ice with a floating platform will rely on physical ice management to reduce the severity of the ice to an acceptable level. The ice conditions produced as a result of ice management are very different than the original ice condition, resulting in various ice interactions on the platform and therefore loads.

This paper discusses how ice management reduces loads on a DP platform in pack ice, and the recent development of a methodology to include the influence of ice management in model tests, by defining a set of managed ice conditions that are representative of what would be expected in full scale. Also included is a discussion on observations and results between a number of DP ice model tests performed for Stena's IceMAX DP drillship, which compares the early tests that represents the traditional method of modeling ice conditions in station keeping operations, to a recent set of tests that adopted the above methodology to model realistic managed ice conditions.

FULL SCALE EXPERIENCE WITH DP OPERATIONS IN PACK ICE

To the author's knowledge, there has only been two full scale dynamic positioning operations that have taken place in the presence of significant pack ice. An overview of each of these operations is provided below.

CSO Constructor, Spring 1999

The first major DP operation in ice was a subsea construction operation which took place offshore Sakhalin over a six week period in the presence of thick first year ice during the spring of 1999, shown in Figure 1 (left) (Keinonen et. al., 1999). The CSO Constructor was selected to perform this operation, which other than an ice class (rated for a maximum of 70cm thick ice) had a relatively conventional open water design, including an open water hull with vertical bow and a conventional DP system that was not designed for operations in ice. The thruster configuration consisted of a main longitudinal propeller, two aft azimuth thrusters and two bow tunnel thrusters, producing a maximum longitudinal and transverse thrust of approximately 96 and 72 tonnes, respectively. The allowable horizontal offset was limited to a maximum of five meters.

The ice conditions present at the time consisted of up to 1.5m thick first year ice, stamukhi with 5 meter sails, a mean and maximum floe size of approximately 20 and 100 meters respectively, and an ice concentration typically within the 8 - $9^{+}/10^{ths}$ range for a significant part of the operations. To enable the vessel to operate in such ice conditions, which exceeded its independent capabilities, an ice management system was implemented using the icebreakers Smit Sakhalin and Magadan to manage the incoming ice. The focus of the ice management vessels was to break the largest and thickest floes that threatened the station keeping ability of the CSO Constructor, and produce high concentrations of brash ice, which allowed the managed floes to move around the stationary vessel. The operation took place successfully with a total ice downtime of only 22%, demonstrating that performing DP operations in thick ice conditions with a relatively low ice capable platform is possible.

Arctic Coring Expedition, 2004

The Arctic Coring Expedition (Keinonen et. al., 2006) was a unique station keeping operation performed in August –September of 2004 to extract core samples from the Lomonosov Ridge, approximately 120 miles from the North Pole. The AHTS Vidar Viking, which was equipped with a DP system and fitted with a custom derrick and moonpool, was selected to act as the drilling platform. The Vidar Viking's maximum longitudinal thrust, which came from its two ducted propellers, was approximately 200 tonnes, while its level icebreaking capability was approximately 1.3 meters. The large water depth (1200m) allowed the Vidar Viking to accept a horizontal offset of approximately 50 meters (~5% of water depth).

The ice conditions experienced in this operation typically consisted of thick first year and multi year ice, with an average observed thickness of 2-3 meters and concentration over 9/10ths. To enable the Vidar Viking to maintain a stationary position in the presence of such thick ice, which well exceeded its independent capabilities, the polar icebreakers Sovetskiy Soyuz and Oden managed the ice by breaking incoming floes to smaller pieces and producing a large amount of brash. Figure 1 (right) shows the ice management operation in progress. Even with ice management, such heavy ice conditions exceeded the available transverse thrust and rendered the Vidar Viking's on board DP system inoperable, which resulted in the Vidar Viking having to manually maintain position using its twin propellers and rudders. Despite the severity of the surrounding ice, a highly successful coring operation took place over a three week period, experiencing less than 10% ice induced downtime.

Figure 1. Previous DP operations performed in pack ice, CSO Constructor in Sakhalin (left) and Vidar Viking during ACEX (right), both supported by physical ice management.

ROLE OF PHYSICAL ICE MANAGEMENT IN DP OPERATIONS IN ICE

The primary role of physical ice management is to reduce the severity of the approaching ice, allowing the platform to operate beyond its independent capabilities. This is typically performed by breaking the incoming floes to smaller pieces and producing a large amount of brash ice, using an ice management technique called traditional ice management. Two icebreakers have generally been used in previous traditional ice management operations, which typically operate in a pre-defined sector updrift of the platform. The larger, more powerful icebreaker operated the farthest updrift of the platform to break the approaching unbroken ice to smaller pieces. Then, the ice broken by the first icebreaker was managed by a second icebreaker, which continued to break the ice and produce a high concentration of brash.

The resulting managed ice condition is much less severe than the original unmanaged ice condition, consisting of much smaller floes, having a reduced maximum and average floe size as well as a large quantity of brash ice. The brash ice is an essential parameter of the managed ice condition, as it is easily squeezable and allows the floes within the managed ice matrix to deviate around the platform while minimizing the loads on the platform. If the brash was not present, then the floes would chain with one another and resist any displacements to move around the platform, resulting in floes having to fail by some other mechanism such as bending, fracture or crushing, which typically have higher associated loads.

Figure 2 shows a comparison of a representative unmanaged ice condition (Toyota et. al., 2011) and a managed ice condition from ACEX, both of which have a maximum floe size of approximately 70 meters. The first observation is that the majority of the area in the unmanaged ice condition (left) consists of large floes, whereas in the managed ice condition (right) the majority of the area consists of brash ice. Also, the unmanaged ice condition shows very little space between the individual floes which will lead to chaining if displaced, whereas the managed ice condition shows the individual floes separated by brash, which reduces the influence on neighboring floes.

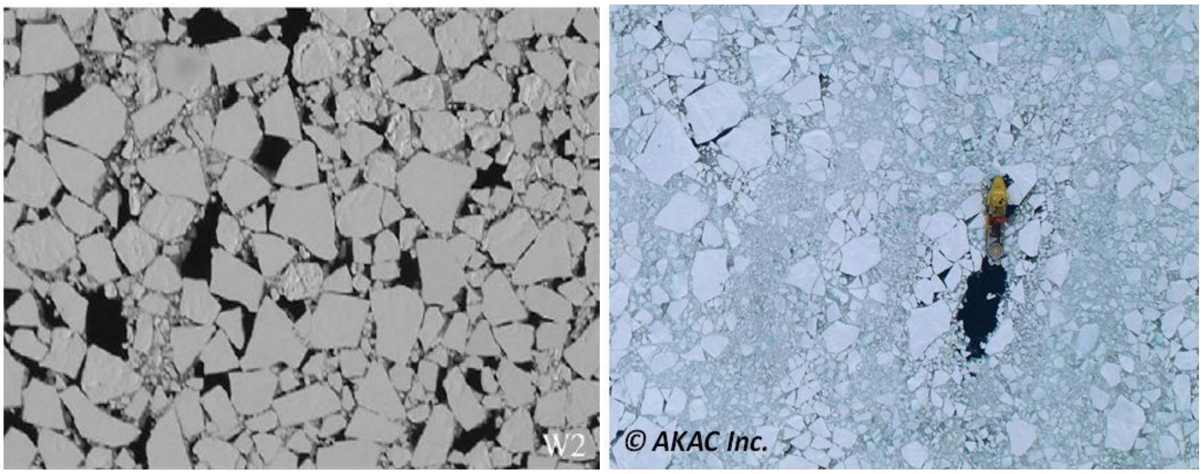

Figure 2. Comparison between unmanaged (left, [5]) vs. managed (right) ice conditions, both with a maximum floe size of approximately 70 meters. A clear distinction is the presence of smaller floes and a large amount of brash ice between them in the managed ice condition. Both images have a width of approximately 560 meters.

DEVELOPMENT OF A METHODOLOGY FOR DESCRIBING MANAGED ICE

The ice condition examples in Figure 2 are highly variable in terms of severity for performing station keeping operations, although the representative floe size is similar. This implies that it is insufficient to use a single floe size value to describe a given ice condition, as the ice condition can take many forms. A more appropriate method for describing the ice regime is to present its floe size distribution. Figure 3 shows a comparison of the floe size distribution for the unmanaged ice condition shown in Figure 2 above and a sample managed ice condition produced during the ACEX operation. The floe size distribution shows that there is a much lower percentage of large floes in the managed ice condition, compared to the unmanaged condition, even while the maximum floe size is approximately the same. For example, in the managed ice conditions, approximately 50% of the area was covered by floes less than 5 meters. In the case of unmanaged ice, over 60% of the area has floes larger than 20 meters.

With regards to brash ice, a general rule of thumb for identifying the largest brash ice piece size is approximately three times the thickness of the level ice. Thus, given that the average ice thickness during ACEX was approximately 2.5 meters, the maximum brash ice piece size was approximately 7.5 meters. According to the floe size distribution curve for the managed ice condition shown in Figure 3, the brash ice concentration for the managed ice condition is approximately 60%. Assuming a similar average thickness for the shown unmanaged ice condition, the brash ice concentration for that scenario is approximately 10%. Such a low brash concentration will not prevent contact between floes and therefore chaining will likely result.

The extracted ACEX floe size distribution was compared to a number of standard distribution types, with the cumulative Weibull distribution (single parameter) offering the best comparison. The ACEX floe size distribution after ice management is shown in Figure 4 (left) with the fitted Weibull distribution.

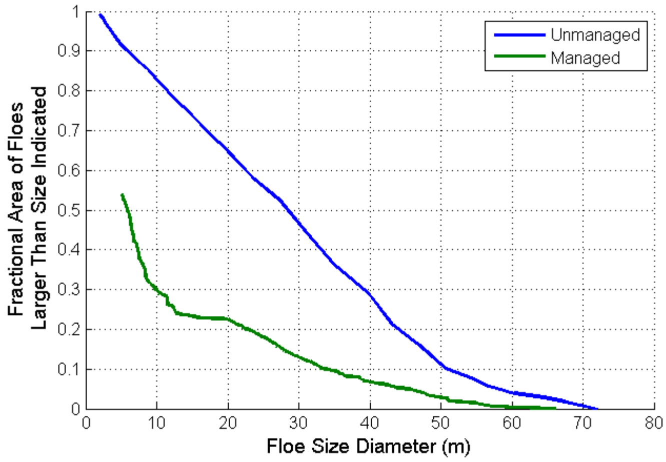

Figure 3. Comparison of Floe Size Distribution for Unmanaged and Managed Ice

The outgoing ice condition resulting from ice management is dependent on three main parameters: the speed of the ice management vessels in the incoming (unmanaged) ice condition, the ice drift speed, and the amount of ice that needs to be managed. With these three parameters defined, it is possible to estimate the characteristics of managed ice conditions resulting from the performance of sea ice management, using an ice management model. To do this, a previously developed ice management model was used, which has been calibrated from empirical analysis of incoming ice conditions, outgoing floe size distributions and associated icebreaker performance data extracted from the ACEX operation. This model outputs an estimated maximum floe size and brash ice concentration produced as a result of the input parameters identified above.

To estimate the managed ice conditions arriving at the platform, it is first necessary to identify a representative ice management fleet that would be similar to what would be used in real life. Once a fleet is selected, its ice management performance can be estimated for a range of input ice conditions. As discussed previously, the drift speed determines the performance of the ice management system. High drift speeds results in less time to manage any given ice and results in larger floes and less brash, as shown in the sample distributions computed using this methodology in Figure 4 (right).

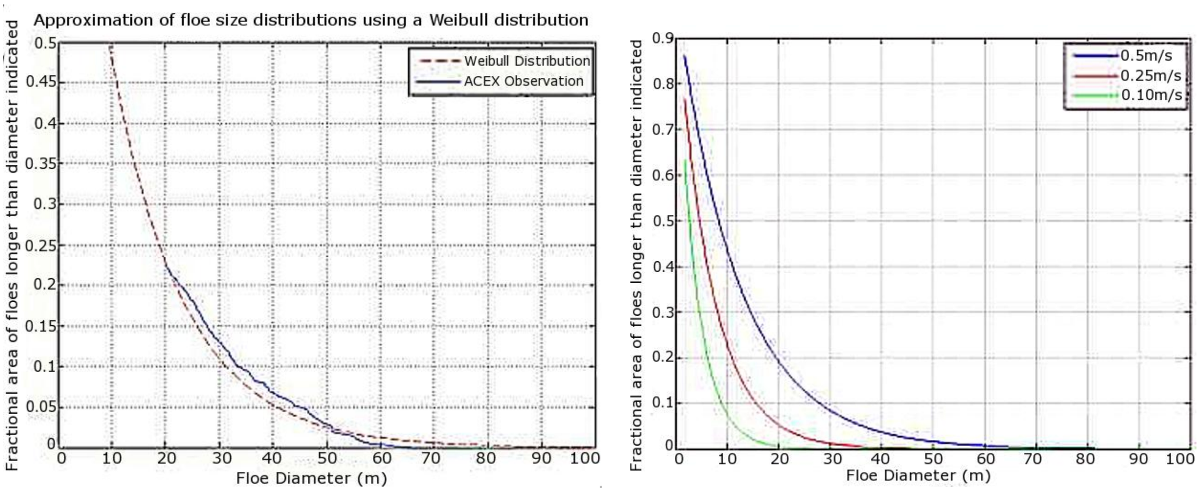

Figure 4: ACEX Floe Size Distribution after two Icebreakers, with fitted Weibull Distribution (left). Sample output showing fitted floe size distributions for various drift speeds for a single incoming ice condition and ice management fleet (right).

EXPERIENCE WITH MODELING MANAGED ICE IN DP ICE MODEL TESTS WITH STENA'S ICEMAX DRILLSHIP

For the past several years, the authors have been involved with the development of Stena's IceMAX ice capable drillship. This involved the preparation of DP ice model test planning and subsequent analysis of model test results to help identify the ice operational capability of the IceMAX in various ice conditions. A key input to these studies is the application of full scale operational experience from similar operations, as a sanity check to ensure that the results are as representative of real life as possible.

Overview of 2009 IceMAX DP Ice Model Tests

Figure 5 shows an example of an early ice model test performed in 2009 with the IceMAX, where the ice conditions were modeled as 50 m floes, 1.2 m ice thickness, and approximately 8/10ths concentration. Another test was also performed in this test program, with the same ice thickness and concentration, but used a floe size of 10-20 m. The purpose of these tests was to obtain a conservative estimate of the ice resistance on the IceMAX. A key observation during both of these tests (particularly for the test with the 50 m floes) was the chaining of floes with one another as the model progressed through the ice. The key reason for this is the lack of brash ice, which hinders the ability of the floes to deviate to the side of the model. As a result of this chaining, the primary failure mechanism of the floes tended to be by fracture and crushing. For platforms that have non-icebreaking hull forms (such as the IceMAX), these failure mechanisms would result in higher forces than those associated with floes deviating around the hull.

Due to the lack of brash ice and a floe size distribution, the ice conditions modeled (particularly the 50 m floe test) are more representative of naturally broken floes due to wave action, such as those found in a marginal ice zone as shown in Figure 3 (left), rather than managed ice.

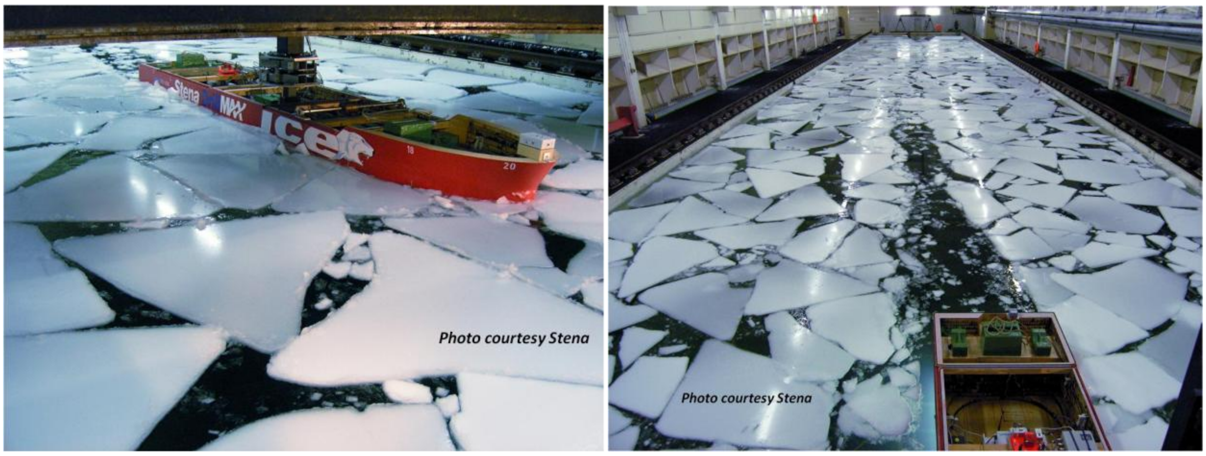

Figure 5. 2009 Ice Model Test Performed with Stena IceMAX in 50 meter floe ice conditions

Overview of 2011 IceMAX DP Ice Model Tests with Full Scale Based Managed Ice Conditions

In January-February 2011, a pioneering set of ice model tests were performed with the Stena IceMAX. The purpose of these tests was to calibrate the DP system, which was developed specifically for this vessel to operate in ice. A DP System was therefore installed on the model, whereas in the earlier tests the model was towed. Although the target ice thickness and concentration were the same as in the 2009 tests (1.2 m and 8/10ths respectively), in this test program there was a high priority placed on modeling ice conditions that would be representative of full scale managed ice. To do this, a theoretical ice management fleet that would be representative of one used to support the IceMAX in such ice conditions. With the incoming ice condition and the ice management fleet defined, the ice management model discussed in the previous section was used to determine what the resulting managed ice conditions would be for a number of ice drift speeds. The resulting managed ice condition is characterized by a floe size distribution and a brash ice concentration, as demonstrated in the probability distribution functions in Figure 4 (right).

Given a target floe size distribution and ice thickness, the ice model basin technicians were able to produce an ice regime that visually resembles full scale managed ice conditions than previous tests, as shown in Figure 6.

Figure 6. 2011 IceMAX DP Model Test in Full Scaled Based Managed Ice Conditions

COMPARISON OF MODEL TEST RESULTS

In the first set of tests performed, the floes had very little motion, leading the IceMAX breaking the floes in flexure, crushing, and splitting to advance through the ice matrix. Observations during the second set of tests revealed that the modeled squeezing of brash ice allowed the larger ice floes to be pushed around the hull. This reduced the peak loads as the IceMAX did not have to break the large floes.

The reduced loads in the second set of tests have been verified by comparing the load traces. Figure 7 shows a comparison of the load traces from a recent 2011 model test with two tests performed in the 2009 test program. The 2011 tests modeled the managed floe size distribution, while the two 2009 tests had fairly uniform floe sizes of 50 and 10-20 m. All tests compared had similar drift speed, ice thickness, and concentration. This comparison reveals that test in 2011 had significantly lower peak and mean loads. This is a direct result of the fact that less floe breakage was required. The results indicate that the peak loads in two different ice regimes, each of which could be considered to have floe size of 50 m, can differ significantly. Even in two different ice regimes with the same average floe size, the difference in loads is significant if the brash concentration is not modeled.

Another point of interest is the chaotic nature of the loads. The load trace in the 2011 test not only has lower peak loads, but the loads did not fluctuate as quickly as they did in the earlier tests. This has a significant impact on the design and operation of DP systems.

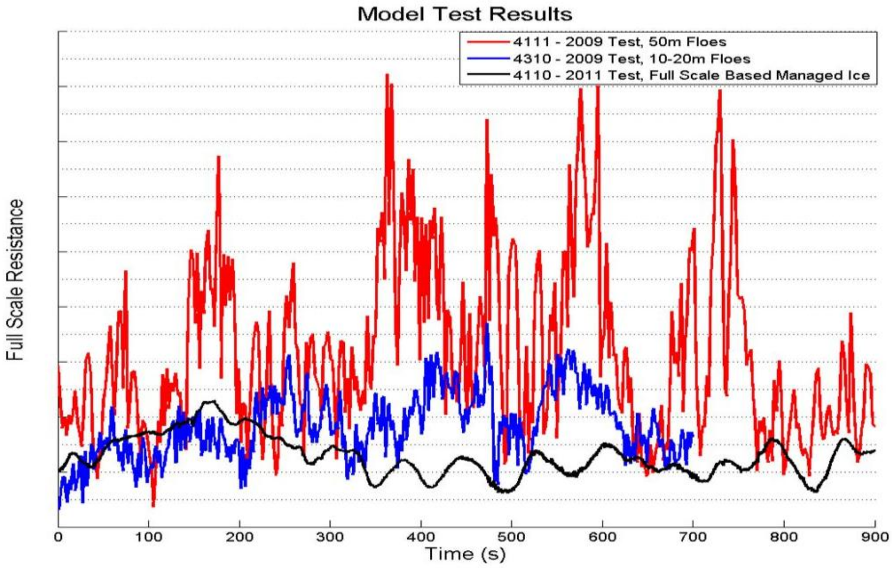

Figure 7. Comparison of load traces from early ice model tests with earlier modelling approach of managed ice conditions (black curve) and recent model tests with full scale data based modelling of managed ice conditions (red).

OVERVIEW OF FULL SCALE ICE INTERACTION SCENARIOS RESULTING IN PEAK LOADS IN MANAGED ICE

The significant difference in ice loads resulting from the different modeling techniques raises questions regarding what test series best predicts the full scale operation of the IceMAX. As full scale data of ice loads on the IceMAX is not yet available, this question can only be answered by considering how well the tests modeled the loading scenarios experience in other full scale operations. This section focuses on identifying the interaction scenarios observed in full scale operations that resulted in peak loads, for the purpose of qualitatively assessing what test series most closely predicts the full scale loads.

Direct Floe Impact on the Bow

The most favourable vessel orientation for minimizing ice loads is to keep its bow pointed into the incoming ice. When a floe directly impacts the stem of the platform in this orientation, as in Figure 8 (left), the interaction initially causes a longitudinal force on the platform. If the momentum of the floe is large enough, it could lead to a longitudinal force that exceeds the station keeping ability of the platform.

Depending on the strength and thickness of the ice, the shape of the bow and the driving forces, a number of release mechanisms may result. The floe could fracture, break in flexural failure, crush causing an indentation, deviate to either side of the bow, or may stay there and not move at all. The presence of sufficient brash will help ensure that the loads are kept as low as possible as it reduces the chances of floes chaining together. Therefore, for a platform with a non-icebreaking bow operating in managed ice conditions, it is less common to see floes failing in fracture, buckling, or crushing. Partial indentation has been observed in low ice strength conditions, as Figure 8 shows for a floe that has initially impacted the stem but has deviated around the platform.

It is important to identify upfront what the floe impact tolerance of the DP platform is, which is dependent on the mass of the floe (thickness and floe size) and the ice drift speed. This will help establish a maximum target floe size, and an appropriate ice management system capable of achieving this. The impact speed assumed to select the maximum target floe size would be at least representative of the highest ice drift speeds to be expected in the region, resulting in a conservative target floe size. During the actual operation, ice drift speed does not appear to have a direct influence on the global loads on the platform, as the impact force of managed ice floes are much lower than the available thrust. However, drift speed does have an indirect influence on loads as an increased drift speed provides less time for the icebreakers to sufficiently manage the ice, resulting in a reduction in brash ice concentration and a more severe floe size distribution arriving at the platform.

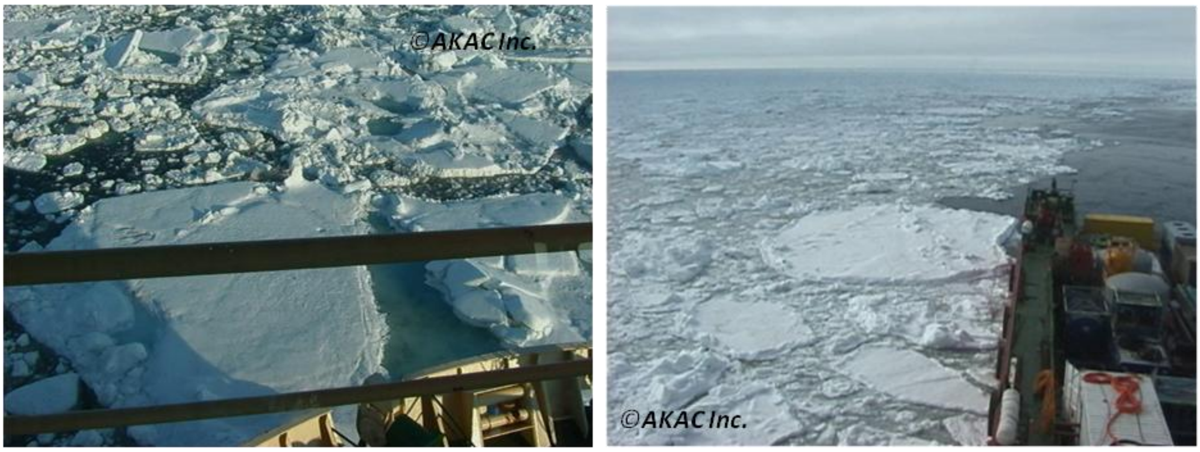

Figure 8. Two examples of ice floe interaction with CSO Constructor in managed ice, at the instant of impact with the bow (left), and after deviation around the platform (right). Note the indentation on the floe from the stem impact (right).

Unsymmetrical Ice Interaction

If ice interacts with the side of the bow, or if the longitudinal axis of the platform is not directly aligned with the incoming ice drift direction, ice could accumulate on the side of the platform, resulting in an unsymmetrical load. If the platform's DP system does not have sufficient transverse thrust and turning moment to oppose and correct that unsymmetrical load, the heading offset could increase. This causes further asymmetric accumulation of ice, compounding the original loading event.

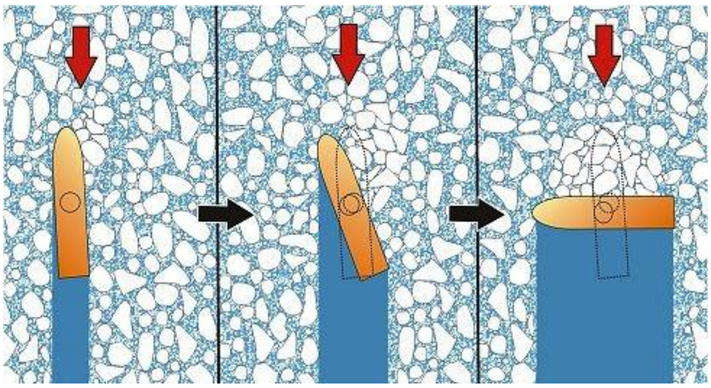

Figure 9. Example of Unsymmetrical Ice Interaction Leading to Critical Situation

High ice concentration interaction with ice pressure

When operating in high ice concentrations with the presence of ice pressure, another ice interaction scenario that has been observed in full scale station keeping operations is the accumulation of ice at the bow of the platform. When the ice cannot easily deviate around the platform, due to insufficient space for the ice to clear around the vessel, ice accumulation can result even in managed ice in ice pressure scenarios. Thus an accumulation ahead of the bow in the shape of a cone can form (Palmer & Croasdale, 2013). This accumulation can cause a gradually increasing axial load on the platform, until the cone is fully formed. The frictional forces between the drifting ice pack and the edge of the cone are then transferred to the platform, until it is finally released. This interaction was not observed in either the CSO Constructor or ACEX operation, but was observed in station keeping operations with moored platforms such as the drillships and Kulluk used in the Beaufort Sea.

CONCLUSION

A number of DP ice model tests have been performed in similar ice thickness, concentration and drift speed conditions, but have resulted in highly variable results. Based on previous experience with full scale DP in ice operations, it is believed that a key source of the variability is the fact that the modeled ice conditions are not consistent. The earlier (2009) tests modeled relatively uniform floe sizes, while the more recent (2011) test program modeled the ice through consideration of the floe size distribution, which had not been done previously. The lower loads produced by modeling the floe size distribution are believed to be more representative of full scale loads as less floe breaking was experienced. This is consistent with full-scale operations where the peak loads have not been a result of the breaking of the floes. Another source of variability could be from the fact that a DP system was used in the most recent tests, whereas the earlier tests towed the model up the basin.

In order to have results that are as close to reality as possible, the ice interaction scenarios observed in the field need to be replicated in an ice model basin. This can only be achieved if the modeled ice conditions follow an appropriate floe size distribution and brash ice concentration that is representative of managed ice. The floe ice conditions modeled in the earlier tests more closely resemble natural ice conditions in a marginal ice zone, and hence did not replicate the ice interaction scenarios witnessed in full scale. The application of a methodology for modeling full scale based managed ice conditions as discussed in this paper is a significant step towards reducing conservatism in ice model tests, which begin to observe ice interaction phenomenon and associated loads that more closely resemble those expected in real life.

However, there are still additional factors that are expected to lead to conservative results, such as the influence of the basin walls, the scaling of the mechanical properties of ice, and the behavior of brash ice at model scale. Full scale data for the Stena IceMAX does not yet exist to do a comparison between model scale and full scale loads but will hopefully be available in the future.

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