Finnish Maritime Administration

SWEDISH MARITIME ADMINISTRATION

GUIDELINES FOR THE APPLICATION OF THE FINNISH – SWEDISH ICE CLASS RULES

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Table of contents

Appendices

References

- Finnish – Swedish Ice Class Rules, 2002, (see www.fma.fi, FMA Bulletin No. 13/1.10.2002)
- The Equivalence between the Finnish – Swedish Ice Classes and Ice Classes of Classification Societies, (see www.fma.fi, FMA Bulletin No. 16/27.11.2002)
- Sjöfartsverkets föreskrifter och allmänna råd om finsk-svensk isklass, SJÖFS 2003:4
- Act on Fairway Dues (708/2002), (see www.fma.fi, FMA Bulletin No. 12/1.10.2002)

1 Introduction

The Finnish Maritime Administration (FMA) and the Swedish Maritime Administration (SMA) 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 2002 (see Finnish Maritime Administration Bulletin No. 13/1.10.2002, available at www.fma.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 the FMA and the SMA.

2 The status of the guidelines

In general, the FMA and the SMA accept class approval based on these guidelines for design of vessels. The approval of the FMA or the SMA 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 1st January 2006 should be done according to these Guidelines.

These guidelines replace all tentative guidelines issued earlier by the FMA or by the SMA.

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 vessels 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 a minimum ice class IA and a minimum deadweight of 2000 tdw. A typical strictest traffic restriction for the ports in the northern Bothnian Bay 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 (708/2002), see Finnish Maritime Administration Bulletin No. 12/1.10.2002, the Finnish Maritime Administration has, on 20 September 2002, adopted a regulation on the structural design and engine output required of ships for navigation in ice (see www.fma.fi, Finnish Maritime Administration Bulletin No. 13/1.10.2002).

Pursuant to section 12 of the Act on Fairway Dues (708/2002), the Finnish Maritime Administration has confirmed the list of ice class notations of authorized classification societies and the equivalent Finnish-Swedish ice classes (see www.fma.fi, Finnish Maritime Administration Bulletin No. 16/27.11.2002). The ice class of a ship, which has an ice class of a classification society, is determined in accordance with this bulletin.

The FMA is responsible for giving icebreaker assistance for ships entering Finnish ports. This assistance service is included in the fairway due. The FMA sets traffic restrictions for ships pending on ice conditions (see Rules for Winter Navigation at www.fma.fi). Finnish icebreakers only assist ships that meet the ice class requirements set out in Finnish Maritime Administration Bulletin No. 16/27.11.2002.

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 (719/2002) (see www.fma.fi, Finnish Maritime Administration Bulletin No. 12/1.10.2002).

3.1.1 Ice class certificate of the FMA

From 1 January 2006 Ice Class Certificates are no longer issued by the inspectors of the Finnish Maritime Administration 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 SMA is responsible for giving icebreaker assistance for ships entering the Swedish ports. This assistance service is free of charge. The SMA 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 Bulletin No.16/27.11.2002). The SMA 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.

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 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 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 the harbour entrance and after that the ship should be able to sail to the port on its own, although the icebreaker often has to escort small ships in particular up to the port. Most of the Finnish 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 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 jamming at open sea, where the ice field may move due to high wind speeds. It should also be noted that the ice-going capacity of small ships will be somewhat lower than that of larger ships having the same ice class.

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) under ice loads which have been measured 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 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 10. 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 weaker than the shaft.

Recent observations on ice damages on ice strengthened vessels indicate that most of the damage on propellers occur 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 for 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 ice thickness of 1.2 m, ice bending strength (cantilever beam test) of about 500 kPa and maximum compressive strength of sea ice about 2 – 5 MPa.
- Ice compression in another 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.

4.2 Application of the old versions of the Finnish – Swedish Ice Class Rules

4.2.1 Ships built in accordance with the Board of Navigation Ice Class Rules, 1971

In determining the ice class of ships, the keels of which are laid or which are in a similar stage of construction before 1 November 1986, the Board of Navigation Ice Class Rules, 1971 (Board of Navigation Rules for Assigning Ships Separate Ice-Due Classes, issued on April 6th, 1971), as amended, still apply, except that existing ships of ice class IA Super or IA shall comply with section 3.2.4 of the Finnish – Swedish Ice Class Rules, 2002.

4.2.2 Ships built in accordance with the Board of Navigation Ice Class Rules, 1985

In determining the ice class of ships, the keels of which are laid or which are in a similar stage of construction on or after 1 November 1986, but before 1 September 2003, the Board of Navigation Ice Class Rules, 1985 (2.9.1985, No. 2575/85/307), as amended, still apply, except that existing ships of ice class IA Super or IA shall comply with section 3.2.4 of the Finnish – Swedish Ice Class Rules, 2002.

5 General (Chapter 1 of the rules)

5.1 Ice classes

Ships with ice class IA or IA Super are intended for year round operation in the Baltic Sea area. This means that the Administrations do not set traffic restrictions for these ice classes. However, size restrictions may apply for ice class IA.

Ships having an 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)

Regulation 2.1 stipulates that *“the maximum ice class draught amidships shall be the draught on the Fresh Water Load Line in summer”*. It should be noted that in the rules LWL means fresh water load line. In paragraph 2.2 LWL is defined as the line through draughts fore, amidships and aft. The line may be broken. The forward design draught should never be less than the draught amidships. The same draught is to be used for the calculation of the minimum engine power of the ship (see paragraph 3.2.2), and the determination of the vertical extension of ice strengthening (see paragraphs 4.3.1 and 4.4.1).

It is recommended that in the design stage, some reserve is allowed for the ice class draught. 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 draft of the vessel is increased at a later stage.

7 Engine output (Chapter 3 of the rules)

7.1 Definitions (Paragraph 3.2.1 of the rules)

The length of the bow (L_{BOW}) should be measured between the flat side and the fore perpendicular at LWL. The same perpendicular should also be used when calculating the length of the bow at BWL.

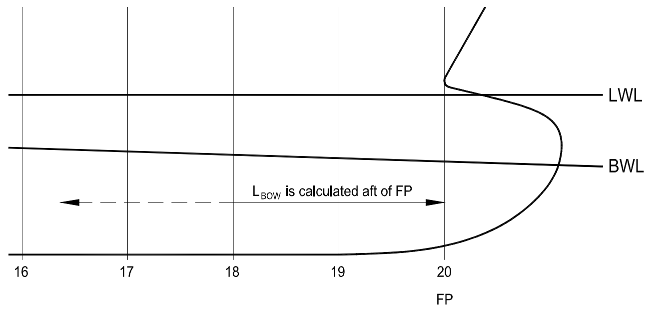

Figure 1. Measurement of the length of the bow.

The length of the parallel midship body (L_{PAR}) should be measured between the aft perpendicular and the flat side, if the vessel has a full beam between these two points.

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.

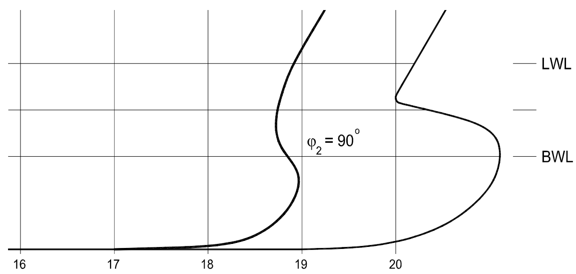

Figure 2. Determination of the angle φ_2.

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 2002.

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 April 6^{th}, 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 2002.

7.3 On selection of the propulsion system

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

- diesel – electric propulsion system
- medium speed diesel, gearbox and controllable pitch propeller
- slow speed diesel and controllable or fixed-pitch propeller

The diesel – 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.

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 slow speed 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 slow speed diesel engine propulsion system.

7.4 Other methods to determine K_e or R_{CH}

According to paragraph 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.

7.4.1 Other methods to determine K_e

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.

Thrust > 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}	+20 % or actual value	+20 % or actual value	-	-
Thrust reduction factor	+15 % or actual value	-	-	-
J-factor	-	+20 % or actual value	-	-
Measuring accuracy	-	±2 %	±2 %	Winch gauge
Factor *)	1.41	1.50	1.00	1.10

*) *The factor will depend on the values (percentage or actual) used. The factors shown are calculated for the percentage values presented in the table.*

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. In general, model tests are recommended, if the displacement of the vessel is greater than 70,000 tonnes. For guidelines of model testing and model test reporting, please refer to Appendix 4.

8 Hull structural design (Chapter 4 of the rules)

8.1 Longitudinal frames

8.1.1 Frame spacing and installation of brackets

According to paragraph 4.4.3, the frame spacing of longitudinal frames *shall not exceed 0.35 metres for ice class IA Super or IA and shall in no case exceed 0.45 metres*. This means that the maximum frame spacing for longitudinal frames is 0.35 m for ice classes IA and IA Super, and 0.45 m for ice classes IB and IC. Longitudinal frames are also to be attached to the supporting structure by brackets.

However, a larger spacing for longitudinal frames than stipulated in the rules can be selected, and/or installation of brackets can be omitted, if calculations in accordance with "Guidelines for the interpretation of the rules with respect to longitudinally framed shell structures" given in Appendix 5 are made and approved by the classification society.

8.1.2 Vertical extension of ice strengthening of longitudinal framing (paragraph 4.4.1)

It is assumed that the ice belt area (Area 1 in the Figure 3) only, as defined in paragraph 4.3.1, will be directly exposed to the ice contact and pressure. Due to 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 4 in the Figure 3). 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 3 and 4 in Fig. 3). If, however, the first frame in the area above the ice belt (frame 4 in the area 2 in Fig. 3) 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 extended to the second frame (frame 5 in Fig. 3) above the edge of the ice belt (*s* is frame spacing in the ice belt).

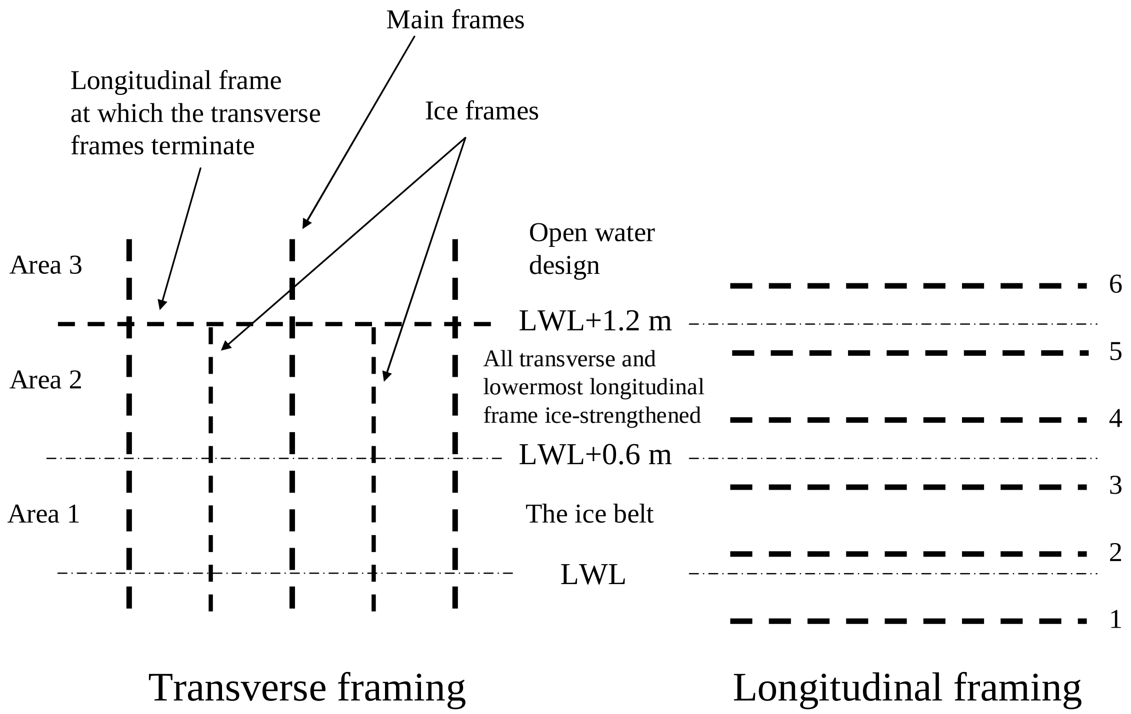

Figure 3. The different ice strengthening areas at and above the LWL. The distances (0.6 m and 1.2 m from LWL) are shown for ice class IA Super; these distances are different for other ice classes.

8.2 Arrangements for towing (paragraph 4.7.2)

According to paragraph 4.7.2, a mooring pipe (fairlead) shall be fitted in the bow bulwark at the centreline. A bitt (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.

Alternatively, two fairleads can be fitted symmetrically off the centreline with one bollard each. The bollards shall be aligned with the fairleads allowing the towlines to be fastened straight onto them. The installation of a centreline fairlead is still recommended, since it remains useful for many open water operations and in some operations in ice as well.

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

9.1 Rudder design

If the vessel has a flap-type rudder, special consideration should be given to the design of the rudder and the ice knife.

10 Propeller, shafts and gears (Chapter 6 of the rules)

10.1 Corrections to paragraph 6.3 of the rules

As mentioned in paragraph 4.1.3 above, the pyramid strength principle is adopted for the design of the propulsion system. For this reason the following corrections should be made in paragraph 6.3:

ct^2 = value for the propeller blade used, on the radius 0.25 D/2, cm^3
(instead of: “value derived by formulae in 6.2.2 a”) and

ct^2 = value for the propeller blade used, on the radius 0.35 D/2, cm^3
(instead of “value derived by formulae in 6.2.2 b)”).

10.2 Corrections to paragraph 6.5 of the rules

The ice factor K_i given in paragraph 6.5

$$K_i = K \cdot \frac{N}{N + \frac{M \cdot I_h \cdot R^2}{I_l + I_h \cdot R^2}}$$

is not correct, at least not if used as proposed. The determination of the variables is also not acceptable, because the torques N and M should be determined for the same rotation speed (if the output nominal torque of the engine is used as N, the ice torque M has to be reduced to the engine speed and vice versa). The best way is to reduce all the variables (N, M, I_l *and* I_h) to the same rotation speed.

Instead of the current rule formula, the ice load application factor, K_i, should be calculated as follows:

$$K_i = K \cdot \left(1 + \frac{M \cdot I_h \cdot R^2}{N \cdot \left(I_l + I_h \cdot R^2\right)}\right),$$

where

K_i is the ice load application factor
K is the rule load application factor in open water
M is the propeller ice torque
N is the nominal propeller shaft torque
I_h is the mass moment of inertia at the high speed side of the reduction gear
I_l is the mass moment of inertia at the low speed side of the reduction gear including the propeller entrained water
R is the reduction ratio of the reduction gear

11 Miscellaneous machinery requirements (Chapter 7 of the rules)

11.1 Sea inlet and cooling water systems

The idea behind paragraph 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 way, ice pieces and slush entering the chest can be defreezed. 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 also designed to operate 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.

A box cooler is 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^{o}C for much of the wintertime and might occasionally go down to about -30^{o}C, and for short periods of time temperatures as low as -40^{o}C can even 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 design temperatures are given for reference in the Baltic Sea area:

- Design ambient temperature: $-20^{o}C$
- Design sea water temperature: $-2^{o}C$

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 - see IACS Unified Requirement S6.1).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 Maritime Administration or by the Swedish Maritime Administration 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 paragraph 3.2.5 of the Finnish – Swedish Ice Class Rules, 2002.

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

$$T_B = K_g \left(P \cdot D_P\right)^{2/3}, \tag{1}$$

where K_g is the efficiency factor of bollard pull being 0.78 for 1 CPP and 0.98 for 2 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 employed. The net thrust T_{NET} takes into account the open water resistance R_{OW} and the change in propeller thrust T at speed v_1 (the K_T curve decreases with increasing J i.e. speed). The force balance in ice at speed v_1 is (R_{CH} is the rule channel resistance)

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

where t_1 is the thrust deduction factor at speed v_1. This basic equation indicates the definition of the net thrust as

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

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

$$T_{NET} = \frac{1-t_1}{1-t_0} \cdot \frac{K_T(J_1)}{K_T(0)} \cdot \left(\frac{n_1}{n_0}\right)^2 T_B - R_{OW}(v_1), \tag{4}$$

where J_1 is the advance coefficient an n_1 RPM at speed v_1, 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)

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

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

$$T_{NET} = R_{CH} \,, \tag{6}$$

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

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

Thus, to determine the net thrust more 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 can be estimated to be 20 % of R_{CH} and 0.15. These lead to the requirement that thrust at a 5 knots speed must be 1.41 R_{CH}. 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 J 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

$$T_{NET} = K_v \cdot T_B \,. \tag{8}$$

Then the extra thrust is taken into account by the factor K_N, where the bollard pull of the nozzled propeller that otherwise is of the same size is

$$T_{B,N} = K_N \cdot T_B \text{ and} \tag{9}$$

$$T_{NET} = K_v T_{B,N} = K_v K_N T_B \tag{10}$$

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

$$\begin{aligned} R_{CH} &= T_{NET} \\ &= K_v \cdot T_{B,N} \\ &= K_V \cdot K_N \cdot T_B \\ &= K_v \cdot K_N \cdot K_g \cdot \left(P \cdot D_P\right)^{2/3} . \end{aligned} \tag{11}$$

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

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

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 ice class rules) or Chapter 3, 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

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 ±2 %.

The measured bollard pull should not be less than $1.50 \cdot R_{CH}$. Open water resistance R_{OW} and J-factor must also be taken into account. (The factor 1.50 corresponds to R_{OW} and J being 20% of $R_{CH.}$). The actual and verified values for R_{OW} and J can always be used.

2. Bollard tow test

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 ±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 6 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

$$R_{iTOT} = R_i + R_{OW} . \qquad (1)$$

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

$$T \cdot (1-t) \geq R_{iTOT} = R_i + R_{OW} \;, \qquad (2)$$

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).

Here it should be noted that the ice class rules use the quantity T_{NET} which is defined in the rules as

$$T_{NET} = T \cdot (1-t) - R_{OW} \qquad (3)$$

and an approximation is used to determine the T_{NET} in the rules. This approximation is given using the bollard pull value T_B as

$$T_{NET} = \left(1 - \frac{1}{3}\frac{v}{v_{OW}} - \frac{2}{3}\left(\frac{v}{v_{OW}}\right)^2 \right) \cdot T_B \qquad (4)$$

where the term in parenthesis is evaluated at 5 knots (v_{OW} is open water speed).

2. The geometry of the ice channel

The rule-based channels have been given a thickness for their mid part (H_M = 1 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 2^0, see Figure 1. This profile is based on channel measurements in fairways to northern ports in the Gulf of Bothnia.

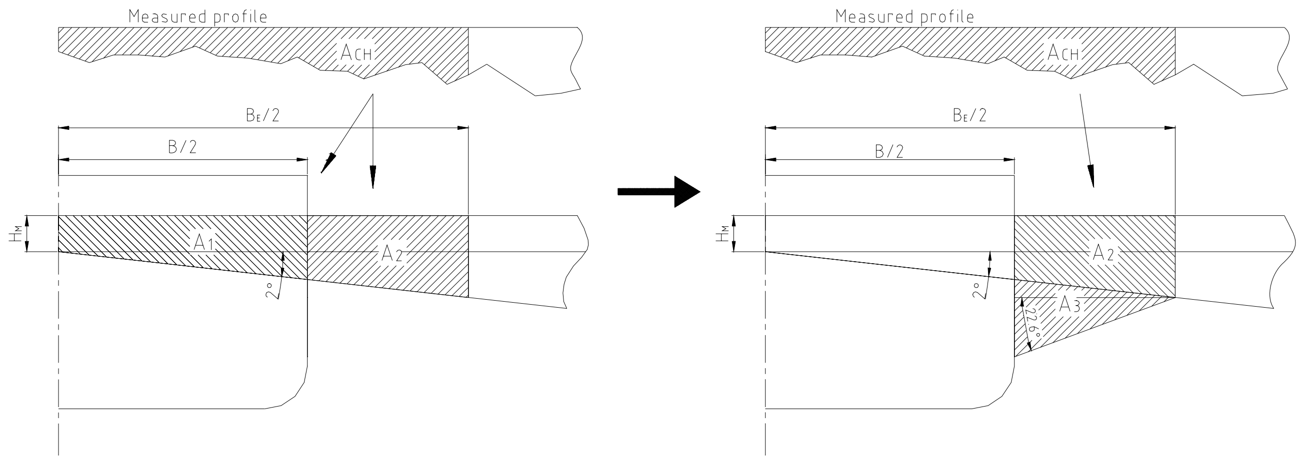

Figure 1. The geometry of a "real" brash ice channel profile and the corresponding profile of a rule channel before the ship's passage and the assumed behaviour of the ice during the passage. The relations between the cross-sectional areas are: $A_{CH} = A_1 + A_2 = A_2 + A_3$.

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

$$H_{av} = H_M + 14.0 \cdot 10^{-3} B \qquad (5)$$

where *B* is the beam of the vessel. In equation 1, *B* need not be greater than 30 m.

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

The channel profile should be measured at sufficiently small intervals (about 10 … 20 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 about 2 m.

3. 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, for example, by using the following formula:

$$R_{CH\left(\text{with } \mu_{\text{target}}\right)} = \left[\left(0.6 + 4\mu_{\text{target}}\right) / \left(0.6 + 4\mu_{\text{actual}}\right)\right] R_{CH\left(\text{with } \mu_{\text{actual}}\right)}, \tag{6}$$

where μ_{actual} is the actual friction coefficient used and μ_{target} = 0.1.

4. 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 in 10 cm thick level ice and the channel resistance.

5. Determination of the propulsion power in full scale

If R_{CH} is determined using model tests, then propeller thrust in full scale should be calculated by means of direct calculations 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.

6. Model test reporting

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

Annex to Appendix 4

Required information for a model test report

The following information should be included in a model test report for acceptance of the engine power according to paragraph 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
3.2 Description of the model propeller
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 about 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 an idea of the coverage of brash ice.
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 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, 2002, with input data

Appendix 5

GUIDELINES FOR THE INTERPRETATION OF THE RULES WITH RESPECT TO LONGITUDINALLY FRAMED SHELL STRUCTURES

1 Introduction

The purpose of these guidelines is to confirm the parameters for the scantling equations for plating and to advise on the calculation of frame section modulus, shear area and web thickness, if the frame spacing exceeds the stipulated value and/or end brackets are not fitted.

According to the Finnish-Swedish Ice Class Rules (see FMA Bulletin No. 13/1.10.2002), the maximum frame spacing of longitudinal frames is 0.35 m for ice classes IA Super and IA, and 0.45 m for ice classes IB and IC (see paragraph 4.4.3). In paragraph 4.4.4.1 it is stipulated that longitudinal frames shall be attached to all the supporting web frames and bulkheads by brackets.

In paragraph 4.1 it is said, *inter alia*, that "For the formulae and values given in this section for the determination of hull scantlings, more sophisticated methods may be substituted subject to approval by the administration or the classification society". Such methods may be considered appropriate if, e.g. the structure consists of a combination of transverse and longitudinal stiffening and the loads are supported by both.

It should be noted that, in general, the weight of a structure built according to the rules is lower than the weight of a structure with higher longitudinal frame spacing and/or a structure without brackets on the frames. The reason for the application of a higher frame spacing and/or omitting the brackets stems from lower production costs, i.e. a smaller number of structural elements to be welded on the structure.

2 Maximum frame spacing and the use of end brackets on longitudinal frames

In this section guidelines for designing longitudinally framed shell structures are given for the cases when the frame spacing exceeds the requirements in the Finnish Swedish Ice Class Rules or end brackets required in these rules on the longitudinal frames are not fitted.

The requirement that the maximum frame spacing s of longitudinal frames 'shall not exceed 0.35 metres for ice class IA Super and IA and shall in no case exceed 0.45 metres' stems from the fact that the ice loading is concentrated on a narrow horizontal strip. This concentration is taken into account by the factor f_2 in the rules for plating thickness (see paragraph 4.3.2) and factor f_3 for framing section modulus and shear area (see paragraph 4.4.3). These factors are a function of the load height divided by the frame spacing h/s.

Analysis carried out, however, confirms that it is possible to use larger frame spacing than stipulated in the rules, if the following issues related to the calculation of the plating thickness and the frame section modulus are applied.

2.1 Plating thickness

The plating thickness should be calculated according to the formula for longitudinal framing given in paragraph 4.3.2

$$t = 667 \cdot s \cdot \sqrt{\frac{p_{PL}}{f_2 \cdot \sigma_Y}} + t_c \text{ [mm].}$$

When calculating p_{PL}, i.e. p, according to paragraph 4.2.2, the factor c_a may be determined based on a load length equal to 2s also when a larger frame spacing than given by the rules is used. See paragraph 4.3.2 for the determination of the other parameters in the formula given above.

2.2 Longitudinal frames with larger frame spacings

The section modulus and the shear area of a longitudinal frame should be calculated by the formulae given in paragraph 4.4.3.

The section modulus of a longitudinal frame should be calculated by the formula:

$$Z = \frac{f_3 \cdot f_4 \cdot p \cdot h \cdot l^2}{m \cdot \sigma_y} 10^6 \left[cm^3\right]$$

The shear area of a longitudinal frame should be:

$$A = \frac{\sqrt{3} \cdot f_3 \cdot p \cdot h \cdot l}{2\sigma_y} 10^4 \left[cm^2\right]$$

In both formulae given above the value of the factor f_3 is to be calculated using the actual h/s ratio. The effective flange used in calculating the frame section modulus is to be taken as the classification society rules demand. It should be noted here that the effective flange may be smaller than the frame spacing. See paragraph 4.4.3 for the determination of the other parameters in the formulae given above.

2.3 Web thickness of the frames

In paragraph 4.4.4.2, sub-paragraph 3, it is stipulated that the web thickness of the frames shall be at least one half of the thickness of the shell plating and at least 9 mm. For larger frame spacings, this requirement gives rise to a web thickness that is beyond that needed for supporting locally the load and for ensuring the buckling strength of the web. With reference to paragraph 4.4.4.2, subparagraph 3, the web thickness of transverse and longitudinal frames need not exceed one half of the shell plating thickness as required for frame spacing of 0.45 m assuming the yield stress of the plate not more than that used for the frame.

2.4 Longitudinal frames without end brackets

According to ice load measurements conducted with ships navigating in the Baltic, the largest loads measured are in the order of two to three times higher than the design loads of the rules. The requirement on brackets stems from a consideration of these load levels. FE analyses undertaken of longitudinal frame structures show that load levels of this magnitude are supported by the bending response of the frame and the shell plating without significant permanent deflection if the rule design equation is slightly modified. When double end brackets are not fitted where the frame is crossing vertical support structure, the section modulus of a longitudinal frame should be calculated by the formula:

$$Z = \frac{f_3 \cdot f_4 \cdot p \cdot h \cdot l^2}{m \cdot \sigma_y} 10^6 \left[cm^3\right],$$

where m should not be taken larger than 11. See paragraph 4.4.3 for the determination of the other parameters in the formulae given above. The span length, l, is to be taken as the distance between the web frames (given in metres), measured along the frame.

In addition, the frame web should be attached to web frames by double lugs and web frame stiffeners, welded to the flange of the frame, fitted in way of every frame support. At frame terminations, effective end fixity should be provided for the frame by end bracket or carling attached to the supporting structures.