



TraFi



SWEDISH
TRANSPORT
AGENCY

**GUIDELINES FOR THE APPLICATION OF
THE FINNISH-SWEDISH ICE CLASS RULES**

**TRAFI/21816/03.04.01.01/2011
Helsinki, 20 December 2011**

Table of contents

- 1 Introduction
- 2 The Status of the Guidelines
- 3 Implementation of the Finnish-Swedish Ice Class Rules in Finland and in Sweden
 - 3.1 Implementation of the Finnish- Swedish Ice Class Rules in Finland
 - 3.1.1 Ice Class Certificate of the FMA
 - 3.2 Implementation of the Finnish-Swedish Ice Class Rules in Sweden
- 4 The Purpose and the Scope of the Rules
 - 4.1 Design Philosophy
 - 4.1.1 The Engine Power Regulations
 - 4.1.2 Hull Structural Design
 - 4.1.3 Propeller, Shafts and Gears
 - 4.1.4 Application of the Rules for the Design of Ships for Other Sea Areas
- 5 General (Chapter 1 of the Rules)
 - 5.1 Ice Classes
- 6 Ice Class Draught (Chapter 2 of the Rules)
- 7 Engine Output (Chapter 3 of the Rules)
 - 7.1 Definitions (Section 3.2.1 of the Rules)
 - 7.2 Existing Ships of Ice Class IB or IC (Section 3.2.3 of the Rules)
 - 7.3 On Selection of the Propulsion System
 - 7.4 Other Methods to Determine K_e or R_{CH}
 - 7.4.1 Other Methods to Determine K_e
 - 7.4.2 Other Methods to Determine R_{CH}
- 8 Hull Structural Design (Chapter 4 of the Rules)
 - 8.1 Frame Connections
 - 8.2 Vertical Extension of Ice Strengthening of Framing (Section 4.4.1 of the Rules)
 - 8.3 Inclined or Unsymmetric Frame Profiles (Section 4.4.4.2 in the Rules)
 - 8.4 Arrangement for Towing (Section 4.7.2 of the Rules)
 - 8.5 Reduction in Corrosion Allowance (Section 4.3.2 of the Rules)
 - 8.6 Propeller Clearance
 - 8.7 Transom Stern
 - 8.8 Bilge Keels
- 9 Rudder and Steering Arrangements (Chapter 5 of the Rules)
 - 9.1 Ice Knife
 - 9.2 Rudder Turning Mechanism
 - 9.3 Bow Thrusters
- 10 Propulsion Machinery (Chapter 6 of the Rules)
 - 10.1 Fatigue Design of Propeller Blade (Section 6.6.2.3 of the Rules)
 - 10.2 Blade Failure Load (Section 6.5.4 of the Rules)

11 Miscellaneous Machinery Requirements (Chapter 7 of the Rules)

11.1 Sea Inlet and Cooling Water Systems

12 General Suitability for Winter Conditions

12.1 Low Ambient Temperature

Appendices

Appendix 1. Instructions for the application of a letter of compliance

Appendix 2. Guidelines for the calculation of propeller thrust for open and nozzle propellers

Appendix 3. Guidelines for bollard pull tests for determining the thrust of the propeller(s)

Appendix 4. Guidelines for the verification of a ship's performance for ice classes through model tests

References

- Finnish-Swedish Ice Class Rules, 2010, (see www.trafi.fi, (23.11.2010 TRAFI/31298/03.04.01.00/2010))
- The Equivalence between the Finnish-Swedish Ice Classes and Ice Classes of Classification Societies, (see www.trafi.fi (23.11.2010 TRAFI/31299/03.04.01.00/2010))
- Transportstyrelsens föreskrifter och allmänna råd om finsk-svensk isklass, TSFS 2009:111
- Act on the Ice Classes of Ships and Icebreaker Assistance (1121/2005) and Act on Fairway Dues (1122/2005), as amended, (see www.finlex.fi)

1 Introduction

The Finnish Transport Safety Agency (Trafi) and the Swedish Transport Agency (STA) have developed the Finnish-Swedish Ice Class Rules in co-operation with classification societies. The development of the rules started as early as in the 1930's. The rules have been amended several times during the past years, for example in 1971 and 1985, and the latest version was published in 2010 (see Finnish Transport Safety Agency TRAFI 23.11.2010, available at www.trafi.fi). Most of the members of the International Association of Classification Societies (IACS) have adopted the Finnish-Swedish ice class rules and incorporated them in their own regulations on the classification of ships.

The purpose of these Guidelines is to provide classification societies, ship designers and shipyards some background information on the ideas behind the rules, to provide a harmonised interpretation for the implementation of certain parts of the rules, and to provide guidance on certain aspects of winterisation of the ship, not mentioned in the rules.

These Guidelines will be updated when needed and published at the websites of Trafi and the STA.

2 The Status of the Guidelines

In general, Trafi and the STA accept class approval based on these Guidelines for design of vessels. The approval of Trafi or the STA for the engine power of a vessel is required in case the engine power is determined by model tests or by means other than the formulae given in the rules in regulation 3.2.5. Instructions for the application of a letter of compliance are given in Appendix 1. Model tests done for vessels contracted for construction on or after 1 January 2012 should be done according to these Guidelines.

These Guidelines replace all Guidelines issued earlier by Trafi or by the STA.

3 Implementation of the Finnish-Swedish Ice Class Rules in Finland and in Sweden

The Finnish and Swedish administrations provide icebreaker assistance to ships bound for ports in these two countries in the winter season. Depending on the ice conditions, restrictions in regard to the size and ice class of ships entitled to icebreaker assistance are enforced. Winter traffic restrictions for ships are set in order to ensure smooth winter navigation and the safety of navigation in ice. Assistance of ships with inadequate engine output or ice strengthening would be both difficult and time-consuming. It would also not be safe to expose such vessels to ice loads and ice pressure.

The traffic restrictions are modified during the winter period depending on ice conditions. A typical strictest traffic restriction for ships bound for the Finnish ports in the eastern Gulf of Finland is, as a minimum, ice class IA and a minimum deadweight of 2000 TDW. A typical strictest traffic restriction for the ports in the northern Bay of Bothnia is ice class IA and a minimum deadweight of 4000 TDW. On the other hand, a lower minimum ice class is required for ships bound for the ports on the south-western coast of Finland where the ice

conditions are less difficult. A typical minimum requirement is ice class IC and a deadweight of 3000 TDW.

3.1 Implementation of the Finnish-Swedish Ice Class Rules in Finland

Pursuant to section 12 of the Act on Fairway Dues (1122/2005 as amended by Acts 1267/2007, 750/2008, 787/2008, 1257/2009 and 1309/2009), the Finnish Transport Safety Agency has, on 23 November 2010, adopted a regulation on the structural design and engine output required of ships for navigation in ice (see www.trafi.fi, 23.11.2010 TRAFI/31298/03.04.01.00/2010). The Act on the Ice Classes of Ships and Icebreaker Assistance has been issued as Act 1121/2005.

Pursuant to section 12 of the Act on Fairway Dues (1122/2005), the Finnish Transport Safety Agency has confirmed the list of ice class notations of authorized classification societies and the equivalent Finnish-Swedish ice classes (see www.trafi.fi, 23.11.2010 TRAFI/31299/03.04.01.00/2010). The ice class of a ship, which has an ice class of a classification society, is determined in accordance with this regulation.

The Finnish Transport Agency is responsible for giving icebreaker assistance for ships entering Finnish ports, if the ice conditions require that. This assistance service is included in the fairway due. The Finnish Transport Agency sets traffic restrictions for ships pending on ice conditions (see Rules for Winter Navigation at www.liikennevirasto.fi). Finnish icebreakers only assist ships that meet the ice class requirements set out in the Finnish-Swedish Ice Class Rules 2010.

The fairway due imposed on a ship entering a Finnish port depends on the ice class of the vessel in accordance with the Government Decree on Fairway Dues (1122/2005) (see www.finlex.fi).

3.1.1 Ice Class Certificate of Trafi

From 1 January 2006 Ice Class Certificates are no longer issued by the inspectors of the Finnish Transport Safety Agency at Finnish ports. The Ice Class of a ship will be determined on the basis of the Classification Certificate of the ship.

3.2 Implementation of the Finnish-Swedish Ice Class Rules in Sweden

The STA is responsible for giving icebreaker assistance for ships entering Swedish ports. This assistance service is free of charge. The STA sets traffic restrictions for ships pending on ice conditions.

Swedish icebreakers only assist ships that meet the Finnish-Swedish ice class rules. Sweden also applies the same equivalencies to the Finnish-Swedish ice classes as Finland (FMA/31299/03.04.01.00/2010). The STA does not issue ice class certificates, but the ice class is based on the Classification Certificates of ships.

4 The purpose and scope of the rules

The Finnish-Swedish Ice Class Rules are primarily intended for the design of merchant ships trading in the Northern Baltic in the winter. The rules primarily address matters directly relevant to the capability of a ship to advance in ice. The regulations for minimum engine output (Chapter 3 of the Rules) can be considered to be regulations of an operational type. Ships are required to have a certain speed in a brash ice channel in order to ensure the smooth progress of traffic in ice conditions. The regulations for strengthening the hull, rudder, propellers, shafts and gears (Chapters 4 to 6 of the Rules) are clearly related to the safety of navigation in ice. In principle, all parts of the hull and the propulsion machinery exposed to ice loads have to be ice-strengthened.

4.1 Design Philosophy

The Finnish-Swedish Ice Class Rules are intended for the design of merchant ships operating in first year ice conditions part of the year. Usually, compromises have to be made when ships are designed both for open water and ice conditions. The basic philosophy of the rules is to require, for operative reasons, a certain minimum engine power for ships with an ice class. However, no general requirements for the hull form have been set. The structural strength of the hull and the propulsion machinery should be able to withstand ice loads with a minimum safety margin. For economic reasons excessive ice strengthening is avoided.

The Finnish-Swedish Ice Class Rules set the minimum requirements for engine power and ice strengthening for ships assuming that icebreaker assistance is available when required. Special consideration should be given to ships designed for independent navigation in ice, or for ships designed for navigation in other sea areas than the Baltic Sea.

The design points for hull and propulsion machinery as well as for the ice performance (propulsion power) are all different. This reflects the fact that different ice conditions in different ship operations form the critical design situations. The design points are as follows:

Item	Design point in FSICR	Description of the design point
Hull	Impact with level ice of thickness h_0	The ship can encounter thick level ice in ridges where the consolidated layer can be 80 % thicker than the level ice thickness. Also channel edges can be very thick.
Propulsion machinery	Impact with large ice floes of thickness H_{ice}	Propellers encounter only broken ice and the design scenario is an impact with these floes. Large ice floes can be encountered among the level ice floes for example in old channels.
Propulsion power	Ship must make at least 5 knots in a brash ice channel of thickness H_M	Ships must be able to follow icebreakers at a reasonable speed and also to proceed in old brash ice channels independently at reasonable speeds.

4.1.1 The Engine Power Regulations

The regulations for minimum engine output are based on long term experience of the Finnish and Swedish icebreaker assistance in the northern Baltic Sea area. The number of icebreakers

is limited, and they have to be able to assist all ships entering or leaving the winter ports. Thus the minimum engine power requirement is “a matter of definition” to be decided by the Maritime Authorities depending on the number of icebreakers, number of ships in need of assistance, ice conditions, and maximum waiting time for icebreaker assistance. In Finland, the maximum average waiting time for icebreaker assistance is defined as about four hours.

The principle of the winter navigation system is that all ships meeting the traffic restrictions are given icebreaker assistance. Ice classed ship is assisted by an icebreaker when the ship is stuck in ice or is in need of assistance, because her speed has substantially decreased. Normally the ship is assisted to (or from) the fairway entrance and after that the ship should be able to sail to the port on its own (or sail out of the port on its own), although the icebreaker often has to escort in particular smaller ships into the port. Most of the fairways leading to Finnish coastal ports are routed through the archipelago area. In archipelago areas the ice cover is stationary. The engine power requirements of the rules have been developed for navigation in brash ice channels in archipelago areas at a minimum speed of 5 knots. Thus the mere compliance with these regulations must not be assumed to guarantee any certain degree of capability to advance in ice without icebreaker assistance nor to withstand heavy ice compression at open sea, where the ice field may move due to high wind speeds. It should be also noted that the ice-going capacity of small ships may be somewhat lower than that of larger ships having the same ice class. This observation which is based on icebreaker operators experience may be attributed partly to the beneficial effect that larger inertia has in ice going.

4.1.2 Hull Structural Design

The rules for hull structural design (Chapter 3 of the Rules) deal with the local strength of the hull (plating, frames, stringers and web frames). Ice loads given in the Rules have been determined based on measurements on ships that sail in the Baltic Sea in winter. The situation where a ship is stuck in compressive and/or moving ice and large ice forces are acting on the parallel midbody is not considered in the rules. It is assumed that icebreaker assistance is available in such cases so that there is no time for a serious compressive situation to develop. However, according to the experience of the Administrations, vessels strengthened to ice classes IA and IA Super rarely get damaged in compressive ice situations. During recent years, ice damages on the midbody of ships with ice class IC have been observed.

Recent observations on ice damages on ice strengthened vessels indicate that most of the damages on hull occur at an early stage of the winter season. These ships are probably operated at open sea at a high speed when the ice coverage is less than 100 %. Damages on the hull may thus occur when the vessel hits an ice floe at high speed.

4.1.3 Propeller, Shafts and Gears

The “pyramid strength” principle, i.e. the hierarchical strength principle is adopted for the design of the propulsion system. This means that the propeller blades are the weakest element in the propulsion train and the strength increases towards the main engine or propulsion motor.

Recent observations on ice damages on ice strengthened vessels indicate that most of the damage on propellers occurs at a later stage of the winter season than the damages on the hull. Obviously, thick ice blocks create the largest loads on propellers.

4.1.4 Application of the Rules on the Design of Ships for Other Sea Areas

If the Finnish-Swedish Ice Class Rules are applied to the design of ships for other sea areas, the following issues should be taken into consideration:

- The Finnish- Swedish Ice Class Rules have been developed for first year ice conditions with a maximum level ice thickness of 1.0 m, ice bending strength (cantilever beam test) of about 500 kPa and maximum compressive strength of sea ice about 5 MPa.
- Ice compression in the sea area should be taken in consideration.
- There is no swell in the Baltic Sea like in the oceans. The vertical extension of the ice belt in the bow area may not be adequate, if the vessel is operated in an area with high swell and floating ice.

5 General (Chapter 1 of the Rules)

5.1 Ice Classes

Ships with ice class IA Super are intended for year round operation in the Baltic Sea area. This means that the Administrations do not set traffic restrictions for this ice class. Ships with ice class IA are intended for year-round operation in the Baltic Sea area, and are escorted if necessary. However, size restrictions may apply for ice class IA.

Ships having the ice class IB or IC may have limited access to Finnish and Swedish ports for part of the year, pending on ice conditions.

Ships belonging to ice classes II and III are not strengthened for navigation in ice. In Finland the fairway dues depend on the ice class of the vessel and for this reason “ice classes” II and III are used.

6 Ice Class Draught (Chapter 2 of the Rules)

The UIWL and LIWL waterlines may be broken lines as these are envelopes of all allowed load situations. The forward design draught should never be less than the draught amidships. The same draught that is be used for the calculation of the minimum engine power of the ship (see paragraph 3.2.2 of the Rules), is to be used in the determination of the vertical extension of ice strengthening (see 4.3.1 and 4.4.1 of the Rules).

It is recommended that in the design stage, some reserve is allowed for the ice class draughts UIWL and LIWL. In doing so, the engine power of the vessel, as well as the vertical extension of the ice belt, will fulfil the rule requirements also in the future, if the UIWL draught of the ship is increased or the LIWL draught decreased when the ship is in operation.

It has been observed that ships in light load condition require more icebreaker assistance than in the fully loaded condition. Thus ships should always be operated so that the waterline is between UIWL and LIWL, preferably closer to UIWL. Consideration should also be given to operating with the deepest propeller submergence feasible.

7 Engine Output (Chapter 3 of the Rules)

7.1 Definitions (Section 3.2.1 of the Rules)

The length of the bow (L_{BOW}) should be measured between the forward border of the side where waterlines are parallel to the centerline and the fore perpendicular at UIWL. The same perpendicular should also be used when calculating the length of the bow at LIWL.

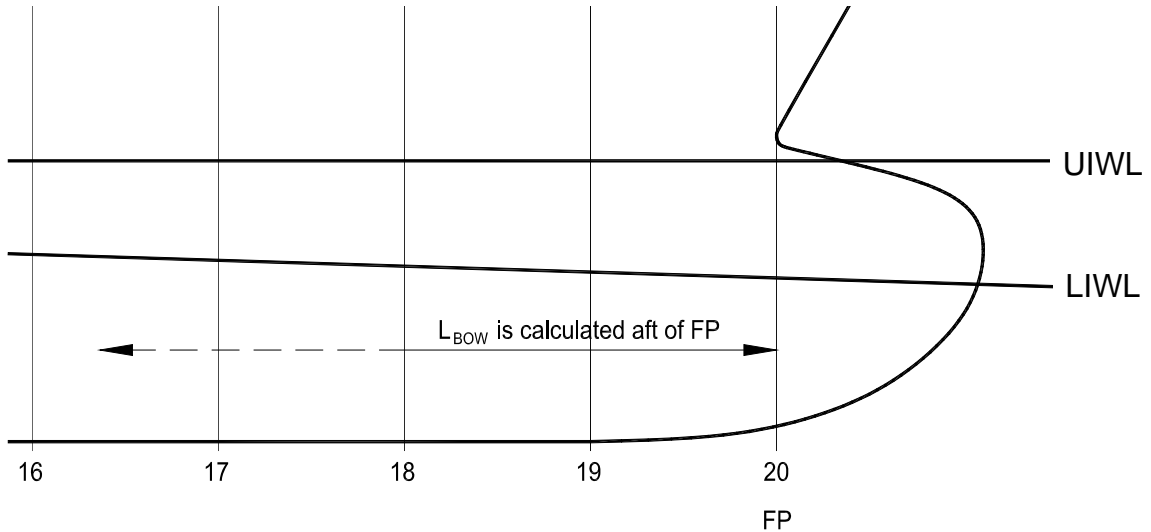


Figure 1. Measurement of the length of the bow.

The length of the parallel midship (L_{PAR}) should be measured from the aft perpendicular if that part of the side where waterlines are parallel to the centerline extends aft of the aft perpendicular.

No negative values of the rake of the bow at B/4 (φ_2) should be used in the calculations. If the rake of the bow has a negative value as presented in Figure 2 below, 90 degrees should be used in the calculations.

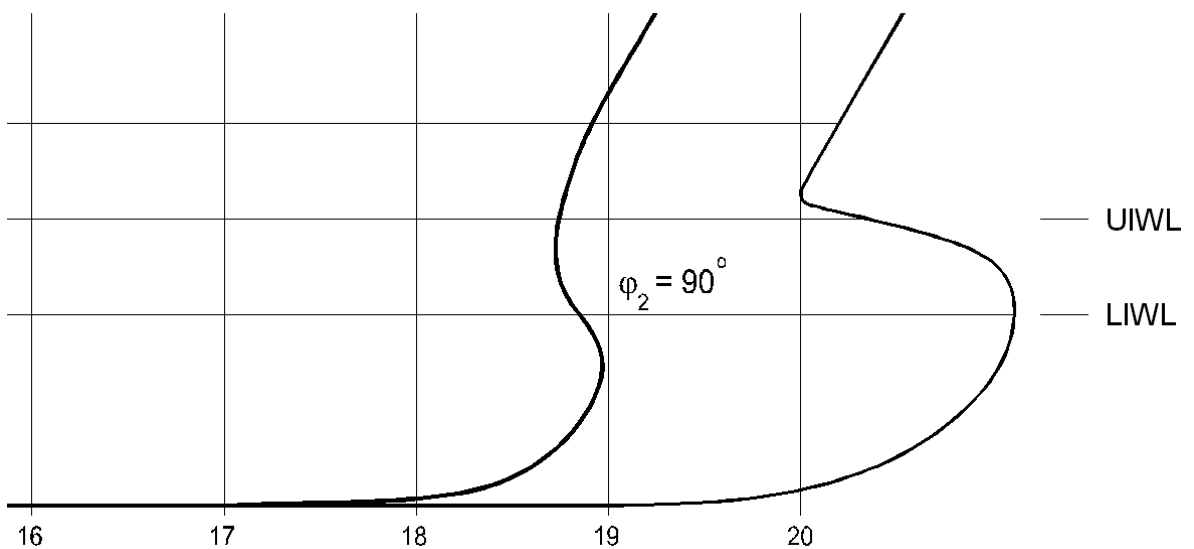


Figure 2. Determination of the angle φ_2 .

7.2 Existing Ships of Ice Class IB or IC (Section 3.2.3 of the Rules)

To be entitled to retain ice class IB or IC a ship, the keel of which has been laid or which has been at a similar stage of construction on or after 1 November 1986, but before 1 September 2003, should comply with the requirements in Chapter 3 of the ice class regulations 1985 (2.9.1985, No. 2575/85/307), as amended. If the owner of the ship so requests, the required minimum engine power can be determined in accordance with the ice class regulations 2010.

To be entitled to retain ice class IB or IC a ship, the keel of which has been laid or which has been at a similar stage of construction before 1 November 1986, should comply with regulation 3 of the ice class regulations 1971 (Board of Navigation Rules for Assigning Ships Separate Ice-Due Classes, issued on 6 April 1971), as amended. If the owner of the ship so requests, the required minimum engine power can be determined in accordance with the ice class regulations 1985 or 2010.

7.3 On Selection of the Propulsion System

The following machinery systems are used in ice-going ships:

- diesel – electric propulsion system;
- medium speed diesel and gearbox;
- slow speed diesel with direct shaft.

The propulsors may include:

- Controllable pitch or fixed pitch propellers;
- Contra-rotating and tandem propellers in azimuths
- Podded or azimuthing propulsors;

The diesel-electric (or steam/gas turbine-electric) propulsion system is very common in icebreakers but not in merchant vessels. It provides very efficient propulsion characteristics at slow speed and excellent manoeuvring characteristics, but due to the high cost, it is very seldom used in merchant vessels. Capability for fast load and direction changes, ability to maintain RPM and good reversing capability are the characteristics of good propulsion systems in ice.

A propulsion system with a medium speed engine, gearbox and a controllable pitch (CP) propeller is the most common propulsion system used in merchant vessels having an ice class. It provides reasonable propulsion characteristics at slow speed as well as reasonable manoeuvring characteristics.

A direct driven diesel engine with a fixed pitch propeller gives poor propeller thrust at a low ship speed. It is recommended that a controllable pitch propeller would be installed in ships having a direct driven diesel engine propulsion system.

7.4 Other Methods to Determine K_e or R_{CH}

According to section 3.2.5 “for an individual ship, in lieu of the K_e or R_{CH} values defined in 3.2.2 and 3.2.3, the use of K_e or R_{CH} values based on more exact calculations or values based on model tests may be approved”. In the following paragraphs guidelines on these issues are given.

If R_{CH} is determined using the rule formulae, then K_e can be determined by using direct calculations or the rule formulae. However, if R_{CH} is determined using model tests then propeller thrust should be calculated by direct calculations using the actual propeller data, instead of using the rule formulae. The reason for this is to ensure that the propulsion system is able to produce the required thrust to overcome the channel resistance. It should be noted that the total resistance in ice, R_{TOT} , is the sum of open water resistance R_{OW} and ice resistance R_{CH} i.e. $R_{TOT} = R_{OW} + R_{CH}$ where the ice resistance R_{CH} is given in the ice class rules, eq. (3.2).

7.4.1 Other Methods to Determine K_e

One of the drawbacks of the Rule equations for power is that the open water resistance is included in a very approximate fashion (the net thrust i.e. the thrust available to overcome the ice resistance at 5 knots is assumed to be $0.8T_B$). This is not correct as the open water and ice resistance are not connected in various ice thicknesses that are related to each ice class. A short study of the open water and channel resistance of some typical ships in different ice classes had suggested a regression formula, these results are given in Table 2.

The calculation of the thrust of nozzle propellers is not dealt with in the current rule text. For guidelines for the calculation of propeller thrust for nozzle propellers and open propellers, please refer to Appendix 2.

The thrust of the propellers can also be determined in full scale by bollard pull tests. For guidelines for bollard pull tests for determining the thrust of the propeller(s), please refer to Appendix 3. A summary is presented in the table below.

Table 1. Summary of Appendices 2 & 3. "Actual value" means the value obtained from tests or from calculations, as applicable.

$$\text{Thrust} > \text{Factor} * R_{CH}$$

	Calculation of Thrust	Bollard Pull Test	Bollard Tow Test 1	Bollard Tow Test 2
Speed (knots)	5	0	5	5
R_{CH}	rule formula	rule formula	rule formula	rule formula
R_{OW}	Table 2 or actual value*)	Table 2 or actual value	-	-
Thrust reduction factor	0.15 or actual value	-	-	-
J-factor	-	0.20 or actual value	-	-
Measuring accuracy	-	±2 %	±2 %	Winch gauge
Factor	Table 2	1.05 times Table 2 values	1.00	1.10

*) The actual value can be calculated using the frictional resistance coefficient $C_f = 0.075 \cdot [\lg(Re/100)]^2$ increased by 50 % to account for the residual resistance coefficient; Re is the Reynolds number.

Table 2. Factors referred to in Table 1.

Ice class	Direct shaft	Azimuthing thruster
IA Super	1.28	1.25
IA	1.32	1.29
IB	1.37	1.34
IC	1.45	1.42

7.4.2 Other Methods to Determine R_{CH}

The resistance of the vessel in a brash ice channel can be determined by model testing in an ice tank. For guidelines of ice model testing and model test reporting, please refer to Appendix 4.

8 Hull Structural Design (Chapter 4 of the Rules)

8.1 Frame Connections

Frame connections have to carry forward the loads stemming from the secondary members to the primary structural members in the structural hierarchy. The load carried by the stringers in the transverse framing system to the web frames is at maximum (p is the rule ice pressure and h ice load height)

$$F = 1.8 p \cdot h \cdot l$$

where l is web frame spacing S in the transverse framing system; and by transverse or longitudinal frames to stringers (or deck strips) or web frames, respectively,

$$F = p \cdot h \cdot l$$

where l is the frame spacing s in transverse framing system or longitudinal frame span l in longitudinal framing system. The background of these equations is in the ice loads the frames are assumed to carry and in the fact that there is a safety factor of 1.8 included in the stringer design. The connection must be designed with a capacity sufficient to carry at least this load without exceeding yield or buckling capacity of the structure. The adequate stiffening of especially the connection between deep web frames and longitudinal stiffeners of large spacing should be noted. Examples of appropriate connections are shown in Figures 3a and 3b. The frame connection to a web frame, stringer, deck or deck strip should use a lug as Fig. 3c shows. The distance of the lug from the shell plating (d in the Fig. 3c) should in higher ice classes be zero i.e. the lug is also attached to the shell. Here requirements of the applicable classification society should be followed.

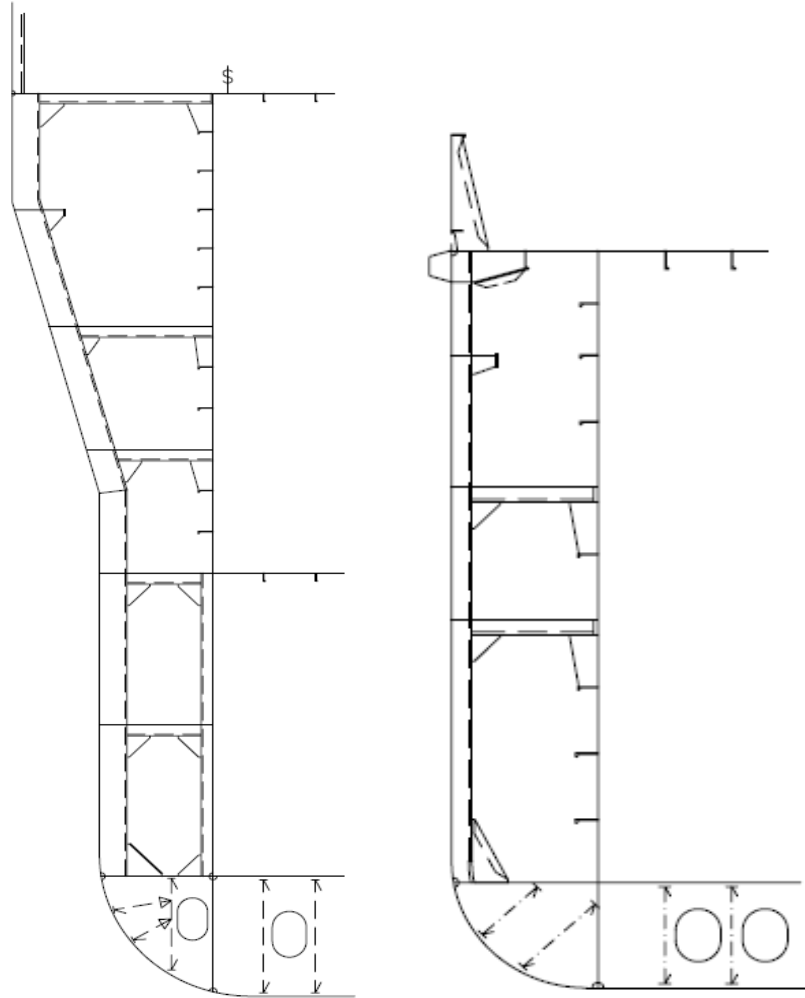


Figure 3a. Examples of frame connections.

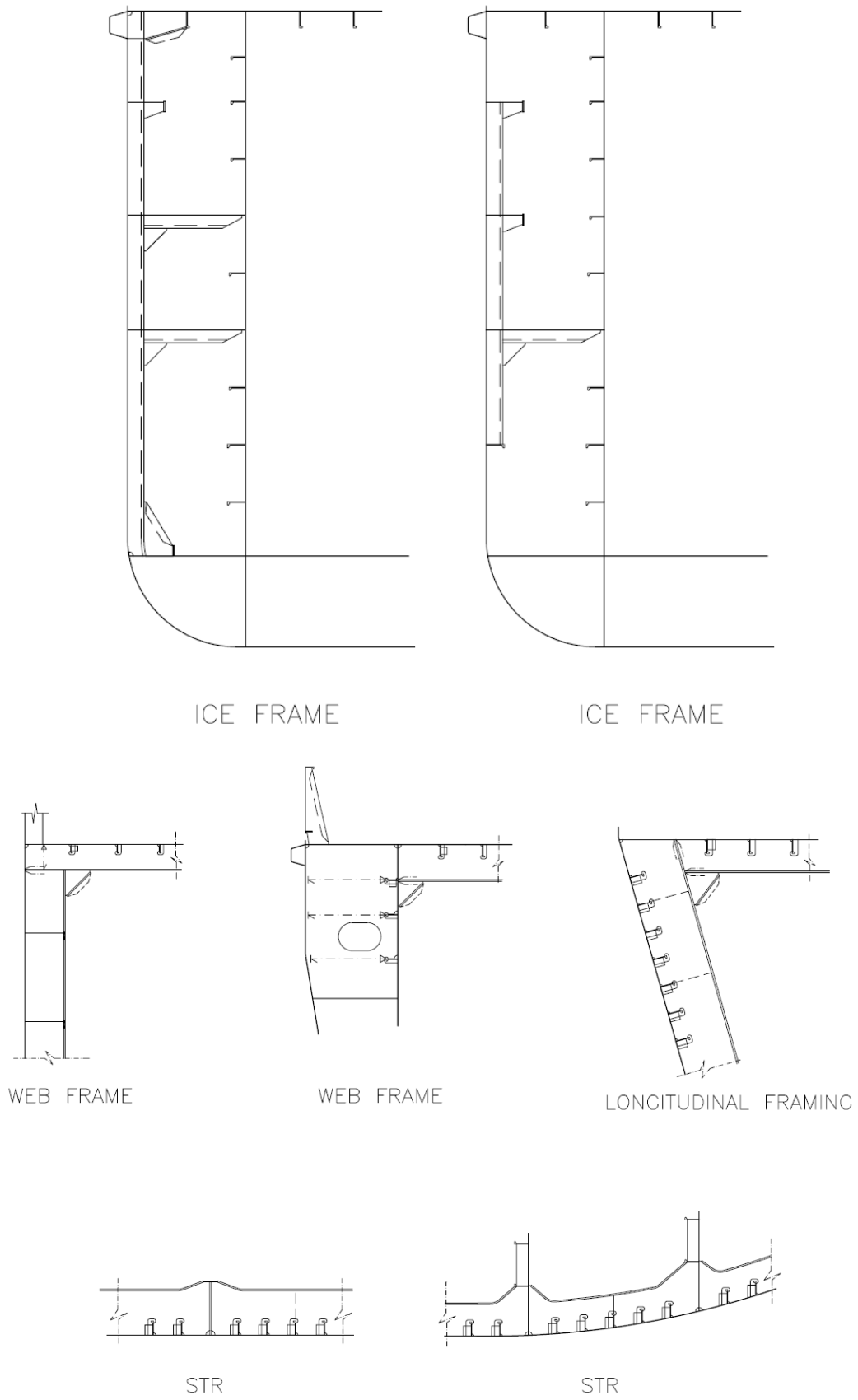


Figure 3b. Examples of frame connections.

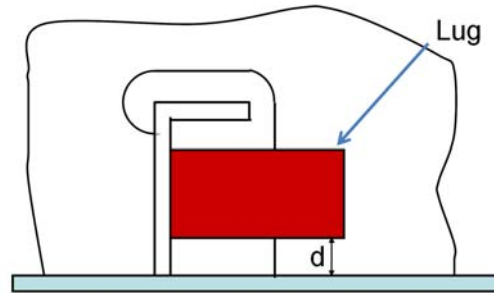


Fig. 3c. Construction of a frame connection using a lug.

8.2 Vertical Extension of Ice Strengthening of Framing (Section 4.4.1 of the Rules)

It is assumed that only the ice belt area (Area 1 in Figure 4), as defined in paragraph 4.3.1, will be directly exposed to the ice contact and pressure. For this reason, the vertical extension of the ice strengthening of the longitudinal frames should be extended up to and including the next frame up from the upper edge of the ice belt (frame 3 in Figure 4). Additionally the frame spacing of the longitudinal frames just above and below the edge of the ice belt should be the same as the frame spacing in the ice belt (spacing between frames 2 and 3 should be the same as between frames 1 and 2 in Figure 4). If, however, the first frame in the area above the ice belt (frame 3 in area 2 in Figure 4) is closer than about $s/2$ to the edge of the ice belt, then the same frame spacing as in the ice belt should be used above the edge of the ice belt i.e. in the spacing between frames 3 and 4 (s is frame spacing in the ice belt).

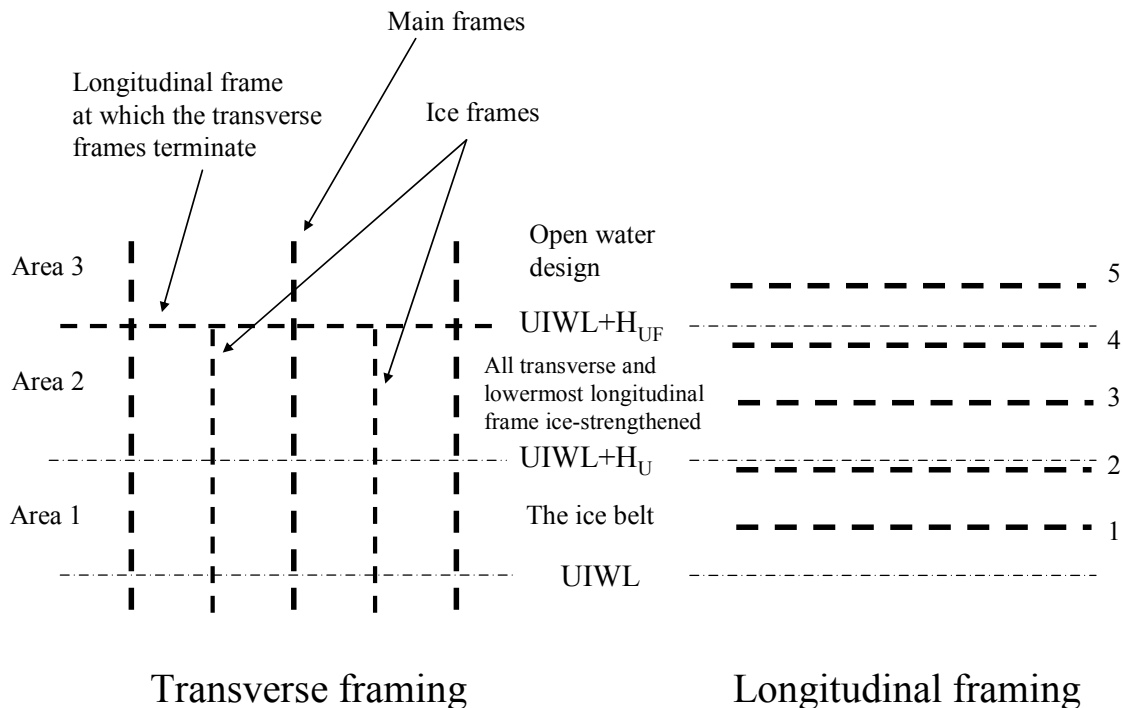


Figure 4. The different ice strengthening areas at and above the UIWL. The distances H_U and H_{UF} are specified in tables in 4.3.1 and 4.4.1, respectively (columns 'above UIWL'); these distances vary with ice class.

8.3 Inclined or Unsymmetric Frame Profiles (Section 4.4.4.2 in the Rules)

Section 4.4.4.2 refers to the need for supporting frames that are 'not normal' or 'unsymmetrical' against tripping, but defines neither 'normal' nor 'symmetric'. For the purposes of design, frame inclination as well as the combined effects of frame inclination and asymmetry on the principal axis of the frame, are to be separately evaluated. Accordingly, if either the angle of frame inclination or the principal axis of the frame (without attached plating) deviates more than 15° from normal to the plating, support against tripping is required. Note that if the relevant classification society has its own standard for these limits, this must be followed.

8.4 Arrangements for Towing

The towing method normally used in the Baltic by icebreakers is notch towing. Notch towing is often the most efficient way of assisting ships of moderate size (displacement not exceeding 30 000 tons) in ice. If the bulb or ice knife makes a ship unsuitable for notch towing, in heavy ice conditions this kind of ship may have to wait for the ice compression to diminish before the ship can be escorted without notch towing. In towage the towed vessel acts as a big rudder for the icebreaker and this causes difficulties especially if the merchant vessel is loaded or the bow does not fit well in the notch.

The towing arrangement usually uses a thick wire which is split into two slightly thinner wires, shown in Figure 5. Two fairleads must be fitted symmetrically off the centreline with one bollard each. The distance of the bollards from the centreline is approximately 3m. The bollards shall be aligned with the fairleads allowing the towlines to be fastened straight onto them. The typical towing arrangement is shown in Figure 5. An installation of a centreline fairlead is additionally still recommended since it remains useful for many open water operations and in some operations in ice as well.

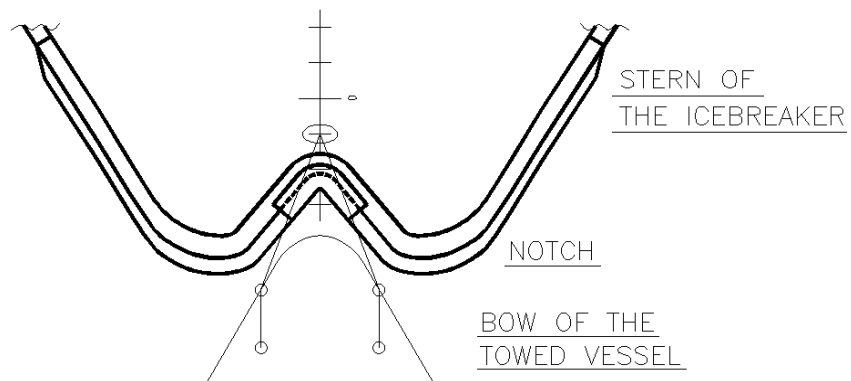


Figure 5. The typical towing arrangement.

A bollard or other means for securing a towline, structurally designed to withstand the breaking force of the towline of the ship, shall also be fitted. From operational experience the bollards can never be too strong and they should also be properly integrated into the steel structure. As a guideline for the bollard design it can be required that they withstand at least the maximum icebreaker winch force which is usually 100 – 150 t. The maximum possible

force on the bollards is given by the breaking load of the cable usually used, 62mm cable. This has a breaking load of about 200 t.

The ship bow should be suitable for notch towing. This suitability involves a proper shape of the bow waterline at the height of the icebreaker notch. This height is about 2.5m. If the bow shape is too blunt, it does not fit well into the icebreaker notch. For guidance, the notch shape of IB Otso and Kontio together with the notch of MSV Botnica are presented below in Figure 6.

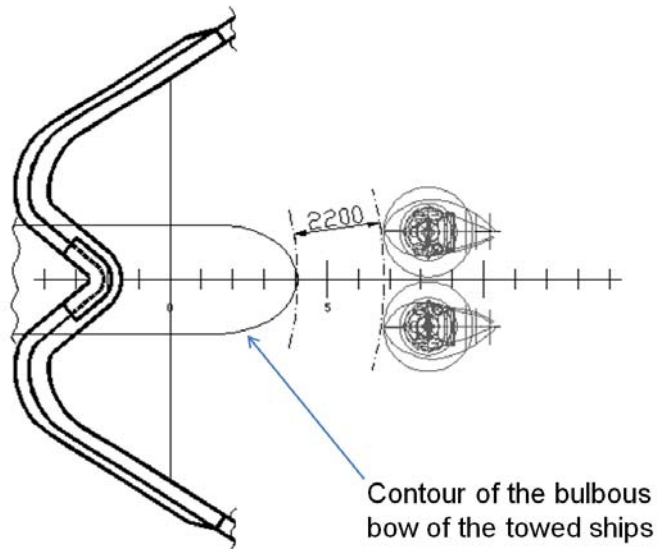


Figure 6a. A sketch of the notch of IB Otso and Kontio showing also the bulbous bow of the towed ship.

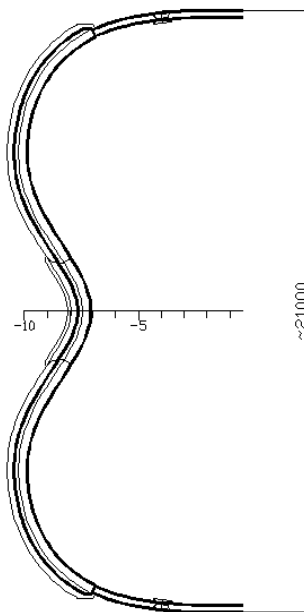


Figure 6b. The notch of MSV Botnica.

Ships with a bulb protruding forward of the forward perpendicular are, however, difficult to tow in a notch. The suitability for notch towing also involves the profile of the bow, when the towed ship has a bulb. The owners must check in appropriate Finnish or Swedish guidelines for winter navigation if the bulb considered allows notch towing. The bulb does not fit into the notch if the bow is too high, see Figure 7. If the bow is too high in the ballast condition, the ship could be trimmed to get the bow down. When the ship is loaded, the bulb is low and can then hit the icebreaker propellers or rudders. The recommendation is that the bulb should not extend more than 2.5 m forward of the forward perpendicular, see Figure 7. This recommendation should be checked along with the details of icebreakers operating in the operational area. For guidance, the stern profiles of two icebreakers are presented in Figure 8.

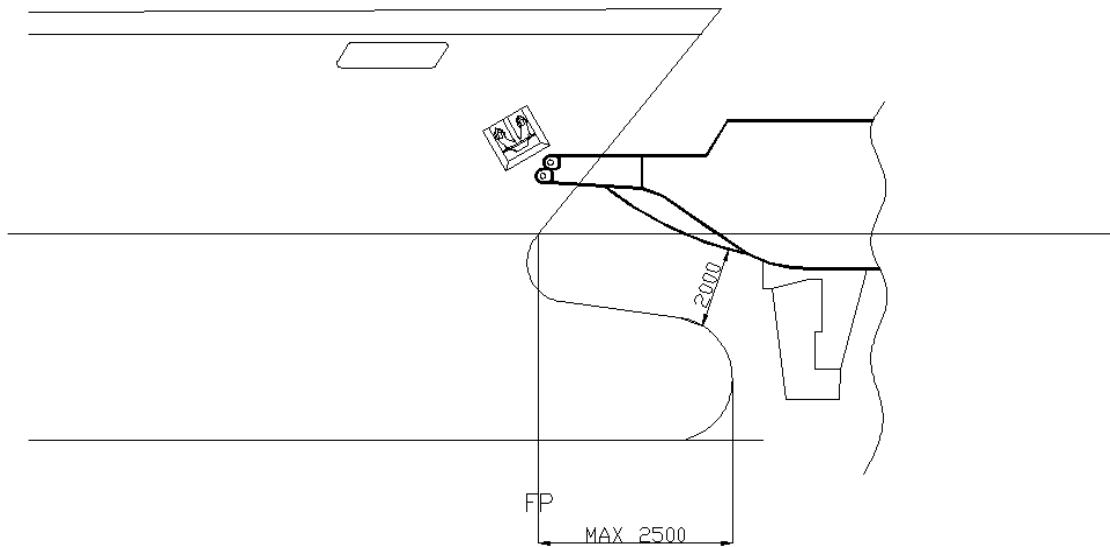


Figure 7a. The extension of the bulb forward of the forward perpendicular with a suitable loading condition.

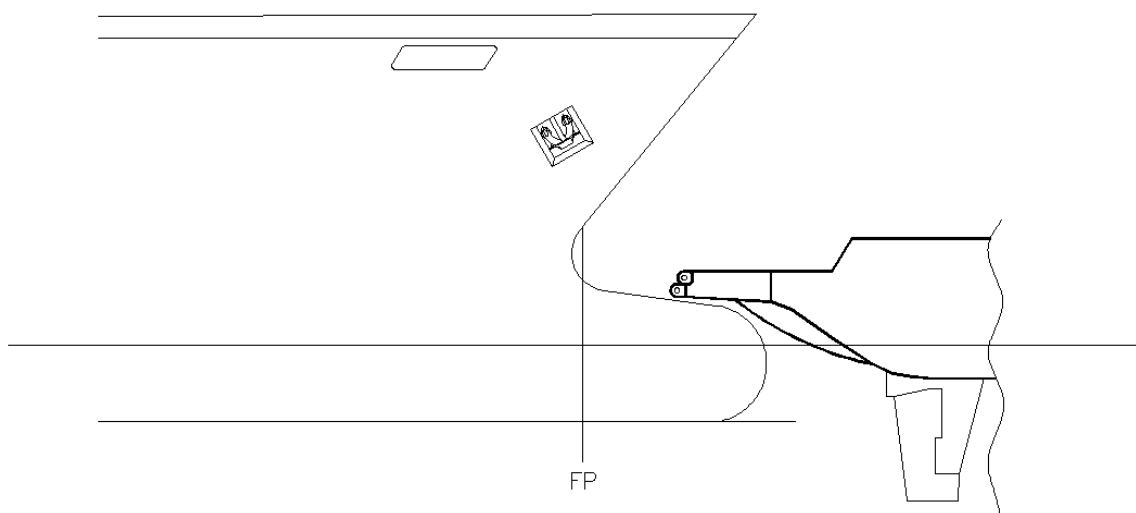


Figure 7b. The problems arising when towing a vessel in ballast with an unsuitable loading condition.

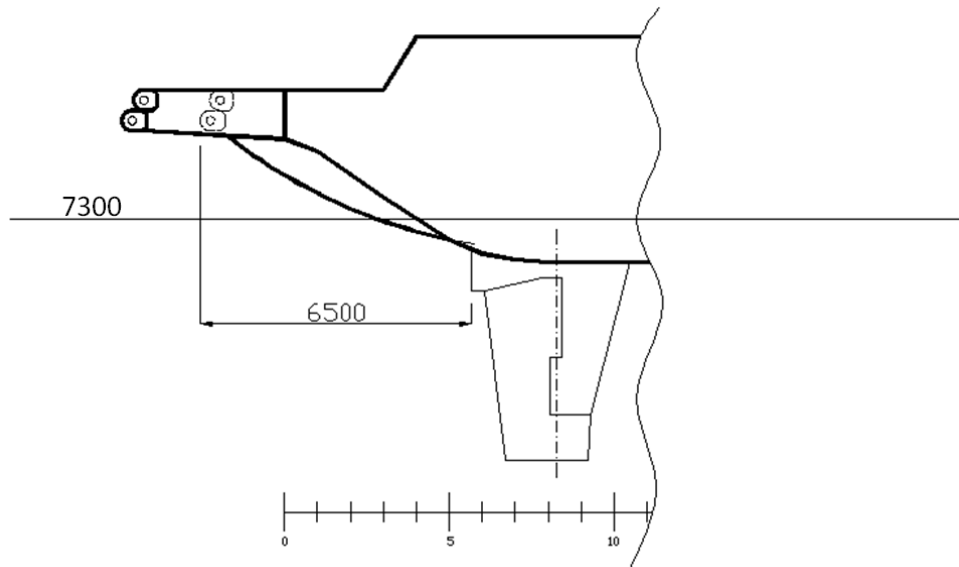


Figure 8a. A sketch of the stern profile of IB Otso and Kontio.

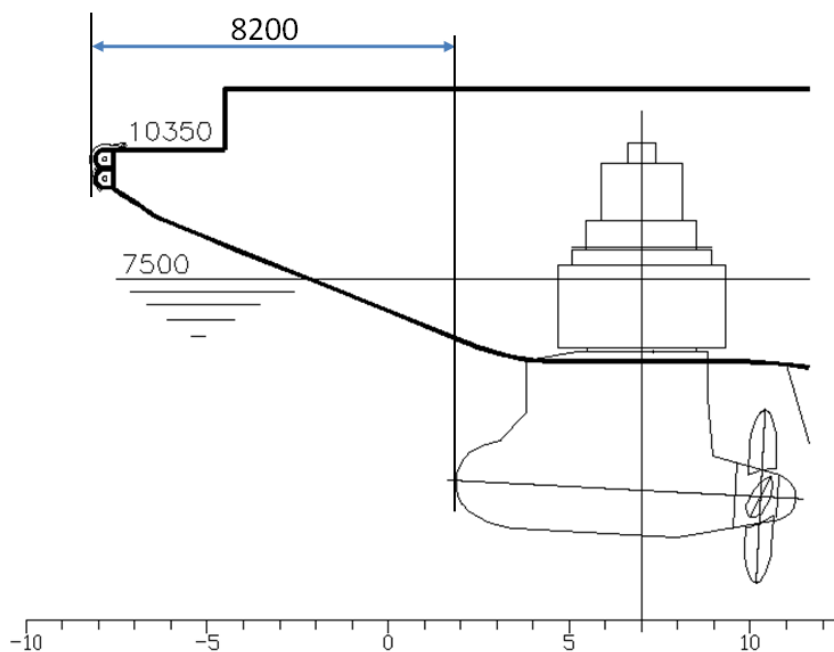


Figure 8b. The stern profile of MSV Botnica.

Some merchant ships have an ice knife fitted above the bulb, see Figure 9. This ice knife is just a vertical plate which presents a sharp edge against the notch at certain draughts. As these ice knives destroy the fendering at the icebreaker notch, their use is discouraged if efficient icebreaker assistance is expected.

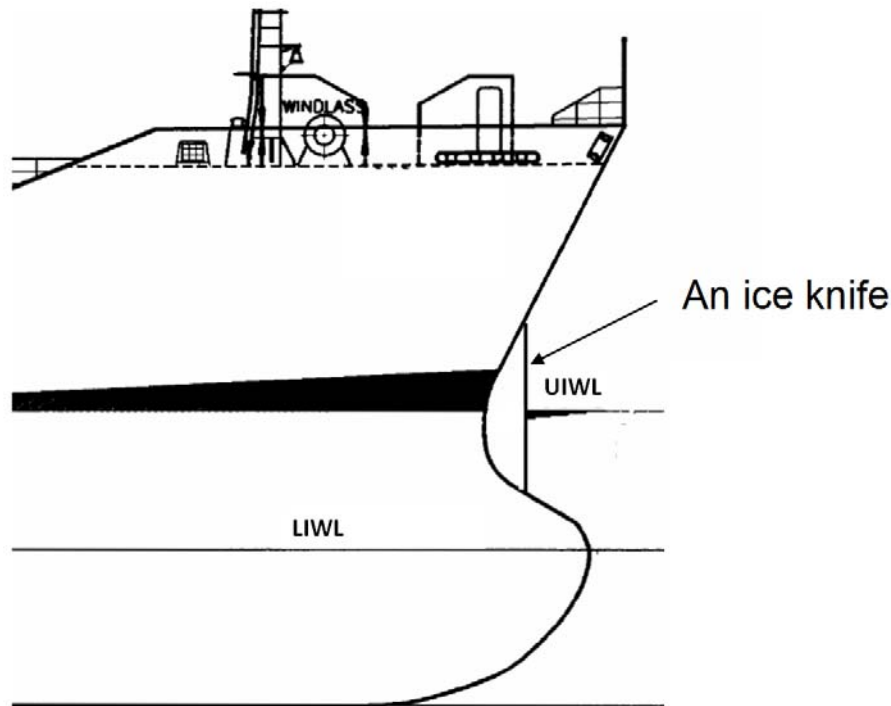


Figure 9. An ice knife fitted in some ships.

8.5 Reduction in Corrosion Allowance (Section 4.3.2 of the Rules)

The corrosion allowance is to be taken as 2 mm. A 1mm reduction in corrosion allowance can be considered if a recognized abrasion resistant coating is applied. In general, recognition of an abrasion resistant ice coating is to be based on satisfactory service experience and laboratory tests. As the actual performance of a coating cannot be accurately assessed in laboratory, service experience is particularly important for assessing such products. Therefore, manufacturers should submit sufficient dry docking reports of ships previously applied with the coating and operated in ice conditions, in addition to laboratory test results. The laboratory tests should be carried out with a recognised coating system as a reference.

The surface preparation and coating application are as important as selecting a correct coating and should strictly follow the manufacturer's instruction. In general, the steel surfaces should be abrasive blasted to Sa2½ (ISO 8501-1) or Sa3 with a surface roughness of at least 75 µm. If a repair painting is applied, similar requirements are to be placed – and the old coating should be roughened and the salinity (chloride contamination level) of the surfaces should be checked and be less than 5 µg/cm².

When considering the laboratory testing, the following testing procedure could be followed:

- Resistance to abrasion (Taber abraser test)
- Impact resistance
- Adhesion strength
- Extensibility (flexibility) e.g. according to ASTM D4145

In addition, the following corrosion tests could be considered:

- Cyclic corrosion test or salt spray test
- Water immersion test
- Cathodic disbondment test.

The test results should be compared with those from a product already recognised by the Classification society. A measure of an abrasion resistance is given by the Taber abrasion test (ASTM D4060) where the rate of abrasion has been 160 mg/1000 rounds using a 1kg weight and CS17 disks.

The acceptance of 1 mm corrosion allowance is subject to adequate documentation submitted to Finnish or Swedish authorities or classification societies.

8.6 Propeller Clearance

An extremely narrow clearance between the propeller blade tip and the stern frame or the bottom of the level ice sheet should be avoided as a small clearance will cause very high loads on the propeller blade tip. In the first case the loads are caused by ice floes being forced between the stern frame and the propeller and in the second case especially in going astern when the propeller might hit the large floes. The stern frame clearance should be at least 0.5 m and the ice clearance should be positive when the level ice thickness is taken as stated in the rules, table in 4.2.1.

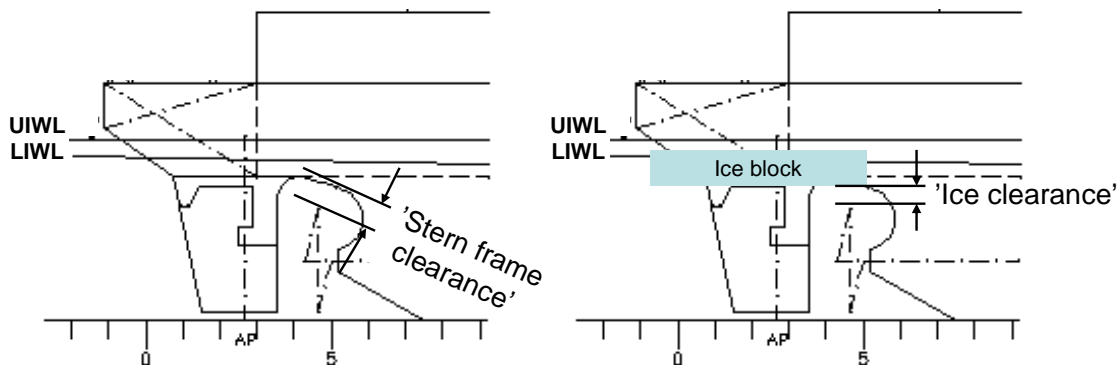


Figure 10. The clearance between the stern frame and the propeller (left) and the ice sheet and the propeller when the ship is at LIWL (right).

8.7 Transom Stern

A wide transom stern extending below the UIWL will seriously impede the capability of the ship to go astern in ice, because the ice will be crushed against the transom. The capability of going astern in ice is most essential for higher ice class ships. Therefore a transom stern should not be extended below the UIWL, if this can be avoided. If unavoidable, the part of the transom below the UIWL shall be kept as narrow as possible in order to restrict the part of the stern where ice is crushed. The part of a transom stern situated within the ice belt should be strengthened at least as for the midship region because the loading at the midbody arises mostly from crushing, as the side at the midbody is commonly vertical.

8.8 Bilge Keels

Bilge keels are often damaged or ripped off in ice, see Figure 11. The reason is that ice floes follow roughly the buttock lines when the ship is proceeding in ice. The connection of bilge keels to the hull shall be so designed that the risk of damage to the hull, in case a bilge keel is damaged, is minimized. A construction often described as ‘A-type’ bilge keels is recommended for strength. An example of this kind of construction is shown in Figure 12. To limit damage when a bilge keel is partly damaged, it is recommended that bilge keels are cut up into several shorter independent lengths. The forward and aft parts of the bilge keels should also be pointed towards the incoming ice when going forward or astern, respectively.



Figure 11. Damage caused by ice on the bilge keel of a ship. Note that this is an example of damage caused by ice, not an example of a good or bad design.

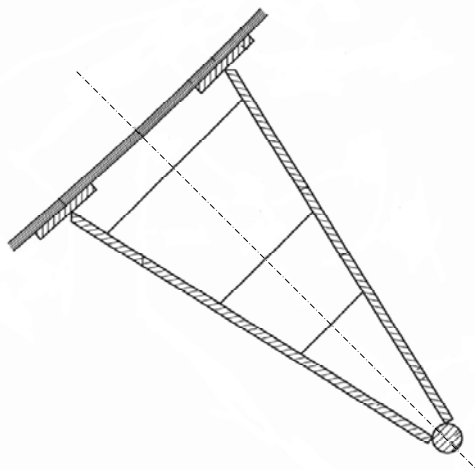


Figure 12. An example of an A-type bilge keel construction.

9 Rudder and steering arrangements (Chapter 5 of the Rules)

9.1 Ice Knife

When going astern, level ice will be broken by the stern and the ice floes forced under the ship. The function of the ice knife is to push the ice floes that are approaching the rudder down so that the rudder will not experience head-on impacts with ice floes and thus large forces that deviate the rudder from the amidships position are occurring more seldom. Attention should be paid to the strength and proper shape of the ice knife considering its function. A properly shaped ice knife is shown in Figure 13. Thus the lowest part of the ice knife should be below water in all draughts. However, if the ship is not intended to go astern in ice at some draughts, a smaller ice knife could be used. An ice knife is recommended to be fitted to all ships with an ice class IA Super or IA.

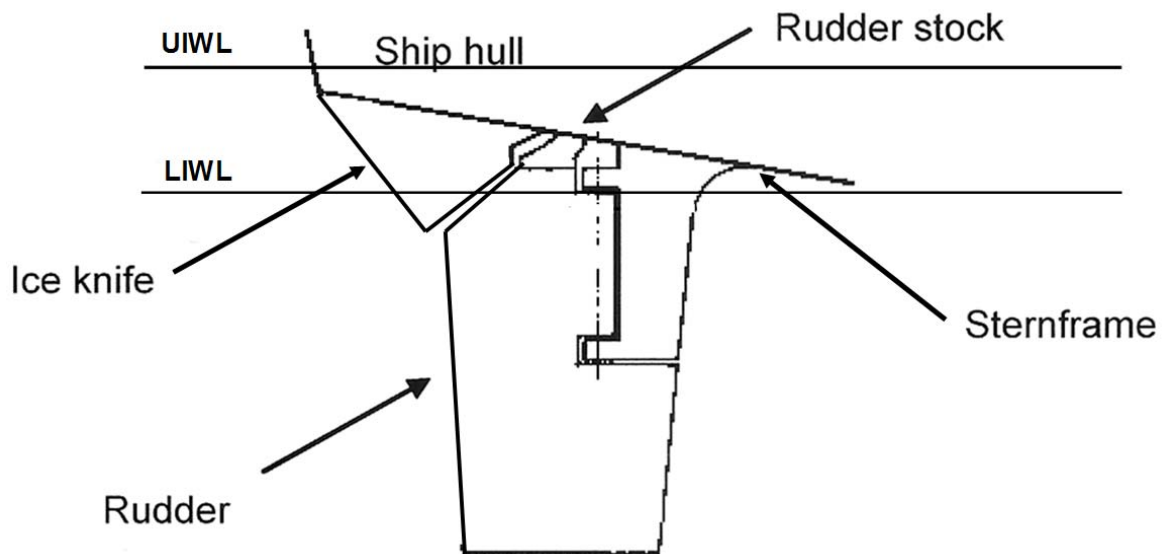


Figure 13. An example of an adequate ice knife design.

If the vessel has a flap-type rudder, special attention should be given to the design of the rudder in combination with the ice knife as the flap mechanism is more vulnerable to ice forces.

9.2 Rudder Turning Mechanism

When going astern, a large turning moment will be applied to the rudder, especially if it is allowed to deviate from the amidships position. In order to avoid a situation where the rudder is forced sideways, the operators should pay attention to keep the rudder amidships when going astern. At the same time, rudder stoppers should be installed in order to avoid excessive movement of the rudder(s).

When the rudder is turned sideways, large pressure will develop in the rudder turning mechanism. Thus the relief valves for hydraulic pressure in the turning mechanism shall be effective. The components of the steering gear shall be dimensioned to withstand loading corresponding to the required diameter of the rudder stock.

9.3 Bow Thrusters

In general, bow thrusters are not used in ice as the ice floes may damage the thruster blades. It is naturally possible to design the thrusters specifically for ice loading as some manufacturers do. The ice floes may get stuck at the tunnel entrance making the thrusters operation impossible. Sometimes a grid is recommended at the tunnel entrance in order to prevent ice floes entering the tunnel. This, however, may diminish the thruster's performance when used in open water. Some classification societies might have their own recommendations for bow thrusters grillage design, these should be noted.

10 Propulsion Machinery (Chapter 6 of the Rules)

10.1 Fatigue Design of Propeller Blade (Section 6.6.2.3 of the Rules)

The fatigue design of the propeller blade is based on an estimated load distribution for the service life of the ship and the S-N curve for the blade material. An equivalent stress that produces the same fatigue damage as the expected load distribution shall be calculated and the acceptability criterion for fatigue should be fulfilled as given in this section. The equivalent stress is normalised for 100 million cycles.

It has to be noted that the criterion given below (eq. (6.28) in the ice class rules) to avoid fatigue analysis applies to materials having a two-slope S-N curve (Figure 14), but not to materials having a one-slope S-N curve. This means that, if the material has a one-slope S-N curve for fatigue, the evaluation has to be done according to section 6.6.2.3, '*Fatigue design of propeller blade*'. The rule text will be modified in the next revision of the Finnish-Swedish Ice Class Rules.

Fatigue calculations in accordance with this chapter are not required if the following criterion is fulfilled (eq. (6.28) in the ice class rules):

$$\sigma_{\text{exp}} \geq B_1 \cdot \sigma_{\text{ref}}^{B_2} \cdot \log(N_{\text{ice}})^{B_3}$$

where B_1 , B_2 and B_3 are coefficients for open and ducted propellers as is given in Table 3.

Table 3. Coefficients B_1 , B_2 and B_3 .

	Open propeller	Ducted propeller
B_1	0.00270	0.00184
B_2	1.007	1.007
B_3	2.101	2.470

For calculation of equivalent stress two types of S-N curves are available.

1. Two slope S-N curve (slopes 4.5 and 10), see Figure 14.
2. One slope S-N curve (the slope can be chosen), see Figure 15.

The type of S-N curve should be selected to correspond to the material properties of the propeller blade. If the S-N curve is not known, the two slope S-N curve should be used.

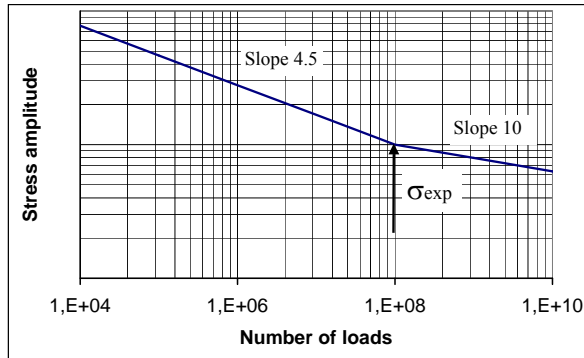


Figure 14. Two-slope S-N curve.
 (Figure 6-4 in the rules)

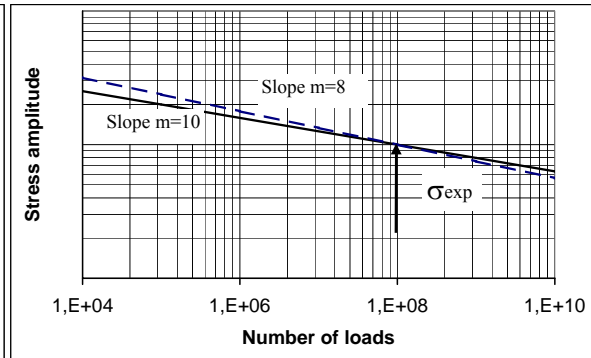


Figure 15. Constant-slope S-N curve.
 (Figure 6-5 in the rules)

10.2 Blade Failure Load (Section 6.5.4 of the Rules)

The ultimate load resulting from blade failure as a result of plastic bending around the blade root shall be calculated from the formula below. The ultimate load is acting on the blade at the $0.8R$ radius in the weakest direction of the blade. For calculation of the extreme spindle torque, the spindle arm is to be taken as $2/3$ of the distance between the axis of blade rotation and the leading/trailing edge (whichever is the greater) at the $0.8R$ radius (eq. (6.25) in the ice class rules):

$$F_{ex} = \frac{300 \cdot c \cdot t^2 \cdot \sigma_{ref}}{0.8 \cdot D - 2 \cdot r} \text{ [kN]},$$

where

$$\sigma_{ref} = 0.6 \cdot \sigma_{0.2} + 0.4 \cdot \sigma_u$$

c , t , and r are, respectively, the length, thickness, and radius of the cylindrical root section of the blade at the weakest section outside the root filet.

For calculation of the extreme spindle torque, the spindle arm is to be taken as $2/3$ of the distance between the axis of blade rotation and the leading/trailing edge (whichever is the greater) at the $0.8R$ radius. It has been proposed that the spindle arm should be reduced to $1/3$ of the distance between the axis of blade rotation and the leading/trailing edge (whichever is the greater) at the $0.8R$ radius.

A study has been carried out for two types of propellers regarding the required spindle arm. In the study the plastic bending of the propeller blades were calculated with FEM and the results were compared with the simple formula results. The methodology of the ice class rules is working well for “narrow” ice propellers. Thus, the plastic hinge is formed around the propeller root area. However, for wide blades the plastic hinge is formed at a higher radius, see Figure 16. The conclusion is that the rule methodology may give too high spindle torque values for wide propeller blades.

It is recommended to evaluate the blade failure loads and corresponding spindle torque values for wide blades by using plastic FEM analyses.

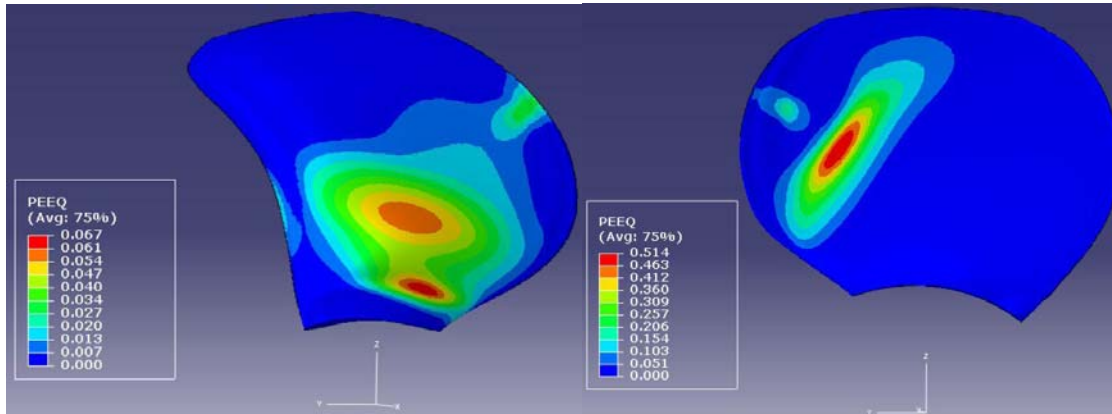


Figure 16. Plastic deformations for two propeller blades.

11 Miscellaneous Machinery Requirements (Chapter 7 of the rules)

11.1 Sea Inlet and Cooling Water Systems

The principle behind section 7.2 of the Finnish-Swedish Ice Class Rules is to ensure safe operation of the machinery also in ice conditions. According to item 4 "a pipe for discharge cooling water, allowing full capacity discharge, shall be connected to the chest". This promotes the melting of ice pieces and slush that may have entered the sea chest. Reference is also made to IMO MSC/Circ. 504 "Guidance of Design and Construction of Sea Inlets under Slush Ice Conditions".

If the vessel is designed to operate also in southern latitudes and with a very high cooling system capacity due to high sea water temperatures, it might be appropriate to design the capacity of the cooling water re-circulating line in accordance with the actual required cooling water capacity of the machinery in ice conditions, when the sea water temperature is much lower. The amount of water entering the sea chest through the recirculation line should allow full capacity discharge of sea water required for cooling of the machinery when sailing in ice.

Box coolers have functioned well in ice and are thus also an acceptable technical solution to ensure supply of cooling water when navigating in ice.

12 General Suitability for Winter Conditions

When designing a ship for winter navigation in the Northern Baltic, certain other issues than those mentioned in the rules should also be taken into account. Particularly the low ambient temperature should be kept in mind.

12.1 Low Ambient Temperature

In the northern Baltic Sea area, the air temperature will be below 0°C for much of the wintertime and might occasionally go down to about -30°C, and for short periods of time temperatures even as low as -40°C can be encountered. This should be taken into account when designing structures, equipment and arrangements essential for the safety and operation of the ship. Matters to be kept in mind include e.g. the functioning of hydraulic systems, freezing hazard of water piping and tanks, starting of emergency diesels, strength of materials at low temperature, etc.

The following temperatures are given for reference in the Baltic Sea area [word design removed]:

- Ambient temperature: -30°C
- Sea water temperature: -2°C

The equipment and material exposed to weather should be capable of withstanding and be operable at the design temperature for long periods. (Note: There have been no reported cases of brittle fracture when material grades for normal world wide service are used for winter navigation in Baltic Sea Areas). The propulsion and auxiliary machinery should be capable of full operation in ambient conditions as required in winter conditions. For example, the engine suction air should be sufficiently heated before entering the engine, or other alternative solutions, such as a specially adapted waste-gate, should be considered.

Appendix 1

INSTRUCTIONS FOR THE APPLICATION OF A LETTER OF COMPLIANCE

If the required engine power of the vessel has been determined by model tests, a letter of compliance issued by the Finnish Transport Safety Agency or by the Swedish Transport Agency is required. Such a letter of compliance should be written for the individual ship. For this purpose, the following information should be forwarded to the Administration for each individual ship:

- The name of the vessel
- The call sign of the vessel
- The IMO number of the vessel
- The main dimensions of the vessel
- A copy of the final lines drawing of the vessel
- The main engine type and the total engine output the propulsion machinery can continuously deliver to the propeller(s) of the vessel
- Reference to the model test report
- Resistance of the vessel and available net thrust of the propulsion machinery in a brash ice channel as defined in section 3.2.5 of the Finnish-Swedish Ice Class Rules, 2010.

Appendix 2

GUIDELINES FOR THE CALCULATION OF PROPELLER THRUST FOR OPEN AND NOZZLE PROPELLERS

It has been suggested that an alternative power requirement should be accepted instead of the one given in the Finnish-Swedish ice class rules based on a better propeller thrust than in an average propeller. The vessel naturally must fulfil the basic requirement of 5 knots in a specified brash ice channel (the thickness of which varies with ice class), but the power used to produce the thrust is optimised. Here two more direct ways to calculate or determine the thrust are examined – propellers in nozzles and direct determination of propeller thrust.

The basic assumption in the rules is that the bollard pull T_B of the vessel can be determined as

$$T_B = K_g (P \cdot D_p)^{2/3}, \quad (1)$$

where K_g is the efficiency factor of bollard pull being 0.78 for single CPP and 0.98 for twin CPP, P ship power and D_p propeller diameter. As the requirement in rules is given as a 5 knots speed, the concept of net thrust is used in the following calculations. The net thrust T_{NET} takes into account the open water resistance R_{OW} and the change in propeller thrust T at speed v_I (the K_T curve decreases with increasing J i.e. speed). The force balance in ice at speed v_I is (R_{CH} is the rule channel resistance)

$$(1-t_1)T(v_1) = R_{OW}(v_1) + R_{CH}(v_1), \quad (2)$$

where t_1 is the thrust deduction factor at speed v_I . This basic equation indicates the definition of the net thrust as

$$T_{NET} = (1-t_1)T(v_1) - R_{OW}(v_1). \quad (3)$$

This definition can be expressed with the bollard pull value and the propulsion coefficients, assuming that the propeller absorbs full power at both velocity points as

$$T_{NET} = \frac{1-t_1}{1-t_0} \cdot \frac{K_T(J_1)}{K_T(0)} \cdot \left(\frac{n_1}{n_0}\right)^2 T_B - R_{OW}(v_1) = \frac{1-t_1}{1-t_0} \cdot \frac{K_T(J_1)}{K_T(0)} \cdot \left[\frac{K_Q(0)}{K_Q(v_1)}\right]^{2/3} \cdot T_B - R_{OW}(v_1) \quad (4)$$

where J_1 is the advance coefficient at n_1 RPM at speed v_I , t_0 is the thrust deduction factor at the bollard condition and n_0 the propeller RPM at the bollard condition. The RPM's can be determined using the torque coefficient from equations (ρ is the density of water)

$$\begin{aligned} P &= K_Q(0) \cdot 2\pi\rho \cdot n_0^3 \cdot D_p^5 \\ P &= K_Q(J_1) \cdot 2\pi\rho \cdot n_1^3 \cdot D_p^5 \end{aligned} \quad (5)$$

Here the crucial assumption is that the propeller absorbs full power at the bollard condition and at 5 knots speed. This assumption is adequate for diesel-electric drives and also for CP propellers but for slow speed engines with a FP propeller it is not valid, and separate, more detailed calculations must be made.

The basic requirement in the rules is that at 5 knots speed

$$T_{NET} = R_{CH}, \quad (6)$$

from which the power can be calculated. As both the T_B and the RPM's contain power, the solution is somewhat complicated. As two points on the T_{NET} -curve are known ($T_{NET}=T_B$ when $v=0$ and $T_{NET}=0$ when $v = v_{OW}$, open water speed), the situation can be simplified, if a parabolic curve fit is done between these points as

$$T_{NET} = \left(1 - \frac{1}{3} \frac{v}{v_{OW}} - \frac{2}{3} \left(\frac{v}{v_{OW}} \right)^2 \right) \cdot T_B. \quad (7)$$

Eq. (4) shows that to determine the net thrust exactly, not only the propeller thrust is needed but also the open water resistance. Based on (3), an estimate of the thrust needed at a 5 knots speed can be made, if the typical values for open water resistance and thrust deduction coefficient are used. These have been estimated for a limited number of ships to be $0.12 \cdot H_M^{-1.3}$ % of R_{CH} ($[H_M] = m$) and $t = 0.15$, respectively (for ice class IA Super the H_M is taken as 1.3 m and for azimuthing thrusters $t = 0.13$). These lead to the requirement that thrust at a 5 knots speed must be *factor* · R_{CH} , where the factor is given in Table 2 in Chapter 7.4.1. This value is not a general figure and thus in principle this kind of generalizations cannot be made. The actual and verified values for R_{OW} and t can always be used.

Another question is posed by propellers in nozzles. At low speeds, the nozzle propellers give higher thrust than open propellers of a corresponding size. This extra thrust is, as a rule of thumb, given as 30 % of the corresponding open propeller thrust. These facts can be cast in an equation if firstly the net thrust, using e.g. (7), is denoted as

$$T_{NET} = K_v \cdot T_B. \quad (8)$$

Then the extra thrust is taken into account by the factor K_N , and the bollard pull of the nozzled propeller is (T_B as in (1))

$$T_{B,N} = K_N \cdot T_B \quad \text{and} \quad (9)$$

$$T_{NET} = K_v T_{B,N} = K_v K_N T_B \quad (10)$$

Now, starting from the basic equation (6), we get

$$\begin{aligned} R_{CH} &= T_{NET} \\ &= K_v(v_1) \cdot T_{B,N} \\ &= K_v(v_1) \cdot K_N \cdot T_B \end{aligned}$$

$$= K_v(v_1) \cdot K_N \cdot K_g \cdot (P \cdot D_P)^{2/3} . \quad (11)$$

In the rule formulation, K_v is assumed to be 0.8. Thus the power requirement for a nozzle propeller is

$$P_N = \frac{1}{D_P} \left(\frac{R_{CH}}{K_v K_g K_N} \right)^{3/2} = \frac{K_e}{D_P} \left(\frac{R_{CH}}{K_N} \right)^{3/2} = \frac{1}{K_N^{3/2}} \cdot P_{OPEN} . \quad (12)$$

This equation shows that in theory, if the open water propeller has a diameter which is $K_N^{3/2}$ times larger than (i.e. about 1.48 times) the nozzle propeller diameter, then the thrusts are the same. Or to put it in different terms, the power of nozzle propulsion can be about 70 % of the corresponding open propulsion, and the performances are the same.

Appendix 3

GUIDELINES FOR BOLLARD PULL TESTS FOR DETERMINING THE THRUST OF THE PROPELLER(S)

The R_{CH} is defined as the channel resistance at 5 knots in a broken channel of a certain thickness. The propeller thrust is to be greater than this channel resistance plus the open water resistance.

Regulation 3.2.5 (in the Finnish version of the Rules) or Chapter 3, section 7 (in the Swedish version) allows for alternative measures to comply with the above requirement. A bollard pull test can thus be accepted as a proof that the powering requirement is fulfilled.

1 Bollard Pull Test 1

By definition, this test is performed at zero speed. For a correct test result, several factors have to be considered, e.g. water depth, towline length etc. When conducting these tests, a bollard pull testing procedure by a Classification Society or the *Bollard Pull Trial Code* by Steerprop should be followed.

The bollard pull should be measured by a calibrated ‘load cell’ with a deviation within the measuring range of less than $\pm 2\%$.

The measured bollard pull should not be less than given in Tables 1 and 2. Open water resistance R_{OW} and t factor must also be taken into account. The actual and verified values for R_{OW} and t can always be used.

2 Bollard Tow Test 2

In practice, this type of test is probably the most convenient one. The vessel is connected to a tug and the two vessels perform a ‘tug of war’ pull moving at a minimum speed of 5 knots in the direction of the test ship.

The force should be measured on the tug either by:

- An independent (external) ‘load cell’ with a deviation within the measuring range of less than $\pm 2\%$. The measured tow pull should not be less than $1.0 \cdot R_{CH}$
- The integrated ‘load cell’ on the towing winch. The measured tow pull should not be less than $1.1 \cdot R_{CH}$.

Appendix 4

GUIDELINES FOR THE VERIFICATION OF A SHIP'S PERFORMANCE FOR ICE CLASSES THROUGH MODEL TESTS

In the Finnish-Swedish Ice Class Rules, powering requirements refer to a certain required level of a ship's performance. The ship's performance is set as the ship's capacity to proceed at a constant speed of 5 knots in old brash ice channels of a certain thickness. For ice class IA Super, it is also assumed that there is a 10 cm thick consolidated layer of ice on top of the channel. In verifying performance through model tests, the following points 2 to 7 should be checked:

1 Definition of the Design Point and Notation

The design point to be checked by the model tests is that the vessel can proceed at five knots in the brash ice channel specified for each ice class. This definition can be used in the propulsion tests, if the propulsion thrust to be obtained in full scale is modelled. If, however, resistance tests are conducted, then the total resistance in ice, R_{iTOT} , is measured. In the ice class rules it is assumed that the superposition assumption is valid. This states that the pure ice resistance, R_i , and open water resistance, R_{OW} , can be superimposed as

$$R_{iTOT} = R_i + R_{OW} .$$

Here the pure ice resistance is either the channel resistance (ice classes IA, IB or IC) or the channel resistance plus level ice resistance (ice class IA Super). Now the ice class requirement is

$$T \cdot (1 - t) \geq R_{iTOT} = R_i + R_{OW} ,$$

where T is the thrust that the propeller develops at 5 knots and the t is the thrust deduction factor at 5 knots (and in principle at the overload condition – the open water thrust deduction factor can, however, be used).

2 The Model Testing Procedure

The rule requirement is that the ship achieves at least 5 knots in a channel that is defined separately for each ice class. The rule resistance in the specified channel is given in the rules. The aim of the model tests is to determine the channel resistance and also the total resistance in the channel i.e. channel and open water resistances and then show that there is enough net propulsion thrust (i.e. taking into account the thrust deduction factor) available to overcome this resistance.

The results of the model tests should show the channel resistance, open water resistance at the same speed and the net thrust of the proposed propulsion arrangement in full scale at that speed. A propulsion test with stock propellers showing a self propulsion point at some speed is not enough. This fact is reflected also in the reporting requirements.

3 The Geometry of the Ice Channel

The rule-based channels have been given a thickness for their mid part ($H_M = 1\text{ m}$ for IA, 0.8 m for IB and 0.6 m for IC), and their profile thickens towards the edges by a gradient of 2° , see Figure 1. This profile is based on channel measurements in fairways to northern ports in the Gulf of Bothnia.

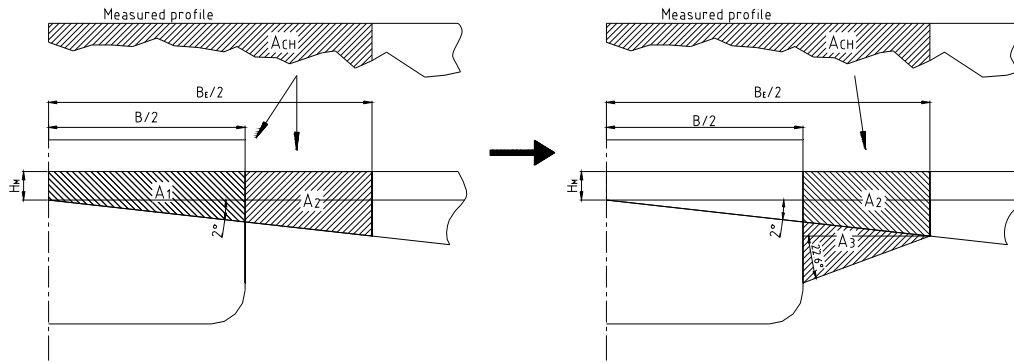


Figure 1. The geometry of a “real” brash ice channel profile and the corresponding profile of a rule channel before the ship’s passage and the assumed behaviour of the ice during the passage. The relations between the cross-sectional areas are: $A_{CH} = A_1 + A_2 = A_2 + A_3$.

However, it is difficult to achieve a channel profile in model test conditions that resembles the one referred to in the rules. An average channel thickness, H_{av} , may thus be used, which is affected by the breadth of the ship, being

$$H_{av} = H_M + 14.0 \cdot 10^{-3} B \quad (1)$$

where B is the beam of the vessel.

The width of the ice channel should be $2 \times B$ with level ice at sides. The thickness profile of the ice channel should be measured at a breadth of $1.6 \times B$.

The channel profile should be measured at sufficiently small intervals (about $10 \dots 20\text{ cm}$ intervals) in order to ensure that the cross sectional area of the ice channel is accurately determined. In the longitudinal direction, the step of cross sectional profiling should be at most 2 m .

The channel should be 100% covered with ice so that there are about two layers of ice pieces on top of each other.

4 The Friction Coefficient

In full scale, the friction coefficient between ice floes and the hull, μ , ranges from 0.05 for new ships to 0.15 for corroded hull surface. In ice model tests a friction factor of $0.05 - 0.1$ is usually applied for the model.

If a friction coefficient of less than 0.1 is used in the model tests to determine the ice channel resistance R_{CH} , the engine power and the propeller thrust should be selected so that the vessel is able to sail at a 5 knots speed with a friction coefficient of 0.1 in full scale. Correction of the resistance due to different friction coefficient can be made by using the following formula:

$$R_{CH(\text{with } \mu_{\text{target}})} = \left[\frac{(0.6 + 4\mu_{\text{target}})}{(0.6 + 4\mu_{\text{actual}})} \right] R_{CH(\text{with } \mu_{\text{actual}})},$$

where μ_{actual} is the actual friction coefficient measured in the tests and $\mu_{\text{target}} = 0.1$.

5 Model Tests for Ice Class IA Super

The preparation of a consolidated ice layer for ice class IA Super is difficult, since it often becomes very inhomogeneous (the pieces in nature are very small, but often larger in the test channels) or also too intact (resembling natural ice). For this reason, these tests could be carried out by superposing the level ice resistance and the channel resistance.

6 Determination of the Propulsion Power in Full Scale

When R_{CH} has been determined using model tests, and this resistance is used to verify the compliance with the speed requirements for the applicable ice class, the actual propeller thrust in full scale should be applied using the actual propeller and engine data, instead of using the rule formulae, in order to ensure that the propulsion system is able to produce the required thrust to overcome the channel resistance. This is especially important for slow speed direct drive diesel engines with a FPP. If the ice is observed to interact much with the propeller in the tests, the losses in propulsion due to this propeller-ice interaction must be taken into account in the calculation of the full scale power and speed of the ship. For the verification of the model scale bollard pull, the corresponding full scale bollard pull is to be given for the propeller planned to be used in the ship.

7 Model Test Reporting

The model test report should contain the information given in the Annex to these Guidelines.

Annex to Appendix 4

Required Information in a Model Test Report

The following information should be included in a model test report for acceptance of the engine power according to section 3.2.5 of the Finnish-Swedish Ice Class Rules, 2002.

1. General description of the ice model basin and the model ice
2. Ship model
 - 2.1 Main particulars of the ship including displacement and deadweight
 - 2.2 Main particulars of the model
 - 2.3 Description of the ship geometry with hull lines drawing
 - 2.4 Model scale
3. Propulsion
 - 3.1 Description of the ship propulsion system including the net thrust and bollard pull curves
 - 3.2 Description of the model propellers
 - 3.3 The bollard pull versus RPM curve of the ship model
4. Test program and procedures
 - 4.1 Model test program
 - 4.2 Hull friction coefficient measurement procedure
 - 4.3 Description of the measurement system for propulsion values
 - 4.4 Description of the measurement system in resistance and/or propulsion tests
 - 4.5 Analysis procedures
5. Model ice
 - 5.1 Data on the parent level ice thickness
 - 5.2 Parent level ice strength (bending strength and also preferably compressive strength)
 - 5.3 Description of the method of producing the channel
 - 5.4 Measurement of the channel profile at sufficiently small intervals (about 10 ... 20 cm intervals) to allow an accurate determination of the cross sectional area of the channel. In longitudinal direction, the step of cross sectional profiling should be at most 2 m. The methods used in this measurement should be described.
 - 5.5 From each cross section an average thickness of the channel should be computed from a channel width of the ship breadth and of 1.6 times the ship breadth.
 - 5.6 Description of the porosity of the brash ice. Photographs from above the channel to give the coverage of brash ice along the whole channel.
 - 5.7 For the ice class IA Super, a consolidated layer of 10 cm in thickness (full scale) is assumed to be on top of the brash ice. If this layer is modelled, the modelling procedure is to be described, including the way it was produced and how its thickness and strength were measured.
6. Test results
 - 6.1 Measurements of the hull coefficient of friction with ice

- 6.2 The time histories of model speed, propeller thrust, torque and RPM from each test. Indication of the part of the time history from which the final values were calculated.
 - 6.3 Description of the behaviour of the brash ice in the channel. A measurement of the cohesion and internal friction angle or some other parameters describing the strength of the brash ice should be done or at least an earlier result for these quantities from a brash ice channel similarly produced.
 - 6.4 Photographs of the channel made by the vessel immediately after the tests, from above.
 - 6.5 The deduced (from time histories referred to in section 6.2 above) and calculated model propulsion, total model resistance and ice resistance values
 - 6.6 Full scale resistance and engine power prediction including a description of the extrapolation method. An estimate of the accuracy of the result obtained by extrapolation is to be given.
7. Other information
 - 7.1 Estimate of the resistance of the model in open water.
 - 7.2 Calculation of the required engine power according to the Finnish Swedish Ice Class Rules, 2010, with input data.
-