ICE OPERATIONAL CHALLENGES AND RECOMMENDED MITIGATION STRATEGIES FOR THE RORO FERRY MV QAJAQ W

FINAL REPORT

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PR-PO1-2018-01

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Executive Summary

Aker Arctic was contracted by Poseidon Marine Consultants Ltd. to conduct a study to assess the ice risk associated with the operation of the RoRo ferry “MV Qajaq W” on the Strait of Belle Isle route. Due to the safe track record of the “MV Apollo” on the same route for nearly 20 years, if the MV Qajaq W meets or exceeds the strength level of the vessel it replaces and is operated with the same level of caution in ice, the MV Qajaq W should be able to continue this safe operational track record in ice. In this scenario, a case to Transport Canada can be made that the MV Qajaq W satisfies the requirements of TP 8941E for the intended operational service.

To identify the ice operational risks of the MV Qajaq W relative to the Apollo, the vessel’s structural and propulsion configuration was compared to existing ice class rules and to each other. Based on the analysis of the ice class equivalency of the MV Qajaq W, the vessel exceeds the requirements for a Type B vessel.

Based on the analysis of the relative strength between the two vessels, the MV Qajaq is much stronger than the Apollo in terms of hull structure and propulsion train. This suggests that if operated with the same level of prudency as the Apollo, the Qajaq W should be able to continue the safe ice operational track record that the Apollo set originally.

To ensure continued safe operation of the ferry in ice, a number of mitigation strategies have been developed to further gain confidence in the ice operational safety of the MV Qajaq W in ice. The key strategies include training of the crew for safe and efficient operation of the ferry in ice to account for the vessel’s unique and different hull and propulsion configuration when compared to MV Apollo, and a more in-depth review of available data to confirm the assumptions made in this study.

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Abbreviations

ABL .... Above Baseline
ASPPR .... Arctic Shipping and Pollution Prevention Regulations
BV .... Bureau Veritas
DNV .... Det Norske Veritas
FSICR .... Finnish-Swedish Ice Class Rules
PC .... Polar Class

1 Introduction

1.1 Background

Poseidon Marine Consultants Ltd. (Poseidon) contracted Aker Arctic Canada Inc. (Aker Arctic) to conduct a study to identify ice operational challenges and mitigation strategies for the MV Qajaq W (formerly MV Grete), a RoRo ferry that is intended to operate in the Strait of Belle Isle between the communities of St. Barbe on the island of Newfoundland, and Blanc Sablon on the south east coast of Quebec near the Quebec/Labrador border. The purpose of this study is to conduct an ice risk assessment of the MV Qajaq W relative to the MV Apollo. Also, for identified areas where the ice operational risk could be reduced, a roadmap for recommended mitigation strategies is provided.

The MV Qajaq W is a DNVGL ice class ICE-1A double ended ferry that has been selected to replace the aging MV Apollo for the Strait of Belle Isle ferry service, beginning in early 2019. Currently the MV Qajaq W is completing refit and upgrades in Norway for Canadian service as well as regulatory approval for Canada flag.

All passenger vessels operating in sea ice regions of Atlantic Canada are expected to comply with Transport Canada's Transport Publication TP 8941E – "Interim Standards for the Construction, Equipment and Operation of Passenger ships in the Sea Ice Areas of Eastern Canada". The standard requires that the vessel is to have a minimum ice class equivalent to that of Type A ship as outlined in the Arctic Shipping Pollution Prevention Regulations (ASPPR).

Prior to the acquisition of the MV Qajaq W by Labrador Marine Services Inc., this route was serviced by the MV Apollo, a 1970-built RoRo ferry also operated by Labrador Marine. The ice class of the MV Apollo is BV Glace I, which is considered in the ASPPR as a Type B ship. The ice class of the MV Qajaq W is DNVGL ICE-1A which is considered under ASPPR as equivalent to a Type B ship. Labrador Marine was allowed to operate the MV Apollo based upon a policy decision granted by Transport Canada for exemption from the requirement in TP 8941E for the ship to have an ice class equivalent to a Type A ship, based in part upon a risk analysis conducted by Oceanic Consulting Corporation (see reference). The MV Apollo has since been safely operating in ice on the route with Canadian Coast Guard icebreaker support for nearly 18 years, through prudent operation of the vessel. Operations were from time to time suspended during peak winter season due to ice. This operating philosophy provides a solid basis for demonstrating that a ship strengthened to a level equivalent to, or greater than, the strength level of the MV Apollo is suitable for operation on the Strait of Belle Isle route through careful operation of the vessel.

1.2 Approach

Using the information provided by Poseidon, the latest classification rules, and the operational track record of the Apollo, the relative risk of operating the replacement ferry, MV Qajaq W, in ice is evaluated.

The premise is that the strength level of the existing ferry (MV Apollo) provides a conservative, minimum level of strength required for the Strait of Belle Isle service. Consequently if the replacement ferry (MV Qajaq W) meets or exceeds the strength level of the vessel it replaces and is operated with the same level of caution in ice, then a case to Transport Canada can be made that the MV Qajaq W satisfies the requirements of TP 8941E for the intended operational service.

This document summarizes the analyses performed to identify the risks of operating in ice for the MV Qajaq W on the Strait of Belle Isle route. Section 2 evaluates the ice class equivalency of the vessel based on the latest ice class rules. The 2017 Finnish-Swedish Ice Class Rules (FSICRs) were used for this analysis. In order to compare the strength level of the MV Qajaq W relative to the MV Apollo, an evaluation of the MV Apollo's strength was also performed using the same 2017 FSICRs, and is summarized in Section 3. Based on this analysis, a comparison between the strength of the structure and propulsion/machinery of both vessels was performed and summarized in Section 4. Section 5 summarizes the analysis and results of the operability assessment performed, which involved using different approaches to assess the ice risk of operating different ice class vessels in the ice conditions experienced in the region. Based on the analysis performed and summarized in the previous sections, Section 6 presents a roadmap developed to identify recommended mitigation strategies to reduce the risks identified for the MV Qajaq W operating in ice on the Strait of Belle Isle route.

2 Ice Class Equivalency Evaluation for MV Qajaq W

This section details the ice class equivalency evaluation of the MV Qajaq W. The aim of the evaluation is to determine the vessel Type according to Schedule 2 of the Canadian Arctic Shipping Safety and Pollution Prevention Regulations (ASSPPR) [1]. The structural and propulsion arrangements were evaluated against the latest 2017 Finnish-Swedish Ice Class Rules (FSICRs) [2]. According to ASSPPR, ice class IA Super in the FSICRs is considered equivalent to a "Type A" ship and ice class IA is considered equivalent to a "Type B" Ship.

2.1 Structural Evaluation

The MV Qajaq W is classed as a DNVGL ICE-1A ship. ICE-1A corresponds approximately to the FSICRs IA ice class; however, at the time of construction of the MV Qajaq W, the requirements in the FSICRs and the DNV rules had more differences than in the current rules. The primary difference between the DNV 2007 rules and the 2017 FSICRs are the shear area requirements for ice stringers and web frames (i.e. the strength requirements for the plating and framing are the same between the two rule sets).

The structural arrangement of the MV Qajaq W 's ice strengthening is consistent with the 2017 FSICRs design principles. The hull structure was evaluated according to the "Extension of Icebelt ICE-1A" plan provided in the Framing Plan (DWG.NO. 63230110). The plan meets the requirements of the current FSICRs with respect to extent of ice strengthened areas.

The Qajaq W is provided with Hemple Multi Strength ice abrasion resistant paint. This is an approved ice abrasion resistant coating and therefore the Finnish Swedish Ice Class rules would allow a reduction in the shell plate corrosion margin from 2mm to 1mm. This reduction has not been considered in the strength calculations. Therefore the strength comparison against the rule requirements is conservative.

The full results and calculations can be found in Appendix A.

2.1.1 Plating

The plating of the MV Qajaq W meet the requirements of a IA ship according to the 2017 FSICRs. The results are summarised in Table 1. Since the ship is symmetric about amidships, only the results for the positive frames are presented.

Table 1. FSICRs plate thickness evaluation for MV Qajaq W

Hull Area	Frame	Required Plate Thickness [mm]		Actual Plate Thickness [mm]	Ice Class
		IA	IA Super		
Midbody	0-8	10.7	13.5	13.0	IA
Bow	8-52	13.1	13.6	13.0	IA
Bow	52-56	13.1	13.6	14.0	IA Super
Bow	56-68	13.1	13.6	15.0	IA Super
Bow	68-72	13.1	13.6	18.0	IA Super

Table 1 shows that for much of the shell plating, the MV Qajaq W has a margin over the minimum requirements. It should be noted that the 0.1 mm difference between the requirement and the actual plate thickness for Frames 8-52 is acceptable and the plating is considered to meet the IA requirements. Despite being classed as a IA ship, the plate thicknesses from Frame 52-72 (the forward bow) meet the requirements of ice class IA Super. This additional strengthening at the bow appears to be a designer / owner's extra which is likely due to expected ice loads for the original service (possibly, but unconfirmed, higher transit speeds in ice and harder manoeuvring in ice to meet schedule demands).

2.1.2 Frames and Intermediates

Similar to the plating, all the frames and intermediate frames meet the requirements of a IA ship according to the 2017 FSICRs. The frames in the bows of the ship have large enough margin to also meet the requirements for the IA Super Class. This approach is consistent with the plate strength distribution adopted. Table 2 summaries the results of the ice class evaluation study for the frames.

Table 2. Summary of framing ice class evaluation for the MV Qajaq W

Hull Area	Frame	Scantling	Ice Class
Midbody	0-8	HP 180x10	IA
Bow	8-24	HP 180x10	IA
Bow	24-32	HP 200x10	IA
Bow	32-36	HP 240x10	IA
Bow	36-52	HP 220x10	IA
Bow	52-56	HP 220x10	IA Super
Bow	56-68	HP 240x10	IA Super
Bow	68-76	HP 260x10	IA Super

2.1.3 Web Frames and Ice Stringers

The ice stringers which support the ice frames meet the design principles of the 2017 FSICRs and the section modulus requirements for ice class IA. However, in the Bow Regions of the ship, the stringers do not meet the shear area requirements of a IA ship, as seen in Table 3. The shear area requirements are one part of the ice class rules that differed significantly between the 2007 DNV rules and the 2017 FSICRs. The difference stems from the factors used to account for load sharing between the frames and the stringers. The MV Qajaq W meets the requirements of the rules to which it was classed. It should be noted that this is to be expected for a ship designed to a different set of ice class rule requirements than the FSICRs. In terms of equivalent strength, the Finnish and Swedish authorities (as with Transport Canada) would consider a DNV ICE-1A equivalent to a FSICR IA ship, i.e. the difference in ice stringer requirements is not considered significant enough to affect the overall strength of the ship (i.e. both ice stringer configurations provide a sufficient level of structural support for the ice strengthening frames to be effective).

Table 3. Summary of shear area requirements for stringers on MV Qajaq W

Hull Area	Frame	Scantling	Shear Area Requirement [cm^2]		Actual Shear Area [cm^2]
			FSICR 2017 IA	DNV 2007 IA	
Midbody	0-8	T370x10+150x10	30.0	13.9	37
Bow	8-76	T370x10+150x10	49.5	22.9	37

The same principles for the shear area requirements apply to the web frames. The current web frames do not meet the shear area requirements for current IA ships in the 2017 FSICRs; however, they meet the DNV ICE-1A requirements from 2007, as shown in Table 4.

Table 4. Summary of shear area requirements for web frames on MV Qajaq W

Hull Area	Frame	Scantling	Shear Area Requirement [cm^2]		Actual Shear Area [cm^2]
			FSICR 2017 IA	DNV 2007 IA	
Midbody	0-8	T500x12+250x20	57.7	23.9	60
Bow	8-36	T500x12+250x20	78.3	39.5	60
Bow	36-48	T500x10+200x15	80.4	40.5	50
Bow	48-52	T600x10+250x20	51.8	26.1	60
Bow	52-68	T500x10+200x20	52.0	26.2	50
Bow	68-76	T600x10+200x20	52.8	26.6	60

The section modulus requirements are met for ice class IA in the entire ship and the web frames have enough of a margin to meet the IA Super requirements in the two bows.

Frame +/- 40 should be noted since the structural plans are somewhat ambiguous with respect to frame span and support. It is assumed that the structure meets the requirements for an ice class 1A ship, since the surrounding structures have a sufficient margin over the rule minimums.

2.2 Propulsion Evaluation

To evaluate the strength of propulsion, the propellers of the MV Qajaq W were compared to the current ice class rules (2017 FSICRs). In general, the design principle for all propulsion lines, especially ice strengthened ones, is the pyramid strength principle, meaning that all other components are designed to be stronger than the propeller blade, and to survive a blade breaking. Thus, a comparison of the propeller will also give an indication of the strength of the other propulsion components such as shafts, gears and couplings.

For the MV Qajaq W, which has two propellers due to the CRP propulsion, only the larger propeller was analysed based on the assumption that both propellers should have similar strength since they have been designed to the same rule basis. The thrusters of Qajaq W are of pushing type, and it was considered that in view of the current ice class rules, which base the propeller design on assumption of blade impact with certain size ice piece, the design scenario for both pushing thruster propeller (MV Qajaq W) and a traditional shaft line propeller (MV Apollo) is similar, and thus the designs can be compared. It should be noted that in case of heavy ramming in thick ridges or rubble ice conditions under ice pressure, the bow propeller of MV Qajaq W might encounter higher loads. Such scenarios should be avoided if possible.

Propeller design methodology of the FSICRs has developed over time along with increasing measurement data, research, and service experience of propellers in ice, leading to a greater understanding on the ice loads. It can be confidently assumed that the propellers of the MV Qajaq W (designed to DNV 2007) and the MV Apollo (designed to

BV Glace 1 1982 / FSICR 1971) are designed to the rules that were in force at the time of construction and fulfil the requirements that were set at that time., For consistency of strength comparison propellers of both vessels are compared using the most recent FSICRs (2017).

For both propellers, the blade parameters were gathered from drawings and information provided by Poseidon, with missing parameters estimated from the provided photos and based on experience and comparable propellers in Aker Arctic's database.

As the actual propeller blade geometry was not available for either propeller the propeller scantlings, in essence the ct^2-values (chord length * $thickness^2$) for the blade sections were estimated by using the relevant rules that would have been used when the ship was designed. It was assumed that the actual propellers were designed to exactly meet the rule minimum requirements.

The main parameters for the MV Qajaq W's propeller are shown in Table 5 and photographs of the propeller and thruster in Figure 1. A total power of the thruster, 2000 kW, was divided among the two CRP propellers relative to diameter and assuming that both propellers have same torque coefficient, resulting in 1309 kW for the 2500 mm propeller and 691 kW for the 2200 mm propeller.

Figure 1. Propeller and thruster of MV Qajaq W.

Table 5. Main parameters of the MV Qajaq W's propeller

Parameter	Value & unit
D	2500 mm
d_{hub}	893 mm
P	1309 kW
n	196 rpm
EAR	0.545
Z	4
$P/D_{0.7}$	1.241
Skew	22°

In the current version of the Finnish-Swedish ice class rules (2017), the propeller strength outside 0.5R is evaluated with finite element analysis, and inside 0.5R with rule formula. As the propeller information available was not complete (and a full finite element analysis on an assumed blade shape considered unsuitable), the propeller evaluation was based on the analytical rule formulation, which was used to compare the propellers at 0.35 R and 0.6 R radiuses. It should be noted that the analytical formula is meant to be used on radiuses between blade root and 0.5 R, and is here used slightly outside its range of applicability at 0.6 R. However, the results show that 0.35 R section is the limiting factor for all cases and would be even if 0.5 R section would be also calculated. Furthermore, as the comparison is relative, Aker Arctic considers this an appropriate tool for the purpose of comparing strength.

The tip of the propeller has not been considered in the analysis, due to the lack of data. Thus, the assessment of the propeller strength is limited to inner sections of the blade. Given that the rules used for the design of MV Qajaq W do consider the effect of propeller skew, it is likely that the tip is at least reasonably strong and should be suited for ice navigation, although quantitative assessment is not possible.

According to the drawings, the material of the propeller is Ni-Al Bronze, i.e. standard propeller bronze CU3. The standard yield strength is 245 MPa and the ultimate strength 590 MPa. Thus, the allowed stress for the blade is 294.6 MPa.

The required ct^2-values are compared to the actual ones in Table 6. It should be noted that the "actual" values are not based on drawings but the rule minimums from the relevant rules for which the vessel was designed originally (i.e. the actual requirements for 1970 and 2007). Thus, the actual propeller might differ from the values presented here. Full calculations are shown in Appendix A.

Table 6. Calculated ct^2-requirements for ice class 1A (FSICR 2017) for the MV Qajaq W, compared to actual (derived from ship rule minimum) ct^2

Location	Actual ct^2 (cm^3)	Required ct^2 (cm^3)	FOS
0.35 R	8742	5880	149 %
0.6 R	4576	2205	208 %

It is seen that the propeller strength level of MV Qajaq W meets the requirements of the current FSICRs for ice class IA and exceeds those by quite a margin. Therefore, and to assess how MV Qajaq W compares to requirements for Type A ship, a comparison to current IA Super requirements was also made. The results for that comparison are shown in Table 7.

Table 7. Calculated ct^2-requirements for ice class 1A Super (FSICR 2017) for the MV Qajaq W, compared to actual (derived from ship rule minimum) ct^2

Location	Actual ct^2 (cm^3)	Required ct^2 (cm^3)	FOS
0.35 R	8742	7296	120 %
0.6 R	4576	2736	167 %

As can be seen, the propeller strength level of MV Qajaq W meets the requirements of the current FSICR 2017 for ice class 1A Super for root and mid parts of the blade, assuming that it was originally designed to the relevant rules in force during construction, i.e. DNV ICE-1A 2007. Information of the real ct^2 values for the blade would be needed for a conclusive result, but the indication is that the propellers and thus whole propulsion of MV Qajaq W should in general meet the requirements of current FSICRs ice class IA Super.

Based on the propeller having ice class DNV ICE-1A, the propeller can be considered to meet the requirements for Type B vessel. Moreover, the analysis results indicate that the propeller is likely to meet the requirements of current IA Super according to FSICR 2017, and thus it could be considered that the propulsion of MV Qajaq W is likely to meet the requirements for Type A vessel.

2.3 MV Qajaq W Ice Class Equivalency Summary

Following the evaluation the following conclusions are drawn:

- In general the Structure of MV Qajaq W is equivalent to a strength level of ice class IA (FSICRs).
- The bow of the MV Qajaq W (both ends) is considered equivalent to a strength level of ice class IA Super (FSICRs).
- The propeller blade (and by assumed extension the remainder of the propulsion system) is considered equivalent to a strength level of an ice class IA Super (FSICRs) ship. However, it should be noted that this analysis is based on limited availability of data and assumptions with regards to the blade geometry.

From the above conclusions it appears that the bow area and propulsion system (which is located in the bow) has been strengthened above the rule minimums for an Ice Class ICE-1A ship. This is likely due (Aker Arctic's opinion) to owner's additional requirements during design/construction reflecting the anticipated operation of the ship on it's originally intended route.

From a compliance perspective, the MV Qajaq W would be considered as that of a Type B ship according to Schedule 2 of the Arctic Shipping Safety Pollution Prevention Regulations [1].

3 Ice Class Equivalency Evaluation for MV Apollo

3.1 Structural Evaluation

The MV Apollo is a vehicle/passenger ferry built in 1970 to the Bureau Veritas (BV) Ice Class Glace I (considered by Finnish and Swedish Maritime authorities equivalent to an ice class IA ship). At the time of design, the ice scantlings were designed based on a percentage increase in strength over the open water scantlings. The design philosophies for ice-going vessels have evolved significantly since the construction of the MV Apollo. Therefore, more discrepancies are expected between the MV Apollo's structures and the 2017 FSICRs ice strengthening requirements than for MV Qajaq W.

To evaluate the ice class of the vessel, the hull was divided into Bow, Midbody and Stern regions according to the 2017 FSICRs. The Bow area extends from Frame 79 to the forward extent of the ship. The Midbody is between Frame 44 and 79 and the stern from the aft extent to Frame 44. For calculation purposes, each area was subdivided further based on cohesiveness of the structures and the frame spacing. Figure 2 shows the division of the MV Apollo into the different ice belt regions.

Figure 2. Structural subdivisions for MV Apollo

According to the 2017 FSICRs, a IA or IA Super ship with a design speed of 18 knots or higher requires an Upper Bow region designed to the requirements of the Midbody. This area extends 2 m above the Upper Ice Waterline and at least 0.2L aft of the FP. The Upper Bow ice belt region does not exist on the MV Apollo and the open water scantlings do not meet the requirements for a 1A ship. This is to be expected as this is a relatively new inclusion in the FSICRs.

The yield strength of the steel plate was not indicated on the construction drawings, and therefore, mild steel with a yield strength of 235 MPa was assumed for all steel structures. This is considered consistent with build and construction practices of the time (1970) where the use of high tensile steels was not commonplace. If any material other than mild steel had been adopted it would have been clearly evident on the ship's construction plans and would be required to be written on the midship section (which it is not).

It was assumed that there is no ice abrasion resistant paint on the hull of the vessel, and therefore, the corrosion margin is 2 mm.

Due to the significant differences in design principles between the 1960s and present day, most of the MV Apollo's ice strengthened structures do not meet the 2017 FSICRs requirements for an ice class IA ship. The following sections present the detailed results of the class equivalency study for the MV Apollo. The full results and calculations can be found in Appendix B.

3.1.1 Plating

The minimum plate thicknesses for the shell plating of the MV Apollo were calculated according to the 2017 FSICRs ice class IA requirements. A comparison between the required and the actual plate thicknesses is given in Table 8.

Table 8. FSICRs IA plate thickness requirements for MV Apollo

Hull Area	Plate Thickness Requirement [mm]		Actual Thickness [mm]	Ice Class
	IA	IA Super		
Bow I / II	16.7	17.2	19.0	IA Super
Bow III / IV	17.6	18.1	19.0	IA Super
Midbody	13.6	15.1	16.0	IA Super
Stern I	12.2	13.3	12.5	IA
Stern II / III	11.6	12.7	16.0	IA Super

As shown in Table 8, the plate thicknesses of the MV Apollo exceed the ice class IA requirements, and therefore, the structures were also verified against the IA Super requirements. All shell plating of the MV Apollo meets the IA Super requirements for thickness. One strake, between Frame 31 and 43 that has a thickness of 12.5 mm would not meet the ice class rule requirements, however this strake is almost entirely below the ice belt: It is likely that the original ice class rules had a lesser extent of ice belt below the Lower Ice Waterline and consequently this strake would have been considered outside of the ice strengthening region. In Aker Arctic's opinion this single non-compliant strake at the lower edge of the ice belt does not affect the ice class equivalency result.

Appendix B provides an annotated shell expansion summarising the compliance of the installed plating on the MV Apollo against the FSICRs.

3.1.1 Frames

The frames and intermediate ice frames were evaluated based on the divisions presented in Figure 2. While some areas of the midbody and stern regions meet the ice class IA requirements, generally, the frames did not meet the requirements for an ice class IA ship according to the 2017 FSICRs. For regions that did not meet the IA strength requirements, an appropriate ice class was determined.

In the structural arrangement of the MV Apollo, there are two stringers within the ice belt: one T-bar (T 500x9 + 200x10) at approximately 4000 ABL and one bulb profile at approximately 2800 ABL. Typically, the span of the ice frame would be defined by the ice stringers that provide end supports to the frames; however, the stringer at 2800 ABL does not effectively provide fixity for the ice frames. Thus, only the decks and the stringer at 4000 ABL are considered as the load carrying structures. The span of the ice frames is exceptionally long, particularly below the Zwischendeck (Tween deck), and the required structural capacity due to bending (section modulus) is increased significantly. The stringer at 2800 ABL, however, provides some benefit to the frames by distributing the load and should not, in Aker Arctic's opinion, be neglected entirely.

To account for the load distributing ice stringers found at 2800 ABL and in the Stern ice belt, the required section modulus and shear area for the ice frames was reduced by 15%, but the span of the frame was taken between the two supporting decks. The reduction is based on a study of the Polar Class (PC) Rules where there are two factors for frames depending on whether load supporting stringers are present. For arrangements where a load distributing stringer is present, the framing requirements were lowered by approximately 15% compared to arrangements without the stringer. In Aker Arctic's opinion this is an appropriate adjustment to enable some load sharing capacity to be recognised in the structural arrangement. The reduction was applied in the FSICRs class equivalency study of the MV Apollo's structures. This conditional class is denoted as (IA) in the results.

The results for the MV Apollo are presented in Table 9. The lowest ice class for each region is given. Appendix B provides the full annotated shell expansion.

Table 9. Summary of framing ice class equivalency study for MV Apollo

Hull Area	Frame Spacing	Scantling	Ice Class
Bow I	600 mm	HP 160x9	<IC
Bow II	600 mm	HP 180x8	<IC
Bow III	650 mm	HP 180x8	<IC
Bow IV	650 mm	HP 160x9	<IC
Midbody I	650 mm	HP 160x9	IB
Midbody II	650 mm	HP 160x9	IB
Midbody III	650 mm	HP 180x8	IC
Stern I	650 mm	HP 200x9	(IA)
Stern II	600 mm	HP 180x8	(IA)
Stern III	600 mm	HP 180x8	(IA)

3.1.2 Web Frames and Ice Stringers

The web frames and ice stringers of the MV Apollo do not meet the requirements of the 2017 FSICRs.

The web frames fail both shear area and section modulus requirements. The web frames within the ice belt of the Apollo are bulb profiles that are only slightly larger than the frames.

Due to the lack of load carrying capacity of the web frames, the span of the T-bar stringer at approximately 4000 ABL is taken between the bulkheads. The large span results in very large section modulus requirements, which the stringer does not meet.

The stringer at 2800 ABL is a bulb profile that varies in size to match the ice frames. The lower stringer does not meet the design principles of present-day structural arrangements and is not considered effective. This is to be expected, given the age of the ship and the ice class rules used during the design of the ship in the 1960s.

3.2 Propulsion Evaluation

The same methodology used to evaluate the propulsion system of the MV Qajaq W was used for the MV Apollo, described in Section 2.2. Using the 2017 FSICRs as a basis of comparison, the minimum requirements needed to meet a IA and IA Super ice class were determined.

One of the greatest challenges associated with the evaluation of the propulsion system of Apollo is the limited data available on the ship’s propellers and propulsion machinery updates. The whole propulsion system of MV Apollo has been renewed in 1982, including main engines, gearboxes and propellers. The original propulsion had directly coupled Deutz diesels operating at 350 rpm, coupled to CP propellers made of chromium steel. The new propulsion has MAN medium speed diesels coupled via a gearbox to CP propellers made of stainless steel (based on observations on the photos provided). Moreover, one of the 1982 MAN diesels is still in operation while the other one has been changed to Wärtsilä around 2003. It has been assumed that while the Wärtsilä engine is slightly more powerful than the MAN, it is operated at the same rated power as the propulsion system components are likely to limit the power to that.

The propulsion renewal invalidates most of the information on the provided original drawings, and the analysis should be viewed more as indication of the probable strength level of the propulsion rather than accurate assessment of the actual strength.

The ice class of MV Apollo is BV Glace 1, which is considered equivalent to FSICR IA. It is assumed that during the 1982 repowering, the propulsion has been designed to the rules that were in force at that time rather than the rules that were in force when the vessel was originally built. This is consistent with Aker Arctic’s understanding of classification society approaches when a ship is re-engined. As BV rules from 1982 were not available, it has been further assumed that the propeller design corresponds to the FSICRs that were in force in that time, i.e. 1971 FSICRs. It should be noted that while these two rules are in principle equivalent, some differences would be expected to exist and that might affect the results of the analysis.

The main parameters for the propeller for MV Apollo are shown in Table 10 and photographs are shown in Figure 3. Based on the limited amount of data available on the ship’s propellers, some of the parameters were estimated in order to develop representative characteristics of the propeller used in the analysis.

Figure 3. Propeller of MV Apollo.

Table 10. Main parameters of the MV Apollo's propeller

Parameter	Value & unit
D	2550 mm (original, assumed to be same for the new propellers)
d_{hub}	875 mm (estimated)
P	3330 kW
n	280 rpm
EAR	0.70 (estimated)
Z	4
$P/D_{0.7}$	0.980 (estimated)
Skew	0° (estimated)

According to the photographs, the propeller is made of stainless steel. As no information on the exact steel grade was available, a typical stainless steel with yield strength of 550 MPa and ultimate strength of 750 MPa was assumed.

The required ct^2-values are compared to those estimated from the assumed original rule basis for the propeller (FSICR 1971) in Table 11. It should be noted that the estimated values are not based on drawings but the rule minimums from the relevant rules for which the vessel was designed. Thus, the real propeller might differ from the values presented here. Full calculations are shown in Appendix B.

Table 11. Calculated ct^2-requirements for ice class 1A (FSICR 2017) for the MV Apollo, compared to estimated ct^2

Location	Estimated ct^2 (cm^3)	Required ct^2 (cm^3)	FOS
0.35 R	7936	7016	113 %
0.6 R	4078	2631	155 %

As can be seen, the propeller (estimated) for MV Apollo meets the requirements of the current FSICRs rules for ice class IA. As the estimated blade exceeds the rule by some margin, a comparison to current IA Super requirements was also made. The results for that comparison are shown in Table 12.

Table 12. Calculated ct^2-requirements for ice class 1A Super (FSICR 2017) for the MV Apollo, compared to estimated ct^2

Location	Estimated ct^2 (cm^3)	Required ct^2 (cm^3)	FOS
0.35 R	7936	8705	91 %
0.6 R	4078	3265	125 %

As can be seen, the propeller (estimated) for MV Apollo does not fulfil the requirements of the current FSICR 2017 for ice class IA Super assuming that it was designed to the rule minimums of FSICR IA at 1982. However, the values are relatively close: This is consistent with Aker Arctic's understanding of the historic development of the propeller rules (for smaller propellers the most recent rules are less onerous than the older rules).

Information of the actual propeller parameters and ct^2 values would be needed for a conclusive result, but the indication is that the propellers and thus whole propulsion of MV Apollo should in general meet the requirements of current FSICR ice class IA.

3.3 MV Apollo Class Equivalency Summary

Following the evaluation described above, the following conclusions are drawn:

- In general the Structure of MV Apollo is not equivalent to a single strength level using the ice class rules as a basis.
- The plating is generally of a level of strength equivalent to a IA Super ship (a single strake being the exception for full compliance which is likely at the very limit of the ice belt extent in any case).
- The framing is generally of a level at or below an equivalent strength to a IC ship. In particular the bow frames are weak, and do not meet current IC requirements.
- The propeller blade (and by assumed extension the remainder of the propulsion system) is considered equivalent to a strength level of an ice class IA (FSICRs) ship. However, it should be noted that this analysis is based on very limited data and a considerable set of assumptions.

From the above conclusions it appears that the MV Apollo would not meet the requirements, or be considered equivalent, to a 2017 FSICRs Ice Class IC ship. However, from a compliance perspective, the MV Apollo is considered as a Type B ship according to Schedule 2 of the Arctic Shipping Safety Pollution Prevention Regulations [1] because of the original ice class, BV Glace I, assigned.

4 Comparison Between the MV Qajaq W and MV Apollo

4.1 Structural Comparison

The double-ended nature of the MV Qajaq W prevents a direct comparison of the structures of the two ships. Therefore, the hulls were divided into five representative areas and the respective areas were compared between the two ships. Figure 4 and Figure 5 present the comparison areas for MV Apollo and MV Qajaq W, respectively.

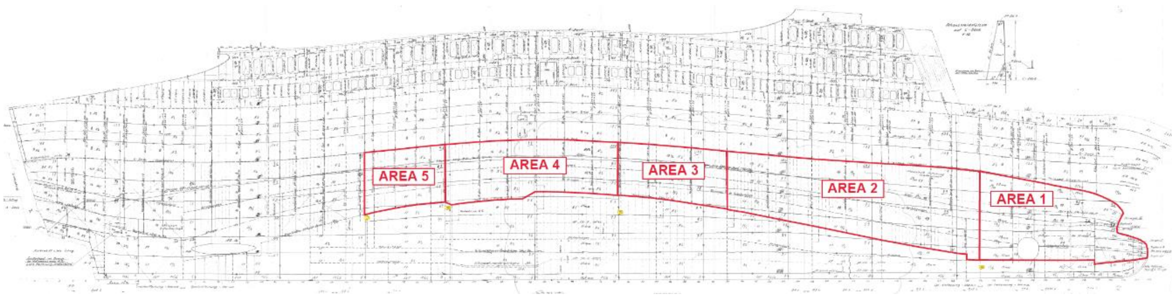


Figure 4. Representative comparison areas for MV Apollo

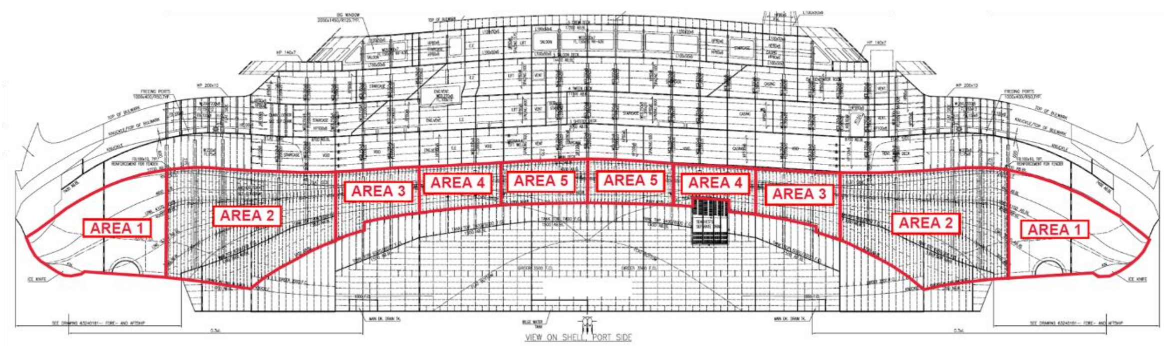


Figure 5. Representative comparison areas for MV Qajaq W

In each area, an indicative structural capacity (design pressure) was determined for the weakest structural member. For the MV Apollo, the weakest structures were the frames between the Double Bottom and the Z-Deck. These are the frames that are only supported by an intercostal stringer. When determining the limiting pressure for the MV Apollo, the benefit of the small stringer was accounted for following the principles in Section 3.1.1. For MV Qajaq W, the shell plating and frames are dimensioned to the design pressure given in the rules.

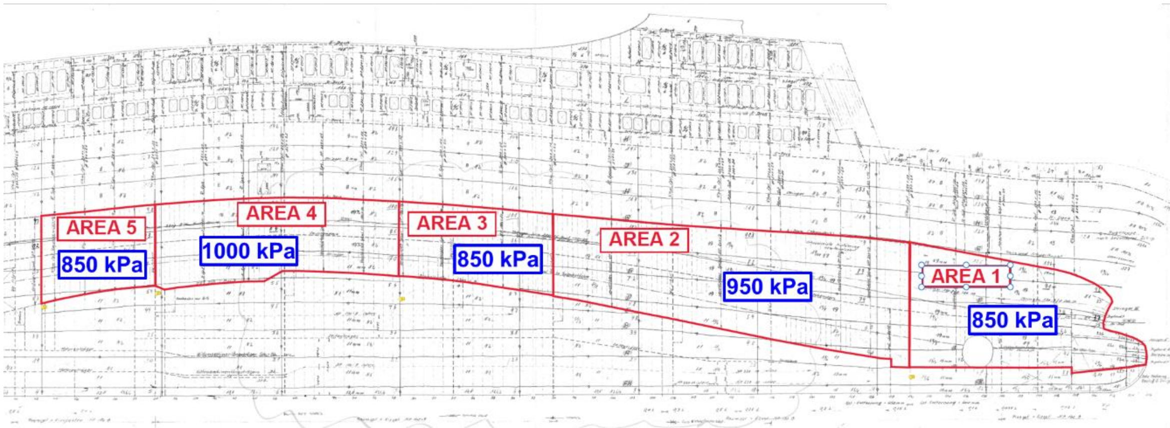


Figure 6. Indicative limiting pressure for the MV Apollo

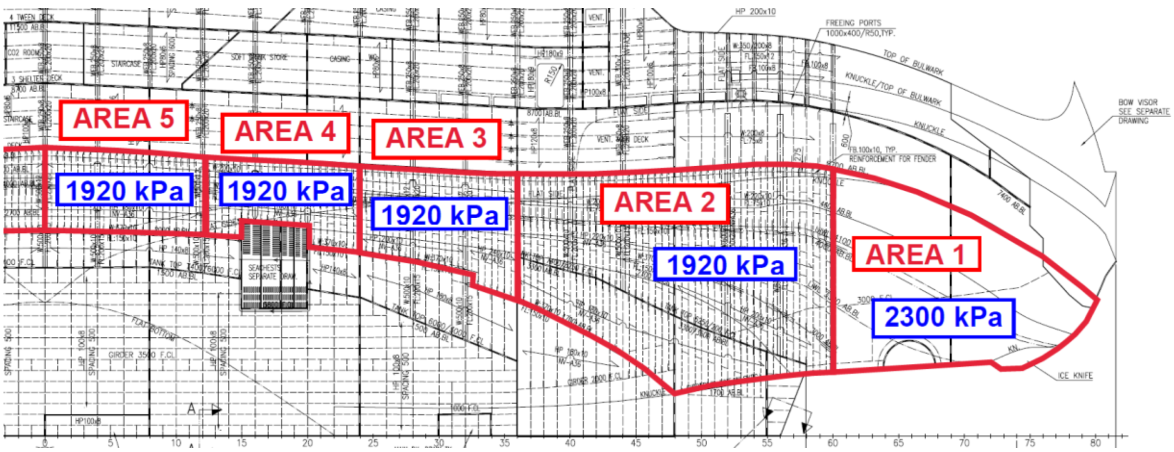


Figure 7. Indicative limiting pressures for the MV Qajaq W

The relative strength of the MV Qajaq W compared to the MV Apollo is presented in Figure 8. Only the forward bow is presented due to the symmetry of the ship about midship. The full annotated shell expansion is presented in Appendix A.

The results indicate that the MV Qajaq W is significantly stronger than the MV Apollo, as expected. It should be noted that the comparison is conservative as the strength of the plating of the MV Apollo is not represented explicitly. The difference is expected to be marginally smaller between the two ships if the capacity of the plates and frames were compared together.

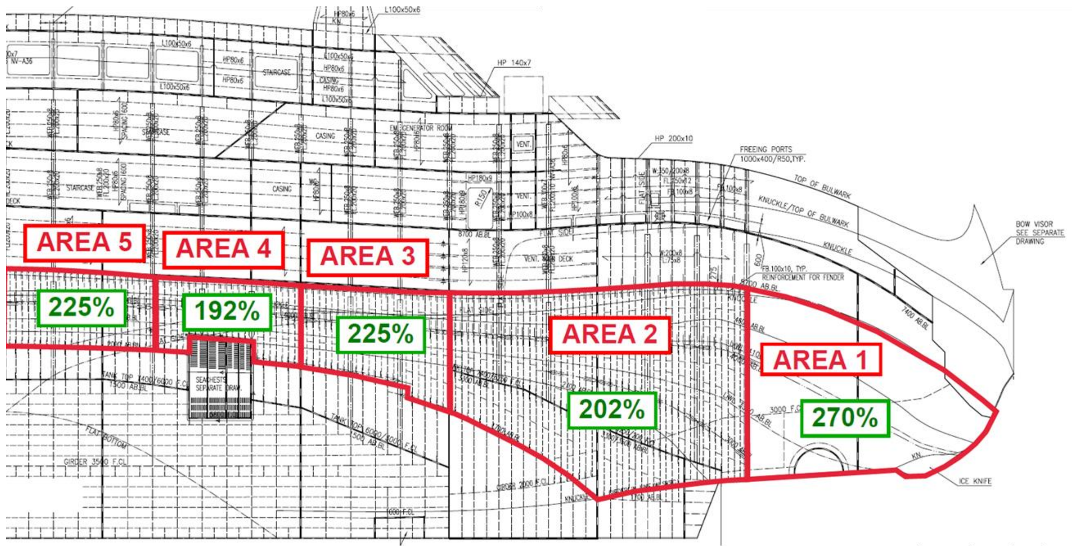


Figure 8. Relative strength of MV Qajaq W over MV Apollo

To understand the relative strength of the plating of the two ships, a separate comparison was made of the plate thicknesses for each area. Adjustments are necessary to account for the different steel strengths of the shell plating. By removing the corrosion addition and multiplying the MV Apollo's plate thicknesses by $\sqrt{\sigma_{y,Apollo}/\sigma_{y,Grete}}$, an approximate plate thickness can be estimated for a situation where both plates were made of the same high strength steel. Table 13 presents the summary of the comparison of shell plate thicknesses.

Table 13. Comparison of shell plate thicknesses

Representative Area	Adjusted MV Apollo	MV Qajaq W	MV Qajaq W/MV Apollo
Area 1	13.8 mm	13.0 mm	94%
Area 2	13.8 mm	11.0 mm	80%
Area 3	13.8 mm	11.0 mm	80%
Area 4	11.4 mm	11.0 mm	97%
Area 5	11.4 mm	11.0 mm	97%

As seen in Table 13, the equivalent high-strength steel shell plates for the MV Apollo are thicker than those of the MV Qajaq W. The relative strength of the two ships based on plate thickness is much closer. The plates of the MV Apollo would add some benefit to the overall strength of its hull; however, the frames remain the weakest point of the structure and the plates cannot account entirely for the frames.

4.2 Propeller Strength Comparison

The comparison of the propulsion strength of the two vessels is limited to the comparison of the propeller strength, estimated from applying the rule minimum requirements in force at the time of build (for MV Qajaq W) and in force at the time of the re-engine (for MV Apollo).

The rule strength level (using the 2017 Rules) for the propeller of MV Qajaq W is considered to be Ice Class IA Super, whereas the rule strength level for MV Apollo is considered to be just below Ice Class IA Super.

As the data is so limited, the general conclusion from the analysis is that the propeller blade strength levels of the two ships are comparable.

4.3 General hull and propulsion configuration

One of the most obvious differences between the MV Apollo and the MV Qajaq W is the hull geometry and propulsion configuration in general. The MV Apollo is a conventional twin shaftline/rudder vessel with an open water bulbous bow, whereas the MV Qajaq W is a double ended ferry with one azimuth propulsion unit at each end of the vessel. The bow of the MV Apollo appears to be optimized for open water operations and thus features steep bow angles and a bulbous bow. When operating in ice, the ice tends to get deflected toward the sides of the vessel rather than beneath the hull.

For the MV Qajaq W, the sloped bow will result in a tendency for ice to get pushed downwards as opposed to getting deflected to the sides of the vessel. As the forward propulsion unit is located on the centreline and relatively shallow in the bow, the forward unit is much more exposed to ice interaction when compared to the propellers of the MV Apollo, resulting in ice loading to the propulsion unit itself as well as propeller ice interaction. With that said, the unit itself is designed to tolerate ice interactions (and this is possibly one reason why the bow and propulsion units appear to be over strengthened compared to the ice class assigned to the ship), but operationally the operation of the vessel will be different compared to MV Apollo, which may result in the need to make adjustments to how the vessel is operated to minimize ice interaction with the propulsion unit.

If the vessel is operated at light drafts, close to the lower ice waterline (LIWL) of 3.3 m, the shanks of the propulsors are very close to surface. While navigating directly ahead or astern, the propulsors are protected by the substantial ice knives. However, when the vessel is turning, the ice knife will have a different track than the propulsor, and the propulsor shank can encounter the intact ice sheet. While that does not necessarily result in damage, it is not recommended, and the recommendation would be to operate the vessel during winter with such drafts that the whole propulsor is well submerged. Recommended draft during ice navigation would be approximately 3.6 m or deeper.

Due to the shallower operating draft and the sloping bow of the MV Qajaq W compared to the MV Apollo, there is considered to be less risk of ice grounding between the keel of the vessel and the seabed.

The MV Qajaq W also has a slightly larger side slope than the MV Apollo, which will help to break ice in flexure rather than crushing when manoeuvring in ice.

4.4 Seawater Intake System

The original objective of this section was to review the existing seawater intake arrangement and cooling water system for MV Apollo and use this as a baseline of a successful arrangement with respect to operating in ice / slush ice conditions on the anticipated route. Because MV Qajaq W adopts a completely different approach to sea water cooling through the use of box coolers, it is of little benefit to compare the arrangements of MV Apollo and MV Qajaq W directly; The experience of successful operation with the MV Apollo cannot be directly transferred to MV Qajaq W as the principles of the system are different.

Notwithstanding the above, a general review was made of MV Qajaq W's seawater cooling system and firefighting suction arrangement and the following comments are offered for operation in ice, based on Aker Arctic's experience:

<u>Box coolers</u>

The MV Qajaq W is equipped with box coolers. In a box cooler system, engine fresh water cooling circulations are cooled as a closed system in submerged tube bundles, thus omitting the need for any forced sea water cooling system for the engines. The box coolers sit in their own sea chests.

Generally, experience with the function of box coolers to cool engine cooling water is good, they are efficient and effective even when there is slush ice in the sea chest (which is very likely in a box cooler system because of the size, number and location of slot openings on the ship's hull).

The one disadvantage to the use of a closed-circuit cooling water system is that the return cooling water (which is warm) is not available to be dumped into the sea chest to melt ice, or to regulate the water temperature in the sea chest to ensure ice does not built up. Typical ice sea chest arrangements include this cooling water recirculation line, which enables the temperature of the water in the sea chest to be controlled. This has been found to be the most effective means to maintaining ice free suctions. While this is not an issue for the engine cooling water, there is an identified risk that slush ice in the sea chests will clog the firefighting suctions; Although the box coolers will keep the immediate area in the sea chest relatively warm, as soon as a suction is drawn there will be insufficient energy from the box cooler coils to keep the suction ice free. Practical experience from ships equipped with box coolers where the fire line suctions are connected to the same chest of the box coolers indicates that the fire lines easily clog and suction cannot be maintained.

The system on MV Qajaq W is configured (as with most non-ice capable ships equipped with box coolers) with the ability to back flush the sea chest with the fire fighting pumps. These may help to unclog the suctions, although if the pump cannot draw suction to begin with (because the source sea chest is clogged with ice) the effect will be limited.

Fire pumps 1 & 3 are drawn from the main engine box cooler sea chests. The ship is also equipped with another sea chest in the centre of the ship which serves the emergency fire pump. This provides some level of redundancy. In Aker Arctic's opinion the position of this emergency sea chest in the centre of the hull is the best practical place for it to be and reduces the likelihood of ice build up in that sea chest. Best practice would be to ensure that this sea chest has at least some means to clear ice. In this case this is provided by means of a compressed air line.

<u>Compliance with the rules</u>

The MV Qajaq W was originally designed to DNV ICE-1A rules. These rules include requirements for sea water cooling:

Rules for Ships, Part 5, Ch1, Section 2

- "301 - The sea cooling water inlet and discharge for main and auxiliary engines shall be so arranged so that blockage of strums and strainers by ice is prevented"
- "303 - A full capacity discharge branched off from the cooling water overboard discharge line shall be connected to at least one of the sea inlet chests. At least one of the fire pumps shall be connected to this sea chest or to another sea chest with de-icing arrangements"

For the MV Qajaq W, as the ship is equipped with box coolers, paragraph 301 does not apply, nor does the first line in paragraph 303. However, the second line in paragraph 303 should still apply – i.e. the rules to which the ship was built require the other sea chest (which the firefighting suction is connected to) to be equipped with de-icing arrangements.

From the drawings available the arrangement of the emergency fire pump sea chest includes de-icing capabilities by provision of a compressed air line to blow ice away from the inlet grill and/or steam injection to clear slush).

Even with the air blow de-icing arrangements for the emergency fire pump sea chest the risk of the fire pump suction clogging in ice should be made aware to the crew, and procedures put in place to monitor the situation closely under slush ice conditions. Operational practices, such as using a heated ballast tank as an emergency source of water, providing additional connections with own cleanable filters from other sea chests for redundancy, or use of a portable steam generator could be options. It is recommended that these are investigated after a more thorough understanding of the arrangement is made by the ship's crew.

Heat recovery system

The engine cooling system makes use of an engine heat recovery heat exchanger. Based on Aker Arctic’s experience these systems are quite sensitive to low temperatures and often systems that have not been designed for cold temperatures will not function effectively: in cold temperatures the system may need a boiler to boost the energy in the system (if the engine is losing too much heat through radiation). As the ship is designed to ice class IA it is expected that low temperature operations were anticipated when the system was dimensioned. However, Aker Arctic recommends that the ship specification is consulted to determine the design temperature for the system (and that that temperature is lower than the anticipated winter temperature on the proposed route).

5 Operability Assessment in Sea Ice

5.1 Assessment using AIRSS and POLARIS

The safety of Type A and Type B vessels operating between St. Barbe and Blanc-Sablon has been assessed using the Arctic Ice Regime Shipping System (AIRSS) and the Polar Operational Limit Assessment Risk Indexing System (POLARIS). AIRSS is a Canadian system that was introduced for application in the Canadian Arctic as a risk based method to supplement, and eventually replace, the zone/date system under the Canadian Arctic Shipping Pollution Prevention Regulations (ASPPR). POLARIS is a similar system that was developed as an international effort to harmonize international regulations. It is based upon AIRSS and incorporates the experience learnt in the Canadian Arctic along with international input from other Arctic nations. POLARIS has also been incorporated into the new ASSPPR rules as an alternative system to AIRSS. While the abovementioned approaches are not a requirement for vessels operating outside the Canadian Arctic, it gives an indicative representation of the risk of operating different ice class vessels in a given operating region.

Both AIRSS and POLARIS evaluate the potential risk to a vessel operating in ice through a combination of ice class specific factors (called Ice Multipliers in AIRSS and Risk Index Values in POLARIS), and the make-up of the ice regime in which the vessel is operating. The partial concentration of each stage-of-development in the ice regime is multiplied by the appropriate factor for that stage-of-development and the vessel class. The results are added together to obtain a single index that represents risk, called an Ice Numeral by AIRSS (IN) and a Risk Index Outcome (RIO) by POLARIS. For both systems, a zero or positive IN or RIO represents a safe operation, while negative values indicate elevated risk.

Both systems have methods for accounting for decayed ice, which effectively results in adding certain Ice Multipliers/Risk Index Values for specific ice types. Hence, the IN/RIO can be increased by up to 10 under specific conditions if the ice is considered sufficiently decayed. However, based on analysis of the available ice data and knowledge of the ice conditions in the area, the ice is not significantly decayed to the point where the IN/RIO can be raised. Therefore, the results shown assume no ice decay is present. By not accounting for decayed ice, the above approach is applied in a conservative manner.

To apply the above systems, Canadian Ice Services (CIS) digital ice charts where used to obtain ice conditions on the transit route for the 2008 to 2017 ice seasons. Digital CIS charts were available weekly throughout each of the ice seasons. Weeks where no ice charts were published, were outside the ice season and hence no ice was on the route. For each available ice chart, a straight line between the two ports was selected, and any ice regimes intersecting with this transect were extracted. Ice Numerals and Risk Index Outcomes were then calculated for every ice regime along the route, and the minimum ice numeral on the route was selected for that week.

The results for each corresponding week number for each of the 10 years were gathered and used to produce the box plots shown in Figures 7 to 10 below. Box plot terminology is provided in Appendix C.

Results for the Type A using AIRSS indicate that for most of the ice season, ice numerals remain above zero. However, there are occasions where ice numerals drop below zero. Although a thorough investigation of these has not been performed, these are most likely caused by the presence of multiyear ice. However, for a Type A vessel, high concentrations of the thick first year ice will also lead to negative ice numerals.

For a Type B Vessel, AIRSS results in positive ice numerals for most years during the early winter (end of February) and after the spring breakup (May and beyond). However, during a significant number of the years, negative ice numerals were produced during the months of March and April. The reason for these differences is due to the presence of Medium First Year Ice (70-120cm), which is considered acceptable (ice multiplier of +1) for a Type A, but unacceptable (ice multiplier of -1) for Type B.

A similar analysis has been performed using POLARIS. The results show similar, but more conservative, trends. Although Type A and IA Super are considered equivalents under the ASPPR, the RIO’s for a IA Super are between 0 and -10 for a large number of years during the months of March and April. As with AIRSS Type B above, this is due to a risk index value of –1 for a IA Super in Medium First Year Ice. For a IA vessel, the risk index value in Medium First Year Ice drops to –2, resulting in a further reduction of RIO’s during the months of March and April.

The overall results indicate that POLARIS is more conservative than AIRSS for low ice class vessels in medium first year ice. Although ARISS considers operations in medium FYI acceptable for Type A vessels, POLARIS considers this to be too high a risk for IA Super, although they are notional equivalents. The results using AIRSS are in agreement with TP8941E, allowing operations on the east coast for a Type A vessel, whilst disallowing operations for a Type B vessel. However, ARISS does indicate that a Type B vessel should be able to safely operate during all months other than March and April in most years.

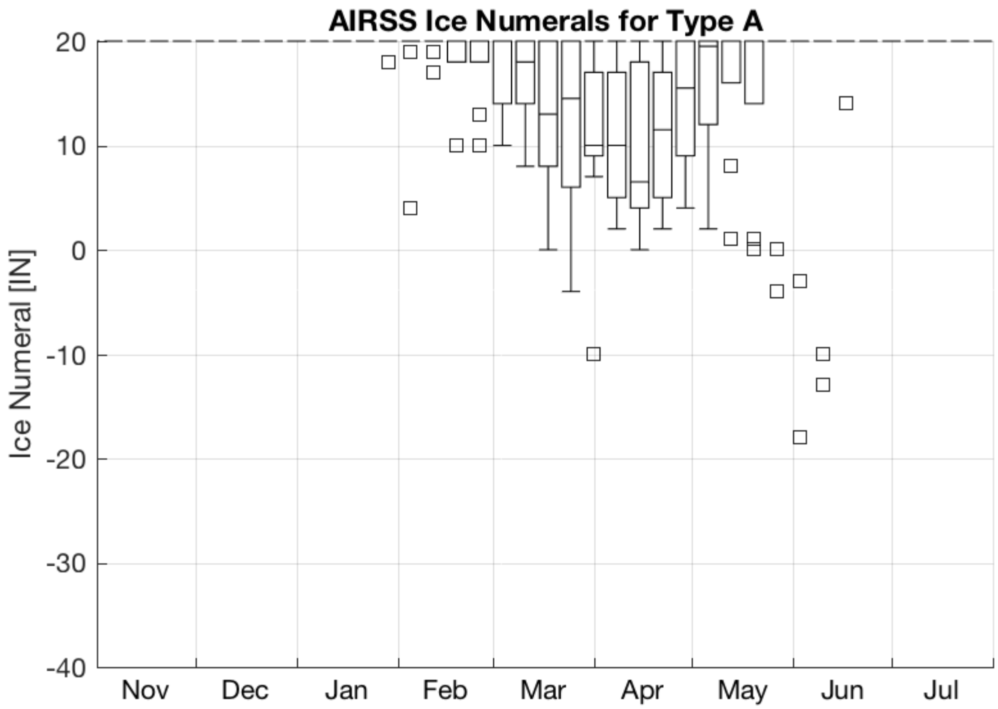


Figure 9. AIRSS Ice Numerals for Type A Ice Class

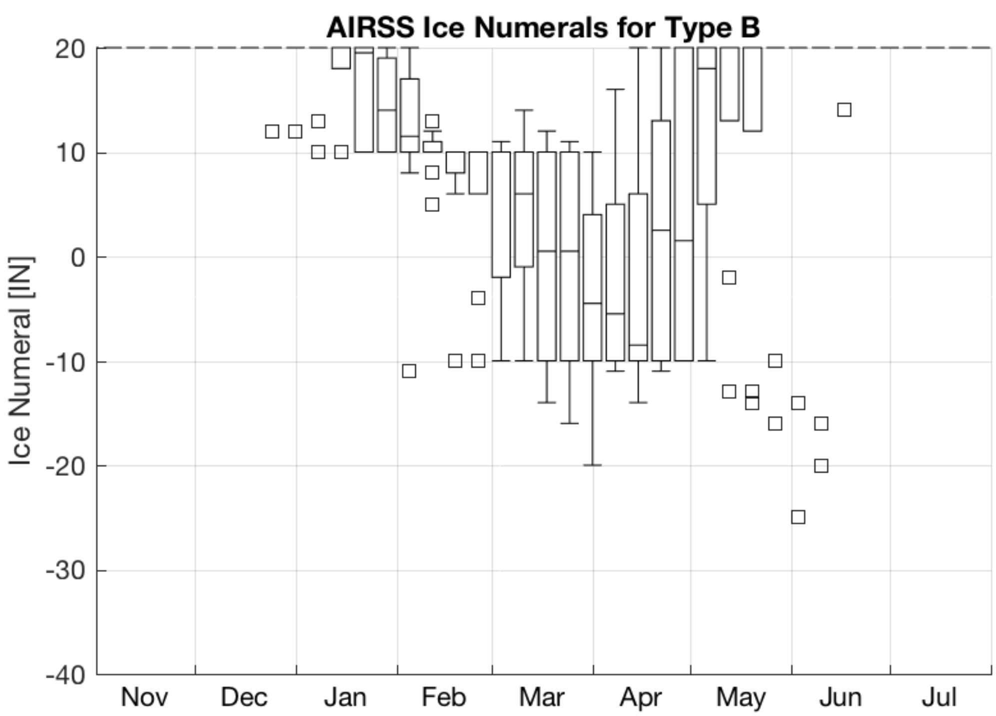


Figure 10. AIRSS Ice Numerals for Type B Ice Class

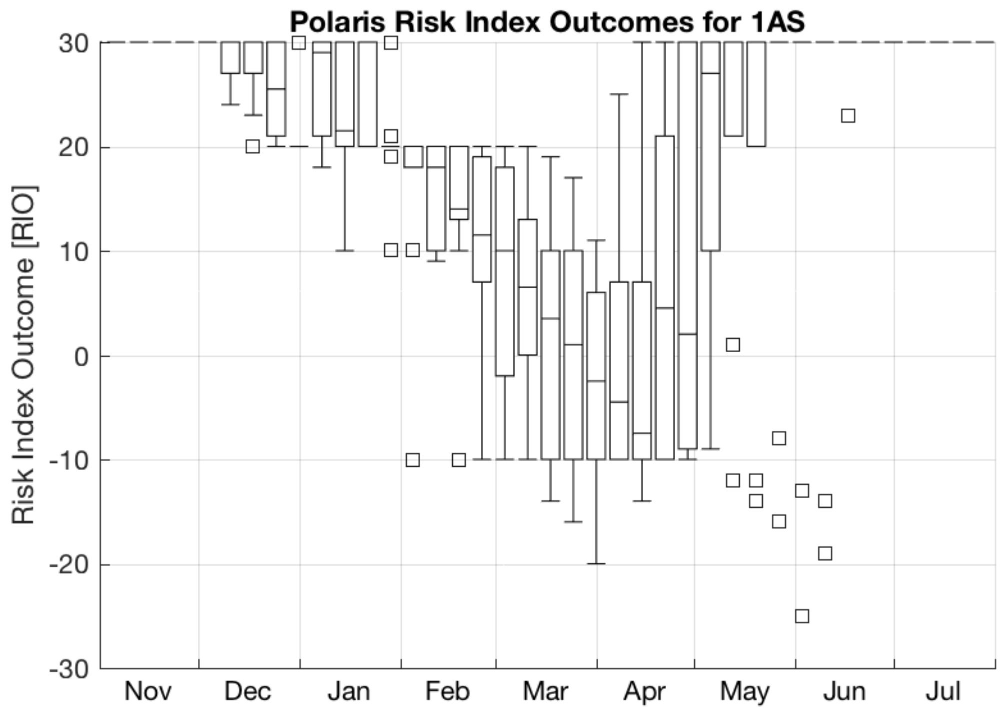


Figure 11 POLARIS Risk Index Outcomes for Ice Class 1A Super

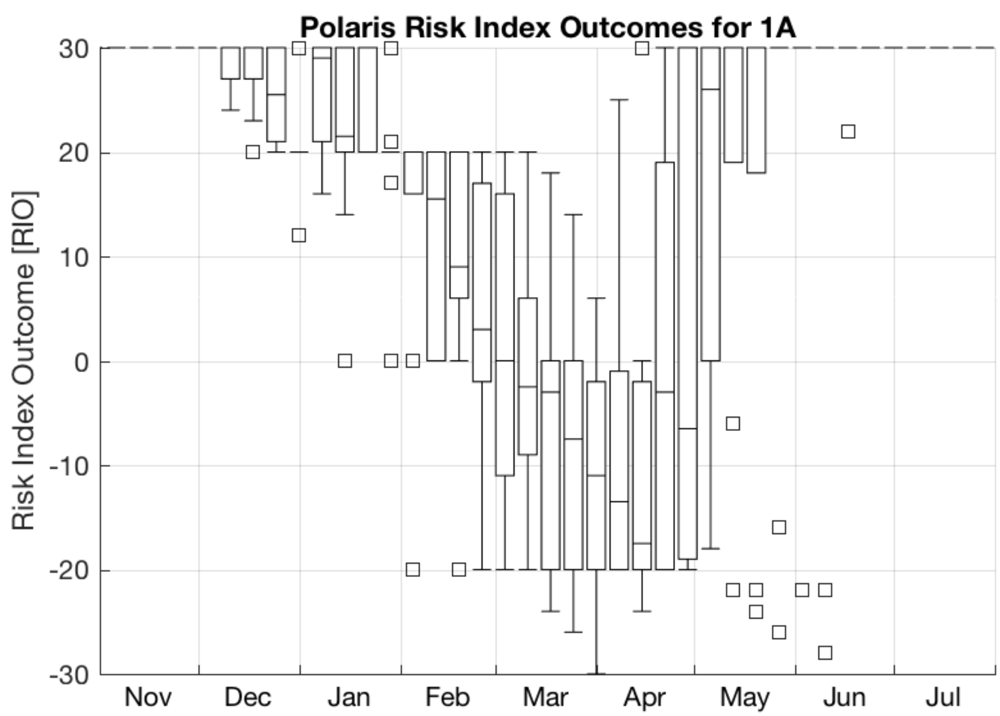


Figure 12 POLARIS Risk Index Outcomes for Ice Class 1A

5.2 Comparison with MV Apollo 2018 Winter Navigation Log

To further assess the safety of operating a Type B vessel on the route and to determine the applicability of assessing the safety based upon the ice numerals, the winter operational log for 2018 was obtained from Labrador Marine Inc. The operational log was completed every day throughout the ice season and included a general description of the operations, the number crossings completed, the number of crossings canceled due to ice and wind, and a summary of whether icebreaker assistance was available and required.

The number of crossings completed with and without icebreaker assistance and the number of cancelled crossings are summarized in Figure 13 along with the ice numerals for the corresponding week. The ice numerals are based upon the weekly ice charts and have been analyzed in the same method discussed above using ice multipliers for a Type B vessel (IA). The number of crossings are total counts per week, with weeks defined as ending on the same day in which the ice chart is published.

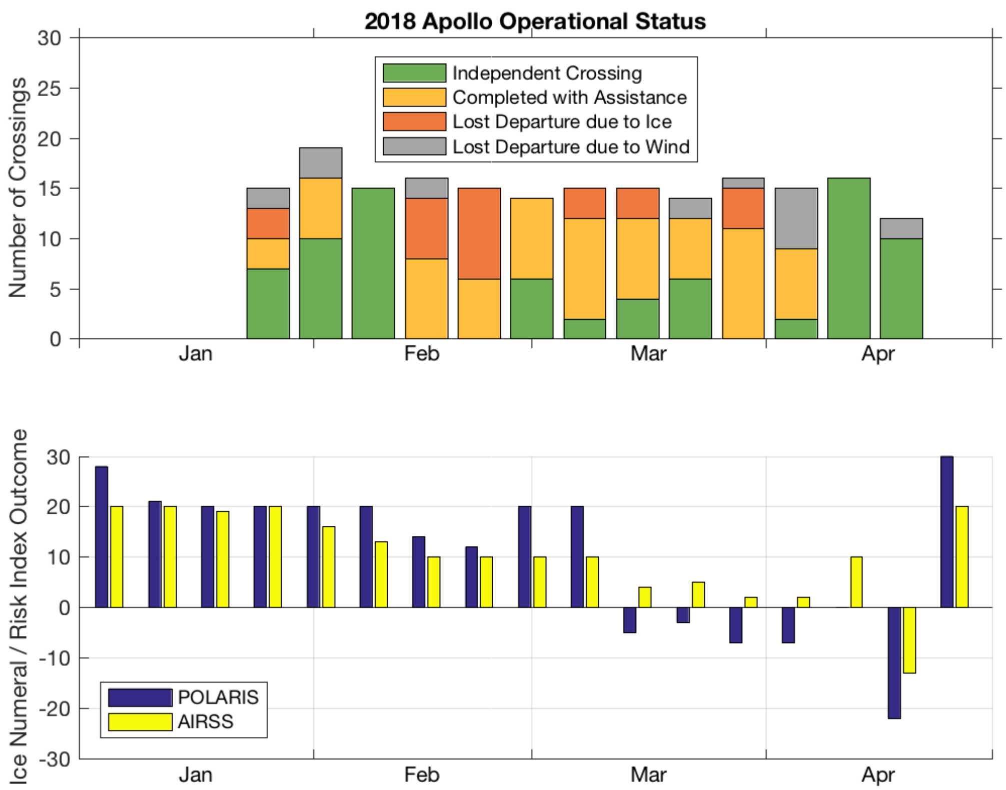


Figure 13 MV Apollo Ice Operational Summary for 2018

The results of analyzing the ice numerals show that 2018 was a relatively mild season in comparison to the years summarized above, with only a single week where ice numerals were below zero. A closer look at the daily ice charts published for this week indicate that ice was only on the route for a single day during that week, with only a small section of the route close to St. Barbe covered with ice. The operational log for this day indicate 'very good' ice conditions, indicating that Labrador Marine did not experience ice conditions they considered a risk to the vessel.

The overall trend indicates that the ice numerals do not align well with conditions where Labrador Marine considered the ice conditions 'Heavy' or 'Severe' and therefore required icebreaker assistance in order to continue operations. Reviewing the operational notes associated with lost departures due to ice indicate that 'Heavy' and 'Severe' ice conditions are typically a result of ice pressure due to winds compressing the ice against the shoreline. These conditions are well known to result in difficult conditions and are potentially dangerous regardless of whether the vessel is a Type A or Type B.

The track record with the MV Apollo has been that it has operated without incident year-round with assistance from Canadian Coast Guard despite negative ice numerals (or risk index outcomes). This could be the result of different factors as examples:

- Due to temporal variations between when the voyage took place and when the ice data was collected, the ice conditions during the voyage were different than what was captured in the ice chart.

- Prudent operation of the vessel, including deviating around the most severe ice where possible.

- The actual route taken by the vessel may have been different than the 'direct' route assumed in the analysis, where the ice data was collected.

6 Roadmap for Recommended Ice Risk Mitigation Strategies

Based on the analysis performed in this project, it appears that the MV Qajaq W has significantly improved hull structure compared to MV Apollo and an equivalent propulsion strength level. However, there are several areas that are noteworthy to consider in terms of risk mitigation. The key areas are outlined below:

1) Even though the strength level of the structure of MV Qajaq W is higher than the MV Apollo, the hull geometry and propulsion configuration are quite different. This will not only result in different ice interaction scenarios with the vessel, but will also likely change how the vessel is operated. For example, the new ferry will no longer have to go astern in ice, potentially eliminating the need to do certain manoeuvres when docking. Due to the significant differences between vessel designs, and the unique challenges that come with a double ended ferry operating in ice (such as ice interactions with the bow thruster unit), it is recommended that a training program is performed by vessel's bridge officers for safe operation of the vessel in ice.

2) Due to the lack of available data on certain equipment, particularly related to propulsion system for both vessels, a number of assumptions had to be made which may influence the accuracy of the results. Additional analysis would provide more accurate results but will require more information on the relevant ship systems.

3) Based on the relative strength level of MV Qajaq W compared with MV Apollo, Aker Arctic's considered opinion is that the successful track record of the MV Apollo could be used to justify acceptance of the MV Qajaq by Transport Canada to operate on the same route. Aker Arctic recommend that a thorough review of records (especially with respect to the propellers) from Poseidon and classification archives be made to find all applicable drawings and information. Following this review, the analysis carried out should be updated, and the results consolidated for presentation to Transport Canada. As the basis for acceptance of MV Qajaq W for operation on the route is the successful performance of MV Apollo, Poseidon should be prepared to collate survey / dry docking records for the MV Apollo to support the case that no significant damage has occurred due to ice while the ship has been operating on the route.

4) Although the main and emergency sea chests have redundancies built in and are equipped with means to clear ice, it is not clear how effective they are at clearing ice when the fire pumps are used. The risk of the fire pump suction clogging in ice should be made aware to the crew, and procedures put in place to monitor the situation closely under slush ice conditions. Different operational practices such as those discussed in Section 4.4 could be potential options. It is recommended that these are investigated after a more thorough understanding of the arrangement is made by the ship's crew.

7 Conclusions

Based on the analyses performed in this study, it is apparent that the MV Qajaq W has an equivalent or greater level of strength than the MV Apollo in terms of structural, propulsion and machinery robustness for operations in ice. The fact that the Apollo has successfully operated for nearly two decades with little to no ice damage suggests that the MV Qajaq W should have no problems continuing this safety track record. However, according to the ice risk assessment discussed in Section 4 using the AIRSS and POLARIS approach, there are still potentially significant risks that need to be considered. To date, these have been successfully mitigated through prudent operation of the MV Apollo. Should the same level of prudency be applied to the MV Qajaq W, it is expected that no safety related concerns should arise from operations in ice.

To ensure continued safe operation of the ferry in ice, a number of mitigation strategies have been developed to further gain confidence in the ice operational safety of the MV Qajaq W in ice. These are outlined in Section 6. The key strategies include training of the crew for safe and efficient operation of the ferry in ice to account for the vessel's unique and radically different hull and propulsion configuration when compared to MV Apollo, and a more in-depth review of available data to confirm the assumptions made in this study.

8 References

[1] *Arctic Shipping Safety and Pollution Prevention Regulations*, Ottawa: Minister of Justice, 2018.

[2] Trafi, Ed., *Ice Class Regulations and the Application Thereof*, Helsinki, 2017.

Appendix A – MV Qajaq W Calculations

Aker Arctic

Ice class scantlings calculation

according to

Finnish-Swedish ice class rules

2017 edition

MV Grete

General data

Ice class	1A		
P	4000	kW	Shaft power
Δ	3530	t	Displacement at UIWL
Protective paint	FALSE		Is the hull protected by an ice-resistant paint?
h_0	0.8	m	Design ice thickness
h	0.3	m	Design ice load heigth
k	3.76		Ship size & power factor

FSICR scantlings calculation

MV Grete 1A

Aker Arctic

2017 edition

Legend

Does not meet requirements

Less than 2x Frame Height

Scantlings calculation, transversely framed structures

Frames	0 - 8	8 - 24	24 - 32	32 - 36	36 - 48	48 - 52	52 - 56	56 - 68	68 - FWD		
Region	Midbody	Bow	Bow	Bow	Bow	Bow	Bow	Bow	Bow		

Shell plating

s	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	m	Frame spacing
σ_y	355	355	355	355	355	355	355	355	355	MPa	Yield strength of plating material
t_c	2	2	2	2	2	2	2	2	2	mm	Corrosion addition, normally 2mm, with protective paint may be taken 1mm
t	10.7	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	mm	Minimum thickness for shell plating
t	13.0	13.0	13.0	13.0	13.0	13.0	14.0	15.0	18.0	mm	Selected thickness for shell plating

FSICR scantlings calculation

MV Grete

1A

Aker Arctic

2017 edition

Legend

Does not meet requirements

Less than 2x Frame Height

Transverse frames

m_0	5	5	5	5	5	5	5	5	5		Boundary condition for frames, see rules table 4-7
l	2	2	2.485	3.6	3	2.75	2.75	2.8	3.32	m	Frame span
σ_y	355	355	355	355	355	355	355	355	355	MPa	Yield strength of frame material
Profile	B	B	B	B	B	B	B	B	B	B / F	Profile type, B = bulb profile, F = flat bar
Profile	HP180*10	HP180*10	HP200*10	HP240*10	HP220*10	HP220*10	HP220*10	HP240*10	HP260*10		Bulb profile type
A	3.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	cm^2	Required shear area of frame
Z	105	174	221	329	271	247	247	252	302	cm^3	Required section modulus of frame
t	9	9	9	9	9	9	9	9	9	mm	Minimum thickness for frame web
A	18	18	20	24	22	22	22	24	26	cm^2	Actual shear area of frame
Z	174	174	221	342	281	281	284	349	440	cm^3	Actual section modulus of frame

FSICR scantlings calculation

MV Grete

1A

Aker Arctic

2017 edition

Legend

Does not meet requirements

Less than 2x Frame Height

Stringers

l	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	m	Webframe spacing = stringer span
σ_y	235	235	235	235	235	235	235	235	235	MPa	Yield strength of stringer material
m_0	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3		Boundary condition for stringers, see rules sec 4.4.3; 13.3 is default
h	370	370	370	370	370	370	370	370	370	mm	Web heigth
t	10	10	10	10	10	10	10	10	10	mm	Web thickness
c	150	150	150	150	150	150	150	150	150	mm	Flange width
s	10	10	10	10	10	10	10	10	10	mm	Flange thickness
A	30.0	49.5	49.5	49.5	49.5	49.5	49.5	49.5	49.5	cm^2	Required shear area of stringer
A_DNV2007	13.9	22.9	22.9	22.9	22.9	22.9	22.9	22.9	22.9	cm^2	Required shear area of stringer for DNV 2007 Rules
Z	520	860	860	860	860	860	860	860	860	cm^3	Required section modulus of stringer
A	**37**	**37**	**37**	**37**	**37**	**37**	**37**	**37**	**37**	cm^2	Actual shear area of stringer
Z	**928**	**928**	**928**	**928**	**928**	**928**	**941**	**952**	**979**	cm^3	Actual section modulus of stringer

FSICR scantlings calculation

MV Grete

1A

Aker Arctic

2017 edition

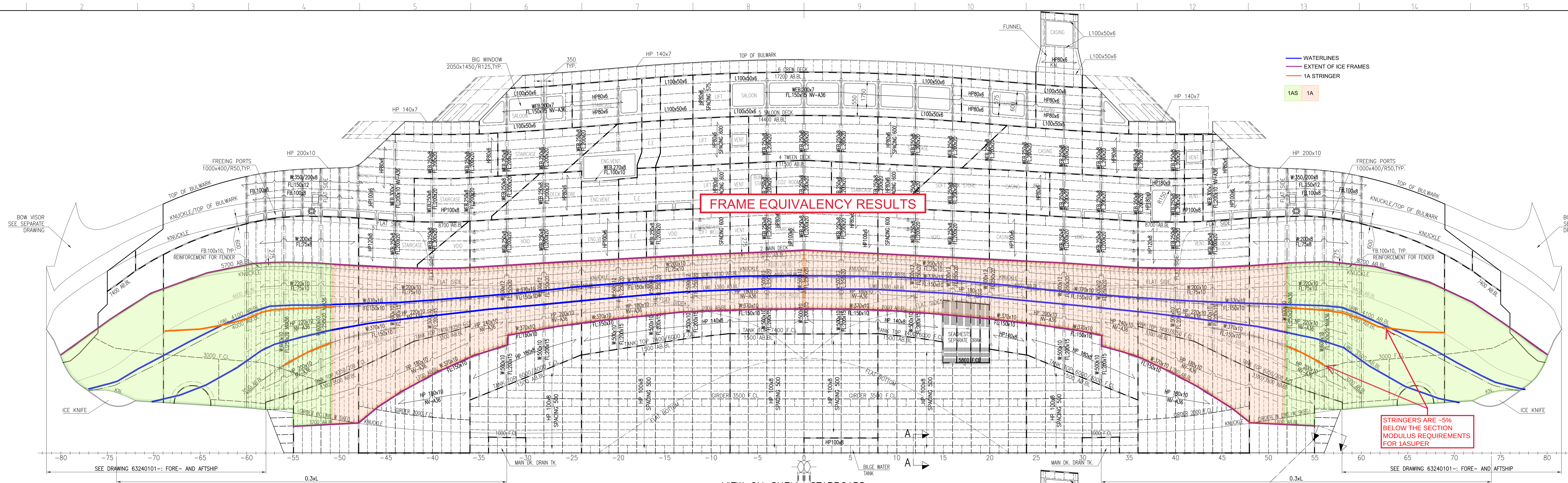
Legend

Does not meet requirements

Less than 2x Frame Height

Web frames

l	2.1	2.1	2.4	2.5	2.4	2.5	2.7	3.3	2.9	m	Web frame span
σ_y	235	235	235	235	235	355	355	355	355	MPa	Yield strength of web frame material
h	500	500	500	500	500	600	500	500	600	mm	Web heigth
t	12	12	12	12	10	10	10	10	10	mm	Web thickness
c	250	250	250	250	200	250	200	200	200	mm	Flange width
s	20	20	20	20	15	20	20	20	20	mm	Flange thickness
A	57.7	78.3	78.3	78.3	80.4	51.8	52.0	52.0	52.8	cm^2	Required shear area of web frame
A_DNV2007	23.9	39.5	39.5	39.5	40.5	26.1	26.2	26.2	26.6	cm^2	Required shear area of stringer for DNV 2007 Rules
Z	1216	1775	2074	2138	2425	1268	1452	1756	1505	cm^3	Required section modulus of web frame
A	**60**	**60**	**60**	**60**	**50**	**60**	**50**	**50**	**60**	cm^2	Actual shear area of web frame
Z	**3054**	**3054**	**3054**	**3054**	**2078**	**3670**	**2555**	**2588**	**3340**	cm^3	Actual section modulus of web frame



VIEW ON SHELL, STARBOARD

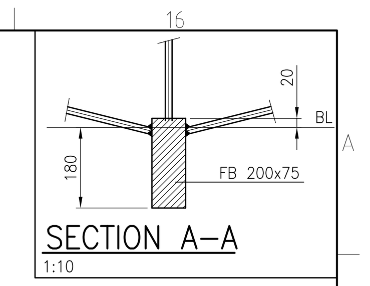
FRAME SPACING 600, ICE FRAME SPACING 300, WEB FRAME SPACING 2400

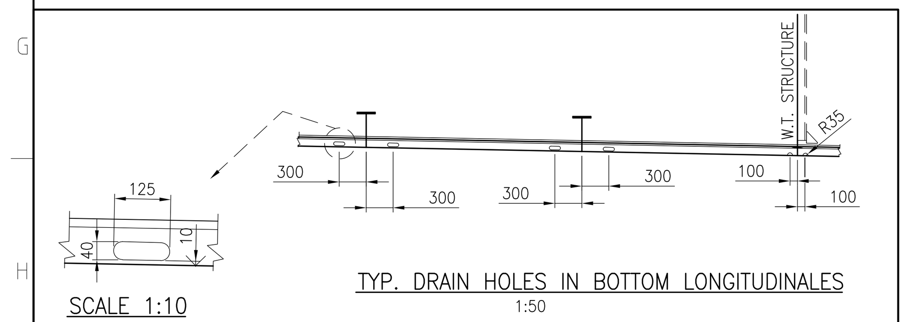
* - BORDER OF PART OF SIDE WHERE WATERLINES PARALELL TO CL

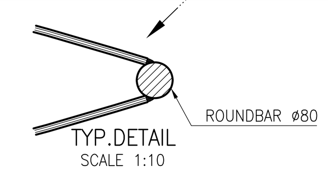
NOTE:

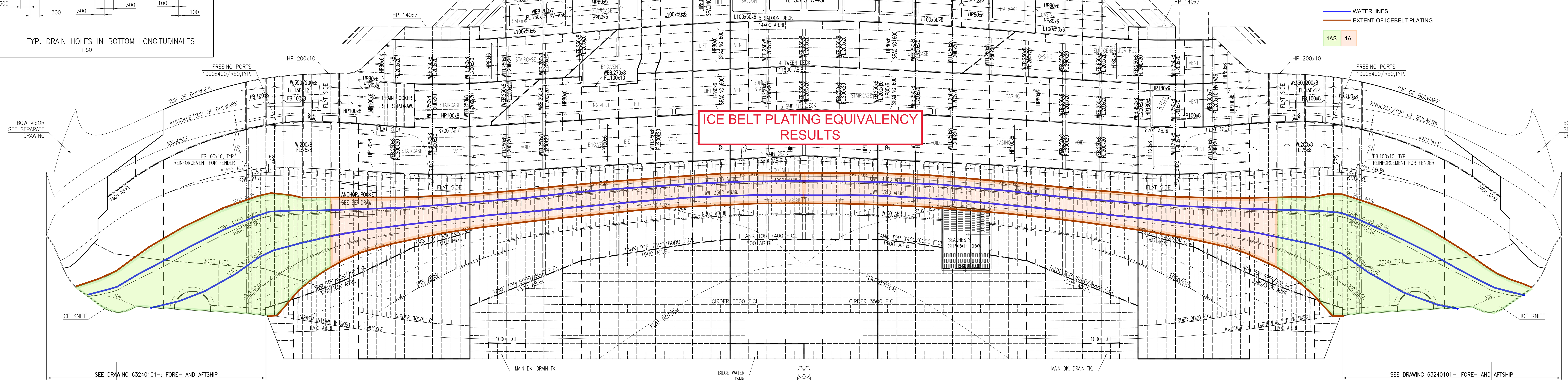
The stringers and web frames do not meet the shear area requirements for IA ship according to the 2017 FSICRs.

The stringers and webframes meet the section modulus requirements for a IA ship according to the FSICRs.





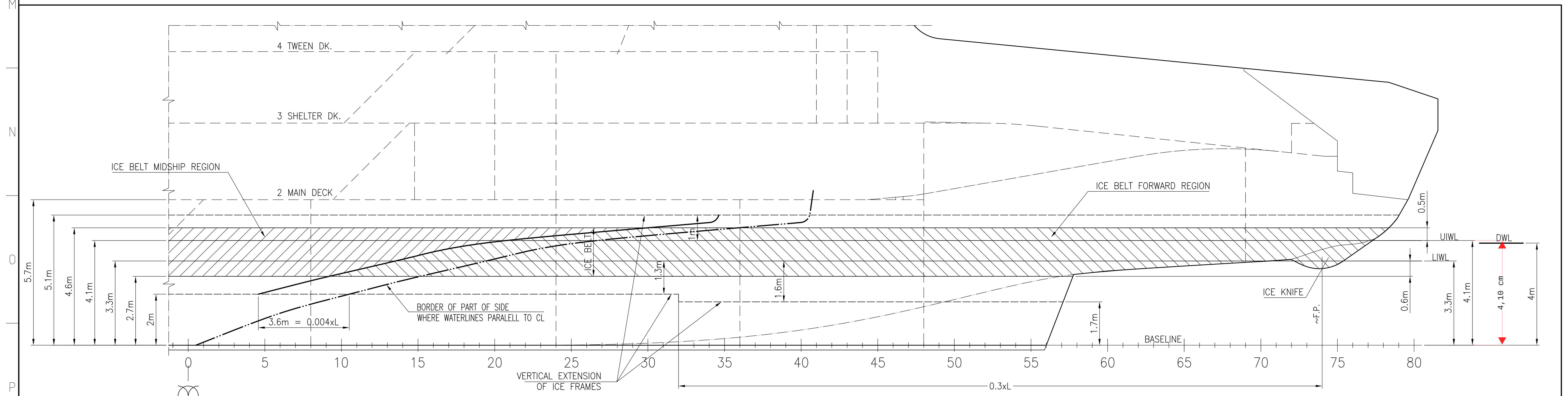




VIEW ON SHELL, PORT SIDE

FRAME SPACING 600, ICE FRAME SPACING 300, WEB FRAME SPACING 2400

* - BORDER OF PART OF SIDE WHERE WATERLINES PARALELL TO CL



EXTENSION OF ICEBELT ICE–1A   RULE REQUIREMENT

FORE,SB SHOWN, PS – SIMILAR, AFTSHIP INVERTED

L=LENGTH P.P.=89,03 m

DISPLACEMENT 4,0M DRAFT:	3450 TONNES
SCANTLING DRAUGHT	4.10 m
BALLAST DRAUGHT HEAVY WEATHER	3.50 m
BALLAST DRAUGHT MINIMUM ICE	3.30 m
SUMMER DRAUGHT	4.00 m
THRUSTER MOTOR OUTPUT (pr.unit)	2000 kW
DESIGN SPEED	15 knots

MATERIAL:

STEEL

NV–NS–GRADE A U.N.O.

REF. DRAWINGS:

63200101	REFERENCE DRAWING
63200103	WELDING TABLE. SHEET 1 – 8 OF 8
63230101	MIDSHIP SECTION I
63230102	MIDSHIP SECTION II
63230103	MIDSHIP SECTION III
63230104	PROFILE AND PLAN I
63230105	PROFILE AND PLAN II
63230106	PROFILE AND PLAN III
63230107	WATERTIGHT TRANSVERSE BULKHEADS
63230108	LONGITUDINAL BULKHEADS BETWEEN MAIN DECK AND SALOON DECK. PROFILES
63230109	LONGITUDINAL BULKHEADS BETWEEN MAIN DECK AND SALOON DECK. SECTIONS.
63230111	SHELL EXPANSION

IMO ....

A	ISSUED FOR APPROVAL	09.11.07.	HJB
REV.NO.	REVISION	DATE	APPR

OWNER | YARD | CLASSIFICATION | MARITIME AUTH. | Date | Approved

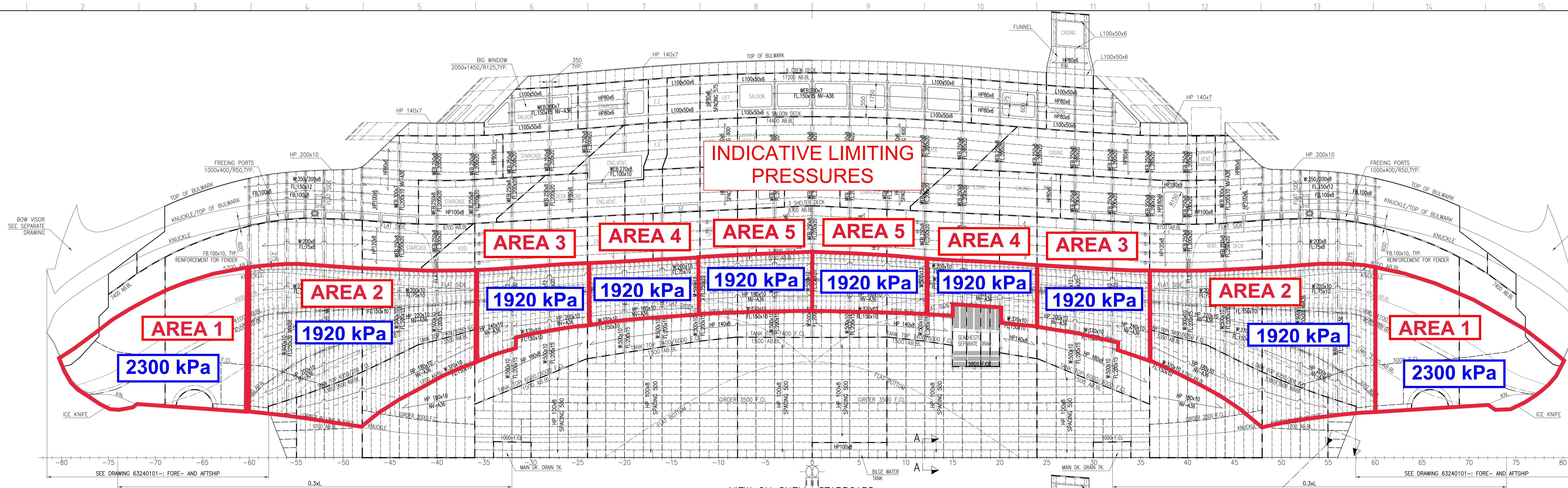
CLIENT: FISKERSTRAND VERFT AS
CLIENT REFERENCE:

TITLE: FRAMING PLAN
SCALE: 1:100
DRAWN A.S. 29.10.07.
CK'D
APPR.

MULTI MARITIME AS
P.O.Box 90, N–6801 FØRDE
Phone 47 57823000
Telefax 47 57828451
E–mail: firmapost@multi–maritime.no

PROJECT NO.	YARD NO.	SFI
268/7	63,64,65	230

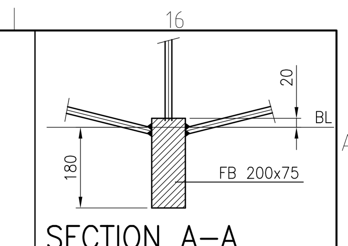
FILE NAME / DRAWING NO.	REV.NO.
63230110	A

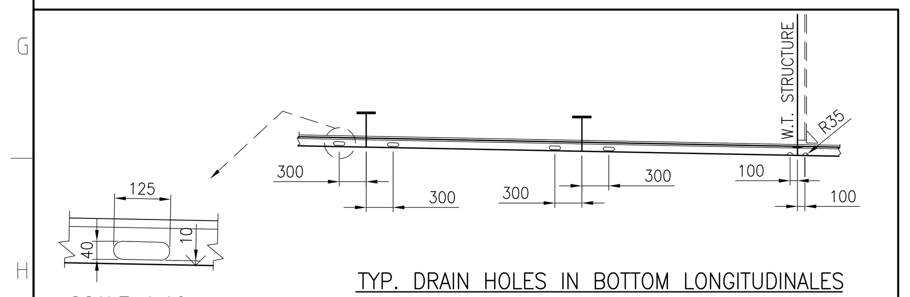


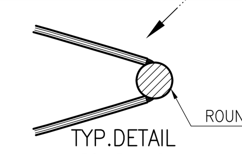
VIEW ON SHELL, STARBOARD

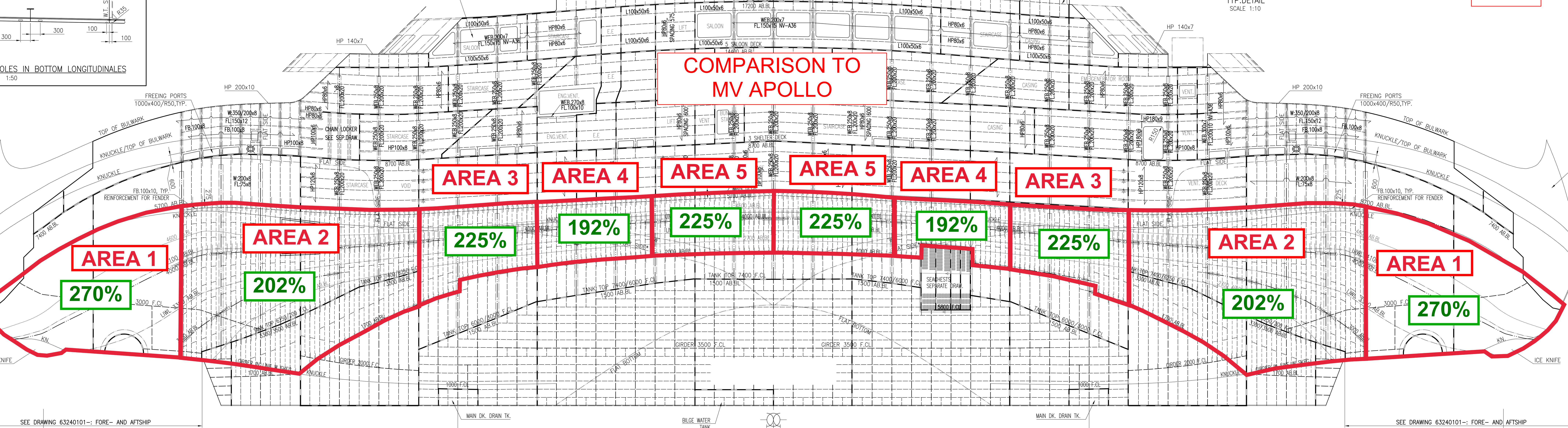
FRAME SPACING 600, ICE FRAME SPACING 300, WEB FRAME SPACING 2400

* - BORDER OF PART OF SIDE WHERE WATERLINES PARALELL TO CL





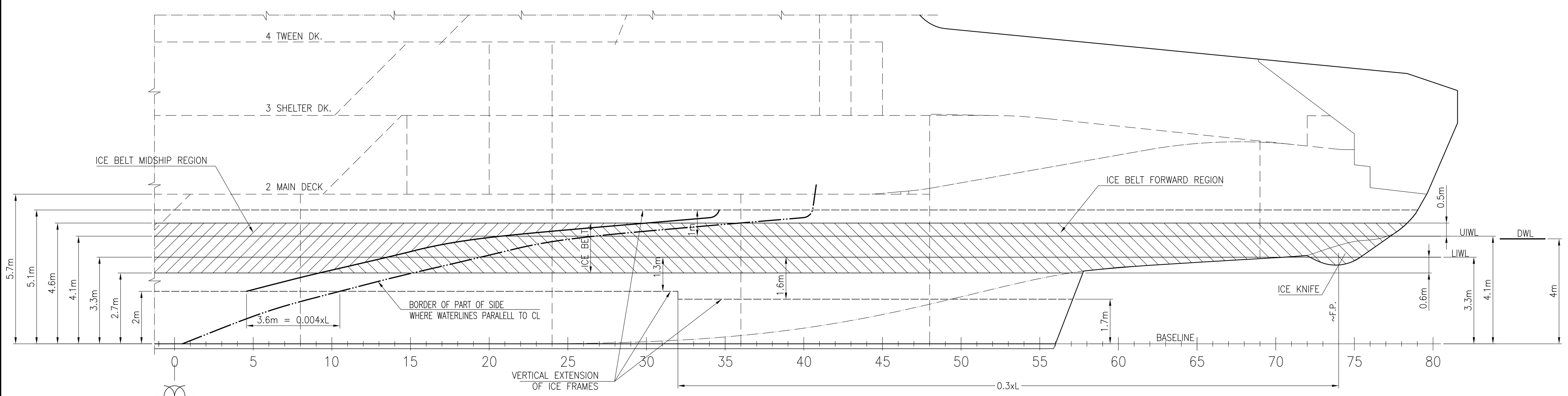




VIEW ON SHELL, PORT SIDE

FRAME SPACING 600, ICE FRAME SPACING 300, WEB FRAME SPACING 2400

* - BORDER OF PART OF SIDE WHERE WATERLINES PARALELL TO CL



EXTENSION OF ICEBELT ICE-1A RULE REQUIREMENT

FORE,SB SHOWN, PS - SIMILAR, AFTSHIP INVERTED

DISPLACEMENT 4,0M DRAFT:	3450 TONNES
SCANTLING DRAUGHT	4.10 m
BALLAST DRAUGHT HEAVY WEATHER	3.50 m
BALLAST DRAUGHT MINIMUM ICE	3.30 m
SUMMER DRAUGHT	4.00 m
THRUSTER MOTOR OUTPUT (pr.unit)	2000 kW
DESIGN SPEED	15 knots

MATERIAL:

STEEL

NV-NS-GRADE A U.N.O.

REF. DRAWINGS:

63200101 REFERENCE DRAWING
63200103 WELDING TABLE. SHEET 1 - 8 OF 8
63230101 MIDSHIP SECTION I
63230102 MIDSHIP SECTION II
63230103 MIDSHIP SECTION III
63230104 PROFILE AND PLAN I
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63230106 PROFILE AND PLAN III
63230107 WATERTIGHT TRANSVERSE BULKHEADS
63230108 LONGITUDINAL BULKHEADS BETWEEN MAIN DECK AND SALOON DECK. PROFILES
63230109 LONGITUDINAL BULKHEADS BETWEEN MAIN DECK AND SALOON DECK. SECTIONS.
63230111 SHELL EXPANSION

IMO ....

OWNER | YARD | CLASSIFICATION | MARITIME AUTH. | Date

Approved

REV.NO.	REVISION	DATE	APPR
A	ISSUED FOR APPROVAL	09.11.07.	HJB

CLIENT: FISKERSTRAND VERFT AS

CLIENT REFERENCE

TITLE: FRAMING PLAN

SCALE: 1:100

DRAWN A.S. 29.10.07.
CK'D
APPR.

MULTI MARITIME AS
P.O.Box 90, N-6801 FØRDE
Phone 47 57823000
Telefax 47 57828451
E-mail: firmapost@multi-maritime.no

PROJECT NO.	YARD NO.	SFI
268/7	63,64,65	230

FILE NAME / DRAWING NO.	REV.NO.
63230110	A

Aker Arctic

PROPELLER CALCULATIONS

according to

DNV rules for Northern Baltic

Based on

DNV Rules for ships, July 2007, Pt.5 Ch.1 Sec.3

Input

Name	Value	Unit	Notes
Ice class	ICE-1A		
Propeller type	FP		
Reversible	Yes		
D	2.5	m	Propeller diameter
Z	4		Number of blades
$c_{0.35}$	0.691	m	Chord at 0.35 R
$c_{0.6}$	0.835	m	Chord at 0.6 R
$H_{0.35}$	2.839		Propeller pitch at 0.35 R
P_s	1931	hp	Propeller power
n_0	196	rpm	Propeller revolutions
U_1	80	MPa	Material parameter, from Pt.4 Ch.5 Sec.1 Table B1
U_2	0.18		Material parameter, from Pt.4 Ch.5 Sec.1 Table B1
σ_b	590	MPa	Ultimate tensile strenght of material
Stainless steel	No		
T_b	70158	Nm	Propeller torque at bollard
Th_b	216000	N	Propeller thrust at bollard
θ	0	°	Rake angle
skew	22	°	Skew angle

Intermediate results

R	1.25	m	Propeller radius
T_{ice}	97500	Nm	Ice torque
K_{mat}	0.80		Material factor
d	2.766		For CP propellers
sin α	0.7188		
k_i	92		
K_4	25788892		
A_1	7.596		
A_2	37.11		
K_1	6621524		
S_r	1.176		
$t_{0.35}$	112.5	mm	
f_{sk}	1.163		
$t_{0.6}$	74.0	mm	

Results

$ct^2_{0.35R}$	8742	cm^3	Required ct^2 at 0.35 R for CP propellers
$ct^2_{0.6R}$	4576	cm^3	Required ct^2 at 0.60 R

Aker Arctic

PROPELLER CALCULATIONS

according to

Finnish-Swedish Ice Class Rules

Based on

Finnish-Swedish Ice Class Rules 2010 & 2017

Input

Name	Value	Unit	Notes
Rule set	FSICR 2017		
Ice class	1A		
Propeller type	FP		
Propeller type	Open		
Reversible	No		
D	2.5	m	Propeller diameter
d	0.893	m	Propeller hub diameter
EAR	0.545		Expanded blade area ratio
Z	4		Number of propeller blades
n	196	rpm	Nominal rotational speet at MCR free running condition
σ_u	590	MPa	Minimum ultimate stress for blade material
$\sigma_{0.2}$	245	MPa	Minimum yield / 0.2-stress for blade material

Intermediate results

n	2.777	rps	nominal rotational speed, 85% of nominal free running speed at MCR for FP and 100% for CP propellers
H_{ice}	1.5	m	From Table I1
S_{ice}	1		From Table I1
F_b	360	kN	$D < D_{limit}$, open
F_b	217	kN	$D \geq D_{limit}$, open
F_b	127	kN	$D < D_{limit}$, ducted
F_b	431	kN	$D \geq D_{limit}$, ducted
F_f	213	kN	$D < D_{limit}$, same for both open and ducted prop
F_f	397	kN	$D \geq D_{limit}$, same for both open and ducted prop
$D_{limit,\ open\ b}$	1.5	m	Open propeller, backwards force
$D_{limit,\ ducted\ b}$	6.0	m	Ducted propeller, backwards force
$D_{limit,\ f}$	4.7	m	Open & ducted propeller, forwards force
F_b	217	kN	The maximum backward blade force
F_f	213	kN	The maximum forward blade force
σ_{ref}	383	MPa	Reference stress for the propeller blade material, FEM calculation
FOS	1.3		Factor of safety
C_1	1.6		Actual stress / beam stress coefficient, FSICR

Results

$ct^2_{0.35R}$	5880	cm^3	
$ct^2_{0.6R}$	2205	cm^3	

Aker Arctic

PROPELLER CALCULATIONS

according to

Finnish-Swedish Ice Class Rules

Based on

Finnish-Swedish Ice Class Rules 2010 & 2017

Input

Name	Value	Unit	Notes
Rule set	FSICR 2017		
Ice class	1Asuper		
Propeller type	FP		
Propeller type	Open		
Reversible	No		
D	2.5	m	Propeller diameter
d	0.893	m	Propeller hub diameter
EAR	0.545		Expanded blade area ratio
Z	4		Number of propeller blades
n	196	rpm	Nominal rotational speet at MCR free running condition
σ_u	590	MPa	Minimum ultimate stress for blade material
$\sigma_{0.2}$	245	MPa	Minimum yield / 0.2-stress for blade material

Intermediate results

n	2.777	rps	nominal rotational speed, 85% of nominal free running speed at MCR for FP and 100% for CP propellers
H_{ice}	1.75	m	From Table I1
S_{ice}	1		From Table I1
F_b	360	kN	$D < D_{limit}$, open
F_b	269	kN	$D \geq D_{limit}$, open
F_b	127	kN	$D < D_{limit}$, ducted
F_b	534	kN	$D \geq D_{limit}$, ducted
F_f	213	kN	$D < D_{limit}$, same for both open and ducted prop
F_f	464	kN	$D \geq D_{limit}$, same for both open and ducted prop
$D_{limit,\ open\ b}$	1.9	m	Open propeller, backwards force
$D_{limit,\ ducted\ b}$	7.0	m	Ducted propeller, backwards force
$D_{limit,\ f}$	5.4	m	Open & ducted propeller, forwards force
F_b	269	kN	The maximum backward blade force
F_f	213	kN	The maximum forward blade force
σ_{ref}	383	MPa	Reference stress for the propeller blade material, FEM calculation
FOS	1.3		Factor of safety
C_1	1.6		Actual stress / beam stress coefficient, FSICR

Results

$ct^2_{0.35R}$	7296	cm^3	
$ct^2_{0.6R}$	2736	cm^3	

Appendix B – MV Apollo Calculations

Aker Arctic

Ice class scantlings calculation

according to

Finnish-Swedish ice class rules

2017 edition

MV Apollo

General data

Ice class	1A		
P	6700	kW	Shaft power
Δ	4392	t	Displacement at UIWL
Protective paint	TRUE		Is the hull protected by an ice-resistant paint?
h_0	0.8	m	Design ice thickness
h	0.3	m	Design ice load heigth
k	5.42		Ship size & power factor

FSICR scantlings calculation

MV Apollo

1A

Aker Arctic

2017 edition

Legend

Does not meet requirements

Less than 2x Frame Height

Conditional 1A

Scantlings calculation, transversely framed structures

	Bow I	Bow II	Bow III	Bow IV	Midbody I	Midbody II	Midbody III	Stern I	Stern II	Stern III		
Region	Bow	Bow	Bow	Bow	Midbody	Midbody	Midbody	Stern	Stern	Stern		
Shell plating												
s	0.3	0.3	0.325	0.325	0.325	0.325	0.325	0.325	0.3	0.3	m	Frame spacing
σ_y	235	235	235	235	235	235	235	235	235	235	MPa	Yield strength of plating material
t_c	2	2	2	2	2	2	2	2	2	2	mm	Corrosion addition, normally 2mm, with protective paint may be taken 1mm
t	16.7	16.7	17.6	17.6	13.6	13.6	13.6	12.2	11.6	11.6	mm	Minimum thickness for shell plating
t	19.0	19.0	19.0	19.0	19.0	16.0	16.0	12.5	16.0	16.0	mm	Selected thickness for shell plating

FSICR scantlings calculation

MV Apollo

1A

Aker Arctic

2017 edition

Legend

Does not meet requirements

Less than 2x Frame Height

Conditional 1A

Transverse frames -> Z to A Deck

m_0	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7		Boundary condition for frames, see rules table 4.4.3
l	2.7	2.5	2.5	1.4	1.4	1.5	1.36	1.36	2.97	2.97	m	Frame span
σ_y	235	235	235	235	235	235	235	235	235	235	MPa	Yield strength of frame material
Profile	B	B	B	B	B	B	B	B	B	B	B / F	Profile type, B = bulb profile, F = flat bar
Profile	HP160*9	HP180*8	HP180*8	HP160*9	HP160*9	HP160*9	HP180*8	HP200*9	HP180*8	HP180*8		Bulb profile type
A	8.8	8.8	9.5	9.5	5.3	5.3	5.3	4.0	3.7	3.7	cm^2	Required shear area of frame
Z	367	338	366	190	106	115	102	78	173	173	cm^3	Required section modulus of frame
t	9	9	9	9	9	9	9	9	9	9	mm	Minimum thickness for frame web
85% A			8						3	3	cm^2	Benefit for load distributing stringer
85% Z			311						147	147	cm^3	Benefit for load distributing stringer
A	14.4	14.4	14.4	14.4	14.4	14.4	14.4	18	14.4	14.4	cm^2	Actual shear area of frame
Z	132	163	164	132	132	129	160	211	160	160	cm^3	Actual section modulus of frame

FSICR scantlings calculation

MV Apollo — 1A

Aker Arctic

2017 edition

Legend
- Does not meet requirements
- Less than 2x Frame Height
- Conditional 1A

Transverse frames -> DB to Z Deck

m_0	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7		Boundary condition for frames, see rules table 4.4.3
l	1.9	3.22	3.22	2.25	2.25	2.25	3.5	3.5	2.72	2.72	m	Frame span
σ_y	235	235	235	235	235	235	235	235	235	235	MPa	Yield strength of frame material
Profile	B	B	B	B	B	B	B	B	B	B	B / F	Profile type, B = bulb profile, F = flat bar
Profile	HP160*9	HP180*8	HP180*8	HP160*9	HP160*9	HP160*9	HP180*8	HP200*9	HP180*8	HP180*8		Bulb profile type
A	8.8	8.8	9.5	9.5	5.3	5.3	5.3	4.0	3.7	3.7	cm^2	Required shear area of frame
Z	249	444	481	326	182	182	293	224	158	158	cm^3	Required section modulus of frame
t	9	9	9	9	9	9	9	9	9	9	mm	Minimum thickness for frame web
85% A	7	7	8	8	4	4	4	3			cm^2	Benefit for having a load distributing stringer
85% Z	212	378	409	277	154	154	249	190			cm^3	Benefit for having a load distributing stringer
t	9	8	8	9	9	9	8	9	8	8	cm^2	Actual thickness for frame web
A	14.4	14.4	14.4	14.4	14.4	14.4	14.4	18	14.4	14.4	cm^2	Actual shear area of frame
Z	132	163	164	132	132	129	160	211	160	160	cm^3	Actual section modulus of frame

FSICR scantlings calculation

MV Apollo 1A

Aker Arctic

2017 edition

Legend

- Does not meet requirements
- Less than 2x Frame Height
- Conditional 1A

Upper Stringers

l	2.4	6	9.1	6.5	11.05	8.45	9.1	7.8	7.2	4.8	m	Webframe spacing = stringer span
σ_y	235	235	235	235	235	235	235	235	235	235	MPa	Yield strength of stringer material
m_0	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7		Boundary condition for stringers, see rules table 4.4.3
h	550	550	550	550	550	360	360	290	290	145	mm	Web heigth
t	9	9	9	9	9	9	9	15	15	9	mm	Web thickness
c	200	200	200	200	200	200	200	150	150	31	mm	Flange width
s	10	10	10	10	10	10	10	15	15	15	mm	Flange thickness
A	56.7	99.3	150.6	107.5	118.7	90.8	97.8	83.8	77.4	51.6	cm^2	Required shear area of stringer
Z	2298	10054	23128	11800	22151	12953	15023	11037	9404	4180	cm^3	Required section modulus of stringer
A	**49.5**	**49.5**	**49.5**	**49.5**	**49.5**	**32.4**	**32.4**	**43.5**	**43.5**	**13.0**	cm^2	Actual shear area of stringer
Z	**1913**	**1913**	**1913**	**1913**	**1913**	**1066**	**1066**	**958**	**1007**	**134**	cm^3	Actual section modulus of stringer


ICE FRAMES CLASS EQUIVALENCY RESULTS
Note: The results shown are only for the ice frames.
The webframes and ice stringers do not meet 1C requirements.
WATERLINES
FRAMING EXTENTS
PLATE EXTENTS
ICE BELT AREA DIVISION
SUBDIVISIONS FOR ANALYSIS
1A
(1A)
1B
1C
<1C
STERN
MIDBODY
BOW
III
II
I
III
II
I
IV
III
II
I
Schanzkleidstützen auf C-Deck 1:10
C-Deck
A-Deck
Außenhaut


ICE BELT PLATE EQUIVALENCY RESULTS
WATERLINES
FRAMING EXTENTS
PLATE EXTENTS
ICE BELT AREA DIVISION
SUBDIVISIONS FOR ANALYSIS
1AS
1A
1B
1C
<1C
Schanzkleidstützen auf C-Deck 1:10
STERN
MIDBODY
BOW
III
II
I
III
II
I
IV
III
II
I
Außenhaut


INDICATIVE LIMITING PRESSURES
AREA 5
850 kPa
AREA 4
1000 kPa
AREA 3
850 kPa
AREA 2
950 kPa
AREA 1
850 kPa
Schanzkleidstützen auf C-Deck 1:10
Außenhaut

Aker Arctic

PROPELLER CALCULATIONS

according to

Finnish-Swedish Ice Class Rules

Based on

Finnish-Swedish Ice Class Rules 1971

Input

Name	Value	Unit	Notes
Ice class	1A		
Propeller type	CP		
D	2.55	m	Propeller diameter
Z	4		Number of blades
H/D	0.98		Propeller pitch ratio
SHP	4466	hp	Propeller pow er
n	280	rpm	Propeller revolutions
σ_b	76.48	kp/mm^2	Minimum tensile strenght for blade material

Intermediate results

m	1.60		Ice class coefficient
M	10.40	tm	Ice torque
H	0.686		Propeller pitch ratio, for CPP 0.7 $H_{nominal}$ / D

Results

$ct^2_{0.35R}$	7936	cm^3	Required ct^2 at 0.35 R for CP propellers
$ct^2_{0.6R}$	4078	cm^3	Required ct^2 at 0.60 R

Aker Arctic

PROPELLER CALCULATIONS

according to

Finnish-Swedish Ice Class Rules

Based on

Finnish-Swedish Ice Class Rules 2010 & 2017

Input

Name	Value	Unit	Notes
Rule set	FSICR 2017		
Ice class	1A		
Propeller type	CP		
Propeller type	Open		
Reversible	No		
D	2.55	m	Propeller diameter
d	0.875	m	Propeller hub diameter
EAR	0.700		Expanded blade area ratio
Z	4		Number of propeller blades
n	280	rpm	Nominal rotational speet at MCR free running condition
σ_u	750	MPa	Minimum ultimate stress for blade material
$\sigma_{0.2}$	550	MPa	Minimum yield / 0.2-stress for blade material

Intermediate results

n	4.667	rps	nominal rotational speed, 85% of nominal free running speed at MCR for FP and 100% for CP propellers
H_{ice}	1.5	m	From Table I1
S_{ice}	1		From Table I1
F_b	589	kN	$D < D_{limit}$, open
F_b	347	kN	$D \geq D_{limit}$, open
F_b	207	kN	$D < D_{limit}$, ducted
F_b	685	kN	$D \geq D_{limit}$, ducted
F_f	284	kN	$D < D_{limit}$, same for both open and ducted prop
F_f	510	kN	$D \geq D_{limit}$, same for both open and ducted prop
$D_{limit,\ open\ b}$	1.5	m	Open propeller, backwards force
$D_{limit,\ ducted\ b}$	6.0	m	Ducted propeller, backwards force
$D_{limit,\ f}$	4.6	m	Open & ducted propeller, forwards force
F_b	347	kN	The maximum backward blade force
F_f	284	kN	The maximum forward blade force
σ_{ref}	525	MPa	Reference stress for the propeller blade material, FEM calculation
FOS	1.3		Factor of safety
C_1	1.6		Actual stress / beam stress coefficient, FSICR

Results

$ct^2_{0.35R}$	7016	cm^3	
$ct^2_{0.6R}$	2631	cm^3	

Aker Arctic

PROPELLER CALCULATIONS

according to

Finnish-Swedish Ice Class Rules

Based on

Finnish-Swedish Ice Class Rules 2010 & 2017

Input

Name	Value	Unit	Notes
Rule set	FSICR 2017		
Ice class	1Asuper		
Propeller type	CP		
Propeller type	Open		
Reversible	No		
D	2.55	m	Propeller diameter
d	0.875	m	Propeller hub diameter
EAR	0.700		Expanded blade area ratio
Z	4		Number of propeller blades
n	280	rpm	Nominal rotational speet at MCR free running condition
σ_u	750	MPa	Minimum ultimate stress for blade material
$\sigma_{0.2}$	550	MPa	Minimum yield / 0.2-stress for blade material

Intermediate results

n	4.667	rps	nominal rotational speed, 85% of nominal free running speed at MCR for FP and 100% for CP propellers
H_{ice}	1.75	m	From Table I1
S_{ice}	1		From Table I1
F_b	589	kN	$D < D_{limit}$, open
F_b	431	kN	$D \geq D_{limit}$, open
F_b	207	kN	$D < D_{limit}$, ducted
F_b	850	kN	$D \geq D_{limit}$, ducted
F_f	284	kN	$D < D_{limit}$, same for both open and ducted prop
F_f	594	kN	$D \geq D_{limit}$, same for both open and ducted prop
$D_{limit,\ open\ b}$	1.9	m	Open propeller, backwards force
$D_{limit,\ ducted\ b}$	7.0	m	Ducted propeller, backwards force
$D_{limit,\ f}$	5.3	m	Open & ducted propeller, forwards force
F_b	431	kN	The maximum backward blade force
F_f	284	kN	The maximum forward blade force
σ_{ref}	525	MPa	Reference stress for the propeller blade material, FEM calculation
FOS	1.3		Factor of safety
C_1	1.6		Actual stress / beam stress coefficient, FSICR

Results

$ct^2_{0.35R}$	8705	cm^3	
$ct^2_{0.6R}$	3265	cm^3	

Appendix C – Other Supporting Documentation

Box Plot Terminology