Project Report

Baffinland Iron Mines Corporation
Mary River Project

Ice Management at Steensby Inlet

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Safety • Quality • Sustainability • Innovation

1. Introduction

Port facilities for the proposed Baffinland Iron Mines (BIM) Mary River project on northern Baffin Island are to be located at Steensby Inlet, which is an approximately 15 km wide by 40 km long water body located to the north of Foxe Basin and about 140 km south of the mine site, at approximately 65° N. latitude (Figure 1-1). The inlet is ice covered with first year landfast ice for approximately nine months of the year, freeze-up occurring in mid- to late- October and clearing not being complete until late July. No program of ice thickness measurements is yet available for the inlet; however, limited measurements during the geotechnical investigations program of 2011 and long term measurements at Hall Beach to the southwest and Pond Inlet to the northeast suggest that end-of-winter thicknesses could be greater than 2 m. According to reports prepared for the Project Environmental Impact Statement, ice in the inlet is normally smooth with little evidence of dynamic effects during freeze-up that might lead to ridging and rafting of the ice cover.

The project will be a year-round production and shipping operation with planned vessel arrivals every few days (the actual expected shipping frequency by month is discussed in Section 3). Such a continuous operation this far north will be unprecedented in Canada, all previous such undertakings being seasonal only, examples being the mining operations at Nanisivik (northern Baffin Island) and at Little Cornwallis Island to the west. The current most northerly year-round operations in Canada are the Raglan Mines, which ships ore from Deception Bay in northern Quebec, and the Voisey's Bay Mine in northern Labrador, both of which, however, operate at reduced shipping frequency during winter.

The operation that could be considered most comparable in terms of year-round operation this far north is the port of Dudinka which is located on the Yenisei River in northern Russia at approximately 69° N latitude and approximately 170 nm from the Kara Sea. The principal user of this port is Norilsk Nickel which uses a dedicated fleet of five identical icebreaking ore carriers which are reported to be capable of independent operation. The differences in this operation and the Mary River project pertain to less severe weather and lower ice thicknesses at the Dudinka port site, fewer vessel arrivals, and considerably smaller ore carriers. The Dudinka vessels would, however, have to negotiate generally comparable ice conditions offshore in the Kara Sea. In the port, both ice management support vessels and government icebreakers are used as required to assist in accessing the port and in berthing and de-berthing.

Thus, in terms of the ice conditions, vessel traffic and type of ore carrier, the Mary River project presents new challenges for ice management in the port; the experiences elsewhere can, however, be used and adapted to determine the most appropriate ice management approach for this project.

In addressing the ice management issues, Hatch reviewed previous approaches for arctic operations in Canada and elsewhere and, together with BIM, met with agencies in Finland experienced in year-round Baltic operations. From these early meetings, a program was laid out for physical model tests to advance the knowledge gained in previous investigations undertaken by BIM, for an ice management workshop involving marine and ice engineering experts from Canada and the Baltic, and for the overall approach to be taken in the work. The discussions arising from these meetings, which essentially constituted the scope of the ice management studies, are reflected in Appendix A.

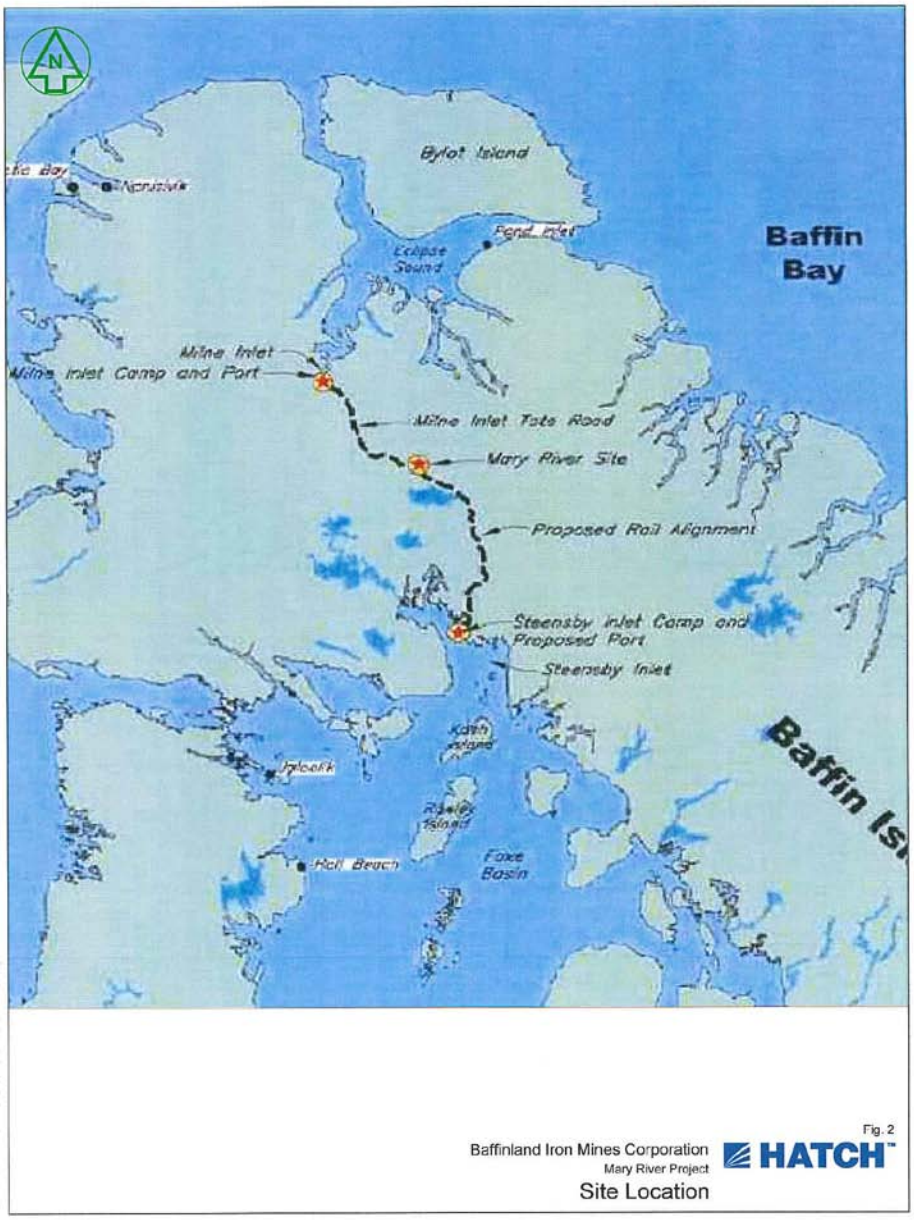

Figure 1-1: Project Location

2. Potential Ice Management Approaches

2.1 Demonstrated Concepts

A brief discussion follows on concepts which have been demonstrated, albeit mostly in more temperate ice climates, and those which have no precedents but which may be worthy of further study.

2.1.1 Ice Management Vessels

It appears that, universally, harbours that are operated in ice conditions, whether year-round or seasonal, engage support vessels to assist in managing the ice in the harbour to facilitate berthing of cargo vessels. These assist vessels may be icebreaking or only ice strengthened depending on the particular ice conditions and operational requirements. In the port of Dudinka, for example, there are a reported five support vessels that could be employed to assist the less capable cargo vessels, the Norilsk icebreaking ore carriers reportedly requiring little or no assistance to reach the dock, but may use assistance in the actual berthing. The five dedicated vessels comprise two icebreakers with power plants of 6.9 MW and 11.2 MW and three tugs ("tow-pushers"), the most powerful of which is about 2 MW. Cargo vessels are typically guided to the port through the river ice by larger icebreakers which apparently steam through the berthing area to facilitate docking by the cargo vessel. The number of cargo vessel arrivals is three to four per month in mid-winter. It is not clear whether the dedicated port vessels are active in breaking ice in the port more or less continuously or if they operate only with the arrival of cargo vessels.

In the Baltic, icebreakers are used when required to assist cargo vessels in the approaches to the harbour and may break up the ice in the harbour also, although dedicated harbour vessels are typically used for this. Bubblers and warm water discharge are also used in some harbours in conjunction with harbour vessels.

In the St. Lawrence River in Canada, harbour vessels clear the berthing area in the case of a continuous or closed face dock. In the case of separated sheet pile cells, the vessels break up the ice behind the dock and then the docking cargo vessel can push the ice between the cells. In previous studies undertaken by BIM, two ice management support vessels were suggested for the Mary River Project. It appears that the larger of these would be used to assist the ore carriers en route to the port in the manner of Baltic and Russian operations while a smaller vessel would be dedicated to assisting the ore carriers in berthing and deberthing by managing the ice in the port (Aker Arctic, 2006).

Further discussion on configuration of ice management vessels and typical powering requirements is included in later sections of this report.

2.1.2 Bubbler Systems

A bubbler is a straightforward, inexpensive arrangement of surface mounted air compressor and perforated pipe laid at depth in a water body or on the bottom so that air pumped through it entrains warm water at depth which is then conveyed to the surface to inhibit ice formation. Bubblers are typically laid in freshwater bodies because of the warmer bottom layer created by sinking denser surface water that has reached 4.4°C upon cooling, this being the temperature of maximum density for fresh water. Installations in harbours and marinas throughout northern countries are common. Bubblers are also used in the brackish water of harbours in the northern Baltic Sea where the salinity is commonly less than 2 ppt and sometimes in conjunction with thermal effluents from industrial plants (Huachen & Eranti, 2007), as discussed further below.

Demonstrations of successful bubbler installations in normal sea water with salinity of 35 ppt are rare because of the lack of a significant temperature gradient which would allow for the movement of warmer water at depth to the surface. Unlike fresh water, the temperature of maximum density at this level of salinity is essentially equal to the freezing temperature of the water. The lack of a thermal reserve is particularly the case in shallow arctic waters where the water column in winter tends to be isothermal to a depth of about 100 m. In deeper water, geothermal heating leads to small temperature differences.

Nevertheless, a demonstration by the US military at Thule in Greenland in 1958 / 1959, as reported by Senior (1961), suggests that a bubbler could be effective in delaying and inhibiting the formation of ice in a harbour during the early part of the ice season by using the thermal reserve remaining after the summer's heating of the harbour water. In the reported case, complete ice coverage of the area in front of the dock did not occur until late December although freeze-up in general started in early October. Since it was determined, through oceanographic measurements, that the heat reserve was expended after about two weeks, the author suggests that surface currents induced by the bubbler also contributed to the inhibition of ice formation. This suggests that some benefit may be derived from a bubbler installation in arctic harbours early in the winter season.

2.1.3 Thermal Discharges

Many Finnish harbours take advantage of thermal effluents in dealing with ice problems. In some cases thermal energy is concentrated to the berth side or turning area by the help of surface current developers or air bubbling (Pan and Eranti, 2009). In some harbours, the available amount of waste heat is typically large (of the order of 100 MW), the efficiency ratio (amount of thermal power consumed for ice melting at the target area as a fraction of thermal input) is usually low when the discharge is not controlled, and as a result most of the thermal energy available for melting ice in the harbour basin is lost.

The paper by Pan and Eranti describes a more thermally efficient arrangement. The Port of Helsinki recently constructed a new harbour for Vuosaari, an eastern suburb of Helsinki. Accelerated growth of brash ice was a problem that the port operator had to deal with especially in the busy main harbour basin. The traffic pushes brash ice to the back of the harbour basin, and large accumulations of brash ice and the consolidated ice collar that tends to attach to the pier wall made access to the berth difficult and time consuming even with the help of a harbour icebreaker. At this location only 11 MW to 16 MW of external thermal energy was available for ice melting. This energy comes from a local power plant in the form of water slightly above freezing point.

Historically the average freezing index in Vuosaari is about 600°C-days. The available external thermal energy was not sufficient to keep the harbour basin open through cold winter periods. However, it had the potential to keep the brash ice layer thin and loose especially at the berth line. No significant difficulties in harbour operations were expected in such conditions even in the harshest winter conditions.

The warm water is discharged from the centre of the harbour basin towards its end. The water entrained in the air bubbles in the bubbler system combine with the warm water discharge to form an upward flow melting the ice above and around the discharge. Approximately 400,000 m^3 of brash ice are melted in the main harbour basin in an extreme winter. The arrangement provides a calculated efficiency of more than 70%.

For the Arctic Pilot Project (a LNG plant proposed for Melville Island in the Canadian High Arctic in the late 1970's) it was concluded that the use of waste heat in the form of a thermal discharge from the liquefaction process was the most effective way to inhibit ice build-up near the terminal (Cammaert et al, 1979). However the project was not realized and the concept was not taken further.

2.2 Unprecedented Concepts

While the criterion for this project is that known ice management approaches would guide the thinking, some consideration of unproven techniques might be considered appropriate in the event that future needs change or questions arise about the applicability of such techniques. Two such concepts, which derive in part from previous studies by Hatch, are described here.

2.2.1 Heated Enclosure

In this concept, a dock with open spans and continuous deck is used to permit ice to be moved underneath the dock and to an extended enclosed area behind if the dock is not wide enough. The area would be large enough to accommodate the ice from a single berthing operation; this ice would then be melted during the period between vessel arrivals. The enclosed area would have to be insulated and closed off from the berthing area during the melting process. This means that the spans between the dock support members would have to be closed during this period; some type of hinged or gate structure or submersible pontoon would be required for this. Since there is no waste heat available, a dedicated warm air furnace fired by diesel fuel would be used to blow air into the enclosure and to maintain the required temperature. The heating requirement would be determined by the heat needed to melt the ice plus that lost to the ambient air and the water. For a vessel arrival interval of three days in the coldest weather, for example, the heating rate required to melt the ice (without any losses) would be 2.6 MW and the fuel consumption over the 3-day period would be about 18,000 L.

It is possible that the ore carrier ballast water could be a source of the required heat if it could be pumped to, and stored in, insulated surface tanks at the port site. Thus, prior to the build-up of significant ice in the berthing area, ballast water would be discharged to tanks rather than directly to the ocean. The total volume of water from a single vessel at 150,000 m^3 could represent a significant heat source. For example, if it were at a temperature of 4°C and were discharged over a 36-h period, the heat transfer rate would be about 30 MW, which suggests that, if losses were controlled, the amount of heat could be sufficient to melt the ice between ship arrivals. It may be possible to increase the temperature of the ballast water through an appropriate use of vessel engine heat prior to discharge and thus increase the potential for success. Further assessment of such a concept would involve the optimization of ballast water temperature, water quantities (since more than one vessel's ballast could be stored), tank insulation parameters, and the potential need for supplementary heating of the stored water.

2.2.2 *Pontoon in the Berthing Area*

In this concept, a submersible steel pontoon extends over the full length and width of the berthing area and prevents ice from forming in the area. The pontoon would be ballasted to the seabed immediately prior to vessel arrival. Some dredging might be required depending on the water depth, vessel draft and depth of the pontoon. The pontoon would be constructed in the south and towed to the site. The pontoon would also minimize or prevent the growth of the ice "bustle" on the dock members or face since it would about the dock during the interval between vessel arrivals. This concept could be used with a continuous face dock or one with discrete members.

2.2.3 *Mechanical Ice Removal*

The paper by Pan and Eranti gives a brief reference to the removal of ice at a dock face by excavation equipment, but to our knowledge this has not been attempted at a large scale. At Steensby Inlet brash ice could be removed by excavation or dredging equipment, and then trucked away or crushed and transported by pipeline. A variation on this concept was proposed in previous studies for BIM.

3. Ice Growth in the Port

While the normal undisturbed ice thickness in the Steensby port by end of the winter is greater than 2 m, it is well known that if the ice is periodically broken by a vessel passage, the growth will be accelerated because of the repeated exposure of open water to the atmosphere. This phenomenon has been studied for many years in North America and Europe, and analytical models predicting such growth as a function of vessel traffic and air temperature have been published.

The most recent published discussion is by Nortala-Hoikkanen at the 1999 POAC conference in Espoo, Finland. In her paper, Nortala-Hoikkanen presents ice thickness measurements over several winters in the 1990's at five different port approaches / channels in the Baltic, and compares these measurements with predictions from two analytical models (Eranti and Sandkvist). She states that for channels that could not be changed during the winter (in some locations, more than one channel could be used), both models gave a reasonable estimate of the end-of-winter ice thickness in the track, although there are some ambiguities in her presentation. Nevertheless, it does appear that, based on Baltic Sea observations, when considering the number of vessel transits anticipated in the current project, the ratio of brash ice thickness in the main part of the vessel track to the normal ice thickness is approximately three while the ratio for the track edge ridges would be higher. Similar results were obtained in model tests by Ettema & Huang (1990) as cited by Nortala-Hoikkanen. They reported that "intense" vessel transitting resulted in brash ice thickness of two to three times the surrounding level ice thickness while the edge ridge thickness was three to four times as thick as the level ice thickness. From these reports, it appears that the brash ice at the end of April at Steensby would be in excess of 6 m for 60 vessel arrivals over the winter period. More frequent arrivals would result in a greater end-of-winter ice thickness without any ice management in the harbour.

Additional analytical modeling work was done by the study team on the current project using the Sandkvist (1981) model, information on planned ore carrier arrivals, and freezing degree-day records for Hall Beach. Three traffic frequencies, based on schedules provided by the owner and as shown in Table 3-1, were used in the modeling. The first (Scenario T76) is based on total arrivals of 76 over the period from November through May, the second (T100) on 100 arrivals and the third (T66) on 166 arrivals over the same period. A sample spreadsheet of the analysis for the second scenario is attached as Appendix B.

The results of the simulations are shown in Figure 3-1, Figure 3-2 and Figure 3-3. The blue line represents the growth of level, undisturbed ice, calculated to be 2.2 m at the end of the winter. The brown line is the growth of brash ice for the given number of transits. For Scenario T76 the total thickness of brash ice is 7.3 m, for Scenario T100, it is 8.3 m, and for Scenario T166, it is 10.5 m. The model was also run for the case of 60 arrivals for comparison with the published results for Baltic traffic referred to above. In this case, the end-of-winter brash ice thickness was calculated to be 6.4 m which is in good agreement with the extrapolation from the published work.

A plot of end-of-winter ice brash thickness as a function of vessel arrivals is shown in Figure 3-4.

Table 3-1: Vessel Schedules for Brash Ice Modelling

Scenario		T76	T100	T166
	Mean monthly temp, °C	Scenario details	Scenario details	Scenario details
No. dedicated vessels		6	8	13
Total ore shipments		18Mt per year	18Mt per year	30Mt per year
Ships (dwt)		3 Cape size 190kt 3 Cape size 155kt	4 Cape size 190kt 4 Cape size 155kt	7 Cape size 190kT 6 Cape size 155kt
Vessel Arrival Interval				
Jan	-31,8	2,7	2,0	1,2
Feb	-33,2	3,4	2,6	1,6
Mar	-29,2	3,5	2,7	1,6
Apr	-20,4	6,0	4,5	2,8
May	-9,0	2,8	2,1	1,3
Nov	-20,2	1,8	1,4	0,8
Dec	-27,5	2,1	1,6	1,0
No.of trips		**76**	**100**	**166**
Comments		25% market vessels summer only	no market vessels	no market vessels

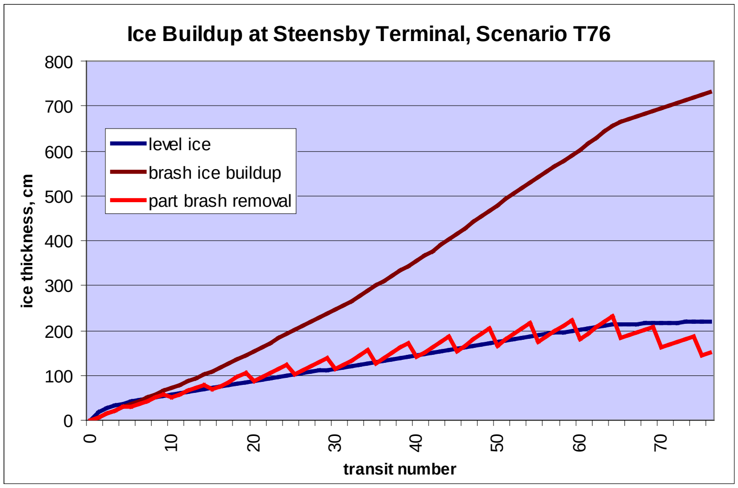

Figure 3-1: Results of Modelling for Shipping Schedule (T76).

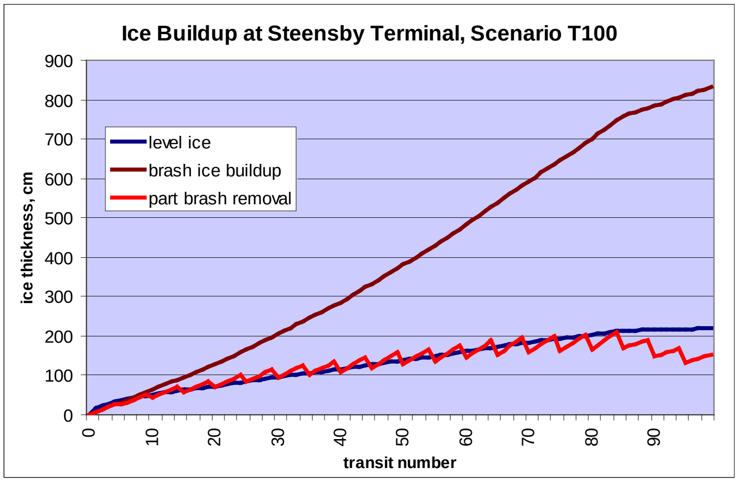

Figure 3-2: Results of Modelling for Shipping Schedule (T100)

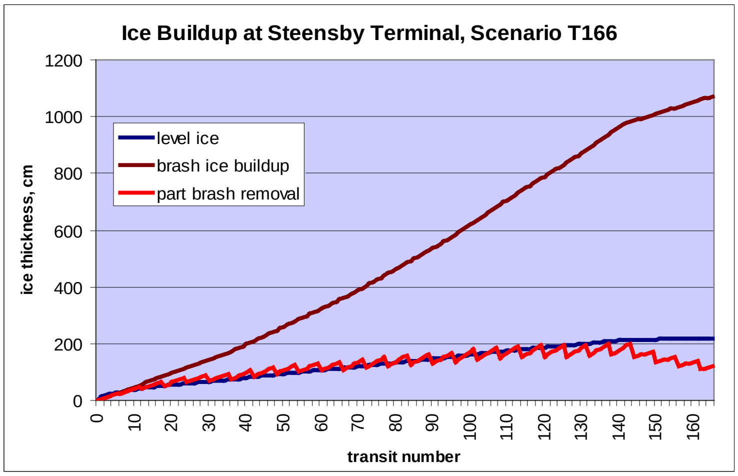

Figure 3-3: Results of Modelling for Shipping Schedule (T166).

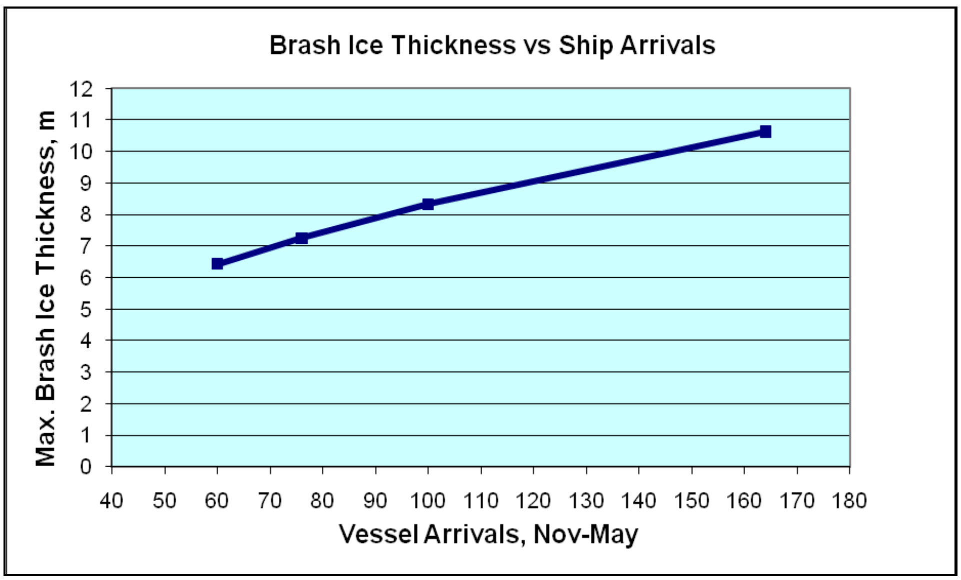

Figure 3-4: Brash Ice Thickness as a Function of Vessel Arrivals for Steensby Inlet

In the three transit scenarios, the ice management model includes the possibility of removing a certain volume of brash ice on a regular schedule. Removal would be effected by using the propeller wash from the ore carrier and ice management vessel (IMV) to transport the ice along a broken track remote from the dock. Several scenarios have been tested. The red zigzag lines in the figures indicate 25% ice removal every five transits. This would result in an end-of-winter brash ice thickness in both scenarios of about 2 m which would facilitate docking operations.

Photos from the modeling tests, Appendix C for instance shows the effect of the azimuth thruster drives of the model ore carrier, both of which are angled slightly away from the centerline of the track for this particular test which results in the clearing away of almost all of the ice in the track. This is not a wholly desirable result, however, since the formation of new ice in the track will be rapid. Ideally a thin layer of brash ice should remain at all times, thus diminishing the rate of new ice growth, and the potential formation of ice fog. (The model tests are discussed further in the next section)

The action of the azimuth thruster drives can have a major influence on ice clearing operations, which was apparent from the model tests. Only the action of an individual ore carrier was simulated; under the combined effect of a double-acting ore carrier and an IMV, it is anticipated that the two vessels would allow a fair degree of "fine-tuning" of the final brash ice distribution to achieve the desired result.

4. Physical Modeling Tests

In order to better understand the need for ice management support in the port and compatible dock designs, in May 2011 BIM contracted Aker Arctic to conduct a series of physical modeling tests at their facility in Helsinki. The tests, which were observed by BIM and Hatch personnel over a ten-day period in late May / early June, were to address berthing behaviour in brash ice of different thickness as a function of dock configuration and vessel manoeuvres. The tests were conducted at an approximate scale of 1:55 using an ore carrier with a conventional icebreaking bow and two different propulsion systems - a conventional system consisting of two 25 MW units and an azimuth thruster system consisting of two 13 MW units.

In particular, the following scenarios were tested in unconsolidated brash ice of 4 m and 8 m thickness (except where noted) with three dock configurations – an open face with 10 m diameter piers at about 50 m spacing, an open face with 30 m diameter concrete caissons at about 90 m spacing, and a closed face continuous dock:

1. Vessel approaching bow first parallel to the dock.
2. Vessel approaching bow first at 6° to the dock axis.
3. Vessel approaching dock stern first.

All of these tests were conducted with solid ice behind the dock. These tests were followed by:

4. Repeat of 2 and 3 with brash ice behind the open faced docks.
5. Maneuvering tests in 4 m thick brash ice with both bow first and stern first configurations.
6. "Ice management" (ice flushing) tests with various propulsion power levels ranging from 2x6.5 MW to 2x18 MW in 4 m of unconsolidated brash.

A draft report of the study was submitted to BIM by Aker Arctic in July 2011 and is attached here as Appendix D.

Paraphrasing from the draft report, the main conclusions arising from the study are as follows:

- The bow first conventional approach had more difficulty in berthing even though the vessel had more power; in the thicker brash ice, it had to ram at full power to reach the dock and not all approaches were successful.
- The stern first approach with the lower powered azimuth thruster units was more successful in docking in all cases and less ice was left between the vessel and the dock.
- The stern first approach caused ice in the open faced dock concepts to be flushed away from the dock, unlike in the closed faced concept, and this facilitated docking.
- While ice flushing in both open faced dock concepts was similar, berthing in the case of the dock with the larger openings was more complicated in that the vessel tended to impact the deck between the dock caissons / piers.
- Manoeuvring with the bow first approach was not always successful even with simulated tug support (using a thruster); manoeuvring using the stern first approach was much more successful, and manoeuvring time was cut in half with simulated tug support.
- Ice flushing with propulsion units was effective, particularly with the larger units. Flushing with the azimuth thrusters was more successful than with conventional propulsion and rudder manipulation.
- The benefit of an ice management vessel for clearing the berthing area prior to ore carrier arrival and for assisting in manoeuvring was clearly demonstrated.
- While the tests showed that berthing was more successful with the open face dock concepts (particularly with a stern-first approach), if ice management is employed, berthing can be successful with any of the dock configurations.

Some observations (by Hatch) from the tests and the results are as follows:

- It is somewhat unexpected that the high powered conventional ship configuration had difficulty in travelling through the brash ice; further discussion and a comparison with an analytical calculation may be warranted.
- The different effect, if any, of brash ice versus solid ice behind the open-face dock configurations is not evident.
- Some comment in the report on the potential effect of boundary constraints of the test basin should be included in the case of the manoeuvring tests.

5. Ice Management Workshop

Another significant component of the ice management studies undertaken by BIM was a workshop that was held in Mississauga on June 13, 2011 and June 14, 2011. This workshop brought together marine experts, arctic and shipping consultants, and port and vessel operations personnel from Canada and Europe. The overall objective of the workshop was as follows:

- To arrive at a consensus on the ice management methodology, equipment needed and compatible dock designs for the successful execution of year-round port operations in Steensby Inlet, Baffin Island".

The supplementary objectives were:

- To understand the general nature of the ice build-up in the port berthing / deberthing area based on winter operations in the Gulf of Bothnia and elsewhere.
- To project, with the help of analytical modeling and empirical results from the Gulf of Bothnia, the overall thickness of brash ice in the harbour from planned vessel traffic and harbour support (ice management) vessel movements.
- To understand, from physical modeling results and full-scale experience, the ice movement and behaviour in the berthing area as a function of dock and vessel configuration, and vessel berthing procedure.
- To understand the required capability of IM vessels and their nominal dimensions and powering.
- To determine the potential application of other ice management techniques, in addition to the use of IM vessels.

The workshop was led by a professional facilitator who used a number of focus questions to guide the discussion. The list of attendees, agenda and facilitator's report are attached to this report as Appendix D.

The main conclusions and recommendations arising from the workshop were as follows:

- The principal issue for ice management is the accommodation or prevention of the accelerated growth of brash ice in the berthing area due to vessel traffic.
- Some form of ice management will be needed to facilitate berthing and deberthing of the ore carriers. Based on common experience, this is best accomplished with a dedicated ice management vessel (IMV).
- Two IMV's are recommended for redundancy; these could be outfitted for different purposes, in addition to ice management, and possibly could be used as tugs during the open water season, although there appears to be some concern that these IMV's will not serve well as tugs.

- An IMV should have sufficient power to handle the worst ice conditions, including pack ice if circumstances require its use outside the port.
- The IMV should be used judiciously within the port to minimize brash ice build-up.
- The dock configuration is not critical if ice management is employed. While an open face dock may, in some cases, facilitate ice flushing, the risk of significant damage due to collision is greater than with a closed face continuous dock. The choice of dock will ultimately be based on cost.
- The use of supplementary ice management concepts such as bubblers and an ice plough for moving brash ice from the berthing area warrant investigation.

6. Powering of Ice Management Vessel

One of the outcomes of both the physical model tests and the ice management workshop pertains to the capability of an ice management vessel that is employed in the port. A determination of this capability will eventually be made by the vessel designer; however, for present purposes, it may be instructive to address the matter here in a preliminary manner.

A basic question for such a determination is whether a vessel powered for travel in the worst normal ice thickness in the port will be effective in the potential brash ice that may result from frequent passage. This would depend on the degree of consolidation of the brash ice. And a potential complicating factor in such a determination is the type of propulsion system and method of traversing the ice cover that are adopted, since it appears that an azimuth thruster arrangement with stern-first operation allows for lower powering than a conventional design and bow-first operation.

Of the limited literature on the resistance offered by brash ice in a ship track, the most comprehensive publication appears to be that by Kitazawa & Ettema who describe the results of model tests in "Resistance to Ship-Hull Motion Through Brash Ice" in Cold Regions Science and Technology, 10 (1985). Their model was a 1:40 scale of an oil tanker vessel, 116 m between perpendiculars, 18 m in beam, and 6.8 m in draft. Both wedged-shaped and icebreaking bow forms were modeled; the results for the latter form are used in the analysis below.

In addition to discussing the results of their own research, the authors do a good job of summarizing the work of others to that time and compare their work with prior analytical models.

Two of the more relevant conclusions of the model tests are:

- Brash ice resistance is little affected by the channel width if the channel is wider than about twice the beam of the vessel. To ensure no effect, the tests were conducted at three times the beam.
- Brash ice resistance is almost linearly proportional to the brash ice thickness, but is affected by bow form, hull draft, and hull speed.

Resistance measurements were made in unconsolidated brash ice thicknesses up to 0.9 of the draft of the vessel and are reported as a function of thickness-to-draft ratio and vessel speed. The latter in the model varied from 0.1 m/s to 1 m/s, which equates to 0.63 m/s and 6.3 m/s full scale since the scaling law for velocity is a square root relationship. If we take the maximum (full scale) unconsolidated ice thickness of 6.1 m (0.9 x 6.8 m) and a vessel speed of 2.5 m/s (4.9 knots), the equivalent resistance (scaling from the model results) is approximately 1500 kN (153 tonnes). This is the thrust required from a similar full-scale vessel to travel through this thickness of unconsolidated ice at this speed.

The approximate powering for a vessel is related to the bollard thrust (thrust at zero speed) by a ratio of 0.01 tonnes / horsepower, and the bollard thrust is related to the thrust at a particular speed by (Johansson, 1977):

$T_0 = T/(1 - v/3v_0 - (2v/3v_0)^2)$

where T_0 = bollard thrust

T = thrust at speed (v)

V_0 = open water speed

If the open water speed of the IMV is 8.2 m/s (16 knots), the thrust at 2.5 m/s (4.9 knots) is 1500 kN as above. The bollard thrust is then calculated to be 1800 kN (183 tonnes) and the equivalent power in unconsolidated brash ice would be approximately 18,300 hp or 13.7 MW. If the speed requirement in the same ice thickness were reduced to the model speed of 0.1 m/s (0.6 m/s or 1.25 knots full scale), the equivalent power requirement would be reduced to 10 MW.

Additional model tests were also carried out with the top of the brash ice frozen to two different thicknesses. In the first case in which the thickness of the brash was 0.3 of the model vessel draft (i.e. 2 m full scale), the equivalent of 4 cm of ice full scale was frozen. The resulting resistance was found to increase by 30 per cent over the unconsolidated case. However, a thicker frozen layer of 12 cm when the total ice thickness was 0.9 of the draft (i.e. 6.1 m full scale) resulted in an increase in resistance over the unconsolidated case of only 10 per cent. The authors suggest that this could be due to the broken track being wider in the latter case thus resulting in less resistance over the length aft of the shoulders. They conclude that additional research is warranted.

It is also useful to compare the resistance experienced by a vessel in unconsolidated and consolidated brash with that in late winter level ice. If the resistance of the latter is greater, then it would dictate the powering of the IMV. A calculation based on the work of Enkvist (1972) and using dimensions for the Aker ARC Terminal Tug (for illustrative purposes only; also see brochure attached, Appendix E) along with typical bow angles for icebreakers, and a speed in 2 m thick level ice of 1.55 m/s (3 knots) resulted in a resistance of 1880 kN and a bollard thrust of 2059 kN (210 tonnes). The approximate power would then be 15.7 MW (21,000 hp). This is about 15% more than the power calculated above for 6 m of unconsolidated brash and suggests that such a vessel would also be able to cope with a certain amount of consolidation within the 6 m brash thickness. If it is concluded that the thickness of brash ice will be less than 6 m, then the design for operation in level ice will govern.

This then appears to be a useful preliminary guide for vessel powering and a possible starting point for addressing a potential reduction in power with an azimuth thruster propulsion, stern-first arrangement.

7. Conclusions and Recommended Ice Management Approach

All of the work undertaken in this study of the potential approaches to ice management at Steensby Inlet points, first of all, to the need for some form of ice management in the port to facilitate ore carrier operations and, then, to the proven method of dedicated harbour ice management vessels as the most appropriate method. Other potential methods of ice management (such as melting or prevention of growth), while being technically feasible, have no precedence in a similar arctic environment and have therefore not been given more than a cursory consideration in this study. One potential exception is air bubblers which are common in fresh water applications for ice suppression, but are considered to be of limited, if any, benefit in sea water applications, although the experience of one application as described in this report suggests that further investigation relating to the extension of the open water season is warranted. Also, in the less severe climate of the Baltic Sea, waste heat discharge from industrial and power plants, sometimes combined with bubblers, has also been shown to be effective in some cases. In the case of the current project, no waste heat will be available (except for ballast water which, without storage at site, would be available only during the time the vessel is berthed), and any such thermal suppression application would have to be achieved through an independent, dedicated operation. Nevertheless, the use of heated ballast water in a storage arrangement, combined with a bubbler, is a concept that is worthy of further analysis, perhaps using a CFD (Computational Fluid Dynamics) approach.

The build-up of brash ice based on three different ore carrier schedules, without any management of the growth, was determined through analytical modeling to range from about 7 m to 10 m by the end of winter. The ice management vessel would be used to reduce this growth by periodically removing ice from the berthing area. The preferred method of clearing ice in the berthing area is by flushing of the brash ice with the propellers of the ice management vessel. Based on the physical model tests, an azimuth thruster equipped ore carrier approaching stern first would provide a significant additional flushing facility. The physical model tests showed that with appropriate powering, a large area of open water or thin brash ice can be created. The ice from the berthing area would be pushed progressively to an area remote from the dock site.

The physical model tests also showed that an ore carrier with conventional propulsion moving bow first would have significant difficulty in manoeuvring in heavy brash ice in the port, even with vessel support, whereas an azimuth thruster-equipped vessel moving stern first would not. Overall, the azimuth thruster equipped vessel would require lower berthing and deberthing times, and hence a lower turn-around time.

Using an ice management vessel to clear, or to minimize the amount of ice in, the berthing area prior to arrival of an ore carrier suggests that the dock configuration is not significant from an ice management perspective, although the model tests indicate that in an open-face dock configuration, additional ice may move into the berthing area from between the piers or caissons. From a berthing perspective, the model tests also indicated some tendency of the berthing vessel to impact between the widely spaced dock members in one open-faced configuration. Opinions expressed at the ice management workshop also suggest that operators prefer a closed face continuous dock, if for no other reason than it is considered a less risky operation with respect to potential damage to individual members in a discrete cell or caisson dock configuration. Therefore, assuming costs are favourable, a closed-face dock configuration is recommended.

The capability of an ice management vessel should be determined by the worst ice that it is expected to traverse. A preliminary calculation in this report suggests that if the vessel can travel in level ice of 2 m thickness at a speed of 1.55 m/s (3 knots), it can also handle somewhat consolidated brash ice of 6 m thickness. The preliminary analysis here suggests that a conventional approach would entail a power requirement of approximately 16 MW for a potential ice management vessel. The powering may be less if a stern-first approach with azimuth thruster propulsion is used.

In summary then, the findings and recommendations arising from the ice management study are as follows:

- based on experience elsewhere, an ice management vessel should be used to facilitate berthing and deberthing of the ore carriers
  - Two such vessels are recommended for redundancy and for other potential services in the port and approaches.
- such a vessel should be powered to permit its operation in the worst ice conditions
  - A preliminary analysis based on physical modeling suggests that a vessel capable of operating in 2 m of cold winter ice would also be able to cope with the potential brash ice build-up in the port as well as ice outside the port.
- based on the physical modeling tests, in terms of berthing capability, turn-around time, flexibility, and ice management potential, azimuth thruster equipped ore carrying and ice management vessels are recommended
- the consensus of operators as expressed at the ice management workshop and the experience with ice management vessels suggests that a continuous face dock is preferred
- to conclusively determine the potential of a bubbler to retard ice growth early in the winter, a test installation should be implemented, preferably at the proposed ore dock location at the port site
- an analytical study should be carried out of the potential for ice management of a combination of stored ballast water and a bubbler.

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R. MacCrimmon

RM:jw

Attachment(s) / Enclosure:

Appendix A: Trip Report
Appendix B: Sample Spreadsheet of Brash ice Build-up Analysis
Appendix C: Physical Model Tests Report
Appendix D: Ice Management Workshop Agenda and Facilitator's Report
Appendix E: Example of Potential IMV

Appendix A

Trip Report

TRIP REPORT

H-337697 Mary River Project, Baffinland Iron Mines Corporation

Notes of Team Visit to Finland, Meetings with Aker Arctic, and Icebreaking Trip from Port of Oulu, April 18 to 21, 2011

BIM Representatives

Mike Zurowski (MZ), Dick Matthews (DM), Oliver Curran (OC)

HATCH Representatives

Harry Charalambu (HC), Bob MacCrimmon (RM), Bob Gill (RG), and Gus Cammaert (AC) , part time

April 18

Met with BIM at 0915 h in Aker Arctic (AA) offices, Helsinki, Finland. Present were: MZ, DM and OC from BIM; HC, RG, RM from Hatch.

Discussed modeling work done by AA for BIM; noted a number of questions for AA. BIM noted that they would prefer to have planned ice management workshop in Canada to minimize cost, on assumption that several BIM people would participate.

Agreed to meet with G. Cammaert on Thursday, April 21 at 0830 AM to discuss ice management issues and the upcoming workshop.

Met with AA at 1130 h. Introduction by M. Niini, Managing Director. Presentation by G. Wilkman, Manager, Research & Testing Services on work done to date by AA for BIM, including the physical modeling study. Several questions were asked by Hatch personnel on the methodology and results of the modeling study, including the influence of dock design on the model results.

Adjourned for lunch at 1230 h and re-convened at 1330 h.

AA noted their work with azimuth thrusters (called azipod by AA) propulsion vessels (so-called Dual Acting icebreaking vessels with bulbous bow) which are effective in an icebreaking mode by going astern when travel forward becomes difficult. Azipod propulsion can also be combined with a conventional icebreaking bow.

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The advantage is that open water performance is better than with conventional icebreaking bow and in addition, having azimuthal capability can help in berthing and deberthing. Trade-off in terms of transit time is better performance over the longer open water distance with reduced performance in the shorter distance through ice, the latter distance being up to approximately one-third of the total distance in the most extensive ice conditions in our project. AA noted that several cargo vessels operated in ice have azipod propulsion, including the five icebreaking ore carriers owned and operated by Norilsk Nickel. These vessels operate without icebreaker assistance in the port of Dudinka. It is believed that harbor support vessel assistance is used, however.

S. Saarinen (Project Manager) of AA made a presentation on work being done on an LNG terminal project in the Kara Sea (Yamal project). The LNG carrier will be 300 m long and have a power plant of 42 MW. It will be capable of operating in 2 m of level ice. Consideration may be given to using heat from the liquefaction process in ice management. He also talked about the buildup up of brash ice in the ship's track and in the berthing area, and about various berthing/deberthing maneuvers.

Some discussion ensued on the use of bubblers in ice management. They are used in a number of locations in Finland; however, the water in the Gulf of Bothnia has a very low salinity which suggests that there would be some heat reserve at depth (since fresh water has its maximum density at 4 deg C and overturns at this temperature. Sea water does not exhibit this phenomenon). Additionally, in some ports, warm industrial waste or cooling water is available. Hatch discounts the potential for bubblers in the current application in sea water, but did undertake to quickly re-visit the issue. Hatch (HC) also noted that an experiment might be conducted at Nanisivik (Baffin Island) to address this.

M. Niini noted areas in which AA could provide further assistance to BIM, principally in the area of an economic comparison of different ship types and shipping arrangements, including transshipment.

In answer to a question on the availability of the model testing facility in the event further modeling is deemed useful, AA noted that it would be very tight this spring although it might be possible to do so in May (they would need 6 weeks for model construction- this is subcontracted- unless an existing model could be used). Any such modeling would pertain to the firming up of the understanding of the behavior of brash ice in the berthing area during repeated berthings and departures.

The meeting concluded with a tour of the model testing facility and agreement to reconvene at 0900 h on April 19.

April 19, 0900 h
AA presented a slide show of icebreaker history and referred to several large ships using azipods. AA stated that in the last 10 years, all icebreakers designed by AA have azipods.

AA noted that azipods are very efficient in level ice, flushing the hull. Ridges are generally loose at propeller level. Speeds astern are generally less than 8 knots.

AA noted that azipods require up to 50% less energy for the same icebreaking, compared to conventional ice breakers.

The visit to Oulu will consist of a voyage on the "Kontio" (Bear), the last conventional ice-breaker designed by AA. It has twin propellers and aft and a bow thruster. Basic characteristics are LOA 99m x Beam 24.2 m x 8 m Draft, 9000 t displacement, 2 x 7.5 MW conventional screws, capable of 10 knots in 0.8 m of level ice. It is expected that conditions will be 0.5 to 0.8 m of level ice. Replacement cost of the Kontio is estimated to be in excess of $100 M euros.

A brief discussion on possible additional modeling was held. Hatch (HC) noted that results would be needed in June latest. The testing would focus on behavior of ice at probably three different dock configurations under repeated arrivals and departures. AA noted that they could model brash ice quite efficiently, adding brash ice at intervals in the order of one hour, but modeling solid ice is a more complex undertaking. AA offers that if the testing is undertaken promptly, they should be able to have a model ready for testing near the end of May or early June. It was generally agreed that a model test that would successfully address ongoing issues about build-up of brash ice and performance of different wharf face configurations would be of significant value to the project. Hatch and BIM will discuss the matter further.

April 19, 1600 h
Sailed from Oulu on the icebreaker Kontio in very good weather conditions with Captain Christian Wennerstrand in charge. Purpose was to free two ice stranded ships about 60 km out in the Gulf of Bothnia, each about 4000 DWT. One had a bulbous bow, the other did not. Our host was Ari Malmi, Offshore Operations Manager of Arctia Offshore Ltd. Matti Arpiainen, Senior Naval Architect represented AA and assisted the team.

During the process of freeing the ships and escorting back to shore, several techniques were used including icebreaking around the stranded ships, flushing ice away with the propellers, and pushing directly against the bow of the stranded vessel with the stern of the icebreaker.

The team stayed on board overnight, anchored about one hour away from Oulu.

April 20, 0915 h
Ari Malmi of Arctia made two presentations onboard the icebreaker:

- Data on the Company vessels and activities. There are several dedicated icebreakers and multi-purpose ice breakers in the company's fleet. Some of these are used worldwide during the off-season largely servicing oil industry clients.
- Noted that some (International Maritime Organization) regulations are changing and that the team should be aware of those that may affect operations in the arctic.
- The primary job of an icebreaker is escort; i.e. the icebreaker takes the lead and has control
- Reference to a "Polar Code" and advisability of confirming what regulations will apply
- Redundancy in heavy ice is important

April 20, pm
Arrived back in Oulu harbor at approximately 1300 h.

Flew back to Helsinki and visited AA at 1630 h to discuss possible model testing further.

- AA presented their proposal for model tests in the form of a slide show (later emailed to BIM/Hatch)
- There is a one week time slot available last week in May. A commitment by BIM within one week is necessary
- AA has a hull that can be stretched to provide a 1:54.7 scale. This model has two azipods and an ice breaking bow
- No need for side thrusters in the model
- AA proposes 4 tests on each of two dock configurations (open and closed). Two tests bow first, two tests stern first
- The test would start May 23 with draft report by June 17 and final report by August 8.
- Cost 102,000 Euros

Discussion ensued:

- Ice management by dedicated harbor vessel is assumed
- Initial runs will be through level ice
- Accumulation of brash ice from repeated passes will be by adding brash ice
- Consolidated and unconsolidated brash ice can be modeled but consolidated takes more time. Time frame is based on consolidated approx. 1.5 hrs between runs.
- AA does not have enough width to establish a full turning circle in brash and level ice but expects that this can be estimated by extrapolating results in the width available. AA is of the opinion that a radius of 4 x LOA is achievable in brash ice. Ice breaking assistance is probably required in level ice.
- Hatch offered that the base case for the open face dock (on columns) will likely be in the form of 10 m. dia columns at 51 m. c/c, but this is to be confirmed.
- Hatch would like to also test 30 m. dia columns (caissons) at 90 m c/c because this is the configuration provided by Sandwell and the tests would help in the trade-off studies. This, of course, is additional work, possibly mitigated by some efficiencies using unconsolidated brash ice.
- AA will consider building docks in tandem to speed up the process, if sufficient length is available.
- Agreed that an ice breaking bow should be used
- Agreed that this testing is required and is good value
- AA will submit the proposal for comment and Hatch undertook to review the proposal for discussion with BIM.
- BIM will seek approval.

April 21, 0830 h

Dr. Gus Cammaert (AC) and Hatch met with BIM to discuss a possible ice management workshop, to be held perhaps in late May.

- AC summarized relevant experience and background
- Agreed that focus will be on ice management by dedicated vessels, not unproven technology.

- AC suggested that most experts would agree that the Russians have the most relevant experience and we should be able to learn from those experiences through AC contacts, some of which are captains with hands-on experience.

- Agreed that it would be good to coordinate the workshop timing with the model testing, therefore early June would be good, venue to be determined (see conclusion)

- MZ expressed the view that the workshop not be an academic exercise, with potentially few clear and useful recommendations, that participants not be unwilling to share what they feel are competitive advantages, that participants way not be looking for ‘exclusivity”, and that the workshop not be a repeat of work done already.

- Hatch (HC) offered that in some ways this is a revisit but the documentation suggests that no clear consensus has emerged . A relatively modest investment in the model study and this workshop would be money well spent. The workshop should address the highest risks and if we have practically minded participants, willing to share, and model tests results, we should be able to move forward on all fronts. However, expectations should be tempered with reality in that there is bound to be a degree of disagreement amongst the participants. Hatch (RG) suggested that the workshop be structured to address (a) ice management strategy, (b) vessel requirements/capabilities, and (c) implications for design of the dock. Regarding sharing, BIM conceded that Fednav, for example, may be reluctant to fully share their expertise, but they will not want to drop out of the picture, and having diverse opinions is part of the workshop dynamics. The focus should be on practical experience that can be brought to bear on the ice management issues. Participants must be prepared for an open forum.

- MZ questioned the relevance of the Dudinka experience citing fresh water vs salt water. RG responded that although freshwater ice is stronger, air temperatures and ice thicknesses at Dudinka (while not as severe as at Steensby) are relevant, and there is frequent traffic so this experience is likely the most similar to our project.

- MZ suggested that risks, mitigations, cost benefits should be addressed. HC agreed.

- Agreed that an experienced facilitator will be required. HC will nominate.

- OC asked about environmental content. AC suggested that while there would not be a dedicated environmental session, these considerations are bound to emerge and therefore an environmental representative should be an observer, at least.
- Agreed that there should be no more than six participants from each of BIM and Hatch.
- Agreed that timing should be early June
- Agreed that preferred venue is Helsinki, but Canada will also be considered.
- AC will contact and nominate three participants, but no commitment will be made until approval by BIM.
- Participants will be paid, including expenses, but preparation time will be limited.
- RG and AC will draft an agenda for review and discussion.
- BIM will seek approval.

April 21, pm

- AC, RG and RM reviewed and provided comments by email on AA's model study proposal to HC for review and action.
- AC and RG drafted a workshop agenda and emailed to HC for review and action.

Reported by R. MacCrimmon and R. Gill, April 22, 2011.

Appendix B

Sample Spreadsheet of Brash ice Build-up Analysis

Spreadsheet for brash ice buildup at Steensby Inlet due to repeated vessel transits

revised by Gus Cammaert, 01 Aug 2011

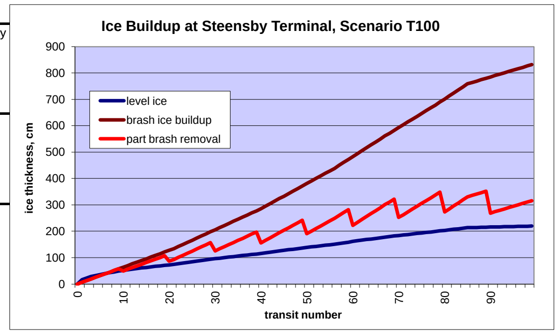
SCENARIO T100A Transits vary each month, ice removal in front of dock to maintain a desired level of brash ice at end of winter

Ice buildup scenario

Graph shows undisturbed (level) ice buildup and brash ice buildup with variable number of transits every month. Also shown is the effect of brash removal if a certain percentage (say 25%) is removed once every 5 (or other number) of transits, in front of dock or in maneuvering area.

Main assumptions:

1. Transit interval for ore carriers assumed variable during winter.
2. All transit data, ice parameters and temperature data is linked to table below
3. Ice buildup data will change when this data is reset.



Transit and ice parameters

Date of first transit:	1-Nov-11
Transit interval (days)	column C
α for level ice (°C, cm)	3.05
α for brash ice (°C, cm)	1.20
no. of trips between removals	**10**
% ice removed each time	**25%**

Average daily temperatures

Nov	-20.20
Dec	-27.50
Jan	-31.80
Feb	-33.20
Mar	-29.20
Apr	-20.40
May	-9.00

Transit No	Transit interval, days	Day No. *note 1*	Date	Average daily temp, degC *note 2*	Incremental degC-days *note 3*	Cumulative degC-days *note 4*	Level ice thickness, cm *note 5*	Incremental brash ice, cm *note 6*	Total brash ice, cm *note 7*	Rubble removal? *note 8*	Managed thickness, cm *note 9*	Brash ice removed, cm
0	1.4	0.0	1-Nov-11	-20.20	0.0	0	0	0.0	0	1	0	0.0
1	1.4	1.4	2-Nov-11	-20.20	28.3	28	16	6.4	6	0	6	0.0
2	1.4	2.8	3-Nov-11	-20.20	28.3	57	23	6.4	13	0	13	0.0
3	1.4	4.2	5-Nov-11	-20.20	28.3	85	28	6.4	19	0	19	0.0
4	1.4	5.6	6-Nov-11	-20.20	28.3	113	32	6.4	26	0	26	0.0
5	1.4	7.0	8-Nov-11	-20.20	28.3	141	36	6.4	32	0	32	0.0
6	1.4	8.4	9-Nov-11	-20.20	28.3	170	40	6.4	38	0	38	0.0
7	1.4	9.8	10-Nov-11	-20.20	28.3	198	43	6.4	45	0	45	0.0
8	1.4	11.2	12-Nov-11	-20.20	28.3	226	46	6.4	51	0	51	0.0
9	1.4	12.6	13-Nov-11	-20.20	28.3	255	49	6.4	57	0	57	0.0
10	1.4	14.0	15-Nov-11	-20.20	28.3	283	51	6.4	64	1	49	8.0
11	1.4	15.4	16-Nov-11	-20.20	28.3	311	54	6.4	70	0	56	0.0
12	1.4	16.8	17-Nov-11	-20.20	28.3	339	56	6.4	77	0	62	0.0
13	1.4	18.2	19-Nov-11	-20.20	28.3	368	58	6.4	83	0	69	0.0
14	1.4	19.6	20-Nov-11	-20.20	28.3	396	61	6.4	89	0	75	0.0
15	1.4	21.0	22-Nov-11	-20.20	28.3	424	63	6.4	96	0	81	0.0
16	1.4	22.4	23-Nov-11	-20.20	28.3	452	65	6.4	102	0	88	0.0
17	1.4	23.8	24-Nov-11	-20.20	28.3	481	67	6.4	108	0	94	0.0
18	1.4	25.2	26-Nov-11	-20.20	28.3	509	69	6.4	115	0	101	0.0
19	1.4	26.6	27-Nov-11	-20.20	28.3	537	71	6.4	121	0	107	0.0
20	1.4	28.0	29-Nov-11	-20.20	28.3	566	73	6.4	128	1	87	20.3
21	1.4	29.4	30-Nov-11	-20.20	28.3	594	74	6.4	134	0	93	0.0
22	1.6	31.0	2-Dec-11	-27.50	44.0	638	77	8.0	142	0	101	0.0
23	1.6	32.6	3-Dec-11	-27.50	44.0	682	80	8.0	150	0	109	0.0
24	1.6	34.2	5-Dec-11	-27.50	44.0	726	82	8.0	158	0	117	0.0
25	1.6	35.8	6-Dec-11	-27.50	44.0	770	85	8.0	166	0	125	0.0
26	1.6	37.4	8-Dec-11	-27.50	44.0	814	87	8.0	174	0	133	0.0
27	1.6	39.0	10-Dec-11	-27.50	44.0	858	89	8.0	182	0	141	0.0
28	1.6	40.6	11-Dec-11	-27.50	44.0	902	92	8.0	190	0	149	0.0
29	1.6	42.2	13-Dec-11	-27.50	44.0	946	94	8.0	198	0	157	0.0
30	1.6	43.8	14-Dec-11	-27.50	44.0	990	96	8.0	206	1	125	31.2
31	1.6	45.4	16-Dec-11	-27.50	44.0	1034	98	8.0	214	0	133	0.0
32	1.6	47.0	18-Dec-11	-27.50	44.0	1078	100	8.0	222	0	141	0.0
33	1.6	48.6	19-Dec-11	-27.50	44.0	1122	102	8.0	230	0	149	0.0
34	1.6	50.2	21-Dec-11	-27.50	44.0	1166	104	8.0	237	0	157	0.0
35	1.6	51.8	22-Dec-11	-27.50	44.0	1210	106	8.0	245	0	165	0.0
36	1.6	53.4	24-Dec-11	-27.50	44.0	1254	108	8.0	253	0	173	0.0
37	1.6	55.0	26-Dec-11	-27.50	44.0	1298	110	8.0	261	0	181	0.0
38	1.6	56.6	27-Dec-11	-27.50	44.0	1342	112	8.0	269	0	189	0.0
39	1.6	58.2	29-Dec-11	-27.50	44.0	1386	114	8.0	277	0	197	0.0
40	1.6	59.8	30-Dec-11	-27.50	44.0	1430	115	8.0	285	1	156	41.3

41	2.0	61.8	1-Jan-12	-31.80	63.6	1493	118	9.6	295	0	165	0.0
42	2.0	63.8	3-Jan-12	-31.80	63.6	1557	120	9.6	304	0	175	0.0
43	2.0	65.8	5-Jan-12	-31.80	63.6	1621	123	9.6	314	0	184	0.0
44	2.0	67.8	7-Jan-12	-31.80	63.6	1684	125	9.6	324	0	194	0.0
45	2.0	69.8	9-Jan-12	-31.80	63.6	1748	128	9.6	333	0	204	0.0
46	2.0	71.8	11-Jan-12	-31.80	63.6	1811	130	9.6	343	0	213	0.0
47	2.0	73.8	13-Jan-12	-31.80	63.6	1875	132	9.6	352	0	223	0.0
48	2.0	75.8	15-Jan-12	-31.80	63.6	1939	134	9.6	362	0	232	0.0
49	2.0	77.8	17-Jan-12	-31.80	63.6	2002	136	9.6	371	0	242	0.0
50	2.0	79.8	19-Jan-12	-31.80	63.6	2066	139	9.6	381	1	191	50.9
51	2.0	81.8	21-Jan-12	-31.80	63.6	2129	141	9.6	391	0	201	0.0
52	2.0	83.8	23-Jan-12	-31.80	63.6	2193	143	9.6	400	0	210	0.0
53	2.0	85.8	25-Jan-12	-31.80	63.6	2257	145	9.6	410	0	220	0.0
54	2.0	87.8	27-Jan-12	-31.80	63.6	2320	147	9.6	419	0	229	0.0
55	2.0	89.8	29-Jan-12	-31.80	63.6	2384	149	9.6	429	0	239	0.0
56	2.0	91.8	31-Jan-12	-31.80	63.6	2447	151	9.6	438	0	248	0.0
57	2.6	94.4	3-Feb-12	-33.20	86.3	2534	154	11.1	450	0	260	0.0
58	2.6	97.0	6-Feb-12	-33.20	86.3	2620	156	11.1	461	0	271	0.0
59	2.6	99.6	8-Feb-12	-33.20	86.3	2706	159	11.1	472	0	282	0.0
60	2.6	102.2	11-Feb-12	-33.20	86.3	2793	161	11.1	483	1	223	59.3
61	2.6	104.8	13-Feb-12	-33.20	86.3	2879	164	11.1	494	0	234	0.0
62	2.6	107.4	16-Feb-12	-33.20	86.3	2965	166	11.1	505	0	245	0.0
63	2.6	110.0	19-Feb-12	-33.20	86.3	3052	168	11.1	516	0	256	0.0
64	2.6	112.6	21-Feb-12	-33.20	86.3	3138	171	11.1	528	0	267	0.0
65	2.6	115.2	24-Feb-12	-33.20	86.3	3224	173	11.1	539	0	278	0.0
66	2.6	117.8	26-Feb-12	-33.20	86.3	3311	175	11.1	550	0	289	0.0
67	2.6	120.4	29-Feb-12	-33.20	86.3	3397	178	11.1	561	0	301	0.0
68	2.7	123.1	3-Mar-12	-29.20	78.8	3476	180	10.7	572	0	311	0.0
69	2.7	125.8	5-Mar-12	-29.20	78.8	3555	182	10.7	582	0	322	0.0
70	2.7	128.5	8-Mar-12	-29.20	78.8	3634	184	10.7	593	1	252	69.8
71	2.7	131.2	11-Mar-12	-29.20	78.8	3712	186	10.7	604	0	263	0.0
72	2.7	133.9	13-Mar-12	-29.20	78.8	3791	188	10.7	614	0	273	0.0
73	2.7	136.6	16-Mar-12	-29.20	78.8	3870	190	10.7	625	0	284	0.0
74	2.7	139.3	19-Mar-12	-29.20	78.8	3949	192	10.7	636	0	295	0.0
75	2.7	142.0	22-Mar-12	-29.20	78.8	4028	194	10.7	646	0	305	0.0
76	2.7	144.7	24-Mar-12	-29.20	78.8	4107	195	10.7	657	0	316	0.0
77	2.7	147.4	27-Mar-12	-29.20	78.8	4185	197	10.7	668	0	327	0.0
78	2.7	150.1	30-Mar-12	-29.20	78.8	4264	199	10.7	678	0	337	0.0
79	4.5	154.6	3-Apr-12	-20.40	91.8	4356	201	11.5	690	0	349	0.0
80	4.5	159.1	8-Apr-12	-20.40	91.8	4448	203	11.5	701	1	273	75.7
81	4.5	163.6	12-Apr-12	-20.40	91.8	4540	205	11.5	713	0	285	0.0
82	4.5	168.1	17-Apr-12	-20.40	91.8	4631	208	11.5	724	0	296	0.0
83	4.5	172.6	21-Apr-12	-20.40	91.8	4723	210	11.5	736	0	308	0.0
84	4.5	177.1	26-Apr-12	-20.40	91.8	4815	212	11.5	747	0	319	0.0
85	4.5	181.6	30-Apr-12	-20.40	91.8	4907	214	11.5	759	0	331	0.0
86	2.1	183.7	2-May-12	-9.00	18.9	4926	214	5.2	764	0	336	0.0
87	2.1	185.8	4-May-12	-9.00	18.9	4945	214	5.2	769	0	341	0.0
88	2.1	187.9	6-May-12	-9.00	18.9	4964	215	5.2	774	0	346	0.0
89	2.1	190.0	9-May-12	-9.00	18.9	4982	215	5.2	780	0	351	0.0
90	2.1	192.1	11-May-12	-9.00	18.9	5001	216	5.2	785	1	269	82.6
91	2.1	194.2	13-May-12	-9.00	18.9	5020	216	5.2	790	0	274	0.0
92	2.1	196.3	15-May-12	-9.00	18.9	5039	217	5.2	795	0	279	0.0
93	2.1	198.4	17-May-12	-9.00	18.9	5058	217	5.2	800	0	284	0.0
94	2.1	200.5	19-May-12	-9.00	18.9	5077	217	5.2	806	0	290	0.0
95	2.1	202.6	21-May-12	-9.00	18.9	5096	218	5.2	811	0	295	0.0
96	2.1	204.7	23-May-12	-9.00	18.9	5115	218	5.2	816	0	300	0.0
97	2.1	206.8	25-May-12	-9.00	18.9	5134	219	5.2	821	0	305	0.0
98	2.1	208.9	27-May-12	-9.00	18.9	5153	219	5.2	827	0	311	0.0
99	2.1	211.0	30-May-12	-9.00	18.9	5171	219	5.2	832	0	316	0.0
												439.2
									total brash ice cleared away (m / m2)			**4.39**

note 1 Calendar days since first transit
note 2 Based on data from Hall Beach Site (Environment Canada), copied from table above
note 3 Freezing degree days in interval
note 4 Cumulative degree days since start of season
note 5 Using Stefan equation (for CDD of 5200, level ice thickness 220 cm, α = 3.05)
note 6 Using Sandkvist approach
note 7 Assuming no brash ice removal, α from Sandkvist data
note 8 0 = no removal, 1 = part removal; specified frequency is no. of trips between removals
note 9 Brash ice thickness with specified removal rate

Appendix C

Physical Model Tests Report

REPORT A-453 DRAFT

Terminal approach tests with three different dock types using a double-acting and a conventional iron ore carrier

for

Baffinland Iron Mines Corporation

July 2011

Teemu Heinonen
Research Engineer

Aker Arctic	**Aker Arctic Technology Inc.**
Name of document: Terminal approach tests with three different dock types using a double-acting and a conventional iron ore carrier	**Type of document:** Model-scale report **AARC report number:** A-453 **Checked by date:** G.WiIlkman/10.7.2011

Summary:

These model tests relate to studies investigating the shipping of iron ore from Baffinland Island. The objective of these ice model tests was investigate how the different dock construction types affect the iron ore carriers ability to arrive to the dock and also how well the big iron ore carries are able to perform near terminal area. Terminal tests were performed with three different dock types with different qualities relating to ice clearance in front of the dock.

The 290 m long iron ore carrier was docked both in ahead and astern modes with two different propulsion configurations. In ahead mode the model represented a 2 x 30 MW conventional icebreaking cargo vessel while running astern the vessel represented 2 x 13 MW double-acting (DAS) icebreaking cargo vessel. A generic model of iron ore carrier was used in order to simulate different concept types.

In addition to terminal tests, manoeuvring tests were performed in which the iron ore carriers ability to turn was investigated. Effect of aiding harbour tugs was simulated in the turning tests. Also tests were carried out in order to study the efficiency of ice management.

The test results show clearly the following:

- Ice management at the terminal area is essential.
- With proper ice management any of the tested dock variants could be used.
- Ice management vessels should be relatively powerful.
- Docking time of the ore carrier is dependent on the vessel concept type.
- Manoeuvrability and flushing abilities of the DAS-version were better compared to the conventional version in the tested ice conditions.

Keywords:

Baffinland, brash ice, terminal, docking, double-acting, ice-bow, ice management, manoeuvring, harbour tug

Client reference:		**Project number:**	**Language:**
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28		Client	Confidential

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1. INTRODUCTION AND OBEJCTIVES

Baffinland Iron Mines is investigating different methods for transporting iron ore to the market from Baffinland Island Mary River deposit. Early stage studies have concluded that the Steensby Inlet would be the most suitable site for shipping the iron ore. In early studies ice management was not included and the question has come up how the terminal area would be managed between the ore carrier visits and how could it affect different dock designs.

The objective of these ice model tests was investigate how the different dock construction types affect the vessels ability to arrive to the dock and also how well the big iron ore carries are able to perform near terminal area.

Terminal tests were performed with three different dock types with different qualities relating to ice clearance in front of the dock.

The 290 m long iron ore carrier was docked both in ahead and astern modes with two different propulsion configurations. In ahead mode the model represented a 2 x 30 MW conventional icebreaking cargo vessel while running astern the vessel represented 2 x 13 MW double-acting icebreaking cargo vessel.

The purpose of the tests was mainly to compare the docks and to investigate how a big iron carrier would be able to perform in general, thus a generic model of iron ore carrier was used.

In addition to terminal tests, manoeuvring tests were performed in which the iron ore carriers ability to turn was investigated. Also tests were carried out in order to study the efficiency of ice management.

2. TEST PROGRAM

Model tests were performed during weeks 21 & 22 in May-June 2011 at AARC. The test program is presented in Table 2-1. Tests were performed in 4 and 8 meters thick unconsolidated brash ice which represents ice area visited and broken many times. The dock types used are presented more detail in chapter 3.3.

The power levels, bollard pull values and propeller diameters presented in Table 2-1 are discussed more detail in chapter 4.3.

Table 2-1: Tests conducted. Propeller diameter is presented after the propulsion power. Power and propeller diameter values are approximations.

Date	Brash ice thickness f.sc. [m]	Performed tests				
24.5.	4	**Test 1.1** Docking to a solid face dock **(Dock #3)** Level ice behind the dock Ahead / conventional Bollard Pull: 5880 kN Power: 2 x 21 MW, 7.4 m	**Test 1.2** Docking to a dock with 8 x 10 m dia. columns **(Dock #1)** Level ice behind the dock Ahead / conventional Bollard Pull: 5880 kN Power: 2 x 21 MW, 7.4 m	**Test 1.3** Docking to a solid face dock **(Dock #3)** Level ice behind the dock Astern / DAS Bollard Pull: 2335 kN Power: 2 x 13 MW, 5.6 m	**Test 1.4** Docking to a dock with 8 x 10 m dia. columns **(Dock #1)** Level ice behind the dock Astern / DAS Bollard Pull: 2335 kN Power: 2 x 13 MW, 5.6 m	
25.5.	8	**Test 2.1** Docking to a solid face dock **(Dock #3)** Level ice behind the dock Astern / DAS Bollard Pull: 2335 kN Power: 2 x 13 MW, 5.6 m	**Test 2.2** Docking to a dock with 8 x 10 m dia. columns **(Dock #1)** Level ice behind the dock Astern / DAS Bollard Pull: 2335 kN Power: 2 x 13 MW, 5.6 m	**Test 2.3** Docking to a solid face dock **(Dock #3)** Level ice behind the dock Ahead / conventional Bollard Pull: 7830 kN Power: 2 x 30 MW, 8 m	**Test 2.4** Docking to a dock with 8 x 10 m dia. columns **(Dock #1)** Level ice behind the dock Managed Ice in front Ahead / conventional Bollard Pull: 7830 kN Power: 2 x 30 MW, 8 m	
26.5.	8	**Test 3.1** Docking to a dock with 5 x 30 m dia. columns **(Dock #2)** Level ice behind the dock Astern / DAS Bollard Pull: 2335 kN Power: 2 x 13 MW, 5.6 m	**Test 3.2** Docking to a dock with 8 x 10 m dia. columns **(Dock #1)** Level ice behind the dock Astern / DAS Bollard Pull: 2335 kN Power: 2 x 13 MW, 5.6 m	**Test 3.3** Docking to a dock with 5 x 30 m dia. columns **(Dock #2)** Level ice behind the dock Ahead / conventional Bollard Pull: 7830 kN Power: 2 x 30 MW, 8 m		
27.5.	4	**Test 4.1** Docking to a dock with 5 x 30 m dia. columns **(Dock #2)** Level ice behind the dock Astern / DAS Bollard Pull: 2335 kN Power: 2 x 13 MW, 5.6 m	**Test 4.2** Docking to a dock with 8 x 10 m dia. columns **(Dock #1)** Brash ice behind the dock Astern / DAS Bollard Pull: 2335 kN Power: 2 x 13 MW, 5.6 m	**Test 4.3** Docking to a dock with 5 x 30 m dia. columns **(Dock #2)** Level ice behind the dock Ahead / conventional Bollard Pull: 7830 kN Power: 2 x 30 MW, 8 m	**Test 4.4** Docking to a dock with 8 x 10 m dia. columns **(Dock #1)** Brash ice behind the dock Ahead / conventional Bollard Pull: 7830 kN Power: 2 x 30 MW, 8 m	
31.5.	4	**Test 5.1** Star manoeuvre Astern / DAS Bollard Pull: 3050 kN Power: 2 x 16 MW, 6.8 m	**Test 5.2** Turning 180° with aiding harbour tug Ahead/conventional Propellers parallel Bollard Pull: 7830 kN Power: 2 x 30 MW, 8 m	**Test 5.3** Turning 180° with harbour tug (150 ton) in managed ice Ahead/conventional Propellers parallel Bollard Pull: 7830 kN Power: 2 x 30 MW	**Test 5.4** Turning 180° with aiding harbour tug (150 ton) Astern / DAS Bollard Pull: 3200 kN Power: 2 x 17 MW, 6.9m	**Test 5.5** Tugs pushing the vessel in to **dock #1** in managed ice Astern / DAS Bollard Pull: 2335 kN Power: 2 x 13 MW, 5.6 m
1.6.	4	**Test 6.1** Ice management / flushing Bollard pull: 1515 kN Power: 2 x 6.5 MW, 4.7 m	**Test 6.2** Ice management / flushing Bollard Pull: 2300 kN Power: 2 x 10 MW, 5.6 m	**Test 6.3** Ice management / flushing Bollard Pull: 2850 kN Power: 2 x 13 MW, 5.6 m	**Test 6.4** Ice management / flushing Bollard Pull: 3925 kN Power: 2 x 18 MW, 7 m	**Test 6.5** Ice management next to **dock #1** Astern / DAS Bollard Pull: 2335 kN Power: 2 x 13 MW

3. THE SHIP AND TERMINALS

3.1. The model

The model M-364 was built to scale 1:54.66. The model was built from an existing icebreaking supply ship model M-257 by adding a 1.6 m long parallel midship section to the existing model. The main particulars of the model and the ship are presented in Table 3-1. During the ice management tests 6.1-6.5 the stern of the model was trimmed up in order to have propellers closer to water surface. In this manner the propellers were approximately 4.1 meters from the surface. The bow draft was not changed. Photographs of the model are presented in Figure 3-1 through Figure 3-3.

The surface of the model was treated in accordance with the AARC standard methods. The target friction coefficient between the surface and the ice was 0.050**.**

Table 3-1: Main particulars of the model and ship

	Ship	**Model**
L_{WL} [m]	290	5.3
B_{WL} [m]	45	0.82
T_{WL} [m]	16.12	0.295

Figure 3-1: Side view of the model.

Figure 3-2: The bow of the model.

Figure 3-3: The stern of the model.

3.2. Propulsion characteristics

The model was equipped with two pulling azimuthing thrusters. Small thrusters were chosen in order to simulate a large ore carrier. Both propellers were rotating in the same direction and they had a constant pitch.

Table 3-2: The propellers parameters.

	Model	Ship
Diameter [m]	0.1025	5.6
P/D	1.4	1.4
Z	4	4

Figure 3-4: Propulsion arrangement in the stern.

3.3. Terminals

Three different terminal types were built and tested:

- Dock #1: a terminal with 8 x 10 m diameter columns (Figure 3-6)
- Dock #2: a terminal with 5 x 30 m diameter columns (Figure 3-7)
- Dock #3: a solid face dock (Figure 3-8)

Pictures of all terminals are presented below in Figure 3-6 through Figure 3-8. More specific drawings of the terminals are presented in Appendix E.

The docks were mounted on an artificial bottom (water depth 23 m) in the basin. The bottom had sanded surface and a sloping edge.

Figure 3-5: The artificial bottom on which the terminals were mounted.

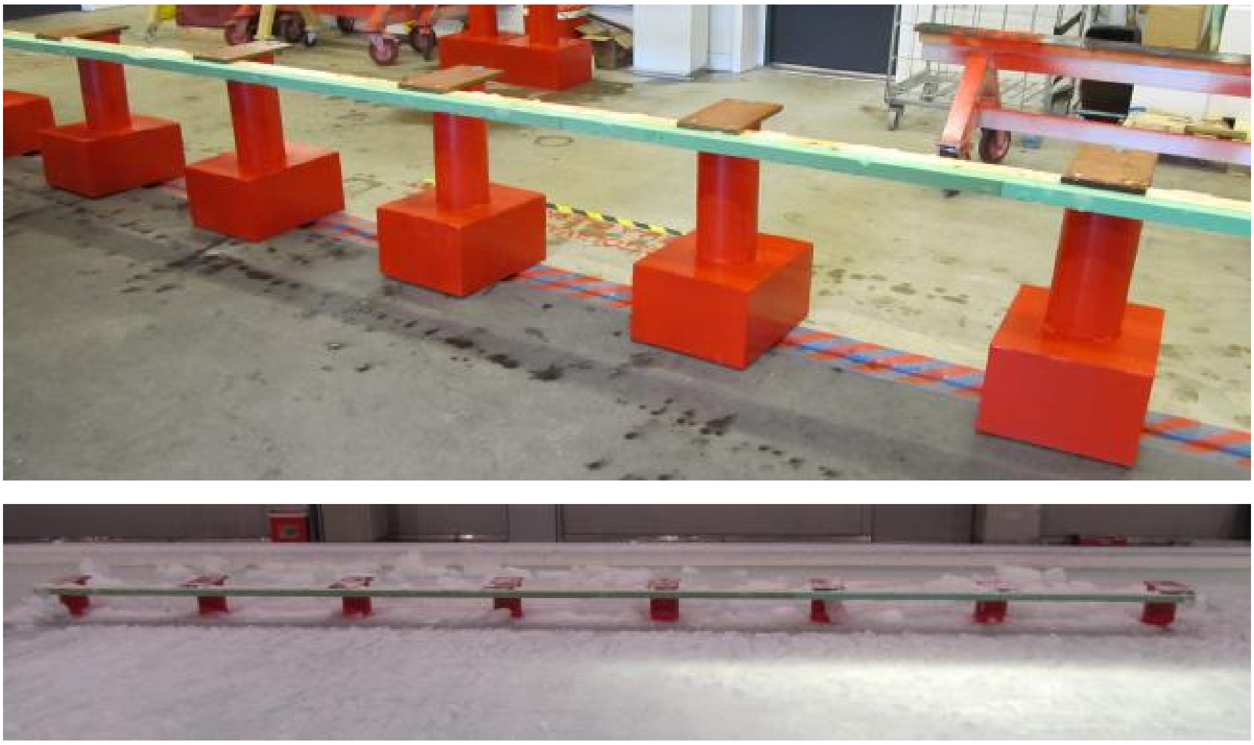

Figure 3-6: Terminal with 8 x 10 m diameter columns (dock #1).

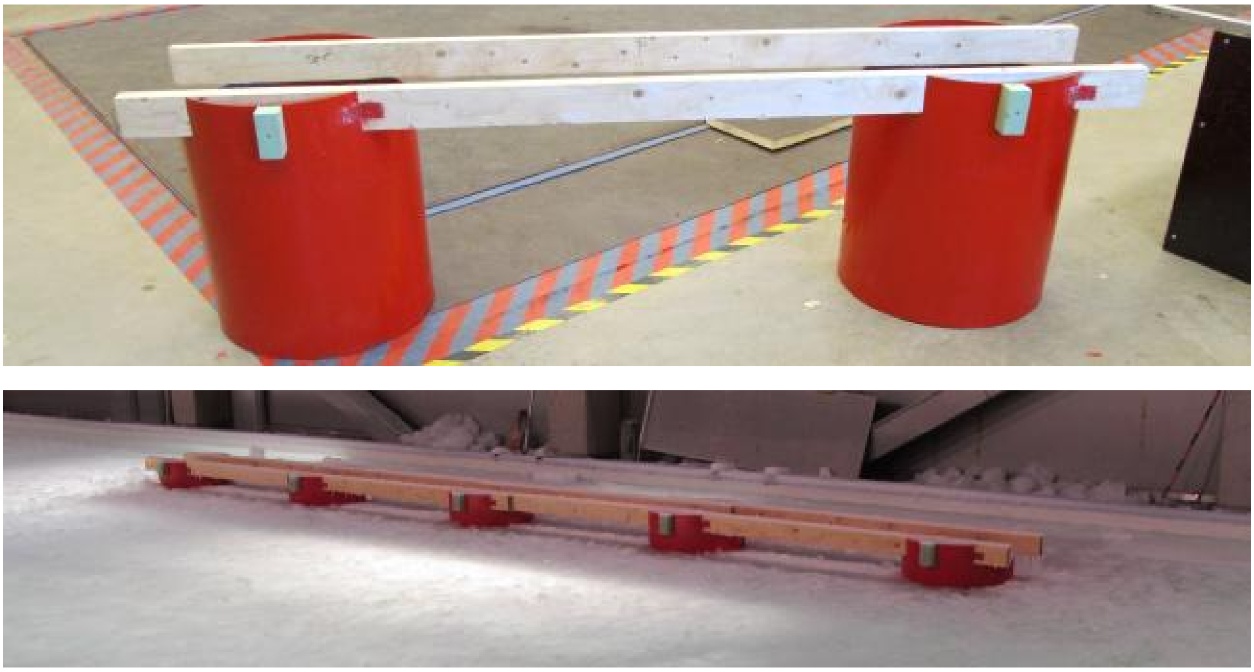

Figure 3-7: Terminal with 5 x 30 m diameter columns (dock #2)

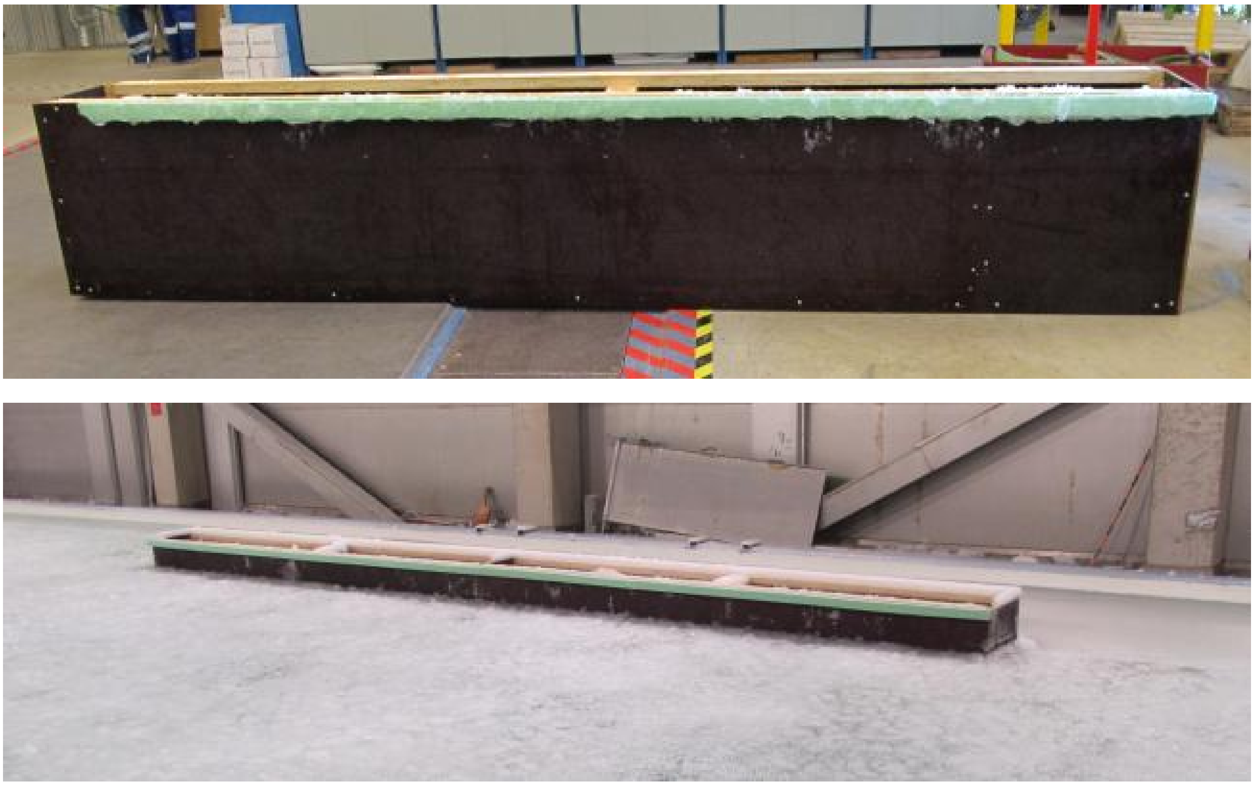

Figure 3-8: Solid face dock (dock #3).

4. TEST PROCEDURES

4.1. Measurements

The following quantities were measured during the tests:

- Speed of the carriage
- Propeller rpm
- Torque from propeller shafts
- Thruster angles

The ice tests were performed as self-propulsion tests and a schematic plan of the measuring arrangement is presented in Figure 4-1. The same arrangement was used in all tests. All tests were performed with a free model.

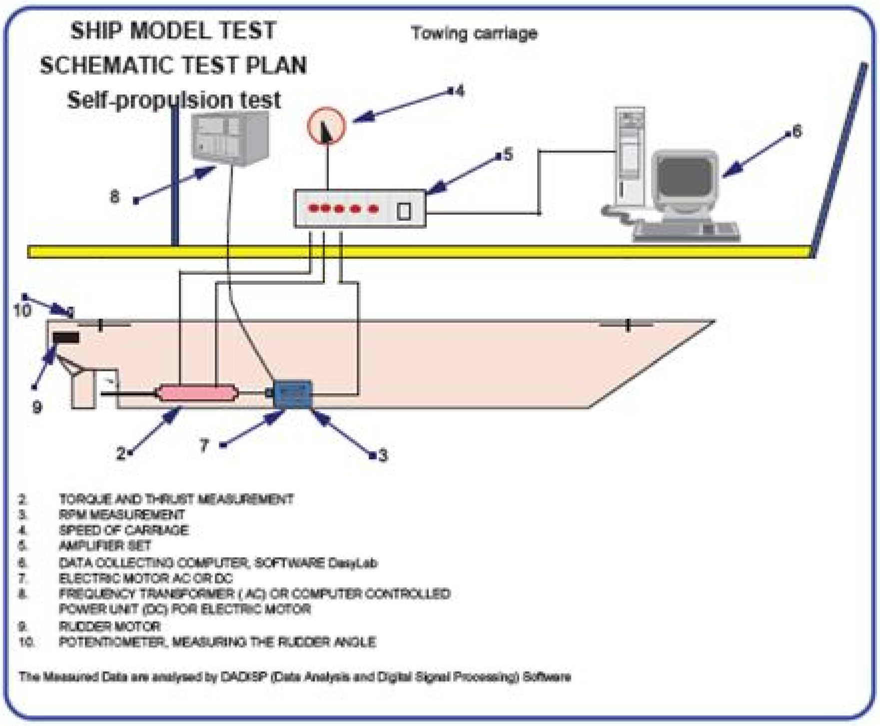

Figure 4-1: A schematic plan of the measuring arrangement, self-propulsion tests.

In the beginning of the test series, all the force transducers were calibrated. The resistance, propulsion parameters and ice properties were measured according to the standards of AARC.

All tests were recorded on video. Videos were taken from two angles on the side of the test basin and underwater video was taken through the windows under the basin. In addition, a camera was mounted on the towing carriage in some of the tests.

4.2. Open-water calibration tests

The open-water calibration tests included bollard pull tests. The bollard pull test was performed for the model only in ahead mode.

4.3. Ahead and astern mode, power levels

Terminal tests were performed both in ahead and astern mode. In ahead mode the model was representing a conventional icebreaking cargo ship with two shaft lines, propellers in nozzles and rudders. Therefore the target thruster turning angles were not more than +/- 30°.

In astern mode the vessel was representing a double-acting icebreaking cargo vessel with freely rotating azimuthing thrusters (360°).
The bollard pull of the conventional version was 7830 kN while the DAS-version had approximately 2335 kN bollard pull. The bollard pull of the DAS-version is calculated by assuming a 18% thrust deduction.

The used power levels are estimated from bollard pull with a following formula:

$$T_{pull} = 0.98 \cdot (P_D \cdot D)^{2/3},$$

where units are [kN], [kW] and [m].

It should be noted that the propeller diameter has been varied only in calculations in order to take into account the fact that more powerful vessels may have bigger propellers. The actual model tests have been performed with the same propellers. The power and propeller diameter values in Table 2-1 are somewhat approximations in order to have a qualitative idea of the power level of the vessel.

The conventional version had propulsion power of 2 x 30 MW by assuming that the nozzles will generate 30% extra thrust. The double-acting version had a propulsion power of 2 x 13 MW.
It should be noted that a smaller power was used in tests 1.1 and 1.2. In addition, a greater power was used in tests 5.1 and 5.4 as a shaft representing a harbour tug was producing additional resistance.

4.4. Brash ice

Tests were performed in unconsolidated brash ice in order to simulate ice conditions around terminals. The brash ice field was produced by breaking level ice sheet into pieces of desired size (~5-10 cm). The level ice was produced by spraying water into air in freezing temperatures. The water drops freeze in the air into small ice crystals and the model ice layer is formed.

The docks were in place during the model ice production in order to have level ice behind the structures as the ice sheet behind the structures was left intact. The brash ice thickness was measured in front of the terminals.

4.5. Position of the docks and approaching to docks

Two docks were positioned in the basin as presented in Figure 4-2. The target approaching angle of the ore carrier model to the dock was 6°. In tests 1.1-2.4 the vessel was parallel to the dock and in tests 3.1-4.1 and test 4.3 the model was inclined to the dock as can be seen in Figure 4-3. Tests 4.2 and 4.4 differ from other tests as these tests were continuing directly after the previous tests and the model was not repositioned for the test. The vessel was approaching to the dock in a steeper angle in the test 4.2 and in test 4.4 the vessel was approaching the dock in a more gentle angle

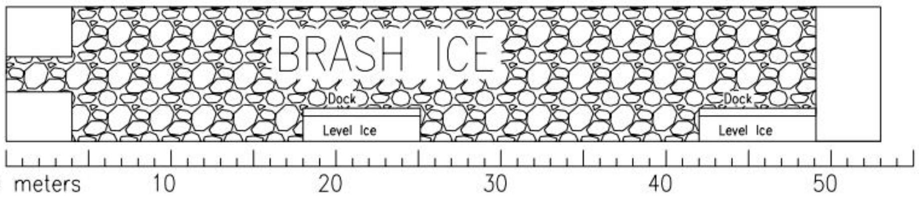

Figure 4-2: Two docks were simultaneously in the basin. Level ice behind the docks.

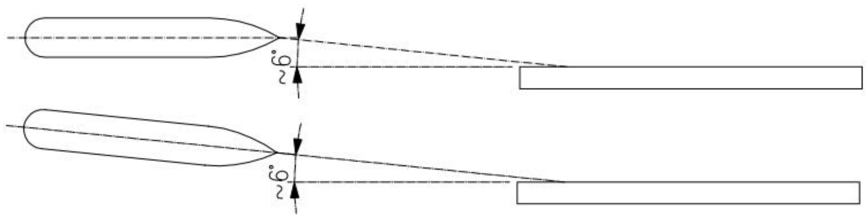

Figure 4-3: Approaching to the dock. Top: tests 1.1-2.4; bottom: tests 3.1-4.1, 4-3.

4.6. Simulation of harbour tugs

Tests 5.2-5.4 were simulating a situation in which the vessel was turning 180 degrees with an aiding harbour tug pushing the vessel at the bow. The turning force created by the harbour tug was simulated by installing a thruster onto the bow of the model as can be seen in Figure 4-4.

Figure 4-4: A small thruster was installed onto the bow of model in order to simulate a harbour tug pushing the vessel.

Three different “harbour tugs” were tested: 50 ton, 100 ton and 150 ton. Bollard pull tests were performed before the tests in order to determine rpm levels which produces the needed thrust. Due to short preparation time for these tests, the data recovering of rpm was not available. The rpm levels corresponding different tugs were only written down.

The test 5.5 was simulating a situation in which two harbour tugs would push the ore carrier to the dock in managed ice. This was done by installing two shafts onto the towing carriage and then pushing the model sideways to the dock with these shafts (Figure 4-6). Shear force transducers were installed onto the upper end of shafts in order to measure the force needed to push the vessel (Figure 4-6). The speed used to push the vessel to the dock was approximately 0.07 m/s (f.sc.).

Figure 4-5: Shear force transducers were installed onto the upper end of the shafts.

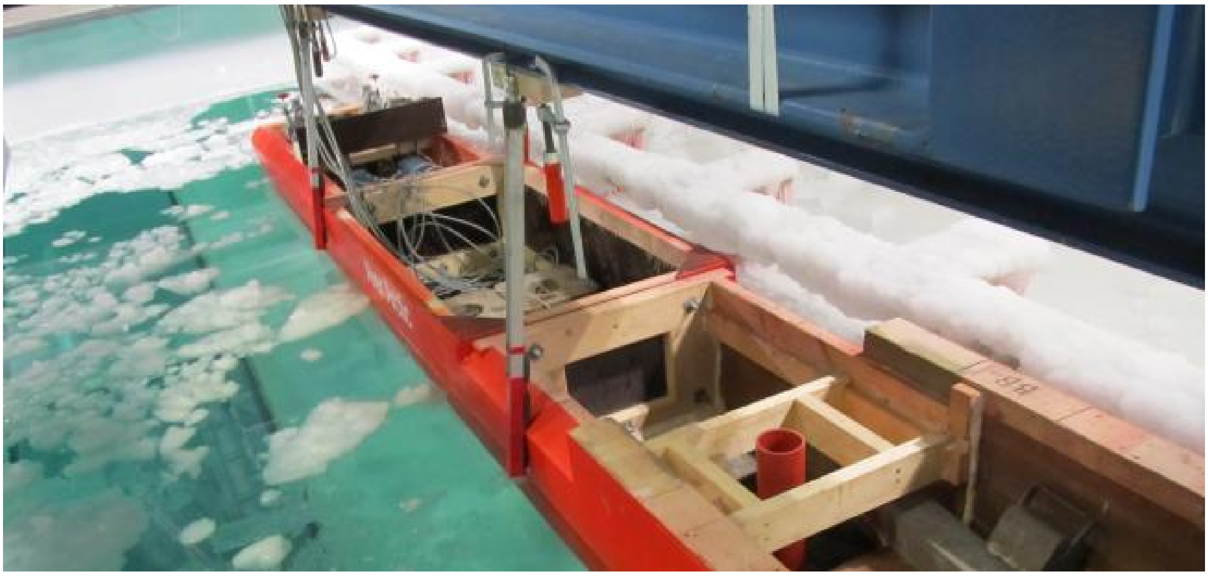

Figure 4-6: The towing carriage was moving sideways and pushing the vessel to the dock.

4.7. Ice management tests

Ice management tests 6.1-6.5 were performed in a following way: the model was stopped in a designated spot and thrusters were pointed sideways, and flushing was started. Thrusters were used for 5 minutes (~37 minutes f.sc.). After this the model was pulled backwards and the managed spot was photographed. After this the model was pushed back to the spot and flushing was started for another 5 minutes after which the spot was photographed again. In test 6.4 and 6.5 the model was swinging from side to side as the higher power levels cleared larger areas of ice away.

5. RESULTS

Results of the performed tests are presented below. Due to the nature of the tests, the results are based largely on visual observations and video footage.

5.1. *Docking tests*

In docking tests following quantities were of interest: time to dock (duration), distance of the vessel to the dock and number of passes the vessel made during docking. The duration refers to the time when the vessel was 165 meter away from the dock and when the test was stopped. The distance is analyzed from photographs. A summary of docking test results is in Table 5-1.

Table 5-1: Summary of the docking tests. Blue: test performed in managed ice. Red: brash ice behind the structures.

	Conventional (Ahead)											
	4 m Brash						8 m Brash					
	Test #	Hi [m]	Duration [h:min]	Passes	Distance to dock [m]	Notes	Test #	Hi [m]	Duration [h:min]	Passes	Distance to dock [m]	Notes
Dock #1	1.2	6.2	3:29	10	5-10	Vessel inclined, stern closer to dock, solid brash ice between the bow and the dock; stern rather ice free	2.4 (blue)	- (blue)	2:21 (blue)	4 (blue)	15-22 (blue)	Vessel inclined; bow closer to the dock; brash ice between the dock and the vessel; stern rather ice free (blue)
	4.4 (red)	6.2 (red)	1:49 (red)	2 (red)	0-23 (red)	Vessel heavily inclined; bow next to the dock; stern rather ice-free (red)						
Dock #2	4.3	5.7	2:06	3	3	Vessel inclined; stern closer to the dock; solid brash ice between the dock and the bow; stern rather ice free	3.3	7.5	2:01	5	25-26	Bow into solid brash ice; stern rather ice free; ramming
Dock #3	1.1	5.9	2:27	5	5	Vessel inclined, stern closer to dock, solid brash ice between the bow and the dock; stern rather ice free	2.3	8.0	2:01	2	3-8	Vessel inclined; bow closer to the dock; brash ice between the dock and the vessel; stern rather ice free
	Azimuth Thrusters (Astern)											
	4 m Brash						8 m Brash					
	Test #	Hi [m]	Duration [h:min]	Passes	Distance to dock [m]	Notes	Test #	Hi [m]	Duration [h:min]	Passes	Distance to dock [m]	Notes
Dock #1	1.4	5.5	0:50	1	2-6	Vessel inclined, stern closer to dock, brash ice between the vessel and dock for the whole length	2.2	8.3	3:23	2	0-6	Vessel inclined; stern to the dock; brash ice between the dock and the vessel
	4.2 (red)	6.5 (red)	3:22 (red)	2 (red)	1-4 (red)	Stern to the dock; area between the vessel and dock rather ice-free (red)	3.2	-	2:37	2	1-2	Vessel to the dock
Dock #2	4.1	6.2	2:06	2	11-12	Vessel away from the dock; area between the vessel and the dock is nearly ice-free	3.1	8.5	2:10	1	1-4	Vessel inclined; stern into the dock; brash ice between the dock and the vessel
Dock #3	1.3	5.6	2:01	2	5-7	Vessel inclined; stern closer to the dock; brash ice between the dock and the vessel	2.1	8.0	5:26	2	2-7	Vessel inclined; stern closer to the dock; solid brash ice section between the dock and the vessel

The brash ice thickness was measured before the tests. It can be seen in Table 5-1 that the actual brash ice was thicker than the target 4 m.

Ramming was necessary when docking with the conventional version, especially in the thicker 8 meter brash ice. Full power was used basically all the time, even though the vessel was close to dock. In addition, turning with the conventional version was difficult. Dimensions of the track which the vessel made near the dock and ice thicknesses at the track edges were measured after first few tests. These tracks are presented in Figure 5-16 and Figure 5-17. It should be noted that the thicknesses and tracks were measured after the test and therefore some of the ice could have moved when the model was removed. It can be seen in the figures that the vessel builds somewhat thicker ice edges when proceeding ahead which makes the manoeuvring more difficult.

The DAS-version was able to manoeuvre better and also flushing was more efficient. The conventional version had difficulties to clear ice from the fore ship area.

Picture series of all docking tests are presented below.

Figure 5-1: Test 1.1

Figure 5-2: Test 1.2

Figure 5-3: Test 1.3

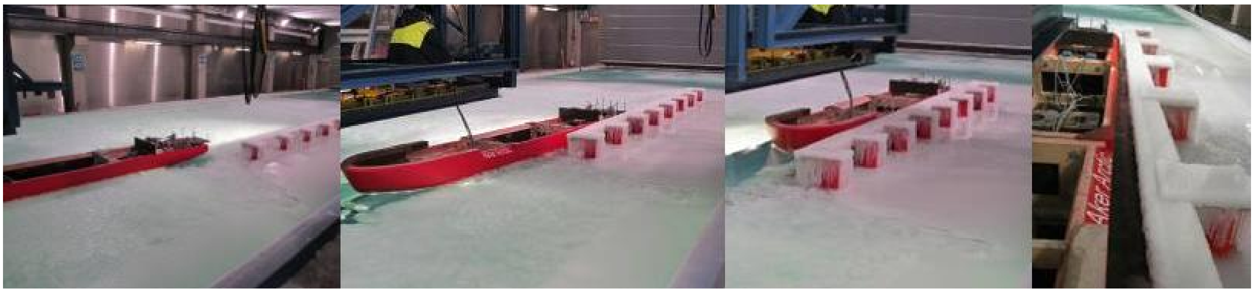

Figure 5-4: Test 1.4

Figure 5-5: Test 2.1

Figure 5-6: Test 2.2

Figure 5-7: Test 2.3

Figure 5-8: Test 2.4

Figure 5-9: Test 3.1

Figure 5-10: Test 3.2

Figure 5-11: Test 3.3

Figure 5-12: Test 4.1

Figure 5-13: Test 4.2

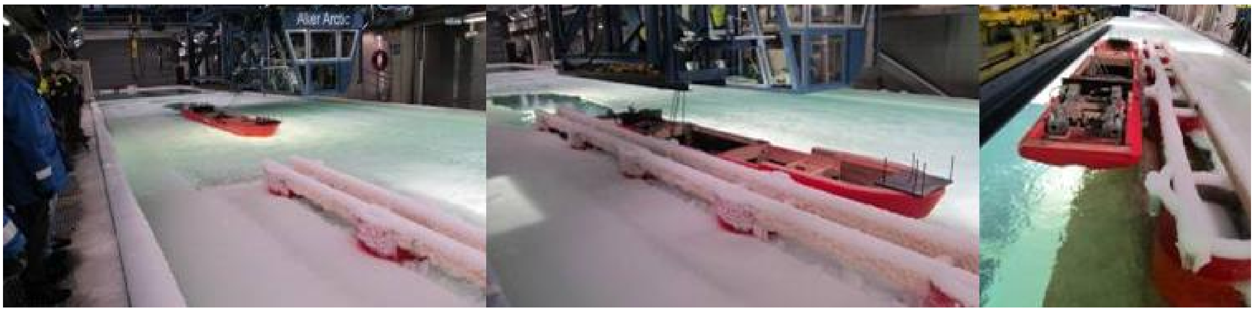

Figure 5-14: Test 4.3

Figure 5-15: Test 4.4

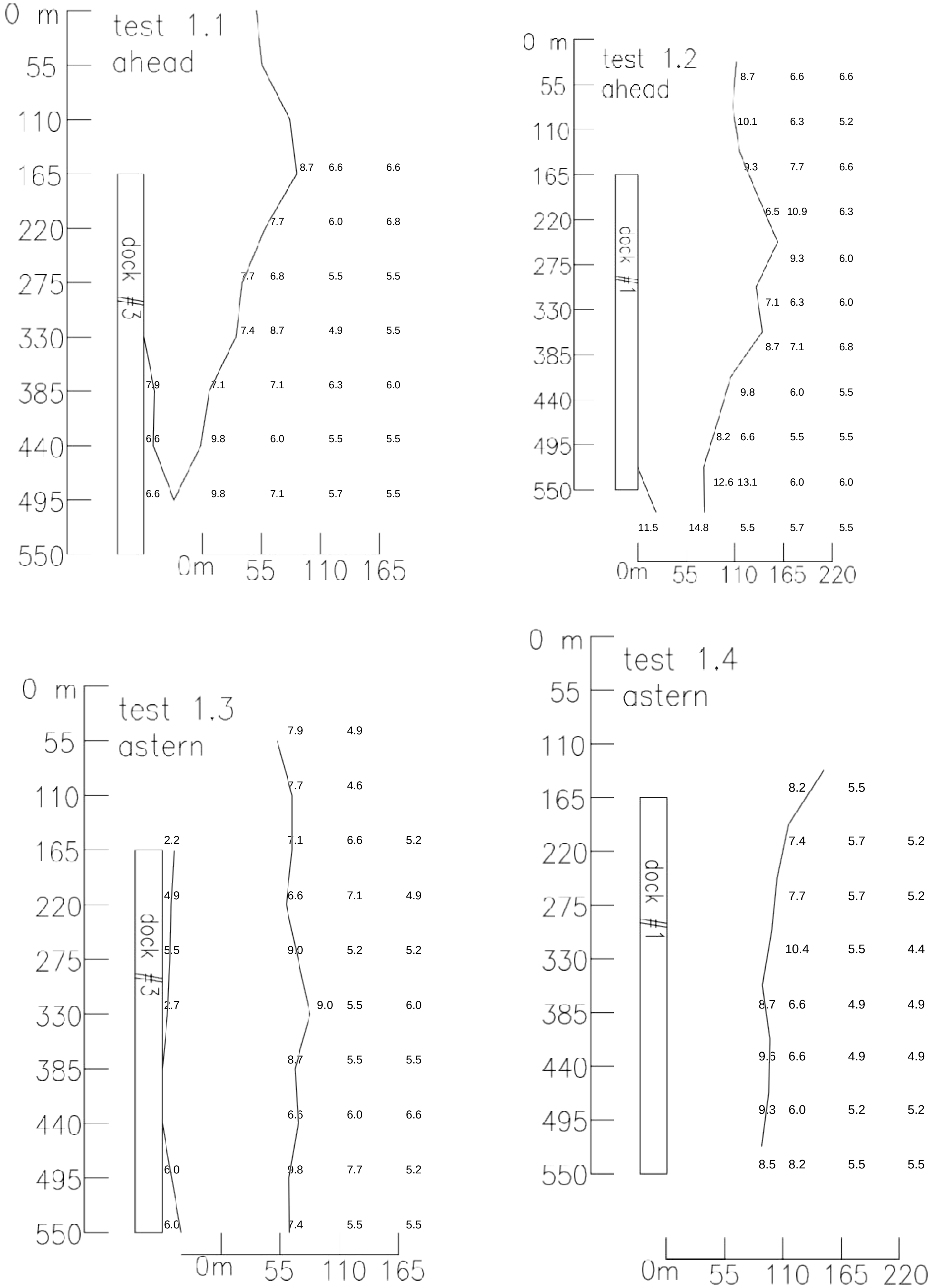

Figure 5-16: Measured tracks and thicknesses near the docks.

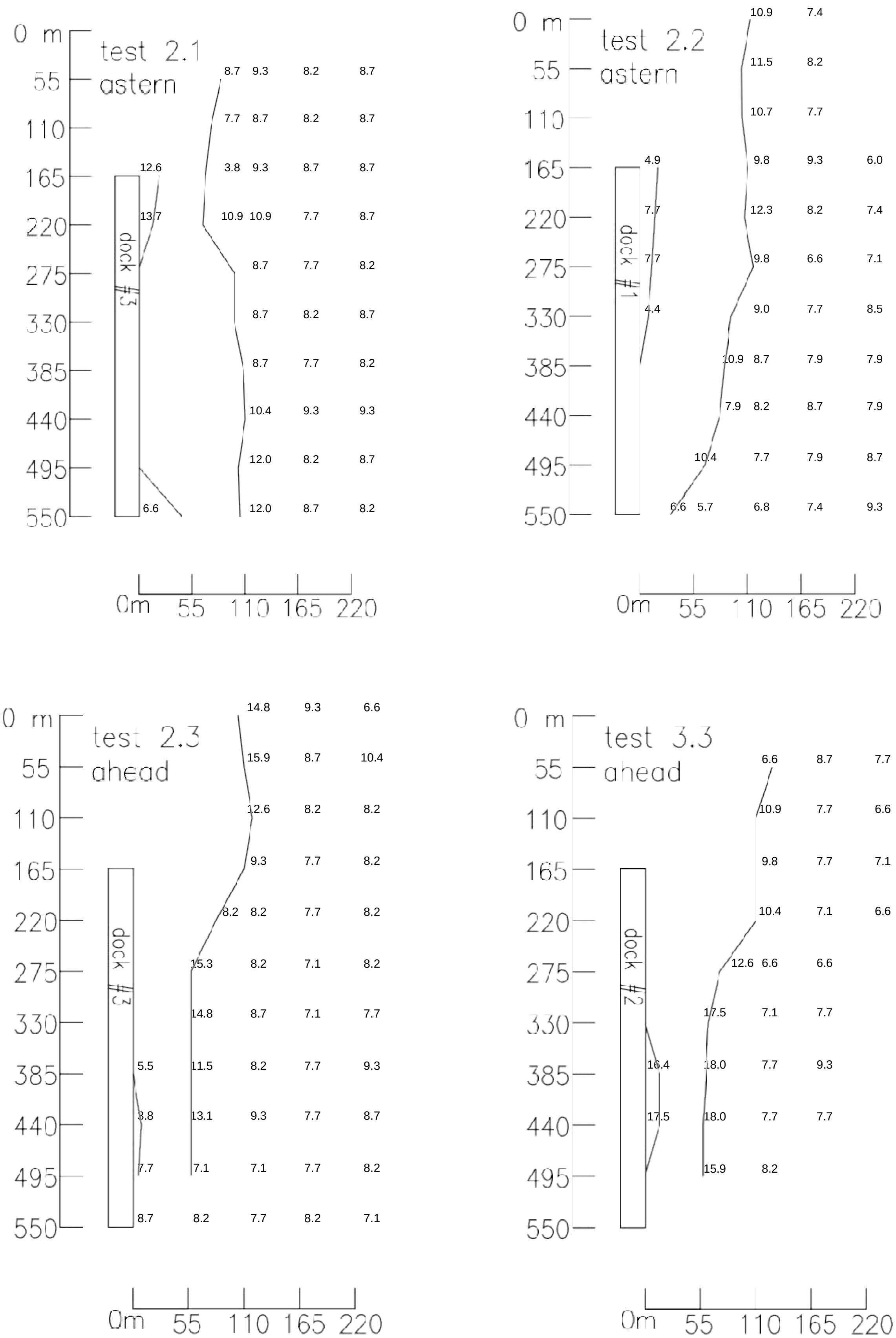

Figure 5-17: Measured tracks and thicknesses near the docks.

5.2. Manoeuvring tests

Manoeuvring tests were performed in 4 meter thick unconsolidated brash ice. Results and observations from manoeuvring tests are presented in below:

Test 5.1 Star Manoeuvre

Star manoeuvre was performed in DAS-mode. The shaft of the thruster representing the harbour tug for the following tests was producing extra resistance and therefore the power level was increased to approximately 2 x 16 MW.
The vessel was able to turn 180° in 4 h 35 min.

Test 5.2 Turning 180° with helping harbour tug in ahead mode

The vessel was inside untouched brash ice and tried to turn in conventional mode. The harbour tug was pushing the vessel from the starboard side in the bow. Thrusters were not turned as they were kept on a straight line. The starboard side thruster was rotating forward while the port side thruster was rotating backwards creating a turning moment. Three different tugs were tested: 50 ton, 100 ton and 150 ton. None of these were able to turn the vessel at all. In addition, a more powerful tug than 150 tons was tested but the pushing force is not determined as it was not possible to measure the rpm level of the propeller of the “tug”. Even this more powerful tug was not able to turn the vessel at all.

Test 5.3 Turning 180° with helping harbour tug (150 ton) in ahead mode in managed ice

As the vessel was not able to turn in untouched brash ice, it was tested in managed ice. Turning was done in the same spot where the star manoeuvre was done with 150 ton harbour tug. The vessel was able to turn approximately 90° in the relatively open-water spots but was not able to turn more when the bow was in contact with thicker ice. The whole test lasted 29 minutes and the vessel turned 90 degrees.

Test 5.4 Turning 180° with helping harbour tug (150 ton) in astern mode (DAS)

Again, the shaft of the “tug” was causing additional resistance and a higher power level was used (2 x 17 MW). The 180 degree turn was performed in untouched brash ice. The turn took 2 hours and 49 minutes.

Test 5.5 Tugs pushing the vessel to the dock #1 in managed ice

In this test the vessel first did ice management in front of the dock and then it was pushed to the dock by harbour tugs (discussed in chapter 4.6). The managed ice before the vessel was pushed to the dock can be seen in Figure 5-18. Thrusters were kept flushing to sides during to the pushing. The first push was aborted as there seemed to be too much ice between the dock and vessel. Therefore an additional flushing was done and the vessel was pushed to the dock on the second try. The measured forces needed to push the vessel to the dock as a function of time are presented in Figure 5-19. The maximum forces were: 2423 kN at the bow and 2859 kN at the stern. The whole test lasted (ice management and pushing to the dock) 3 hours 36 minutes.

Figure 5-18: The managed ice in front of the dock before the vessel was pushed to the dock.

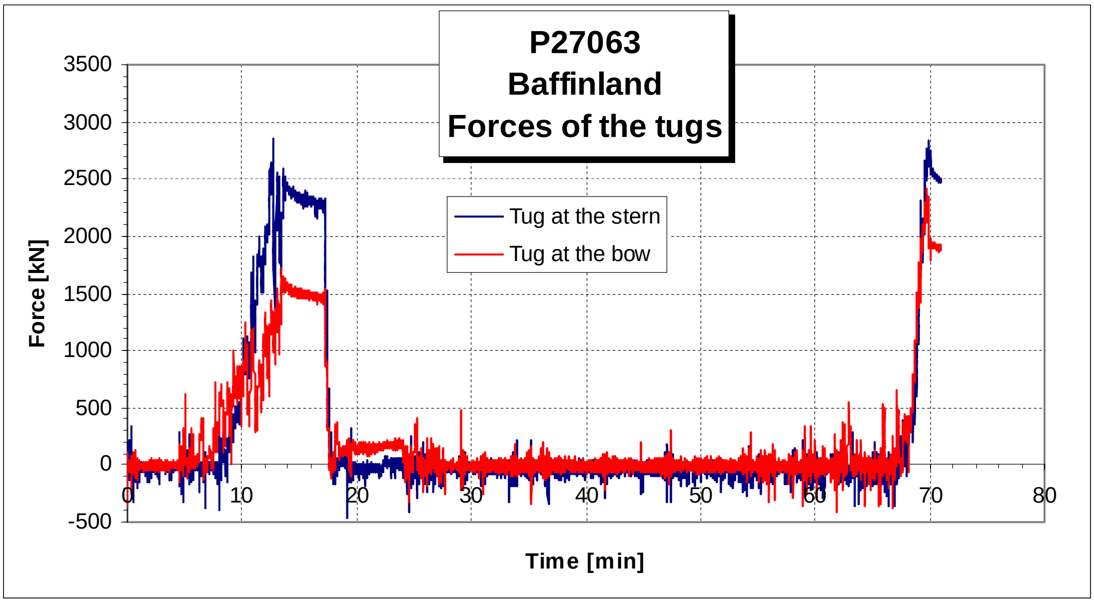

Figure 5-19: The measured forces of the "tugs" pushing the vessel to the dock. The first push was aborted as too much ice was still between the ore carrier and the dock.

5.3. Ice management tests

Ice management tests were also performed in 4 meter unconsolidated brash ice. Results of the ice management tests are presented below. The volume of cleared ice is determined by estimating the ice-free area from test pictures and comparing this area to the thickness measurements made before tests. Before test 6.1, a smaller power 2 x 5 MW was tested, but the test was stopped as no significant results were visible. Pictures of the ice management tests are presented below.

Figure 5-20: Test 6.1, 2 x 6.5 MW. Left: after 37 min; right: after 1h 14min.

Figure 5-21: Test 6.2, 2 x 10 MW. Left: after 37 min; right: after 1h 14min.

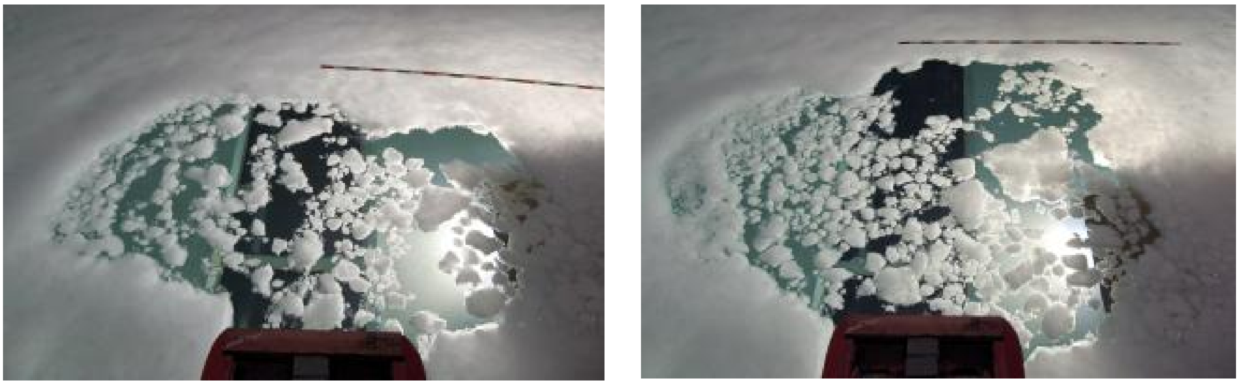

Figure 5-22: Test 6.3, 2 x 13 MW. Left: after 37 min; right: after 1h 14min.

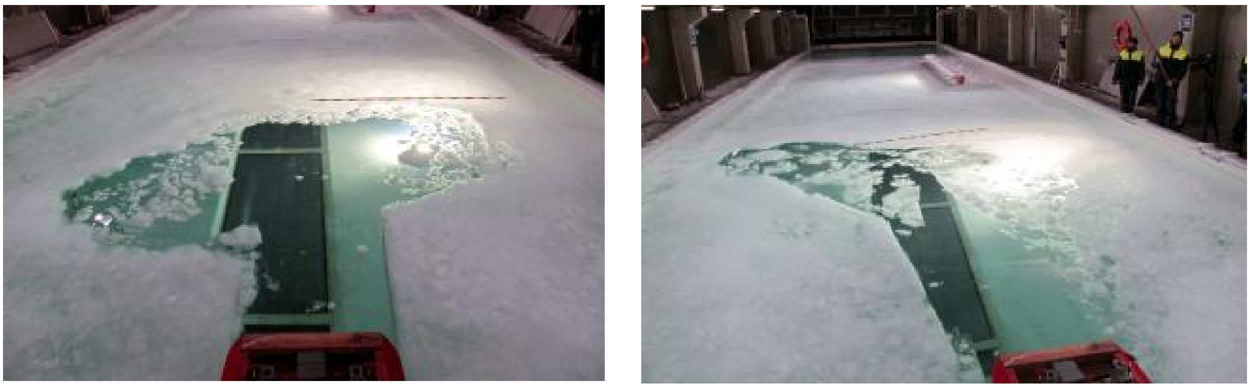

Figure 5-23: Test 6.4, 2 x 18 MW. Left: after 37 min; right: after 1h 14min.

Table 5-2: Results of the ice management tests. Before the test 6.1 a low power level of 2 x 5 MW was tested but the test was stopped as no significant results were visible.

Test #	Power	Cleared area in 37 min [m^2]	Cleared area in 1h 14 min [m^2]	Cleared ice in 37 min [m^3]	Cleared ice in 1h 14 min [m^3]
6.1	2 x 6.5 MW	1890	3140	10 350	17 150
6.2	2 x 10 MW	11 040	11 680	56 340	59 590
6.3	2 x 13 MW	10 310	15 120	60 850	89 250
6.4	2 x 18 MW	18 460	37 370	100 930	205 340

In latter part of test 6.4 the vessel was swinging from side to which allowed the vessel to clear large areas free from ice. While the vessel is flushing to the sides stationary, there is only limited width where ice can be cleared and nothing really happens after the maximum extent has been reached. This is clearly visible in the results of test 6.2 as the vessel has not cleared much ice away in the latter part of the test. In test 6.3, the vicinity of the dock and artificial bottom could have influenced the vessels ability to clear ice.

In test 6.5 the vessel (2 x 13 MW) was clearing ice in front of the dock #1, using swinging. The vessel was able to clear nearly 100 m wide area in front of the dock rather ice-free in 37 minutes. The managed area is shown in Figure 5-24.

Figure 5-24: The managed area in front of the dock after the test 6.5.

6. CONCLUSIONS AND DISCUSSION

The test results show clearly the following:

- Ice management at the terminal area is essential.
- With proper ice management any of the tested dock variants could be used.
- Ice management vessels should be relatively powerful.
- Docking time of the ore carrier is also dependent on the vessel concept type.

DOCKING TESTS
Both conventional and DAS-versions were tested during the docking tests. The DAS-version had a superior manoeuvrability in brash ice compared to the conventional version. The conventional version had difficulties to turning in the tested ice conditions. In addition, the conventional version was slow in shipping lane when approaching the dock and ramming was necessary in thicker brash ice, even though the vessel had a propulsion power of 2 x 30 MW. The full power was used also near the docks which is probably undesired in real-life and could be dangerous as sudden ice failures could cause accidents. The bow-first operation leaves more ice between the dock and the ship.
The DAS-version was able to manoeuvre better and flush the dock area more efficiently. Still, the bow of the vessel often was left some distance away from the dock.
It should be taken into account that in these tests a generic model representing different type of ore carriers was tested. More research should be carried out on different iron ore carrier concept types in order to have more conclusive results.

The open caissons allowed the ice to move better while with the solid face dock (dock #3) the flushing of the ice was difficult especially in thick brash ice. Docking to the dock #1 (8 x 10 m dia. columns) seemed to be easiest and also fastest based on the results. It allowed good ice movement and it was easy to flush. In dock #2 (8 x 10 m dia. columns) flushing was also efficient but the long span between the columns made the docking more difficult as the vessel was able to go between the columns. Especially the fenders made docking difficult as they were sticking out of the dock and it would have been easy to have a perpendicular collision with the fender as the ice was pushing the vessel to dock.

It should be also noted that the test results have a human factor in them and they are dependent also on skills of the captain.

MANOUEVRING TESTS
Again, the DAS-version was able to manoeuvre better as turning seemed to be impossible without thrusters. The conventional vessel was not able to turn even with help of harbour tug. For the DAS-version, the harbour tug decreased the time turn 180° by approximately 50%.

ICE MANAGEMENT TESTS
In ice management tests it was visible that the ice management vessel should have relatively high propulsion power. This allows the vessel to clear ice away from wider area around the vessel. Movements of the vessel also help in ice management as the swinging from side to side made clearing ice away from large areas at once relatively easy and quick.

Appendix D

Ice Management Workshop Agenda and Facilitator's Report

Facilitation Record

Baffinland Iron Mines Corporation
Mary River Project

Ice Management Workshop

Mississauga, Ontario
June 14th & 15th, 2011

Facilitated by:

Agree

Rick Russell

1-800-524-6967

www.agreeinc.com

Table of Contents

DAY ONE - Tuesday June 14th, 2011

Baffinland Introduction - Michael Zurowski

- Introduction to Baffinland

Workshop Expectations – Rick Russell

- Exploring versus debating orientation
- Guidelines for participation
- Working assumptions
  - How to have the discussions
  - Constructive participation
  - Get good information for owner
  - Share information and point of view

Overview of Baffinland Project - Harry Charalambu

- BIM is owned by Acerlor Mittal (70%) and Nunavut Iron Ore (30%)
  - Hatch is acting as the owners representatives
- Current project status of MRP
  - Current project phase - final feasibility
  - Construction schedule - Q1 2013 to Q3 2016
  - Doing some trade off studies to find the most economical dock
    - At the moment do not really see a distinction (from an ice point of view might have a better idea by the end of the day)
  - Have geotechnical information
  - There is an island so need to connect with a bridge
- Discussion of project overview (location environment, etc.)
  - Pre dock operations
    - Expect 18 mtpy of iron ore (potential to grow)
    - Ore carriers
      - Dedicated fleet of icebreaking ore carriers
      - Operating independently of icebreaker assistance
      - Ore dock structural options – dimensions
  - Port needs to work 12 months of the year, expect large ice breaking every 2 days or so – 149 km railroad built between mine and port
  - Stockpile iron ore at Steensby – have two locations to build
  - Severe climatic conditions – continuous day light and continuous darkness for a few months
  - Port site
    - Steensby inlet, stockpile on island, whole area is covered in ice (2m thick)
  - Done tradeoff studies to find out which is the more economical dock – don't see a distinction as of yet
  - Option 1 – ice is forced under structure – option 2 is face on

- Exporting 18 million tonnes a year but need the amount to grow
- Dedicated ice breaking vessels (7 to 10 vessels) in the winter – need to operate without assistance – to what extent do we need to manage ice in the port with other vessels?
- We cannot anchor to the ocean floor
- Every time you break through ice it re-forms thicker and thicker – how thick is the ice? How do we consolidate it? Passage through ice is a big issue
- Doesn't matter if we achieve consensus – as long as we are working in the right direction and look at developing techniques
- Berth dedicated to ore loading via travelling ship loader
- During completion of the DFS, three types of vessels were considered:
    - Diesel-electric ore carrier
    - Conventional arctic ore carrier
    - Double-acting arctic ore carrier (DAS)

- Current climate conditions
    - Continuous daylight: *May 5 to August 7*
    - Continuous darkness (with less than 2 hours of twilight): *Nov 12 to Jan 29*
    - Mean Temperature: *-30.9 °C (January)*
    - Freezing Degree Day: *>5600 (°C · day)*
    - Frost free: *late June to late August*
- Ice Management – Approach / Berthing
    - Controlling ice growth due to frequent traffic is a challenge as every time you break the ice it reforms thicker and thicker – how do we control this (Brash ice)
    - Approach channel (width, maximum number of passes)
    - Ice management, ice breaking tugs strategies and requirements
    - Ice management area for berthing
    - Berthing in fast ice / during ice break-up season
- Ice Management – Ore Carrier at Berth
    - Ice forces on ore vessels
    - Ice breaking tugs strategies and requirements (fast ice / ice break-up)
    - Ice management scheme (fast ice / ice break-up)
    - Ice management area
- Ice Management – Deberthing / Departure
    - Controlling ice growth due to frequent traffic is a challenge
    - Departure channel (path, width, maximum number of passes)
    - Conventional
    - Double acting ship
    - Ice management; icebreaking tugs strategies and requirements
    - Ice management area for deberthing
    - Deberthing in fast ice / during ice break-up season

- Approach for Ice Management
  - Based on known ice management approaches, not unprecedented
  - Application of these approaches to unprecedented operating conditions
- Workshop Overall Objective
  - To arrive at a consensus on the ice management methodology and equipment needed together with compatible dock designs necessary for the successful execution of year-round port operations in Steensby Inlet.
- **Questions and Comments**
  - Use a qualifier "unprecedented" is that related to frequency of shipment?
    - Nowhere near the frequency or the scale
  - Ship every 2 to 3 days, says that you will have some lost time and some loading time and de-balasting time– what sort of load rate are you looking for?
    - System we are currently looking at would operate at 16,000 tonnes per hour – may push it to 18,000 to 20,000 tonnes per hour
  - Looking at 107 loads per year so the frequency is about 1.6 days
  - Comment that they don't achieve that rate in Brazil where they don't have any ice

Overview of Ice Condition and Dock Designs

- **Ice Conditions at Port and in Approaches – Bob Gill**
  - Ice forms in a relatively quick manner – don't find deformation
  - No program of ice thickness as of yet (1.5 to 2.5 m in May)
  - Pond Inlet (further North) has smaller ice thickness (of concern for engineering aspects)
  - Steensby Inlet Ice Conditions
    - Inlet is covered with fast ice for approximately 9 months of the year; ice starts to form in mid to late October and clears by mid to late July
    - Fast ice extends southward to Koch Island, a distance of 35 nm; pack (drift) ice south of this
    - Ice in inlet is generally level with little evidence of deformation
    - To date, no program of ice thickness measurements in Steensby Inlet; have used other locations for preliminary design purposes
    - Historical ice thickness measurements at Hall Beach to the SW show end-of-winter thicknesses often greater than 2 m while measurements at Pond Inlet to the NE show thicknesses of 5 to 10 percent less, despite having a larger number of freezing degree-days.
    - Normal growth ice thickness is of more concern for design than for ship operations; brash ice build-up is the predominant concern for ice management in the port.
- **Questions and Comments**
  - Has there been any trend in thickness of ice in these areas?
    - No. We only have measurements from one month this year and as a result have been using measurements from other locations

- Observation of different ice thickness: two totally different geographic locations – different water circulation and water temperature

Overview of dock design and concepts - Bob MacCrimmon

- Solid / open face, concrete / steel caisson, etc. – different alternatives we are considering
- Picture (hung in meeting room) illustrates typical maneuvers that one may expect around the two dock locations
- Nothing is cast in stone
- Potential dock structures
    - Solid Face / Open Face
    - Concrete Caissons
    - Steel Caissons
    - Hybrid Steel/Concrete-Combination
    - Sunken Hull – various combinations

- **Questions and Comments**
    - What are the docks like that are now being used in the Arctic?
        - Many of them are solid sheet pile structures, sunken caissons
        - Most of the docks are nowhere near the depth that we need at Steensby
        - Example: Caisson dock used for summer season so when we started to ship year round there was concern about the ice being wedged in the middle of the dock and it has been subsequently replaced by a flat faced dock (before just made do with what the dock was because they couldn't afford a new one) – depth of water there was 12-13 m – ship does own ice management up to 2 meters – vessel is 225 m
        - Ice breaks off easier on flat face because you have one big solid piece of ice
        - Problem is that when vessel passes caisson the large piece of ice in the middle can flow out and reset
        - Have to be gentle with caisson
    - Dreaded pingos (permafrost under the dock) – do they occur here?
        - No they do not
    - Line handling – do you have line handler to accept lorry from ship? Does ship ever use propulsion units for ice management while it is tied up alongside dock?
        - Engine is kept running while it is parked – moved a meter all the time –effects loading but if you have an ice management vessel you won't need to move it
    - Parking lot – we have examined different ways of ice management to different degrees – other potential methods (engineering side) – raise temperature of water – are there methods that would reduce the need for ice management?
        - Thermal activity site – looked at using heat – learned from another project that you need to direct warm water to the underside of the ice in order to gain any efficiency in melting ice – need more warm water then what we have at our

disposal at Steensby –there has been talk of using bubblers but would be extremely difficult to use

- Explore geothermal and air bubbling as a way to reduce the need for ice management

How do the knowledge and experience of other regions translate to, or provide for Decision making at the project site?

Baffinland Ore Mine Loading Wharf – Captain Patrick, R.M. Toomey

- Ideal loading Berth
    - Align directly so ship goes straight in and straight out – impossible if have to get boat in on angle
    - Finger-pier is best solution – can use both sides of pier
    - Pessimistic about the number of boats to travel to the pier
    - Continuous pier built on top of solid cells of steel piling with space between, filled with crushed rock, capped with cement
    - Continuous pier with paved roadway and rails laid on top of cells, longer than largest vessel to use berth
        - That's so you can move up and down
        - They need to be strong they will take heavy loads
    - Need mooring dolphins with catwalks placed clear of each end of berth, with mooring bollards at frequent intervals along berth
    - Loading system should be able to load all the holds of any vessel alongside without moving the vessel
    - Submerged bubbler-system for full length of the pier on both sides to width of widest beam vessel to use berth
    - Difficult to do tight turning circles unless you have very powerful vessel – ship should go in head first
- The approach
    - Ice should be displaced on both sides by the arriving vessel
    - The vessel should make her final approach to the berth in a straight line from seaward so that she does not get rubble building up – can expect very thick ice rubble
- Very thick ice rubble in the river Dvina at Arkhangels'k , Russia in February, no way to flush it out – need to consider size and power of ship
- The departure
    - Backs out of berth in a straight line along the track she entered – need to turn 180 degrees in the turning basin
    - Berth built on cells as for Ideal Pier, for the same reasons
    - A turning basin of broken ice about four to five maximum ship lengths in diameter must be provided offshore from the berth
- Two other options
    - Berth parallel to channel

        - Advantages
            - Easy to build with simple interlocking metal piling
            - Ice-rubble can be cleared in favourable wind conditions
            - Unlikely to be damaged by ice-pressures during winter
        - Disadvantages
            - Difficult to keep ice away in unfavourable onshore winds
            - Difficult to berth/unberth in heavy ice if initial approach is at an angle
    - Berth in excavated basin
- **Questions and Comments**
    - What effect is putting large ballast dumping into icy waters?
        - Benefit, quantifiable? It is hard to say – more of a benefit if you pump it out on the surface – potential benefit is keeping the ship from freezing in – won't really assist with the ice management
    - Is most experience with conventional bows – can you speculate if recommendation would be different with different kinds of ships?
        - Yes experience is with conventional ships but different ships would probably work better in these conditions – would need to ask an expert who handles those
        - Experience from literature is that they would probably work better than conventional ships
    - At Steensby, will ships always be activating in rubble ice?
        - Yes, will need ice management to move ice offshore
    - As you approach Steensby you are limited by new tracks because it is only so wide – but once the ice is broken it comes up wet and you get thick ice rubble that acts like big cannon balls
        - Will have 8 to 9 parallel tracks by the end of the season – can use one track several times but rubble comes up and freezes which will limit the number of times you can use it
        - One way of doing it is to create a new track but still use old one

Experiences in Arctic shipping in European Arctic Ocean – Mikko Ninni

- Philosophy on how ice breaking was developed
    - Ice breaking is something that is not new – more than 120 years from across the world
    - Canadian technologies along the developments in Beaufort sea in the 80's (maximum power and thrust, ramming with the bow)
    - Main focus on high power in propellers
    - Traditional solutions can be used but they are expensive and lead to high emissions which is problematic

- More than 200 conventional ships were stuck this winter despite having icebreakers with them
- This led the Russians to using nuclear powered icebreakers
- Design philosophy in Europe was "what can you achieve with the least possible energy"
- This led to advanced hull forms and new propulsion systems and development of the independent stern-working Double Acting ships
- In 2002 new technologies were implemented in merchant shipping
  - Summer bow versus winter bow
- In the Baltic "Tempera" and "Mastera" set the "standard": This winter only they saved Russians from shutting down the Primorsk trunk pipeline - in 9 years no icebreaker assistance was needed

- Case Norilsk Nickel and Dudinka
  - Built 5 Norilsk Nickel – now in operation – operating shuttle system – old ships (Finnish-built SA-15 type Arctic General Cargo vessels) were very expensive and expensive to operate forcing to use extensive ice breakers
  - Operate between forward and stern mode – stern first in difficult ice
  - Operate between 10-12 knots
- Port of Dudinka
  - Managed ice but the fairway comes directly to the pier so they don't do turns in the port area
  - Use a former four screw 12,000 hp for ice management in the port terminal – always come into pre-broken ice – water is practically clear behind stern, use propeller to move ice away
  - Relatively small vessel compared to what we are discussing today
  - Haven't heard any critics that this system would not meet expectations
  - Today azimuthing thruster solutions are not yet ready for high powers in arctic conditions – therefore we need to cooperate with suppliers to create best possible solution
- In our opinion, Arctic LNG is a possibility
  - The screening studies have revealed that based on the stern-ahead-working principle in Arctic LNG transports would be competitive
  - Needs development – need more than 25 mw in power
  - Today´s azimuthing thruster solutions are not yet ready for high powers in Arctic conditions; therefore we need to co-operate with suppliers to create best possible solutions

- **Questions and Comments**
  - Not been able to duplicate same bubble tests or other tests in the same conditions that we will experience
    - We have been able to – will discuss later

Experience - Ari Malmi

- Block ice development mechanism when breaking ice continuously – more traffic means more compressed ice
- Control of the ice situation is most effective when directing the energy close to the quay line. Half of the problem is solved when ice collar developemet is controlled – then you get the vessel closer to the berth
- Ice preventing systems in harbours
  - Bubbling system (air compressor – hose – orifice pipe – air is released throught the pipe and buoyancy will create rising flow for air bubbles which leads to water circulation)
  - Flow and heat transfer by using cooling water from power plant
  - Discharge of cooling water from steel factory in Raahe harbour keeps harbour area mostly free of ice.
- Ice breaking usually occurs 1 to 2 hours before vessel arrival / departure.
- In difficult condition, ice breaking occurs justs before departure/arrival
- Other problems
  - Ice, snow and temperature

- **Questions and Comments**
  - How does the knowledge and experience provide direction? Hear more about buildup of brash ice – has it prevented ships from loading?
    - Look at Nordica in very hardest conditions it just takes more time but didn't stop operations
  - How heavy did brash ice build up to?
    - No systematic measurements – 12 to 15 m is filled with brash ice
  - We have been operating in ice conditions for last 30 years in Quebec – have flat dock and refinery dock – ice sometimes builds up to 10 m – ship at refinery is 150 tonnes – refinery dock works well because you can break ice inside beforehand. When the ship comes the ice gets pushed underneath. To work in brash ice you need power and weight and those types of ships aren't on the market right now
  - Key is in reducing density of ice as much as possible – can't do what you can with a small ship as what you can do with a large ship
  - Practicality of reducing ice thickness is zero – so we need to work around this issue
  - Maybe there are operational practices that you can use to reduce the amount of brash ice
  - Mikko – when vessels operate they turn first in the approach so the speed is reduced. What they do is they use one ice breaker for channel management before the vessel enters – so the ice moves for the vessel – no fixed ice in the way
  - When we are talking about brash ice and freezing temperatures – when you make open water you always make more ice
  - Encouraging to see the effects that the bubbler systems had

  - Parking lot – mentioned that under worse conditions get 10 to 15 m of brash ice – so considering frequency of movement here – the modeling that was done -- was there indication of how much brash ice we should expect?
  - Parking lot - revisit brash ice going down to the bottom – expect that this is due to the water and current being affected by turbulence from the boat. Will the brash ice accumulate at the bottom or is it river related?
    - Issue it that the brash ice has nowhere to go in Steensby and it is going to get worse every trip
    - Suspect that brash ice is cause by the river current – might not have the same problem at Steensby

Double Acting Tankers

  - Electric – can go from zero to full in 30 seconds – considerable advantage
  - Move 180 degrees in 30 seconds as well
  - Visibility in the winter due to fog is reduced but can see 200 m ahead using 3 search lights
  - Different approach for approaching – need two tug boats to remove ice between the jetty and the ship

- **Questions and Comments**
  - Open dock? – ice is pushed under jetty (should break ice beyond the jetty so there is more space to break ice and push it under)
    - Reduced time to make trips because you don't need to wait for ice breakers
  - Huge investment for ships – longevity and resistance to damage that may occur when operating in ice – how much damage has been noticed to propeller and azipod?
    - Coating wasn't perfect and needed re-painting, azipod needs overhauling every 5 years, no damage to the propeller at all
  - Is there any way you could improve the vessel to make it a bigger ship
    - Recommend two azipods
  - Would you also keep the bow thruster
    - Yes, for sure. Then you don't need any tugboats
  - How thick is the ice you are going through on average
    - Up to 120 cm of ice to 150 cm. Usually 50 to 80 cm of ice but travelling through high traffic areas.
  - There are two ice capabilities you need – for both the port area and getting through Hudson Strait – need to build a ship to deal with two types of ice
    - If you have a particular type of ship then it can assist with the ice management itself but there is no way around the fact that you need ice management
  - Anything can happen on a ship – need to consider what would happen if there was a ship break down on the dock – but you still need to clear the dock for continuous operations

  - Where do we put a broken down boat so that it doesn't freeze in during the winter?
  - "Dedicated and skilled crew" – where do you get them? How are we going to get a qualified crew and how are we going to keep them?
    - Trained a crew in 2003 and still using that crew for this year
    - Need in excess of 800 qualified people
    - In Finland have ice training courses
  - Need to stay focused on ice management around the port
  - Thinking of an insulated blanket at the dock (operate at high winds and extreme temperatures) that will stop the ice from developing. This means that the ship will need less assistance and will be able to berth on its own. Churning ice up in basin is a nonstarter. Solution needs to be technology borrowed from elsewhere and adapted to this situation.
  - Whatever is developed here needs to deal with the development of ice around the dock. First we need to know what amount of ice we are expecting.

Analytical Model for Brash Ice Buildup – Gus Cammaert

- Basis of Brash Ice Buildup
  - Repeated ship passages in an ice covered channel cause an accelerated ice growth in the ice track, and under the surrounding ice cover
  - A model which estimates the amount of brash ice which forms was developed by Jim Sandkvist, Lulea Univ., in 1983
  - The model was based on Baltic field programs in Lulea harbor, Sweden
  - The model has been tested again with available field data in 1999, and "was found to give reasonable estimates at the end of the navigation period"
- Been working on this model that has been verified in the fields
- Developed estimate for how much brash ice to expect
- Repeated ship passages cause increased ice growth
- Model is based on transits every 2.5 days
- The undisturbed ice sheet will grow to be about 2.1 m at the end of the season but with 2.5 transit days the brash ice buildup in front of the terminal is estimated to be 8m at the end of the season (other models have come up with more or less the same results – if you change transit or environmental parameters then it will be different)
- 8 m is kind of tough if we don't do anything about it
  - What about if you remove ice at certain intervals? (tested this in the tank)
  - 25% of brash ice removed once every 5 transits, 2m of brash ice will build up by the end of the winter (never want to go ice free because it will only increase the buildup) – therefore can have a certain amount of control
- By keeping IMV vessel stationary, and directing azipods sideways, brash ice was displaced more than 2x ship beam – power level for this test was 15 MW full scale (a lot of ice was pushed under surrounding ice sheet, therefore washed ice considerable distance away)
  - Need to develop strategy but theoretically it is possible to move ice

- It appears viable to use azipods on the IMV and the ore carriers to exercise a certain degree of brash ice transport
- Case 2
  - o With an objective of a maximum of 4 m of brash ice at the end of the winter, a revised ice removal rate could be established since less ice needs to be transported - would need to remove 25% every 14 transits
  - o Suggests that hypothetically we can control the ice and manage the ice by the main carriers themselves
- In the test, 25% refers to volume of ice – hypothetically you skim off a meter
- What happens to the 25% that is pushed away?
  - o The thicker the ice is, the slower it will grow. Let the ice grow thicker, further away from the port where you aren't trying to navigate
- The final brash ice thickness will depend on the % removed at certain intervals (measured as the number of ship transits between removals)
- The ideal situation is to remove as little ice as possible to retard the rate of brash ice buildup
- More work is needed along these lines but it is extremely promising – needs IMV and vessels to work together
- At 15 MW can push the ice up to 3x
- Tank was 2.1 m in depth
- **Questions and Comments**
  - o In practical terms how would the 25% removal work?
    - ▪ This is an arbitrary number – experience will tell us what number is ideal
    - ▪ How should it be done? It will be very uneven how much ice will be moved around.
    - ▪ Mass is already broken, therefore dealing with brash ice.
    - ▪ Ice blocks are fairly uniform. Each time IMV goes through the chunks of ice get smaller.
  - o Need very substantial scouring protection
  - o What depth was this scaled to (the water tank model)?
    - ▪ Started off with 4 meters, depth of the tank is 2.5 meters, 1-54 scale

Docking and Ice Management Tests – Goran Wilkman

- Objectives
  - o to compare three alternative dock designs
  - o to use 2 different ore carrier propulsion configurations
  - o to study the efficiency of ice management
- Measured how long it took vessel to get to dock
- On the repeat tests, the ice returned to starting point. Haven't considered 1.6 transitions a day just because we didn't have enough time – it is possible to do.
- Didn't have bow thrusters in non-tug phase
- In each test there is driver's error - everything is dependent on the skill of the captain

- Conclusions
    - Bow first operation leaves more ice between the vessel and the dock
    - Open caisson dock allows ice to move better
    - Smaller caissons seem to be better, longer span
    - Open caisson dock can be managed, better IMV could go even partly under the dock
    - Sheet pile dock can handle better accidental collisions
        - Ice failure may cause accidental movements
        - Dock should have a continuous fender
    - Ice management is one kind of insurance
    - In thick ice the IM vessel should have relatively high power
    - Pre-managing brash ice prior ore carrier arrival, especially close to the dock
    - Ice should be broken and moved but not fully destroyed, otherwise you have more and more ice accumulating in the place
- Significant difference between open dock and continuous face as you can get closer with open dock
- Ore carrier – big ship is quite rigid – smaller ship is easier to handle, hybrid propulsion
- Ice management vessels – one big c. 25 MW, two smaller, c. 10 MW (these two smaller tugboats can be used in the summer as well)
- **Questions and Comments**
    - Did you ever consider the repetitive use of the dock by the ship?
        - No, because you'd have to freeze the place and that would take a lot of time that they didn't have
    - Didn't have bow thrusters at this point (test results day 2)
    - Need to use 4 tugs to berth and unberth
    - Analysis and model testing was done side by side

Consensus

1. Ice Management off the dock is best done by "flushing" ice away from the dock (generic statement regardless of design of dock)
    - Assuming that this is the principle method, but not the only type of ice management
    - Y:16
    - ?: 2
        - o Haven't accepted the way the statement is written. The word best is bothersome. Would agree if the statement read "one of the best".
        - o If you get high winds then it isn't going to be very effective. Like the idea of using an IMV.
    - N: 0
2. Ice Management off the dock must be carried out by both the ore carrier and IMV
    - Y: 20
    - ?:0
    - N:0
        - o Don't use an IMV at Deception Bay due to the fact that they do not own one. If it fit into their budget then they would definitely use one.
3. Two ice management ships are required for dock ice management (as part of tug fleet)
    - Y: 20
    - ?:0
    - N:0
    - What form is the IMV? Need to decide what type of vessel it is before you decide whether or not one is sufficient.
    - Need to consider financial risk between having one or two IMV
    - Is it used purely for ice management or is it also used in the tug fleet?
    - Need to address redundancy – might as well have IMV in the tug fleet
    - If everything were great and we were sure nothing was going to break down then one IMV can do the job in the winter time
        - o What would be the minimum power requirement for IMV?
    - One of the issues is redundancy
    - If there is only going to be one IMV there is a tremendous risk that something is going to go wrong – risk is compounded in seasons when nothing else can come to take IMV out of ice– project can be shut down for months
        - o Think that there should be two IMV's – under sizing the project with just one IMV - take some of the risk out by just getting one IMV for the first season and purchasing the second in the winter or in the second season as need arises
        - o Assuming the two IMV's can be used in the tug fleet
        - o Need two robust IMV's and two robust tugs to start
    - What risk levels are they willing to accept for the whole operation?

    - Client has to make the decision – need to look at it from the other end of the telescope. We would have to recommend how many to use otherwise people would use one IMV because it is possible to obtain the tonnes required.
  - Idea of the IMV's is that they will serve multiple purposes
  - Robust = equipped for purpose (can't define it right now)
4. An air bubbling system should be investigated
  - Y:20
  - ?:0
  - N: 0
  - Air bubbling gives you ice management around the dock face whereas IMV's give you management in a much larger area
  - One of the things we looked at many years ago is an unsymmetrical ice management system – vessels coming in every few days – want to reduce the amount of rubble so when it is unsymmetrical you just push the rubble down the berth and it will go underneath – this creates a mound of ice off to one side – stays within manageable limits because it is only 1 foot at a time – piece of steel
    - May need to look at other systems
    - Aren't you creating a maximum amount of ice this way?
5. An ice management "plow" should be investigated?
  - Y: 17
  - ?: 3
  - N: 0
  - Is this a feasible idea?
  - Need to be careful because it is possible for the tug to be submerged
  - Interesting to see the brash ice test with the ice going
6. The preferred dock design
  - Closed face:
    - Y: 14
    - ?:5
    - N:1
  - Large Diameter Caissons
    - Y: 0
    - ?: 1
    - N:18
  - Small Diameter Caissons
    - Y:4
    - ?:17
    - N: 0
  - When you have small caissons there is more room for ice to move underneath and then behind. But need to consider if you are close to the island
  - Is there a difference between the continuous face and the partial face?

    - There is – depending on how your handling your ice management - everything can be done with the proper training and vessels
    - Have to be careful when coming in that you are hitting the right spot. Can't make ice management area too wide. Can make either one work
  - Dock design should be the most robust at the cheapest price. IMV's are going to take a lot of the problems away – no question.
  - Need to consider berthing times as well when thinking about dock design
  - Should we be considering finger piers? They have many advantages if it is a windy day.
    - Finger pier is a dock sticking straight out and using both sides. Finger pier would have to be located at the North dock (which is the more expensive option)
  - Fear of exerting excessive ice forces on a continuous face – if approach was not perfectly parallel – slightly angled
  - With a full face for IMV it is easy – you can go right up to the dock – but this is not always the case with a caisson – caisson is good if you have ships on both sides, otherwise there is no real advantage
  - Advantage to caisson: always a fear with a high class vessel that if you hit the dock and the caisson is wrecked completely – don't know which is easier to repair.
  - Cost difference between caisson and straight face dock
    - Depends on how you build it – cheap if you sink an old ship
  - Remoteness of location makes risk so much greater
  - Use Ice management before the ship gets in
  - Staying in thin ice is easier than open water because it is holding you in place

7. Energy absorbing fenders should be investigated. (too detailed of a question to explore further)
  - Y:
  - ?:
  - N:
  - We need energy absorption, which means money.
  - Continuous? Means fenders that are very close together.
  - Pneumatic fenders is the best option
  - Confused about what we are protecting the dock from? Is it a collision on arrival or on departure? Or is it so that ships can land between the fenders?
  - What is the right angle to come in on?
  - Fog is not an issue at the port

Parking Lot

- Raise temperature of surrounding water i.e. thermal warming nearby
  - How warm is ballast water?
  - What are the regulations around ballast water and exchanging it? Environmental issues surround this.
  - Vessel will change water in two suitable locations. Ships are built with ballast water treatment

- Geothermal technology?
    - Worth investigating
    - Heat is coming from the ground – need to drill down
    - Mike is looking into geothermal technology
- Air bubblers?
    - Voted that its worth looking at air bubblers
- How much brash ice do we expect to accumulate?
    - Already had a lot off conversation around this issue
- Will the brash ice accumulate at the bottom or is it river related?
    - This condition does not apply to Steensby
- Lack of current wind conditions to move brash ice
    - No natural conditions will effect brash ice at Steensby

DAY TWO - Wednesday June 15th, 2011

- Reviewing what was talked about yesterday but also looking more specifically at limitations and applications of peoples thoughts and ideas

Overview from Day One

- Decided that ice management is critical and you need both an ore carrier and IMV
- Need to get ice away from the dock whether it is by creating paths, using IMV – we must find a way
- Need at least two IMV's that can manage ice around the dock. They will be a part of the tug fleet. Still need to be decided whether or not more tugs are required
- Shied away from saying we MUST have air bubblers but they will be investigated. This is a low cost but may provide great benefits
- Concluded that boat ice-plows will be investigated
- Pertinent to the immediate phase of design is the consideration of dock design. Fairly unanimous is that a closed face dock should be used. Next best option was small diameter caissons.
- Comments:
    - Reasoning behind two IMV's is to avoid compounding problems

Can we, at this stage, recommend an appropriate ice management methodology in conjunction with dock design and vessel type and capability? (led by Gus Cammaert)

Discussions

- Vessel maneuvers at the dock
- Ice management at the dock
    - Primary method

  - Secondary methods
- Two Ice Management Vessels
  - Separate functions
- Turning basin
- Finger pier configuration

Vessel maneuvers at the dock

- Regardless of the type of ship, seems to be best if we go in straight – some distance from the dock – and then move in closer
- With IMV's it will be quite possible to get close to the dock on the first go
- Discussion that the IMV should be an azipod – it is an easier system to maneuver
- Have to consider that the IMV will also be a tug in the summer – this gives you a limitation in size as a large vessel in the summer would be useless
- How much water is available to starboard and port when you are making the final approaches? You can't decide on the vessel maneuverability without the wind, weather data etc.
- Power
  - Is there a consensus on what power the IMV's should have?
    - It is all about standard frame sizes
    - Need to start by looking at ice thickness before you decide what power you need
    - If you're breaking 1.5 m of ice then you will start at 12 MW up to 16MW
    - Fuel capacity will be a large consideration when determining the size of it
    - Ice will be broken and managed through the period (every 1.5 days) – at the most we will have 30 to 40 cm of new ice formed around the ship in an ice harbor that could be easily tended by the ice breakers
- Taking these ships on a large turning circle is a waste of time and money
  - From testing we are never dealing with solid ice, we are dealing with brash ice that is 4m or less
  - From records of McKinley bay – ice built up and the rubble got thicker and thicker, therefore breaking the ice continuously is not a good idea
- Before deciding how to approach and depart the dock, need wind and weather data – prevailing weather
  - Hatch is in the process of developing the proper charts – working on tides, wind, waves as we speak – not here right now but we are certainly aware of the need
- Intent of drawing was to look at turning radius and address challenges
- Have to have a basic approach philosophy and for different weather you will need to modify. We should discuss a basic approach given the best weather possible.

Ice Management Techniques

- Are we happy with just one primary method or is it necessary to discuss another method

- Secondary strategies
    - Is there a bubbler system deployed elsewhere?
        - In the Baltic – 100 m long bubbler system in wreckage water – relatively low cost – good to see empirical data
        - Have not been proven to be 100% effective yet
- Wasting time to further discuss as we have one primary method and secondary methods will be investigated

Two IMV's

- Need to serve two functions: ice management at dock and rescue capability
- Can have the ships the same but outfit the vessels differently – same shells with different equipment packages – may make sense to have different specialties for each IMV
    - Comment that it is better to have same equipment on both ships as you don't know when one will break down
    - From risk management point of view you need capacity to go rescue a ship. Charge ships if you are providing some sort of coast guard service
    - Have to investigate marketability

Concept of Turning Basin

- Ultimate turning basin will be function of ship design and maneuverability and captains' preference based on prevailing weather conditions
- Should we refer to model tests?
    - Showed what ships were capable of doing (turn within 2 ship lengths)
    - Ship requires a lot of effort to move – takes time
    - In principle – have to distinguish between at the dock and in the channel
        - Want to break more ice at the dock because it builds up more
    - Seems that in order to accomplish that – the best way to take the ship out is the longest way – which is also the most costly way
    - To the north there are a lot of shoals that aren't shown
        - Number of shoals off to the north
    - Need larger turning circle because of IMV
    - Dredging could be possible but there are no geotechnical info or bore holes up there for that
- Largest radius is 3600 m, intermediate is still 36000 m
- All things being equal - is a large turning radius better than a small one?
    - Is it land-fast ice? Yes, initially – unless we do something with it
    - Problem with the larger turning circle is that you are going to end up having several tracks and it will get ugly – but at least it will get ugly further away from the dock
    - There are places that are -13.5 m but for the most part it is -20 m which we should be able to get around just fine - so there are some very high points in the bay that need to be looked at – if they do exist then they should be avoided or they should be marked

- What's going to happen in practice is that the ship can turn very tight – as ice thickness grows then the turns will get bigger and bigger – it will regulate itself
- 40 ship lengths will be the turning diameter
- Wide circle (when ice conditions are the worst)
    - Y: 6
        - Idea is to get the ship away from the dock as soon as possible
    - ?: 8
    - N: 1
        - It will take greater amount of fuel and more effort with no outweighing advantages
        - Brash ice buildup with a tight circle will not be an issue because the IMV will be able to clear a circle
        - Argument is that IMV will be burning fuel clearing the area if you are marking tight circles – so fuel will be being burnt no matter what
    - Reservations on wide turning circle
        - Feel that you should take the appropriate departure depending on conditions
        - Two and a half ship length NW to the berth there is very shallow waters – physical restriction – feel it is an unnecessary risk to follow a very narrow passage
- Tight circle (when ice condition are the worst)
    - Y: 8
    - ?: 7
    - N: 1
- Can't further discuss vessel maneuvers without proper data

What are the potential limitations and risks (financial and environmental) associated with any recommended methodology and equipment?

- We've run a number of scenarios on what we think is going to happen
- Created a monthly analysis
- In winter time we are not operating at 1.5 day transitions, more like 4 day transitions – summer time has a lot more activity
    - Jan 8 loadings
    - Feb 6.4 loadings
    - April 7 loading
    - In the summer up to 14

RISKS	
Planning / Design	**Mitigation**
❖ **Ship Building – Over specify – we can ask for a little too much that isn't necessary and blow the budget**	❖ Focus on what is necessary and consider whether or not extra 'goodies' are necessary – if not, then it saves a lot of money as does the power requirement – it's all relative to the capital cost, running cost, number of people/crew, access of crews to vessels, outfitting
❖ **Ship operation side – dock design and the location of load on**	❖ Can mitigate issues with a longer loading arm - not too concerned about whether or not the ship can get that close to dock because all load arms are somewhat adjustable- ship size is likely going to vary
❖ **Dock design – alignment**	❖ Reliable data, research, site specifications (don't have a lot of leeway on the orientation of dock or location)
❖ **Off-shore geotechnical**	❖ More investigation (Hatch has a summer program in place)
❖ **Bathymetry**	❖ reliable return
❖ **Phase 1 needs to be up scalable (don't lose sight of the opportunity) – don't build too much flexibility**	
❖ **Human factor**	❖ Alcohol / drug free
❖ **Availability of crews**	❖ Training / retention of crew
❖ **Weather (currents, tides)**	❖ More studies need to be completed
❖ **Transport Canada Communication**	
❖ **Not having a necessary navigation system recognized by the Coast guard**	
❖ **Equipment breakdowns due to severe weather conditions**	❖ Redundancy, research on other ports 'tried and true' practices, appropriate maintenance and repair capacity (if you had spare on site – how are you going to put it on?) – at all locations need to be able to do everything yourself because no one is coming to help

Next steps

- Make sure we have proper hydrographic charts
  - How long before we have better data on area of focus?
    - We already have a lot of data. Problem is that the data hasn't been properly calibrated with hard data – all data doesn't necessarily match each other. Data needs to be titled properly.
- Are there going to be any aids to water navigation? Still need assistance regardless of the fact that there are now GPS's. Strong recommendation to have aids – especially ones that are lit.
- Complete geotechnical field work
- Detailed review of ship loading operations with respect to ice conditions (ex/ rails will freeze up) – integration of material handling and ice conditions (ex/ standoff)
- Ship loading reconciliation (cargo weight)
- Power of IMV's
- Modeling with regards to Ice management
  - What was the final view on optimum ship size?
    - 2 (1 with 52 m that will move 60% of load and 1 which is smaller that will be able to go into the rest of Europe and will move the remaining 40%)
  - Should sit down and talk to people who are doing ice management instead of doing testing
    - Idea that we should still investigate moving a portion of the ice through testing
    - There is nothing comparable to what we are trying to do
  - Do we accept proof of concept on using simulator
- Firm up dock design and design of IMV's and then reconsider model testing
- More detailed modeling work based on the best model available
  - Don't have 100 percent confidence – it is all based on brash ice buildup in ship track so there may be a better model that reviews brash ice buildup in a much larger area
- Full-proof simulations as proof of concept
  - Where?
    - MSRC in Quebec City
    - St.John's, Newfoundland
    - Holland College, PEI
    - Wallingford, England
- Lost time scenarios
  - Ex/ Ship loader, weather
  - Develop potential costs
  - BIM is using 300 days a year
  - 65 – 70% on the port without the merge (67% is the right number)
- Formal risk management studies
  - Some work done but it should be reviewed
- If possible, arrange a test voyage to Steensby

- Doesn't need to be done with an ore carrier but can be done with a capable ice breaker to see how it handles and what the area is like
- 1000 mile approach is the biggest problem, not the port
    - Because of the winter ice conditions in the Hudson Strait – will be the ultimate test
    - Will face all sorts of surprises in the Hudson Strait
    - Benefit of taking an ice breaker as a test voyage is that you will figure out more about ice management in the Hudson strait
    - Will get more data from a trial voyage than from anything else
    - People don't know how we can go forward without making this voyage – have to figure out to make it happen so the project can go forward – need information for a baseline
- Waste of time if trial voyage is to anywhere other than Steensby, so many considerations are site specific
- Explore how to make this possible – best month to do it is April

- Is a trial voyage to Steensby highly desirable
    - Y: 19
    - ?: 1
    - N: 0
- Should the vessel be a bulk carrier for the trial voyage?
    - Y:17
    - ?: 2
    - N: 0
    - The problem is that there is no ship that is available
- Will an ice breaker suffice for the trial voyage?
    - Y: 12
    - ?: 7
    - N: 0
        - From regulatory point of view it is dangerous, because if we make the initial test voyage(s) in an ice breaker, the license issued to us may *require* an ice breaker to escort bulk carriers and that would make the enterprise uneconomic

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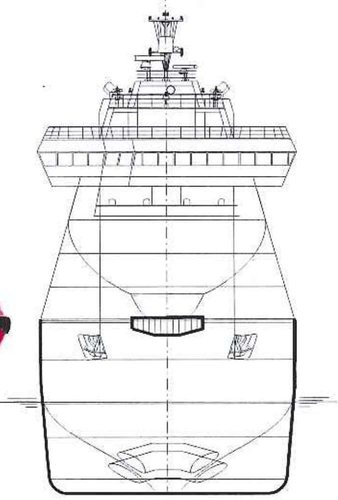
Appendix E

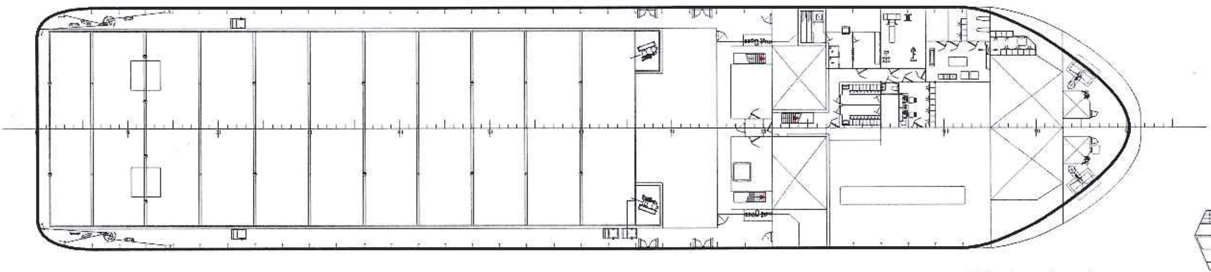
Example of Potential IMV

Aker ARC 105

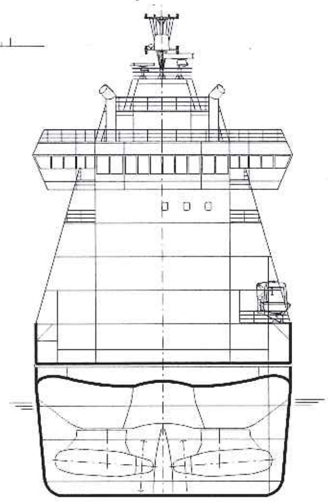
Icebreaking Platform Supply Vessel

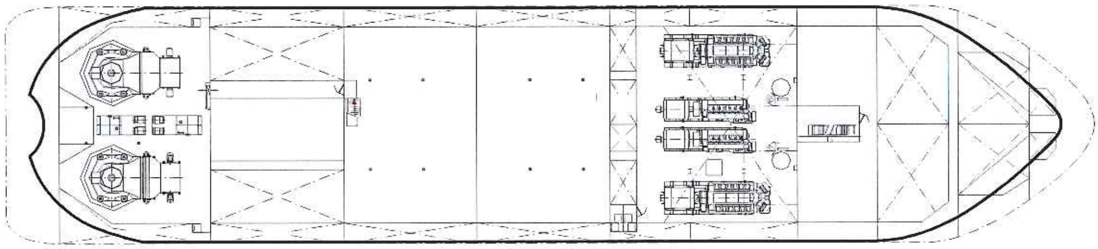
Aker Arctic





Main deck





Tween deck

Aker ARC 105 main particulars

Life saving appliances

Rescue boats	1 pcs
Lifeboats	2 pcs
Life rafts	4 pcs
LSA	38 pers.

Accommodation

Cabins	33 pcs
Captain class, single	2 pcs
Senior Officer, single	2 pcs
Officer, single	12 pcs
Crew, single	10 pcs
Spare cabins, single	2 pcs
Spare cabins, double	5 pcs

Machinery

Fuel MDO

Main engines

2 x12V32, 750 rpm, 6000 kW

2 x 6L32, 750 rpm, 3000

Total 18 000 kW

Propulsion

Azimuth thrusters 2 x 6500 kW

Bow thruster 2 x 1100 kW

Class Notation DNV or similar

1A1, Supply Vessel SF, Icebreaker ICE-10, E0, Standby Vessel, DYNPOS-AUTRO, E0, Winterized, DAT (-35°C), DK(+), Fire Fighter II, Deice, COMF-V(3), Clean Design, NAUT-OSV

Main dimensions

Length, overall about	99.2 m
Length, WL, 8.0 m	95.1 m
Breadth, moulded, 8.0 m	21.0 m
Breadth, max	21.7 m
Draught, design	8.0 m
Draught, scantling	8.2 m
Height to main deck	11.2 m

Tank capacities

Fuel oil	ca 1800 m³
Ballast water	ca 2500 m³
Stabilising water	ca 230 m³
Fresh water	ca 400 m³

Cargo deck

17.2 m x 52.5 m ca 900 m^2

Deadweight

At the design draught 8.0 m 4200 t

Deadweight distribution

At the design draught 8.0 m

Payload	
Deck Cargo	1500 t
Other Payload	1000 t
Ship Consumables	
Fuel oil	1500 t
Lub. Oil	40 t
Fresh water	100 t
Crew, stores, inventories and provision	20 tons

Speed, performance

Open water speed

16 kn at 90% of propulsion power

Ice-going properties

Astern

1.8 m level ice at 1 kn

1.6 m level ice at 3 kn

0.9 m level ice at 7 kn

Ahead

1.2 m level ice at 3 kn

0.6 m level ice at 8 kn

Endurance

Fuel stores are sufficient for 30 days operation at 65 % propulsion power.

Options

Payload section adaptable to owner specifications.

Length adjustable according to DWT requirement (+7.2 m, -7.2 m or -14.4 m).

Helicopter deck

Oil recovery functionality.