Tanker Design Considerations for Safety and Environmental Protection of Arctic Waters – Learning from Past Experience

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Abstract

Oil and gas transportation from the Arctic will have many challenges, but experience available from tanker operations in the winter Baltic can provide valuable information for the industry. The paper reviews data on the operations in the Baltic. It compares the new Polar Class requirements with the Baltic ice class requirements, and discusses design aspects which are not covered by traditional ice class rules.

Keywords

Tanker design, tanker traffic, ice damage, Baltic Sea, Arctic, Ice Class Rules.

1. Introduction

As oil and gas exploration moves to cold climates it presents challenges not only for drilling and production but also for seaborne transportation. The increased transportation of oil from the Baltic year round has introduced many owners and operators for the first time to ship operations in ice covered waters, and a large number of ice strengthened tankers have been ordered as a result. The experience from Baltic operations will be valuable as the focus moves even further north to the Arctic. Compared to the Baltic the Arctic has a much harsher environment and it is remote with little infrastructure to support year round transportation. This will bring new challenges to the ship design and operation.

Vessels operating in the Arctic region are exposed to a number of unique demands. The presence of first-year and multi-year ice imposes additional loads on the hull, propulsion system and appendages. Low temperatures impact the ship, and the cold, the lack of light and visibility affect the crew. In addition, the protection of the unique Arctic environment is of particular concern as the resources in this new frontier are exploited.

This paper reviews the experience gained in the Baltic and presents data on tanker traffic, ice conditions, accidents and ice related damages. The conclusions can be helpful in developing further requirements for the Arctic.

The ships intended for the Baltic winter operation are built in accordance to the Finnish-Swedish Ice Class Rules (FSICR). The paper compares these requirements with the recently adopted IACS Polar Class requirements, and highlights the differences in the rule approach.

2. Experience with Tanker Traffic in the Baltic

The increase in tanker traffic in the Baltic is driven by Russian oil exports to customers outside the existing pipeline network. The oil terminals in the Gulf of Finland in the Baltic provide access for tankers and connect the existing pipeline network with the world oil trade (Fig. 1).

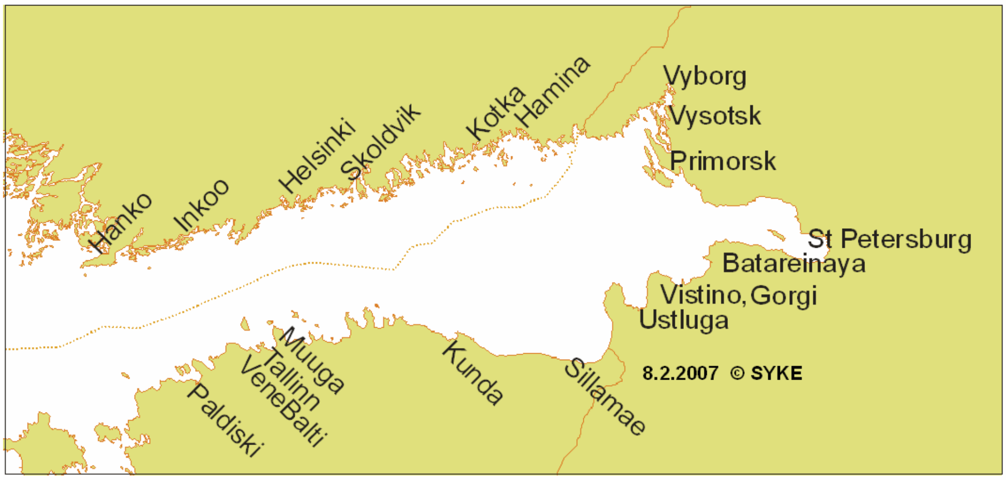
There are two main oil terminals in Russian Gulf of Finland; Primorsk and Vysotsk, two in Estonia (Tallinn and Muuga) and one in Finland (Porvoo) (Fig. 2). Planned new developments include an Estonian terminal at Sillamäe and a Russian terminal at Ustluga. There are also plans to transport LNG from Russia through a terminal in the Gulf of Finland.

The amount of crude oil exported from the Gulf of Finland has been increasing from about 40 million tons in the beginning of the decade to about 140 million tons at present, and the export volume is predicted to grow as shown in Fig. 3 and in Table 1. The predicted oil export amount for year 2010 is 165 million tons. The predictions are very sensitive to new terminal development. Especially the timetable for the terminals at Sillamäe and Ustluga are unclear.

2.1 Ship Calls

The basis of analyzing the seaborne traffic rests usually on the statistics of the number of ship calls in the sea area considered. This data is, however, very difficult to get from all Baltic rim countries. The Finnish data is well collected and presented by the Finnish Maritime Administration but data from Russia or Estonia is more difficult to obtain. When the Automatic Identification System (AIS) started operating in 2005, a realistic image of the ship traffic could be obtained.

Fig. 1: **The Russian oil and gas pipeline system** (*Source: Der Spiegel International online*)



Tallinn includes Old City Harbour, Muuga, Paldiski South and Paljassaare

Fig 2: **The oil terminals in the Gulf of Finland** (*Source: Finnish Environment Institute*)

Available numbers of tanker traffic in the Baltic are collected and presented in Table 2. The data for years 2005 and 2006 are based on the AIS data whereas the data given for year 2000 is collected from different sources and analyzed using a statistical trend model (Hänninen and Rytkönen 2004a).

The growth in the ship traffic – and also the subsequent accident data - is analyzed using a simple exponential model (Hänninen and Rytkönen 2004a). Thus the trend N – for example the number of annual port calls - is given in the form

$$N = ae^{bt} \tag{1}$$

where a and b are constants and t is time. The constants a and b are determined by a curve fit to the statistical data.

Based on the trend analysis the annual increase in the tanker traffic is 4.6% for the whole Baltic and 5.2% for the Gulf of Finland traffic. It must be noted that these figures are based on a very small sample.

Fig. 4 shows data on tanker traffic to Primorsk in the winter 2006. Thirty-nine (39) different tankers visited Primorsk during winter 2006 with an average deadweight of 102,300 dwt. The size distribution of the tankers is shown in Fig. 4. The ice class distribution of these vessels was: 1 ice class ID, 11 IC, 8 IB, 15 IA and 4 vessels had an ice class IA Super (or equivalent). This distribution reflects roughly the distribution of the ice classes in the world crude carrier fleet (Fig. 5).

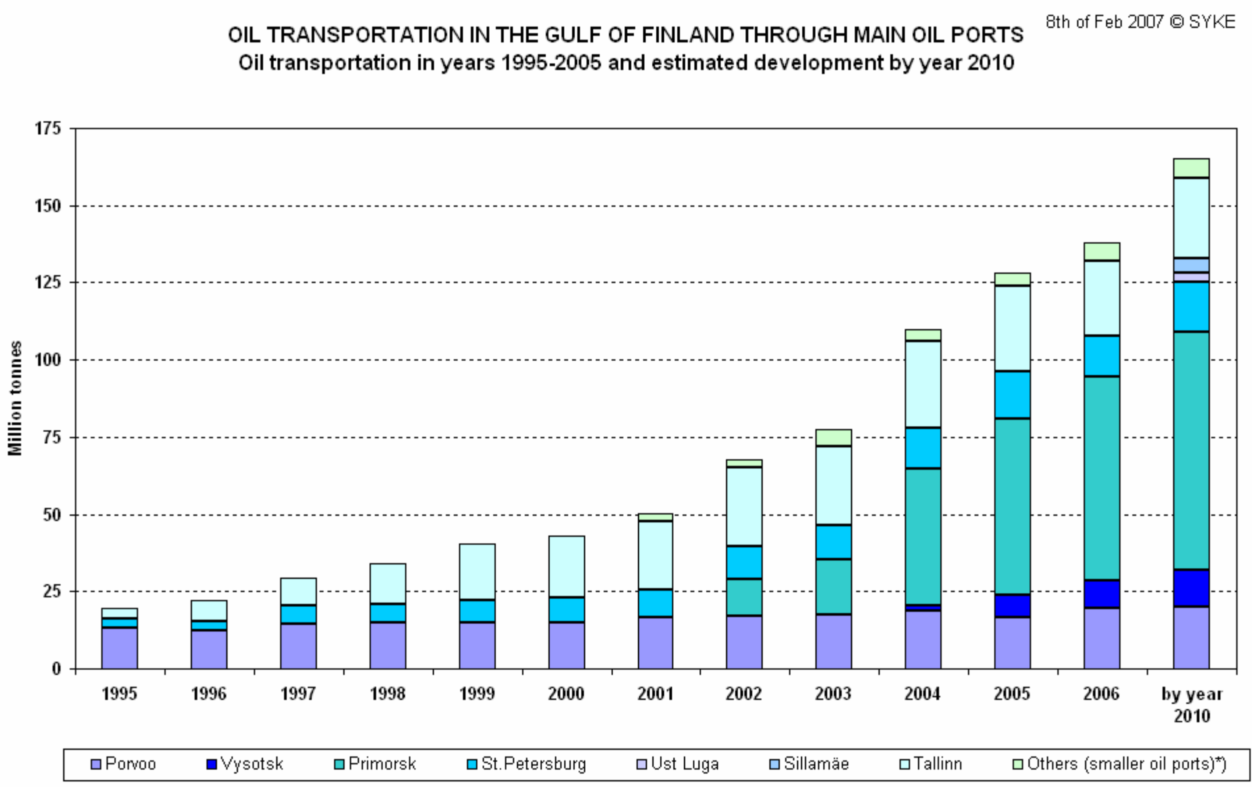
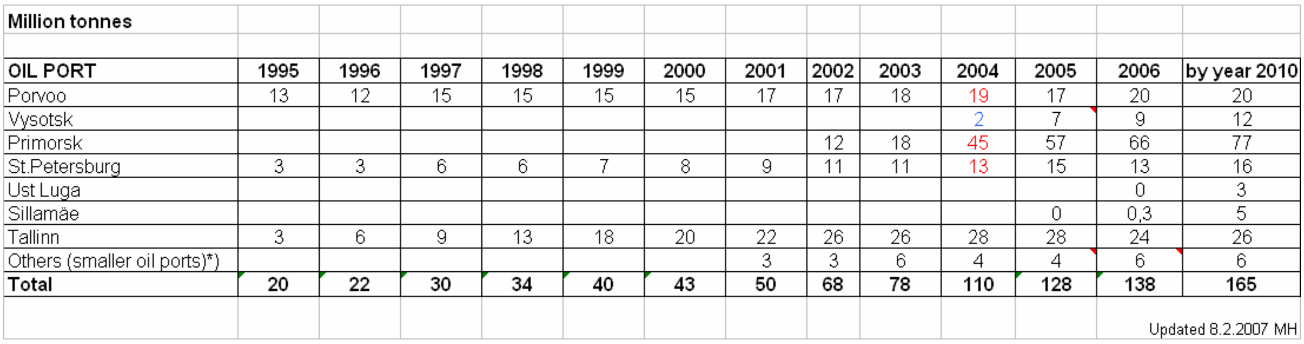


Fig 3: **The oil transport from the ports in the Gulf of Finland from year 1995 to year 2006 with a prediction for year 2010** (*Source: Finnish Environment Institute*)

Table 1: **The oil export amounts from the Gulf of Finland terminals** (Source: Finnish Environment Institute)



Million tonnes

OIL PORT	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	by year 2010
Porvoo	13	12	15	15	15	15	17	17	18	19	17	20	20
Vysotsk										2	7	9	12
Primorsk								12	18	45	57	66	77
St.Petersburg	3	3	6	6	7	8	9	11	11	13	15	13	16
Ust Luga												0	3
Sillamäe											0	0,3	5
Tallinn	3	6	9	13	18	20	22	26	26	28	28	24	26
Others (smaller oil ports)*)							3	3	6	4	4	6	6
Total	**20**	**22**	**30**	**34**	**40**	**43**	**50**	**68**	**78**	**110**	**128**	**138**	**165**

Updated 8.2.2007 MH

Table 2: **The available data on the number of tanker calls** (*Source: HELCOM*)

Year	Tanker calls to Gulf of Finland ports	Tanker call to ports east of Bornholm
2000	2520	4850
2005	3286	6105
2006	3425	NA

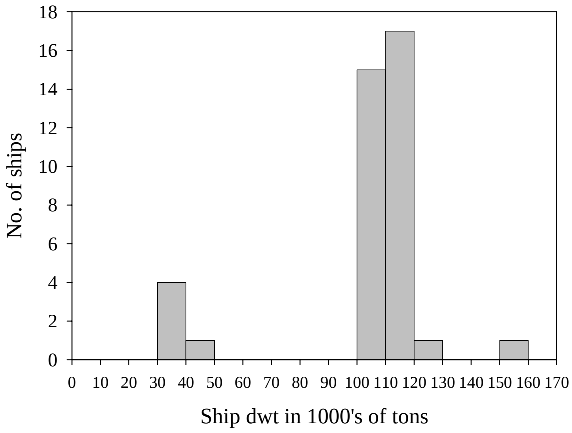


Fig. 4: **The size distribution of tankers that visited Primorsk and Vysotsk in winter 2006** (*Source: Liljeström 2006*)

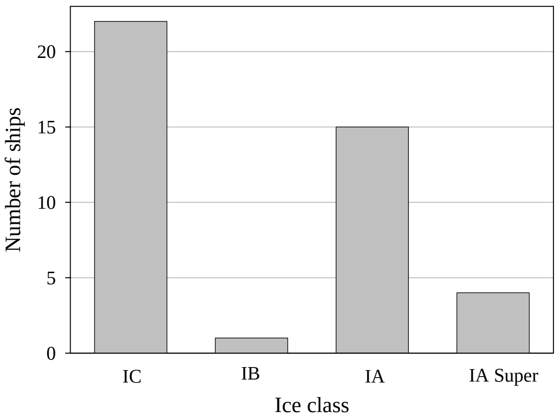


Fig. 5: The ice class tanker fleet at the end of year 2005 (*Source: Liljeström 2006*)

2.2 Winters 2000 – 2007

The winters during the present decade have been mild or at most average in terms of the ice cover extent. Data on the winters during the present decade are shown in Table 3. The ice covered area refers to the whole Baltic. Table 3 shows that the level ice thickness correlates well with the ice cover extent with some variation, but the maximum overall ice cover extent and the maximum extent of ice cover do not necessarily occur at the same date. This is because the ice cover extent is very sensitive to winds. The table shows an overall trend that the dates of maximum ice cover extent have been shifted later in the winter. A long term average date for the maximum ice cover is 2nd March and most of the dates in the table are later.

Table 3: Data of winters during the present decade

Year	Ice maximum coverage [km^2] and its date [day.month]	Maximum distance to Primorsk from ice edge [nm] and its date	Maximum level ice thickness in Primorsk [cm]	Maximum traffic restriction to Kotka
2000	95 000 24.2.	70 24.2.	35	-
2001	128 000 26.3.	130 1.3.	40	-
2002	102 000 1.2.	35 18.3.	40	-
2003	232 000 5.3.	220 6.3.	75	IA 2000 dwt
2004	152 000 11.3.	140 4.3.	40	IB 2000 dwt
2005	177 000 16.3.	175 14.3.	45	IB 2000 dwt
2006	210 000 16.3.	200 27.3.	60	IA 2000 dwt
2007	c. 120 000 5.3.	100 5.3.	35	IB 2000 dwt

2.3 Tanker Accidents in the Baltic

HELCOM maintains a database of maritime accidents in the Baltic. The database contains 91 tanker accidents for years 2000 – 2005. The accidents that took place in the Gulf of Finland and those that took place in the Baltic east of Bornholm (south of Sweden) are shown in Fig. 6. The number of accidents in the Baltic proper seems to be increasing while the number in the Gulf of Finland seems to be decreasing.

The distribution of the accident types in 2005 is shown in Fig. 7. The data for year 2005 is typical; out of the 24 accidents included 50 % were collisions and 17 % groundings. It is also important that only 2 cases of fire occurred (8 %).

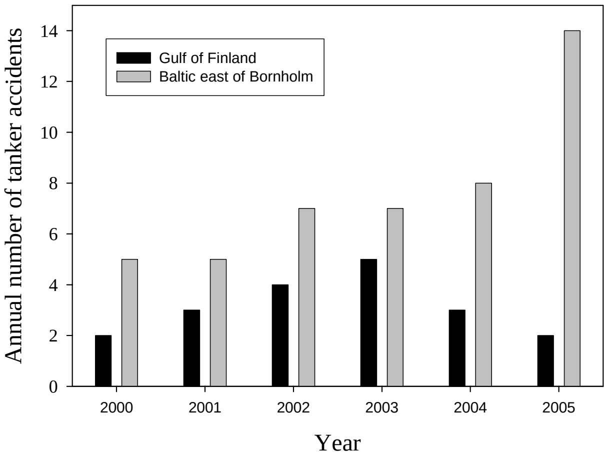


Fig. 6: The tanker accidents in the Baltic, including Gulf of Finland and in the Gulf of Finland (*Source: HELCOM*)

2.4 Winter Accidents

The ship incident and accident data for winters 2003 and 2004 have been collected by the Helsinki University of Technology on commission from the Finnish Maritime Administration (Hänninen 2004, 2005). Here the term incident includes ice related damages not caused by an accident such as denting of ship plating, propeller and rudder damage. During winter 2003 there were 108 ice related incidents or accidents while during winter 2004 only 3. The incident and accident types are shown in Fig. 8. The ice damage on the propeller and hull was most common. There were also many collisions – these were often collisions between an escorting icebreaker and the escorted merchant vessel. These accidents occurred mostly in the Gulf of Finland and operating in ice alone, as shown in Fig. 9.

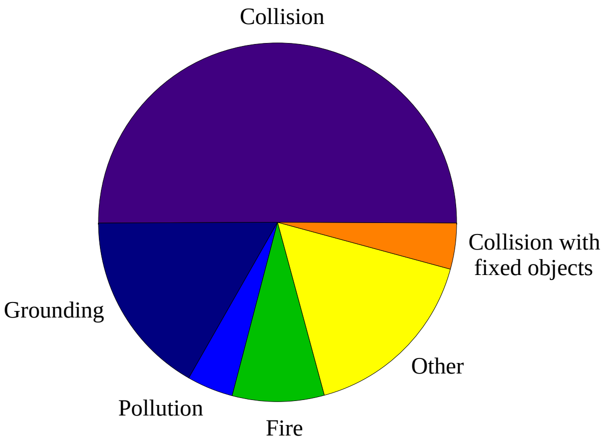


Fig. 7: The distribution of tanker accident types in the Baltic during the year 2005

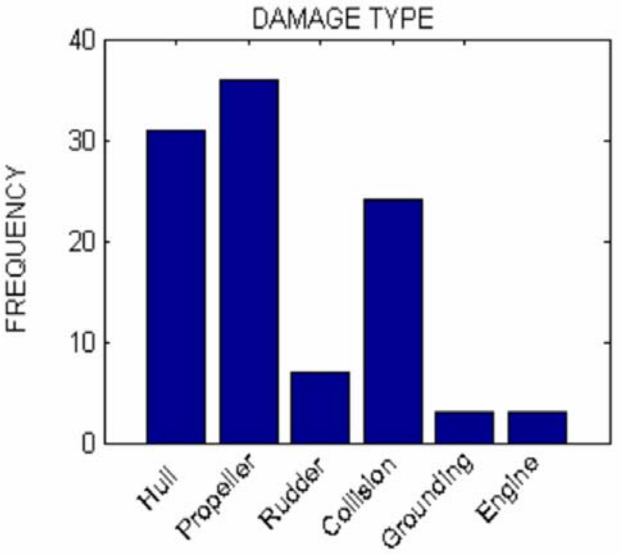


Fig. 8: The types of ice related accidents and incidents during winter 2003 (*Source: Hänninen 2005*)

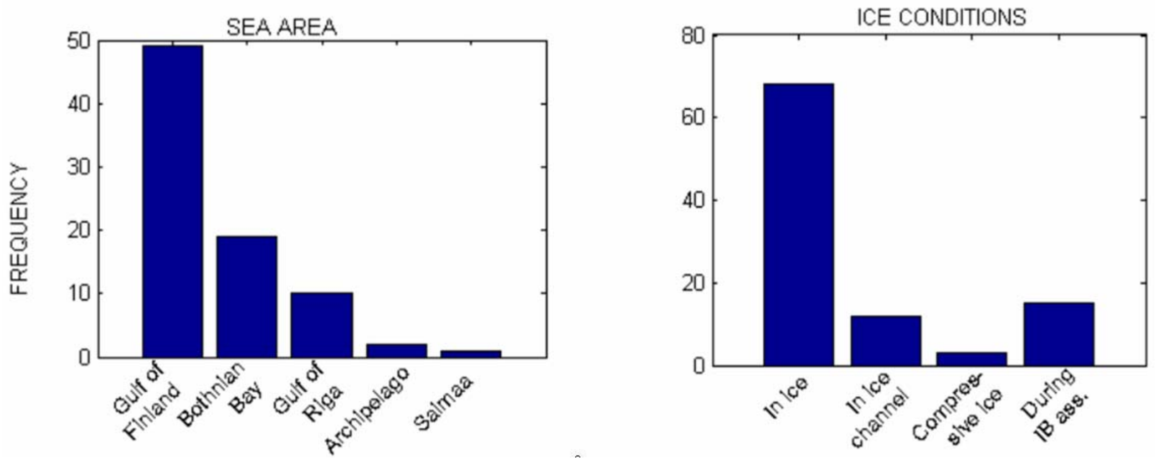


Fig 9: The distribution of sea areas where the ice related accidents occurred and the ice conditions (*Source: Hänninen 2005*)

In searching the reason for the large amount of accidents during winter 2003, and the subsequent drop in accident number in winter 2004, it is interesting to note at what date during the winter the accidents occurred. Fig. 10 shows the cumulative distribution of the accident (and incident) dates for hull and propeller/rudder ice damage and collision and grounding accidents. The hull damages occurred earlier in the winter whereas the collisions and groundings occurred more often in late winter. The reason for this is likely that the requirements for ice class were given a bit later when the ice ridging increased. Thus the early winter hull damages have occurred in relatively thin ice but with presumably higher speeds. This data does not, however, shed much light on the causes of the accidents. More data is needed to draw definite conclusions.

It should be also noted that the ice strengthened aframax tankers trading to eastern Baltic ports are young and the age is not considered a factor in the accident rate.

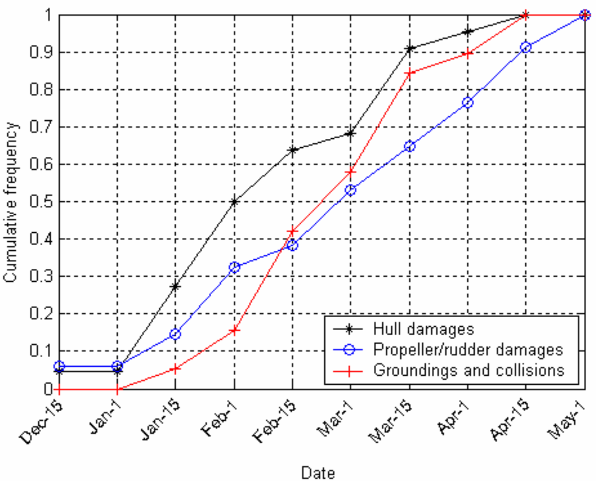


Fig. 10: The cumulative distribution of the dates of ice related accidents for year 2003 (*Source: Hänninen 2005*)

As the data on ice conditions show, the winter 2003 was slightly more severe than the long term average. However, it was relatively a normal winter after a long series of mild winters. The last average winter – in the terminology of classifying the winters according to the ice covered area – before winter 2003 was in 1996. Thus there was a series of 7 mild winters before winter 2003 (Fig. 11). The marine accidents excluding ice damage incidents for years 1971 – 2003 are plotted in Fig. 12. The highest number of accidents (21) occurred in winter 2003 although it was not the most severe ice year as shown in the figure.

The combination of increased traffic and inexperience in more severe ice conditions are the likely causes for the increase in the accidents in 2003. The data supports the argument that experience in winter navigation is the best way to avoid accidents in ice.

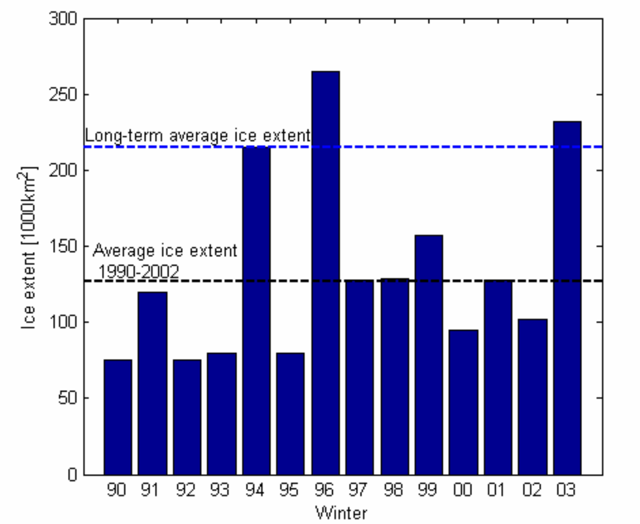


Fig. 11: The extent of ice cover during the 13 winters leading to winter 2003 (*Source: Jalonen et al 2005*)

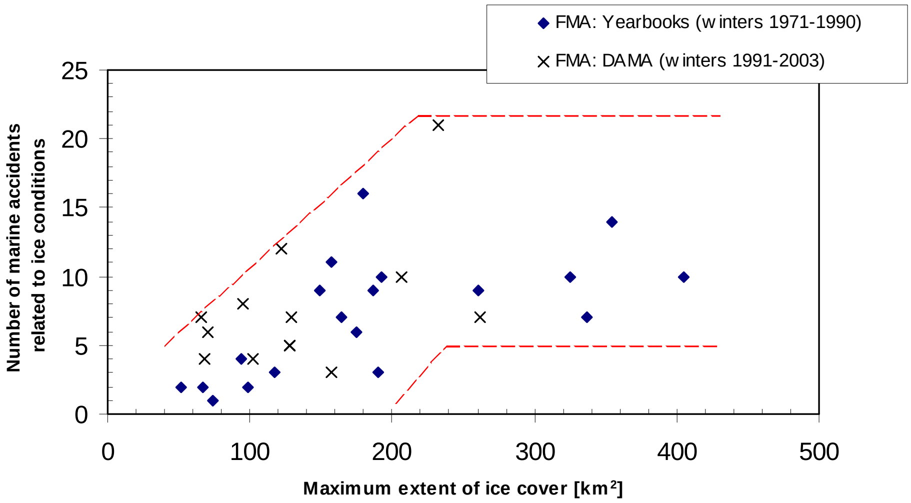


Fig. 12: The number of accidents related to winter, plotted versus the maximum ice extent in different winters (*Source: Accident data from Finnish Maritime Administration*)

3. Comparison of FSICR and IACS Polar UR

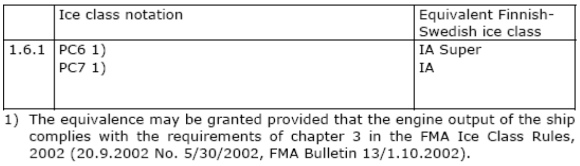
Although the experience from Baltic operations will be valuable as the focus moves further north to the Arctic there are major differences between the Baltic and Arctic operations. Compared to the Baltic the Arctic has a much harsher environment and it is remote with little infrastructure to support year round transportation. This will bring new challenges to the ship design and operation. The presence of multi year ice imposes additional loads on the hull, propulsion system and appendages, which must be accounted for in the design.

To promote the safety of navigation and to prevent pollution from ship operations in Arctic ice-covered waters, the Marine Safety Committee (MSC) and Marine Environment Protection Committee (MEPC) of IMO approved the *Guidelines for Ships Operating in Arctic Ice-Covered Waters* in October 2002. These Guidelines are recommendatory rather than mandatory for vessels traveling in the Arctic ice-covered waters.

IMO Guidelines refer to the IACS Unified Requirements (UR) for Polar Class for structural design and construction. The IACS Polar Class requirements were adopted by IACS in 2006, and they will be effective in March 2008.

Since the ships intended for the Baltic winter operation are generally built in accordance with the Finnish-Swedish Ice Class Rules (FSICR) designers are familiar with them and want to understand the differences between the FSICR and the Polar Ice Class requirements.

Because the FSICR were developed specifically for the Baltic ice conditions whereas the Polar Classes were developed for the Polar Regions, there are differences in the requirements. However the lowest two Polar ice classes are considered equivalent with the two highest Finnish- Swedish ice classes (Fig. 13).



	Ice class notation	Equivalent Finnish-Swedish ice class
1.6.1	PC6 1) PC7 1)	IA Super IA

1) The equivalence may be granted provided that the engine output of the ship complies with the requirements of chapter 3 in the FMA Ice Class Rules, 2002 (20.9.2002 No. 5/30/2002, FMA Bulletin 13/1.10.2002).

Fig. 13: FMA equivalency *(Source: FMA Bulletin 4/2.4.2007)*

The navigation ice condition for FSICR classes is the first-year ice in Baltic, and the assumption is that the vessels are to be escorted by icebreakers. The two highest ice classes 1A and 1A Super are based on 0.8 meter and 1.0 meter ice thicknesses respectively (Table 4).

Table 4: FSIC notation and ice thickness

Ice Class	*For Navigation In:*	*Ice thickness – First Year Ice (cm)*
IA Super	Extremely difficult ice conditions	>100
IA	Difficult ice conditions	>50 - 100
IB	Moderately difficult ice conditions	30 - 50
IC	Easy ice conditions	15 - 30
Category II	Very easy ice conditions	10 - 15

There are seven Polar Ice Classes and their assumed operational profile varies from a "year-round operation in all Polar waters" for the highest ice class PC1 to "summer/autumn operation in thin first-year ice which may include old ice inclusions" for the lowest ice class PC7 (Table 5). The Polar Class requirements are based on the assumption that the ship is able to operate independently in the designated ice condition.

Table 5: Polar Class Descriptions (*Source: IACS 2006a*)

Polar Class	*Ice Description (based on WMO Sea Ice Nomenclature)*
PC 1	Year-round operation in all Polar waters
PC 2	Year-round operation in moderate multi-year ice conditions
PC 3	Year-round operation in second-year ice which may include multi-year ice inclusions.
PC 4	Year-round operation in thick first-year ice which may include old ice inclusions
PC 5	Year-round operation in medium first-year ice which may include old ice inclusions
PC 6	Summer/autumn operation in medium first-year ice which may include old ice inclusions
PC 7	Summer/autumn operation in thin first-year ice which may include old ice inclusions

The following a list of some of the main differences between the approach adopted by the two rule sets.

- The definition of the ice belt, which defines the extent of reinforcement, is different in the two rule sets. The FSICR divides the ship into three regions: forward, midship and aft. Only forward region is further divided into three sections in the vertical direction: upper forward ice belt, ice belt and fore foot. This means that for the midship and aft regions, the sections below the ice belt are not reinforced. The extent of reinforcement for side shell plating and framing are different in the FSICR. The Polar Class requirements divide the hull into four sections longitudinally: bow, bow intermediate, mid body, stern, and three sections vertically: bottom, lower and ice belt region.
- The ice load definition in the Polar Class requirements depends on hull form angles whereas the FSICR load does not. The FSICR load depends on propulsion power, whereas the Polar Class requirement does not directly relate to the propulsion power. The Polar Class ice load model is based on theoretical analysis models for the glancing (tangent impact) ship/ice interaction scenario, while the FSICR ice load is more based on experimental measurements in the Baltic Sea. In Polar Class requirements, peak pressure factors are used to account for the pressure concentration on local structural members when the ice load is applied to determine scantlings, while in the FSICR, the pressure is assumed uniform inside the load

patch.

- In the FSICR the corrosion margin is constant 2 mm, whereas in the Polar Class the corrosion/abrasion margin depends on the location, ice class, and coatings.
- The main difference in the approach to the scantling requirements is that the FSICR frame strength requirement is based on the elastic section modulus and in the Polar Rules on the plastic section modulus. The FSICR require brackets at the connection of a side longitudinal to a web frame.
- Polar Class includes longitudinal strength requirement for the ramming scenario, whereas the FSICR does not.
- Polar Class machinery requirements include ice loads and failure criteria but the detailed scantling design is to be done either using advanced analysis methods or accepted industry engineering practice. The FSICR include scantling equations.
- Polar Class does not have a requirement for minimum propulsion power.
- Polar Class gives clear requirement on material class selections to prevent material failure in low temperature, while FSICR does not include requirements for material selection

Based on above it is clear that both the approach and the application of the requirements in the FSICR and in the Polar Ice Class UR are quite different. The equivalency between the lower Polar Ice Classes and the higher FSICR classes is not exact. However this does not mean that equivalencies established by the administrations are not valid. They are generally based on the principle of equivalent safety and equivalent performance in the same ice conditions, and therefore they serve the needs of the administrations and provide guidance to the industry in the selection of the ice class for the vessel's intended operational profile.

4. Operation in Cold Temperatures

The average and extreme temperatures in the Arctic are lower than in the Baltic and the design and the operation must be adjusted to these temperatures. The reliability and the redundancy of the machinery and safety equipment, insulation of spaces, and ergonomic considerations are some of the issues that need to be addressed in the design of vessels for the Arctic. Since these aspects are not covered by the traditional ice class requirements Classification Societies have developed additional criteria for winterization and cold weather operations (ABS Guide for Vessels Operating in Low Temperature Environments).

Design considerations critical for cold weather operations but not covered by Ice Class Rules are listed below.

- Material and coatings selection beyond ice class requirements.
- Hull construction/ arrangement and equipment considering tank contents freezing, protection of the personnel and vessel stability.
- Vessel systems and machinery beyond ice class requirements.

  Machinery arrangements may be required to be modified as a result of low ambient temperatures.

  Sea water supplies for essential operational systems and safety systems must be provided during navigation and at port in ice-covered waters.

  Essential equipment and systems must be available at all times and in any temperature conditions.

  The methods to adapt the equipment to the Arctic environment may vary and will depend on the type of equipment and systems, their criticality for the safety of the ship and its crew, and the protection of the environment.

  Heating of spaces and equipments must be considered.

  The definition of the design service temperature (DST) for the vessel is important for setting the requirements for materials and equipment. For example the definition adopted in *ABS Guide for Vessels Operating in Low Temperature Environments* is based on the IACS Unified Requirement S6, Use of steel grades for various hull members-ships of 90 m in length and above, section 6.3. It defines DST as the lowest mean daily average temperature in the area of operation for data taken over at least a 20 year period.

  Essential equipment and systems ideally should be located in spaces protected from the extreme cold weather, however, it is recognized that often exposure to extreme ambient weather will be unavoidable. For these situations the equipment is to be suitable for operation at the minimum anticipated temperature (MAT) which is 20°C less than the DST.
- Requirements for safety systems including life saving equipment, fire fighting equipment, and navigational equipment.
- Environmental protection

  Ships intended to trade in the Arctic Regions should be designed to take into account all the current and foreseeable statutory Regulations for environmental protection in addition of coastal state requirements related to the same issue. IMO Guidelines (IMO, 2002) make a strong statement in this regard by referring in a considerable number of its sections to the need for preventing pollution from ships navigating the Arctic Regions.

- Crew considerations including basic information on human performance and health hazards when working in Arctic conditions.
- Crew training
- Information for Weather Conditions, Vessel Operations, Administrations and Meteorological Organizations

5. Conclusion

The experience from tanker operations in the winter Baltic provides valuable information for the industry as it prepares for future transportation of large quantities of gas and oil from the Arctic. The data on the vessel traffic in the Baltic is still somewhat limited because it is not readily available from all Baltic countries. The accident data is available since 2000, but because of the changes in the accident reporting in 2003, the data before and after may not be comparable. However, the data indicates clearly a peak in the number of accidents in 2003. Although the ice conditions in 2003 were above average in severity, the conclusion is that lack of experience in ice operation was the likely reason for the increase. Experience and proper training in ice operations is critical for the safe operation under these conditions.

The environmental conditions in the Arctic are more severe than in the Baltic, and the ice class requirements must take that into account. The comparison between the Finnish-Swedish Ice Class Rules and the IACS Polar Class requirements is only meaningful for the highest FSICR classes and the lowest Polar ice classes. Because the approach adopted in the rules is different in many aspects of the requirements a direct comparison of the rules difficult. The industry prefers harmonization of the rules at least for the same ice conditions, and the need for harmonization was one of the drivers for the development of the Polar Ice Class Unified Requirements.

The ice class rules do not cover all aspects of the design which are critical for the safe operations in the cold temperatures and ice covered waters, and further guidance from Classification Societies can be used to design a ship for operations in low temperatures.

In summary the oil and gas transportation from the Arctic has many challenges but the technology and the experience needed to address these challenges is available for developing solutions for safe the Arctic.

References

ABS, (2006), Guide for Vessels Operating in Low Temperature Environments

Finnish-Swedish Ice Class Rules (2002), Regulation for the Strengthening and Design of Ships for Navigation in Ice, Finnish Maritime Administration

Conachey, R., Legland, E., Wang, G. and Baker, C., (2007), “Winterization Guidelines for Vessels Operating in Arctic Waters”, presented at Lloyd's Maritime Academy Seminar on Risk Management in Ice Navigation, 25 and 26 January 2007

Hänninen, S. (2004), “Ice Related Damages of Ships in the Baltic Sea, Winters 2003 and 2004”, Unpublished memorandum by Helsinki University of Technology, Espoo, 15.12.2004.

Hänninen, S.(2005), “Incidents and Accidents in Winter Navigation in the Baltic Sea, Winter 2002-2003”, Winter Navigation Research Board, Research Report No. 54, Helsinki, 39 p.

Hänninen, S. and Rytkönen, J., (2004a), “Oil Transportation and Terminal Development in the Gulf of Finland”, Press Conference at Ministry of Environment, Helsinki, 29.9.2004.

Hänninen, S. and Rytkönen, J., (2004b), “Oil Transportation and Terminal Development in the Gulf of Finland”, VTT Publications 547, Espoo, 141 p. + app. 6 p.

Hänninen, S. and Rytkönen, J., (2006), “Transportation of Liquid Bulk Chemicals by Tankers in the Baltic Sea”, VTT Publications 595, Espoo, 121 p. + app. 30 p.

IACS, (2006a) “Unified Requirement UR I1 - Polar Class Descriptions and Application”, International Association of Classification Societies.

IACS, (2006b) “Unified Requirement UR I2 - Structural Requirements for Polar Class Ships”, International Association of Classification Societies.

IACS, (2006c). “Unified Requirement UR I3 - Machinery Requirements for Polar Class Ships”, International Association of Classification Societies.

IMO, (2002) “Guidelines for Ships Operating in Arctic Ice-Covered Waters”, MSC/Circ. 1056, MEPC/Circ. 399. International Maritime Organization.

Jalonen, R., Riska, K. and Hänninen, S. (2005) “A Preliminary Risk Analysis of Winter Navigation in the Baltic”, Winter Navigation Research Board, Research Report No. 57, Helsinki, pp.206

Liljeström, G.(2006) “Icebreaker Operations and Large Tankers in Ice”, Deliverable D4-2.1 from the SAFEICE project.

Rytkönen, J. (2002) “Statistical Analyses of the Baltic Maritime Traffic”, HELCOM meeting in Turku, 29.4.2002.

Rytkönen, J., Hänninen, S. and Sonninen, S., (2002) “Sea-Borne Traffic in 2000 up to 2015 in the Gulf of Finland”, VTT Technical Research Centre of Finland, Espoo, 21.3.2002.

Wiernicki, C. and Tikka, K. (2006) “New Regulatory Challenges for the Transportation of Energy from New Frontiers”, presented at Energy Shipping Conference, Athens, Greece, 2006.