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STATION KEEPING IN ICE – CHALLENGES AND POSSIBILITIES

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ABSTRACT

Station keeping in ice covered waters must react to forces caused by drifting ice. The reaction forces from a station keeping system can be generated by dynamic positioning in light ice conditions. In more severe ice conditions, only mooring can create large enough forces to counteract the ice forces. An intermediate system is DP assisted mooring where DP controls the heading towards ice drift. The paper describes various station keeping methods and their operational envelopes in terms of ice conditions. Further, methods to estimate the operational envelopes are described. The effect of ice management on the operational envelope is considered. Finally, the future development of methods to estimate the operational envelopes of station keeping systems are described as well as development in station keeping systems.

INTRODUCTION

The hydro carbon exploration and also production activity is shifting towards deeper waters in Arctic areas; and at the same time towards areas of more severe ice conditions. These new operation areas like Kara Sea are bringing a change in the type of platforms that can be used in drilling (and naturally in production). The primary function of a drilling platform is to support all the equipment needed in the drilling operation as well as offer a stable foundation to these equipment. The support function means that certain payload (vertical loading) must be carried as well as a large enough area is offered for everything needed. The stability requirement entails a resistance to horizontal forces caused by the environment; these forces can be caused by wind, current, waves or drifting ice. The largest forces are caused by waves and ice – these forces are different in the sense that the time average of wave loads is zero (apart from a second order drift force) but that of the ice loads is definitely not zero.

The solution for the platform to be used in ice covered waters has so far been almost solelly bottom founded structure - apart from some areas where semisubmersibles at DP (Dynamic Positioning) have been used if ice coverage has been low. The bottom founded structures used have been jacket structures in lighter ice conditions in the Bohai Bay and Cook Inlet or caisson type platforms (or GBS – Gravity Based Structures). The most known caisson is the Moliqpak that have been used in the Beaufort Sea and is at present operating in the Okhotsk Sea. The vertical force (payload) is supported by the sea bottom for the bottom founded structures. The horizontal loads are also transferred to the sea bottom and then the shear forces provide the resistance (with piles / skirts for the jackets or just the soil for caissons).

Operating in deeper water or in more severe ice conditions makes caissons, GBS's or jacket structures either uneconomic or unpractical because of the growing size of the structures – and anyway the mobility of these is not good. The alternative solution, at least for exploratory drilling, is to use floating structures and convey the horizontal loading to sea bottom through mooring or to the sea by using DP. At least two examples of this kind of structures exist: The FPSO at the Terra Nova that is turret moored and the Kulluk, a conical downward breaking moored platform used in the Beaufort Sea. Terra Nova FPSO is in operation year round in relatively mild ice conditions off Newfoundland while Kulluk has been used in quite severe ice conditions with the support of an ice management fleet. Apart from these platforms, a SALM (Single Anchor Leg Mooring) has been used in the Sakhalin operations.

Aim of this paper is to investigate the possibilities to use floating platforms in (deeper) Arctic waters with or without employing an ice management fleet. The elements of a station keeping system for ice covered waters are investigated. Different solutions are sketched with an emphasis on their operational envelope in terms of depth and ice conditions. The paper is qualitative and it reflects the early planning stage for Arctic station keeping operations.

STATION KEEPING IN ICE

The main function of the station keeping is to keep a floating platform within the operational limits in terms of the excursion from the central position. A typical limit for drilling operations or risers is maximum excursion of 5% of the water depth. There are other limits arising from for example the pitch/roll angle of the platform. In very simple terms the selection of the method for station keeping depends on the water depth and the design ice loading. Different alternatives for station keeping are:

- Dynamic Positioning (DP)
- DP with Ice Management (IM)
- Mooring
- Mooring with IM
- Mooring with Heading Control (HC)
- Mooring with IM and HC
- Bottom founded structures.

Heading control in the above list refers to moored ship-shape structures that are kept facing the ice drift by a DP system. Each type of station keeping (DP, mooring or sea bottom support) has its limits as depicted in Fig. 1. The severity of ice conditions set the maximum design loading on the station keeping system, thus the limits for ice conditions are denoted by a symbol for force, F.

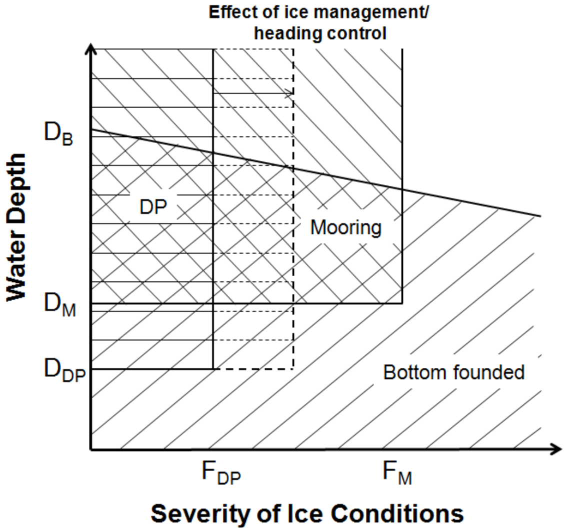

Fig. 1. The design envelope of station keeping systems.

The bottom founded caisson type structures have a maximum water depth where these structures are economically viable, based on the structure size getting excessively large. In open water bottom founded jacket structures or GBS’s are used up to about 400 m depth. The Hibernia GBS, located in 80 m deep water, is the deepest caisson type structure that is made to resist ice forces, the design case being caused by iceberg impact. In milder ice conditions it could be envisaged that other types of bottom founded platforms could be used in deeper water – platforms like jackets or even TLP's or flexible towers might be possible. The practical maximum depth for bottom founded structures in ice covered waters seems to be about 100 m while there is no real upper bound for resistance for horizontal forces.

Mooring systems require some water depth to be practically possible, this minimum depends much on the type of mooring – but a minimum depth of about 50 m is typical. The maximum horizontal force mooring can exert depends also much on the type of mooring. In order to get an idea of the limits, it can be envisaged that the maximum force (within the operational excursion) per one mooring line is of the order of 10 MN, thus the total force from all the mooring lines is of the order of 100 MN. The maximum allowable excursion depends on the water depth; as mentioned it is in normal operation about 5% of the water depth while about 10% can usually be tolerated. This leads to an estimate of the mooring system stiffness; in a depth of 100 m the maximum stiffness of the mooring system is about 20 MN/m.

Dynamic positioning (DP) refers to using propellers (thrusters) to produce the resisting force for the horizontal ice forces. The depth restriction in using DP arises from shallow water effects as well as from the fact that the structures here are floating; thus the minimum depth for DP is somewhere about 20 m i.e. in the range where the bottom founded structures are already competitive. The horizontal force the thrusters can provide depends on the propeller diameter(s) and power(s) allocated. Again, a rough estimate of the maximum force the thrusters can provide is about 0.2 MN/MW – meaning about 10 MN for a power of 50 MW.

The severity of ice conditions gives in principle the maximum loading exerted on the platform. This severity of ice conditions cannot be described by a single parameter; the question of determining the forces from ice conditions will be discussed later. The severity of encountered ice conditions can be decreased by using an Ice Management System (IMS). This system includes observation, forecasting as well as ice breaking tasks with the aim of avoiding hazardous ice features and if avoiding is not possible, decreasing the severity of the ice conditions by breaking the ice into less hazardous ice features by Ice Management Icebreakers (IMIB's). The selection of the performance of ice management system is an economic trade-off with the mooring / DP system capability as suggested in Fig. 2.

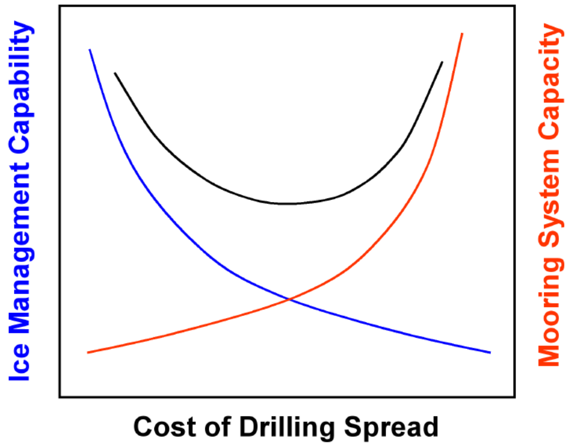

Fig. 2. The qualitative trade-off between ice management capability and mooring system capacity (Hamilton 2011).

ELEMENTS OF AN ICE MANAGEMENT SYSTEM

As the Ice Management System (IMS) is an integral part of any station keeping system in ice, a description of ice management is given before tackling station keeping. The aim of an IMS is to decrease the potential ice loading from the force level that the intact drifting ice might cause to be within the operational envelope of the Floating Platform (FP). As all hazardous ice i.e. ice that causes loading in excess of the station keeping capacity not necessarily hits the FP, ice management attention must be paid only to ice that potentially hits the FP. This means that any Ice Management System must include an observation and forecasting function in order to restrict the amount of ice to be managed. The IMS must have the following functions:

- Detect hazardous ice;

  Ice features that could cause loading and thus excursion beyond the permissible values must be identified as early as possible. Typical hazardous ice includes icebergs, multi-year ice floes or heavily ridged areas.

- Forecast the ice motion;

  Ideally only a very narrow corridor of the ice cover is to be managed. This assumes a perfect forecasting of the ice motion. The uncertainty in modelling ice motion makes the ice management corridor wider and increases the amount of ice to be physically managed.

- Monitor the ice conditions and ice drift;

  Hazardous ice must be monitored in order to direct the Ice Management Fleet. The accuracy of the ice motion forecasts must be followed and deviations from the forecasts act as warning signs. The monitoring also gives the updated ice data for initializing the near range forecasts.

- Anticipate the ice action on the FP;

  Especially if the FP station keeping is based on DP, the DP control system must have some pre-warning about ice loads as the ice loads increase suddenly when there is a contact with ice (zero ice loads when there is no contact).

- Create an Alert-zone;

  If hazardous ice is estimated to be impacting the FP, the disconnecting procedure must be commenced. The extent of the Alert-zone depends on ice drift speed and time required to disconnect, see e.g. Coche et al. (2011);

- Deploy the Ice Management Fleet according to the forecasted ice conditions;

  Directions what ice the IMF should break are obtained from the forecasting function.

- Change the ice conditions within the Ice Drift Corridor so that ice loading on the FP is within the design values;

  It is the function of the IMF to do the physical ice management.

The functions of the Ice Management System can be organized into different tasks as Fig. 3 shows. It is not the purpose of this paper to organize the Ice Management System, suffice it to say that it would be most efficient to collect all the observation and forecasting functions onboard the FP. The ice observation elements of an IMS are shortly described below.

Hazard detection, ice monitoring and forecasting

The requirements for detection of hazardous ice are dependent on the spatial scale. An early warning must come from feature identification analysis of satellite images or other remote sensing means. Once potentially hazardous ice features have been detected (identified), these must be monitored in order to assess the possibility of them hitting the floating platform. Further, at each instant of time, a prediction must be made of the drift pattern in order to determine the trajectory of hazardous ice.

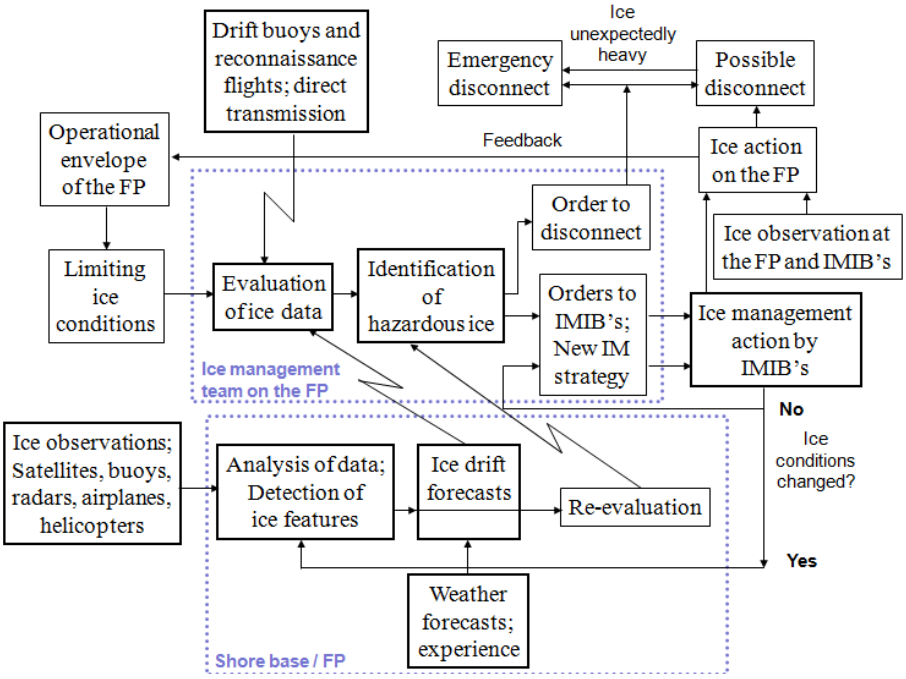

Fig. 3. The elements and logical connections (data flow) in Ice Management System. The 'lightning' arrows refer to data transmission.

Physical ice management action is directed based on the detection of hazardous ice and the drift prediction. Once a hazardous ice feature has been detected, the possible variation in the drift trajectory prediction creates an Ice Drift Corridor, Fig. 4. The width of this corridor is described by the sector opening angle φ and that determines the area where ice must be managed. The better the forecasts (or actually the larger the confidence in forecasts), the smaller the Ice Drift Corridor is. The uncertainty of the drift forecasts has been analyzed by e.g. Blunt et al. (2012). The ice drift corridor can be inverted to create warning zones for the alert of the Ice Management Fleet. Fig. 5 is an example from the Shtokman development. The efficiency of the IMF is dependent much on the width of the Ice Drift Corridor.

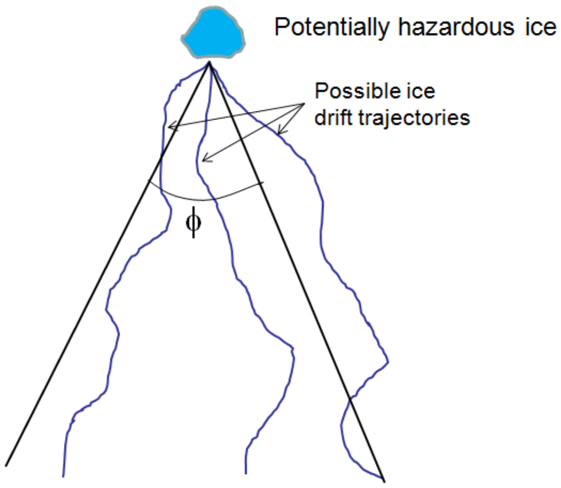

Fig. 4. The definition of the Ice Drift Corridor.

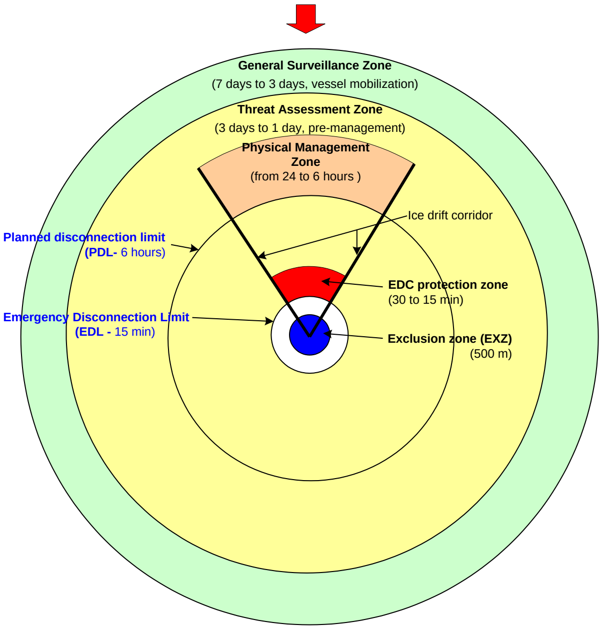

Fig. 5. The ice management zones.

The detection / identification function should identify potential ice action which exceeds the design envelope of the platform. This can happen when the incoming ice is too severe and loading exceeds the design loads. The other possibility is that changes in ice motion cause too high loading – most common case is the case where the drift direction changes abruptly; in worst case reversing. In drift reversal conditions even lighter ice causes loading that can exceed the design values, consequently monitoring all ice is necessary to some extent.

Anticipation of ice action

The aim of the station keeping system is to keep the floating platform within the limit circle determined by the water depth and type of function the FP is fulfilling. The best way to minimise the ice loading is to keep always the bow towards the incoming ice drift. This requires a system to counter the ice loading. As the ice loading is caused by the contact between the structure and ice (and naturally relative motion between these), the load is zero when no contact exists and quickly rises to large values when a contact exists. As the ramp-up time for the thrusters in a DP system may be much longer than the growth rate of the ice force, the DP system might be late in preventing excursion outside of the limit circle. A way to improve the ramp-up rate is to anticipate ice action. This must be done some minutes before ice is impacting the FP. The observation of the ice at close range is a challenge here.

Ice detection and monitoring are major issues in the Ice Management Concept. The directions for the Ice Management Fleet are based on the ice observations and sea ice drift forecast results. The methods for ice observations can be based on the following resources, see e.g. Haugen et al. (2011):

- Ship-based observations;

  The IMIB's make ice observations and report them to the Ice Management Headquarters (IMHQ). This should be the responsibility of the Ice Management Coordinator that is present onboard all IMIB.

- Helicopter and aircraft based observations;

  Aircraft – used occasionally to update the understanding of the large scale ice conditions – and helicopters used more frequently to make ice observations. These observations are reported to IMHQ. Helicopter flights should be twice a day so a dedicated helicopter is required.

- Buoy observations

  Buoys are deployed in sea ice. The buoy monitoring is done at the IMHQ. The knowledge about the motion of ice can be used to tune the short term sea ice forecasts. There should be at least four buoys deployed at any time.

- Radar imagery

  Radar should be deployed on the FLSO and/or ice management icebreakers. The radar images are digitized and the sea ice motion can identified from the digitized images. This requires a special software under development at least in Finland and Canada. The radar images are used as an input (initial conditions) to the short term ice forecasts.

- Satellite images

  Satellite images are downloaded at the IMC. Both radar wave length images, SAR and visual wave length images (e.g. NOAA, MODIS,…). The problem with satellite images is that their availability is not continuous i.e. only one to four images can be obtained per day per area. At least one satellite image per day should be downloaded.

- EM measurements

  Electromagnetic Method is based on the ice conductivity. An average ice thickness can be obtained on a quite large footprint (about 20 m^2) depending on the height of the device. EM is used from helicopters and also in the vicinity of the FP. One airborne unit should be available and at least one at the FP.

- Upward looking sonar

  A sonar located at the sea bottom will give the draught of ice features passing the sonar. Sonars may be located in the vicinity of the FP. The problem with sonars is that they are at the sea bottom and thus their signal is valid only occasionally when the sonar is closer to the FP. The upward looking sonar system should be integrated with the buoy observations network and connected in real-time to the FP.

- Laser profilometer

  The laser profilometer measures the height of the ice surface elevation making it possible to estimate the ice thickness. At least one laser should be used but the laser deployment includes the same problem as the sonars – if the ice is drifting from a different direction than where the laser is used, no useful information may be obtained.

The ice anticipation provides a challenge for all these methods. The observation in order to serve anticipation must be fixed on the FP – thus a CCTV system supported by radar image processing and real-time buoy observations is the most obvious system. This does not, provide any thickness information and thus an interpretation function must be provided.

Deployment of Ice Management Fleet

Some different ice management strategies have been developed, see Hamilton et al. (2011), Fig. 6. All these assume that the Ice Management Fleet is deployed up-stream w.r.t. the platform. This is relatively simple in steady and slow drift direction but gets more challenging when the drift direction changes drastically or the ice is more severe. Simulation is the only way to study the effect of ice drift reversals on the deployment of the Ice Management Fleet. Hamilton et al. (2011) show simulation results and the icebreakers seem to manage to stay upstream from the FP. The deployment of the IMF was investigated in a simulation tool developed by el-Bakkay (2012). The simulation showed that if the IMIB's follow their selected method of ice management blindly, the FP is likely to meet occasionally some un-managed ice. An example of the simulation is shown in Fig. 7. Much development is required to develop the most efficient strategy for ice management in quickly varying ice drift patterns.

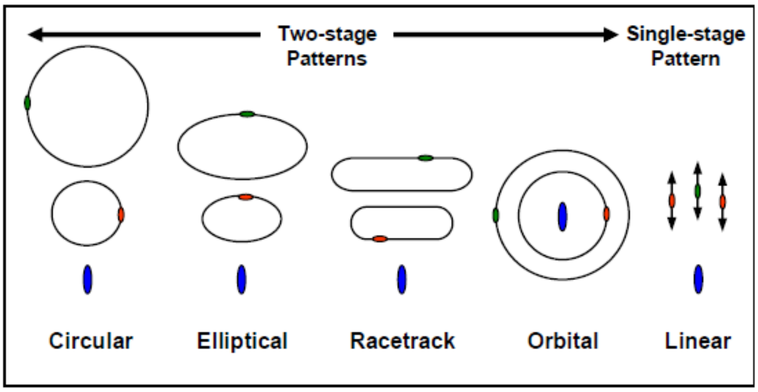

Fig. 6. Different ice management patterns that can be used in front of the FP, Hamilton et al. (2011)

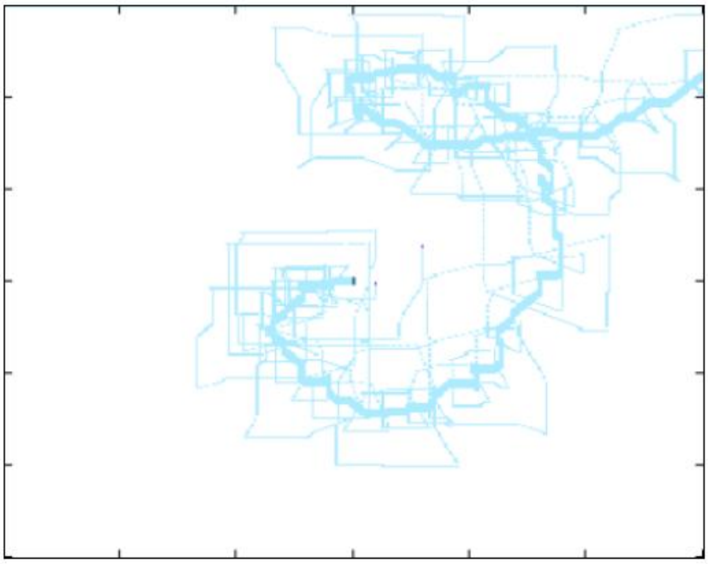

Fig. 7. Simulation of ice management using two IMIB's. The thick line is the platform and narrow lines are icebreaker tracks. The drift pattern is an observed one from northern Barents Sea (El-Bakkay 2012).

ANALYSIS OF THE EFFECT OF THE ICE MANAGEMENT

The organization of IMS the way it is presented here includes a tacit assumption that the ice loading arising from 100% ice coverage can be decreased by physical ice management. Large ice features like icebergs drift driven by forces caused by wind, current and surrounding ice cover. Thus when a large ice feature collides with the FP, the contact load is initially due to inertial effects (ice feature slowing down and eventually stopping). After the initial phase the loading is caused by the driving forces – especially by the surrounding ice cover pushing the ice feature further. In terms of the type of force (see e.g. Palmer & Croasdale 2013, p. 109) it can be stated that first the contact force is based on Limit Momentum and then later on Limit Force. The Limit Stress force i.e. the force determined by breaking ice at the contact follows initially the force due to Limit Momentum but after the momentum is consumed, the contact force is the smaller one of the forces due to Limit Stress and Limit Force, the situation is depicted schematically in Fig. 8.

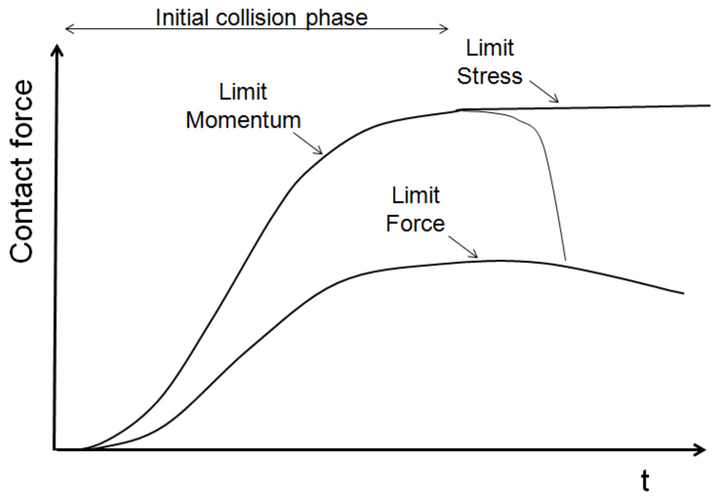

Fig. 8. The contact forces during a collision with a large ice feature.

It is clear that the size (and naturally drift speed) of the ice feature influences the Limit Momentum force. The Limit Stress force is influenced by the platform / ice feature dimensions as well as the ice failure mechanism. The ice failure mechanism usually ultimately develops into pile-up/down loading (or perhaps ride-up/down loading) through a sequence of crushing, bending sequence, see Riska et al. (1996). The final contact force depends on which one of the forces from Limit Stress and Limit Force is smaller (or the large ice feature breaks to allow another collision).

The question relevant for ice management is if there is a lower end of distinct ice feature size below which the Limit Momentum forces are small enough so that the largest force is determined by the forces from Limit Stress/Limit Force. It is a usual assumption that this lower limit is a floe diameter of about 25 m, see e.g. Keinonen et al. (2000) or Vachon et al. (2012). Thus, if the ice features are broken to floes smaller than 25 m in diameter, then the Limit Stress / Limit Force forces dominate. When the floe size is small and the ice coverage is large, the ridging, pile-up or pile-down process occurs at vertical sides; then the forces from these processes give the Limit Stress. Some estimates of these forces are given in Table 1.

Table 1 Ridging forces from different models and field experiments. Ice thickness is marked with *t*, and *h* is the ridge height (Tuhkuri et al. 1999).

Pile up against an obstacle:			[kN/m]
Parmerter and Coon (1973)	Model	h_i=1m	10
Kovacs and Sodhi (1980)	Model	h_i =1m	10…350
Hopkins (1998)	DEM	h_i =1m	300
Croasdale et al. (1992)	Field data	h_i =1m	40…300
Croasdale et al. (1992)	Molikpaq	h_i =1m	85…550
Timco and Sayed	Lab. Data	h_i =1m	150…500
Deformation of a rubble pile:			
Sayed and Frederking (1986)	Model	H=15m	150…200
Two ice sheets pushed together:			
Tuhkuri and Lensu (1998)	Lab. Data	h_i =1m	70
Hopkins and Tuhkuri (1998)	DEM	h_i =1m	35
Reference value:			
Buckling	Model	h_i =1m	950

The above discussion did not mention the effect of ice concentration. As discussed below, the ice concentration has a large effect on the forces acting on the FP. The effect is twofold. If the loading from the Limit Momentum dominates, then the response of the platform is also dominated by dynamic excursion as the momentum of the ice is absorbed by the energy accumulated into the mooring system. If the FP is in DP, this energy is not available and just the forces (thrusters thrust and contact force) must balance.

The effect of physical Ice Management carried out by Ice Management fleet is to break ice into smaller floes and to break ridges into ice floes. The ice coverage is more difficult to influence; if the original coverage is 100%, it is likely to be close to that even after ice management action. The loads from this kind of floe field may be large due to the bridging action between ice floes. This mechanism is suggested in Fig. 9. When a floe field is compacted (or moving against a stationary structure), the force is transferred through the contacts between floes forming a network of contacts. This phenomenon of higher forces that is concentrated in a tree like pattern has been noticed also in numerical calculations, see Fig. 10. This 'force tree' is something that should be prevented of forming by the Ice Management Fleet.

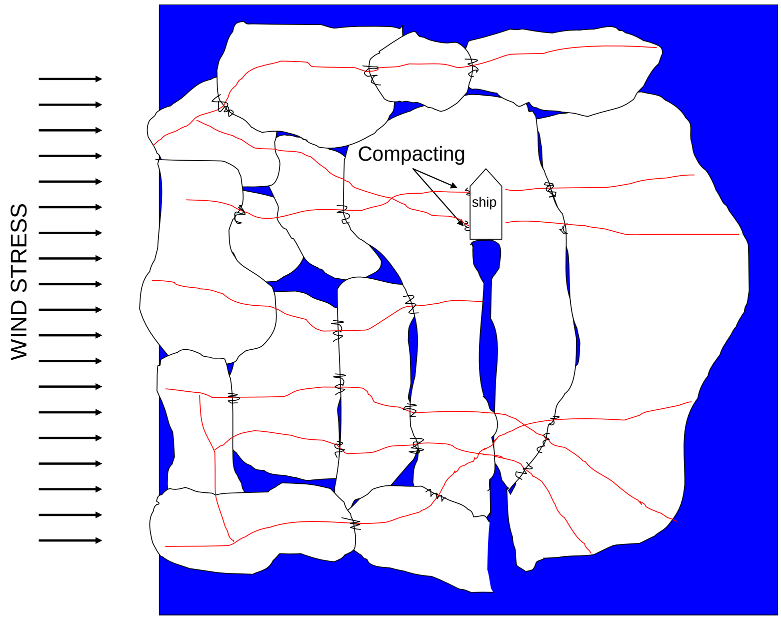

Fig. 9. Ship in compressive pack ice field. The red lines shown in the sketch are areas of higher stresses forming the 'force tree'. When the force tree encounters the ship, ice will start compacting against the hull (Leisti & Riska 2011).

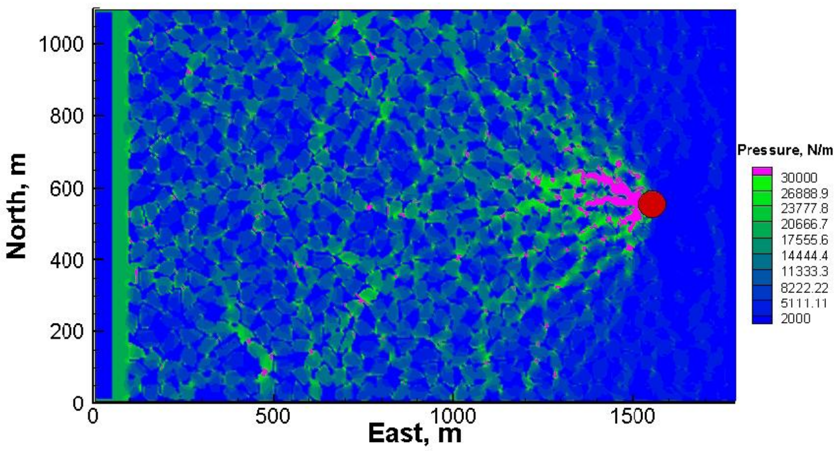

Fig. 10. Calculation of the ice pressures in 1.2 m thick floe field acting on the Kulluk platform (Sayed et al. 2012).

The ice loading from managed ice has been studied in several projects, see e.g. Allan et al. (2009), Croasdale et al. (2009) or Eik (2011). The difference between managed ice and intact ice cover is that managed ice consists of smaller size floes and presumably it has a lower concentration. The Croasdale et al. (2009) approach is to consider managed ice to be a continuum which then can be analyzed as rubble ice using cohesion and internal friction angles. Thus the effect of ice management is to change the ice type.

Eik (2011) analyzed ice forces by using the equivalent ice thickness concept. The equivalent ice thickness is a level ice thickness that corresponds to the natural inhomogeneous ice cover containing ice floes, having a concentration up to 100%, including ice ridges etc. The ice concentration influences the equivalent ice thickness in linear fashion (Eik 2011, eq. 7). Other possibilities have also been suggested. Allan et al. (2009) show how that the concentration C influences the loads with a proportionality factor of $C^{4.2}$. Other possibilities have also been suggested in other (proprietary) projects; it has been suggested that the equivalent ice thickness is proportional to C^3. No physical foundation for these estimates have been presented, they represent at best fits to scant full scale and model scale evidence.

The effect of the floe size is also included in the description of the equivalent ice thickness (Eik 2011). It is suggested that the effect of the floe size is logarithmic on the equivalent ice thickness. Thus if the floe size is 25 m, this then corresponds to 63 cm thick equivalent ice if the original ice thickness was 1m. Again, no physical justifications for these estimates are given. These estimates are necessitated by the need to evaluate ice management and for this purpose all different factors pertaining to ice conditions must be tackled.

The difficulty in using the equivalent ice thickness concept is that it averages; smears, off the effect of the occasional large ice features. If the effect of ice would be linear with thickness, then the equivalent ice thickness would work well, but this is unfortunately not the case. A study on the use of the equivalent ice thickness was carried out in the EU funded IRIS project. The general outcome was that if the equivalent ice thickness is defined as the average ice thickness of all ice, it gives better results for ship transit calculations than for ice load estimates. Even for ship transit calculations the equivalent ice thickness gives higher speeds than using the actual variability in the ridged ice cover. An example of the calculations is shown in Fig. 11, the average speed in uniform ice cover is about 6 knots whereas in a varying ice (with the same average values) it is about 5 knots.

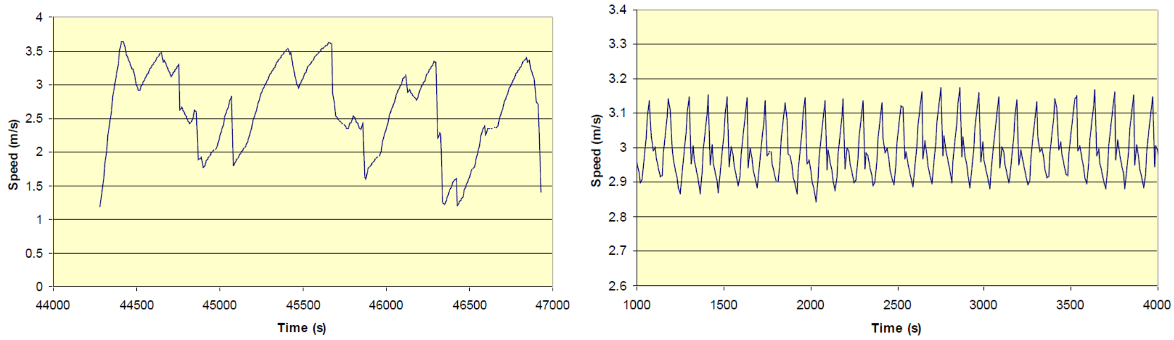

Fig. 11. Calculated ship speed in uniform ice conditions with level ice thickness 0.4m, average ridge thickness 3.2m and ridge average density 3 ridges per km (right) and similar calculation where ridges are assumed to be statistically distributed (left) (Hannikainen 2004).

EXAMPLES OF STATION KEEPING IN ICE

The experiences of station keeping, especially at DP in ice are very scarce. The most famous case of DP in ice is from an Arctic coring expedition where two icebreakers did ice management for the drill ship (Vidar Viking) in the Arctic during summer ice conditions, see e.g. Keinonen et al. (2006). The experience from this operation was that station keeping with DP is difficult especially in varying ice drift conditions. It was also observed that the DP control system did not operate well and manual operation was more reliable. Another known example of station keeping in ice is from a moored platform, the Kulluk (see e.g. Wright 2009). Kulluk needed also ice management even if she was moored. The difference between the Kulluk and Vidar Viking drilling was that Vidar Viking was taking relatively shallow samples from the sea bed whereas Kulluk did drill for hydrocarbons.

Several model testing campaigns have been carried out for station keeping in ice. Many of these have focused on the extreme cases where the loads are very high. One such case is the ice drift reversal – where the ice drift changes direction about 180°. This often happens when the ice drift is caused by tidal currents but also wind direction changes could cause drift reversals. An example of this kind of model test is shown in Fig. 12. The high loading encountered should be noted. Using these loads and the ice thickness, an estimate of the limiting thickness of level ice where DP still could work gives a limit ice thickness of 1m.

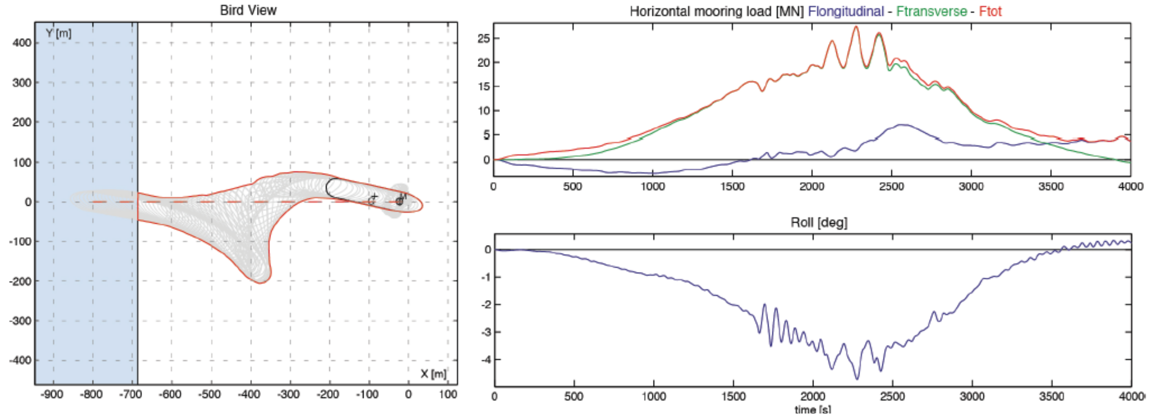

Fig. 12. Reversing ice drift test for a moored ship in 1.9 m thick ice, Bonnemaire et al. 2011.

Another model testing campaign investigated DP in broken ice, especially the control system for the thrusters was investigated (Jenssen et al. 2012). A result from the tests is shown in Fig. 13 where the ship displacement in broken ice cover of thickness 0.75m is shown. The success of keeping within the control circle supports the above estimate of the limiting thickness for DP operations; even if here the ice cover was broken. This testing campaign did not report any tests in extreme conditions like strongly varying ice drift; the results can be, however, considered as promising.

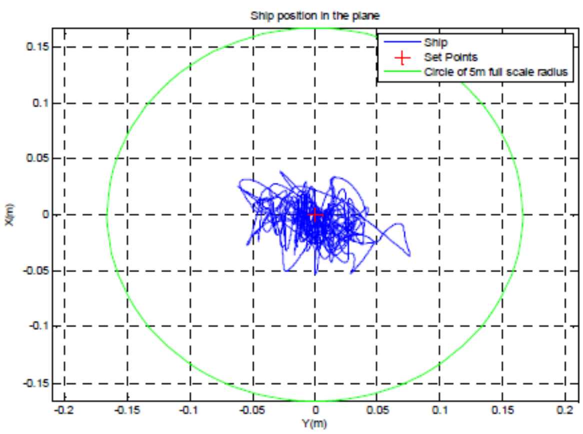

Fig. 13. The ship displacement under the action of a broken ice sheet of thickness 75cm (Jenssen et al. 2012).

Several projects of numerical simulation of station keeping have been carried out. Here only two cases of some special interest are mentioned. One is a numerical study of a ship in DP in level ice (Sørbø 2008). The study included an ice observer that gave information to the DP control system about pending ice impacts (ice anticipation). The DP control system is shown in Fig. 14 and the effect of the ice observer in station keeping is shown in Fig. 15. It is clear that the maximum excursion is almost halved by using an ice observer. In the thesis it was assumed that ice observation is visual.

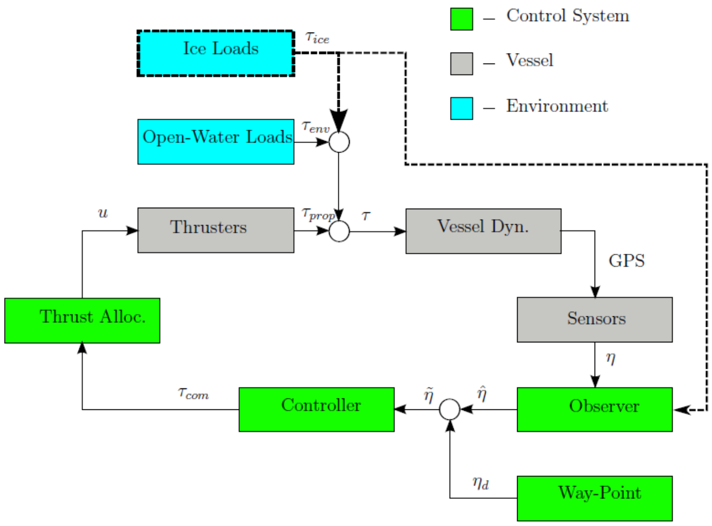

Fig. 14. A schematic presentation of the DP system (Sørbø 2008, fig. 4.1).

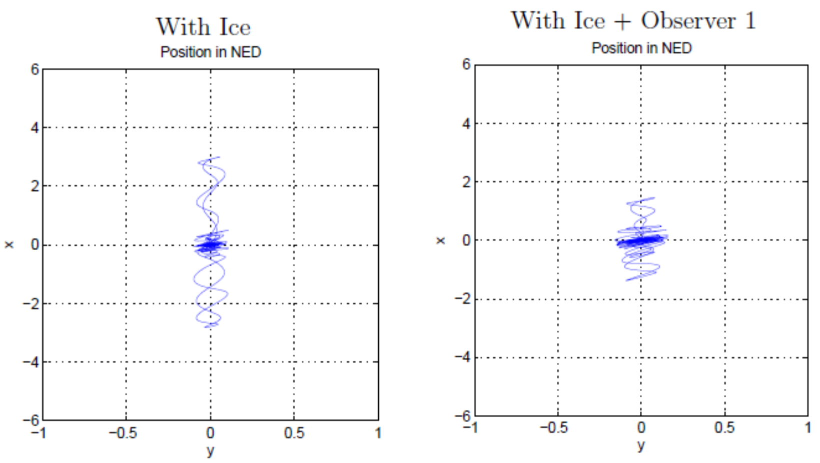

Fig. 15. The position plot of the ship in DP without and with an ice observer that anticipates the ice action (Soerboe 2008, Fig. 4.6).

The other example of numerical calculations is provided by a doctoral dissertation carried out at NTNU in Trondheim, Norway (Zhou 2012). In this work a model to calculate the ice loading from level ice was developed. The ice interaction model included the pile-up/down process at the vessel parallel midbody when the ice drift was at an angle against the ship side. The ship was assumed to be moored but the heading could be controlled by DP. The resulting capability plot is shown in Fig. 16. It is clear that the capability increases when using the heading control turning the ship bow towards ice drift. The relatively low capability in cases of ice drift starting at 90^{o} degrees angle should be noted; the limiting ice thickness is only 50cm even if the ship is moored. The limit is caused by the control circle, 5m in radius. The total thrust of the thrusters used in calculations was assumed to be 2.4 MN. The studies carried out about station keeping in ice have seldom considered ice ridges even if ridges, especially with a consolidated layer, cause large loading. It would be interesting to see if there is a possibility to reduce loading from large ridges by IM action, as the amount of ice forming the ridges would not decrease by IM, but is only spread out more evenly.

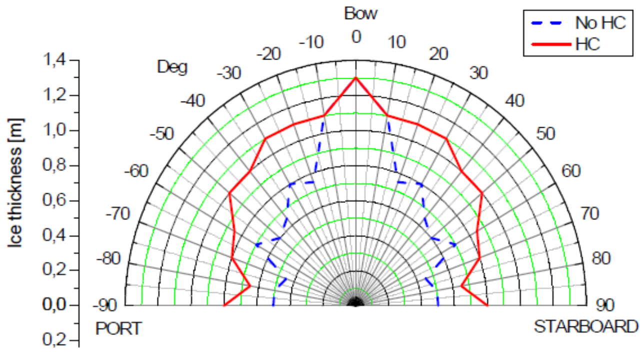

Fig. 16. Capacity plot for a moored tanker (MT Uikku) with (HC) and without (No HC) heading control (Zhou et al. 2012).

CONCLUSION

The limiting ice thickness beyond which a DP system cannot perform depends on the ship particulars, propulsion system and also on the control system. The cases described in this paper seem to suggest that this limit ice thickness is, even in managed ice, somewhere in range 50 – 100cm. If this is correct then year round operation at DP is hardly possible at most of the Arctic sea areas. This estimate is based on scarce data and no systematic assessments of the limits for DP have been carried out.

A requirement for the station keeping system is that it keeps the vessel always within the control circle. If hazardous ice is detected and it is estimated to cause too large excursion/load (this naturally is based also on a forecast that this ice will interact with the ship at station), a disconnect must take place. Thus the reliability of the drift forecasts, load estimates and ice management actions must be very high as the decision to disconnect / not disconnect is based on these. The state-of-the-art of these drift forecasts cannot be considered mature enough to allow DP operations in any ice conditions where there is a risk to encounter thicker ice.

The alternative for DP is to use mooring with possibly a heading control system. Mooring can be considered when operating in the arctic areas where the open water period is short and the depth is beyond the range of bottom founded gravity structures (or caissons). Even mooring cannot be considered operative in the most harsh ice conditions. In general the questions about the station keeping concern risk management. The DP as well as mooring may work in average ice conditions – mooring naturally in more severe conditions – but the risk of encountering ice that cause too large loads or excursions is the question. If disconnection is the only way to lower the risk, the downtime probably becomes too long. Some joint efforts to tackle these questions in order to develop reliable methods to estimate the safe operational envelope of different station keeping methods are welcome.

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