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COMPARISON OF THE SCANTLINGS DERIVED FROM DIFFERENT ICE RULES IN ORDER TO ESTABLISH EQUIVALENCIES BETWEEN ICE CLASSES

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1. INTRODUCTION

There exist several sets of ice class rules which are different from each other. As the concept of ice load is different in several of these and also the design limits are set in various fashions, it is not easy to compare the different ice classes. When the maritime authorities set requirements for ice classes for ships entering their jurisdiction, a need to compare the classes arise. The basis of ice class requirement may be the safety of the vessel, limiting the possible pollution resulting from a loss of ship integrity or the continuity of the ship traffic. The aim of this report is to make calculations about scantlings of ships in different ice classes so that the equivalency between certain ice classes can be established. The aim of this report is NOT to establish these equivalencies as this is a decision which maritime authorities will make - this report can at most give some recommendations as a conclusion based on the calculation results.

The basis of equivalency between two ice classes is that these meet the same general requirements placed by the maritime authorities. Thus two classes are in principle equivalent if they meet the same requirement for safety and vessel performance. The latter is usually given by a requirement for vessel propulsion power – this kind of requirements are given only in the Finnish-Swedish ice class rules intended for Baltic use and in the Russian Maritime Register rules. Both these rule sets assume that there is icebreaker assistance, and both these rule sets are intended for an area where the volume of ship traffic in ice covered waters is large. Several classification societies have adopted the Finnish-Swedish rules including the performance requirements. These performance requirements are not treated in this report.

The question of meeting the same safety requirement is not easy to answer as the required safety level is not given explicitly in any ice class rules. It might be possible to compare the ice loading used in each class. Even this is not possible as the ice loading is given in widely varying form and also because – even if the loads are explicitly given – the scantling equations contain some elements of loading implicitly. This leaves now only the possibility to compare the resulting scantling values; plate thickness, section modulus and shear area. It is here assumed that the larger structural elements follow the strength trend of the plating and frames. This simplifying assumption is made because stringer and web frame design in the rules follow often more direct design making the comparison difficult. Finally it should be mentioned that it is the intention to decide about the equivalence of the Finnish-Swedish ice classes with other classes based on the power requirement and hull strength. Thus the machinery design is not taken into account in deciding about the equivalence.

Two suggestions to do the comparison of scantlings exist. One is that a large number of example vessels are chosen and then the required scantling values are calculated for these. This has the drawback that not all parameter combinations are checked and then somebody might take advantage of this to get a certain ice class with smaller scantlings than originally intended by using parameter values outside the comparison range. The other possibility is to check all the combinations. This is a very cumbersome approach because there are so many parameters in the scantling equations that the number of possibilities is large. This approach of using all the values of all the parameters is anyhow chosen here. The principle of the calculations will be that the parametres present in all rule sets are chosen as main parametres and the rest of parametres in each class are used to give a minimum to maximum scantling value range. If this range between the maximum and minimum becomes large, no comparison is possible but it turns out that the range is not too large to preclude a comparison.

2. RULE SETS USED

There exist many different ice class rules for the Baltic or Arctic use. The range of possible different rule sets is decreased as many classification societies have adopted the Finnish-Swedish ice class rules as their Baltic rules. The only exceptions here are the Russian Register rules where the lower classes are intended to Baltic, the Lloyd's Register rules where the Baltic ice classes (IASuper etc) are **not** the same as the Finnish-Swedish classes and the proposed International Association of Classification Societies (IACS) PC classes. The ice classes which are equal to the Finnish-Swedish classes are given in Table 1. Most of these classes use also the Finnish-Swedish ice class rule power requirement from year 1999; only ABS uses the power requirement from year 1985. It is, however, understood that the classification societies mentioned in Table 1 intend to update their Baltic rules according to the Finnish-Swedish ones.

Table 1. The rules and ice classes which have adopted the Finnish-Swedish ice class rules and the corresponding notations.

Rule System	**Corresponding Classes, Notation**			
Finnish-Swedish Ice Class Rules 2002	IA Super	IA	IB	IC
American Bureau of Shipping 2002 Pt 6, Ch.1, Sec. 2	I AA	I A	I B	I C
Bureau Veritas, Pt F, Ch. 8	IAS	IA	IB	IC
Det Norske Veritas 2001 Pt. 5, Ch. 1, Sec. 3	ICE-1A*	ICE-1A	ICE-1B	ICE-1C
Germanischer Lloyd 2002 Pt. 1, Sec. 15-A,B	E4	E3	E2	E1
Nippon Kaiji Kyokai (ClassNK), Pt. C, Ch. 28	I*A Super*	I*A*	I*B*	I*C*
Registro Italiano Navale, Pt. F, Ch. 9, Sec. 1, 2002	IAS	IA	IB	IC

It was decided, however, to make slightly wider comparison using a mixture of Baltic, general first year ice and Arctic ice classes. Thus five class sets for first year ice were included in the comparison (the Finnish-Swedish ice class rules (FSICR), American Bureau of Shipping rules (ABS), Lloyd's Register of Shipping Baltic rules (LR) and the old and new Russian Register of Shipping rules (RS86 and RMRS99)). Also eight Arctic ice class sets were used (ABS, the Canadian Arctic Shipping Pollution Prevention Regulations (CAC), Det Norske Veritas rules (DNV), Germanischer Lloyd rules (GL), the IASC polar rules (IASC), LR Arctic classes, RS86 and RMRS99 Arctic rules). The classes used to derive the scantlings are given in the Table 2 below. The table gives the class description and the limiting level ice thickness given in the rule set (C is the ice concentration). Here it should be remembered that the limit ice thickness is only a reference value and it does not constitute a basis of comparison between the ice classes. In the table also the rule set reference is mentioned and the version of the rules used in the calculations.

Table 2. The rule sets compared in the calculations

Rule System	Notation	Class Description	Ice Thickness
Finnish-Swedish Ice Class Rules 2002	IA Super	Escorted operation in all Baltic ice conditions	1.0 m
	IA	Escorted operation medium (smaller vessels) and severe Baltic ice conditions	0.8 m
	IB	Escorted operation in medium ice conditions	0.6 m
	IC	Escorted operation in light ice conditions	0.4 m
American Bureau of Shipping 2002 Pt 6, Ch.1, Sec. 1	A1	Independent summer operation in Arctic	1.0 m
	A0	Independently in FY ice	0.6 m
	B0	Independently in FY ice	0.3 m
	C0	Independently in FY ice	0.3 m (C 6/10)
Arctic Shipping Pollution Prevention Regulations 1995	CAC3	Independent Arctic operation	
	CAC4	Arctic operation	
Det Norske Veritas 2001 Pt. 5, Ch. 1, Sec. 4	ICE-05	Arctic navigation with no ramming	0.5 m
	ICE-10	Arctic navigation with no ramming	1.0 m
	POLAR-10	Arctic navigation with accidental ramming with speed 2.0 m/s	1.0 m
Germanischer Lloyd 2002 Pt. 1, Sec. 15-D	Arc 1	Navigation in first year ice	1.0 m
	Arc 2	Navigation in multi-year ice	1.5 m
Polar Classes (IACS) 26 April 2001 PS1	PC6	Summer/Autumn operation in medium FY ice with MY ice inclusions	
	PC7	Summer/Autumn operation in thin FY ice with MY ice inclusions	
Lloyd's Register of Shipping July 2001 Pt. 5, Ch. 9, Secs. 6-9	1AS	Baltic navigation	1.0 m
	1A	Baltic navigation	0.8 m
	1B	Baltic navigation	0.6 m
	1C	Baltic navigation	0.4 m
	AC1	Arctic and Antarctic navigation	
	AC1,5	Arctic and Antarctic navigation	
USSR Register of Shipping 1986 Pt. II, Ch. 26	ULA	Independent summer/autumn navigation in the Arctic	
	UL	Independent summer/autumn navigation in the Arctic in light ice, year-round in non-Arctic seas	
	L1	Summer in Arctic in broken ice, light ice conditions in non-Arctic seas	
	L2	Broken ice in non-Arctic seas	
	L3	Broken ice in non-Arctic seas	
Russian Maritime Register of Shipping 1999 Pt. II, Ch. 3.10	LU7	Summer SY ice / winter FY ice	3.2 m / 2.0 m
	LU5	Summer medium FY ice / winter FY ice	- / 0.9 m
	LU4	Summer FY ice / winter thin FY ice	1.0 m / -
	LU3	Escorted navigation in FY ice	0.65 m
	LU2	Escorted navigation in Fy ice	0.5 m

3. THE BASIS OF CLASS COMPARISON

3.1 Principles of comparison

The principle of comparison will be to compare scantling values for each hull area (bow, bow intermediate, midbody and stern) using two sets of parametres; those included in all rule equations and those included only in certain rules. A range of the latter ones for a fixed set of the former (common) parametres to give the maximum and minimum scantling value is used. Thus e.g. for plate thickness the values given are t_{min} and t_{max} for fixed values of the common parametres. The maximum value corresponds to a certain combination of the parameter values specific only to the class in question, naturally within the range selected for these parametres.

The scantling elements to be used in the calculations are the plate thickness t, frame section modulus Z and frame shear area A. The loads are not compared as some factors belonging to ice loads are also included in the scantling equations. Further, the stringer and webframe design is not used here as some of the rules state that these should be calculated directly from loading and a wide variation of formulations exist in rules. A *bona fide*-principle is used which assumes that the above mentioned three scantling values are enough to establish a comparison. This principle assumes then that the (t,Z,A) triple set the strength level and other scantlings are derived correctly in relation to the strength level deduced from the triple.

Many rule sets include corrosion and wastage allowances. These are not included in the calculations and thus the so called net scantlings are compared. This might be slightly incorrect in some rules as the separation between corrosion allowance and the value required for strength might not be well separable. If this is the case, this should be taken into account in deciding about the equivalence.

3.2 Hull Areas

The first task in the comparison between classes is to establish the extent of the different hull areas. The ship hull is divided into regions of different ice strengthening. Longitudinally the very stem, bow, bow intermediate i.e. bow shoulder, midbody and stern areas are distinguished. In many rules the vertical extent is limited to an ice belt but sometimes there exist vertically several hull areas. The major difference between the different rule sets is the areas below the ice belt which exist in IACS rules and some other Arctic rule sets. How to treat this discrepancy in establishing the equivalency is to be decided. This is not a large drawback as the FSICR include only the ice belt as defined by hull areas and thus other rule sets having areas below it require more strengthening. Also some differences in defining the limits of the hull areas exist. In Appendix 1, Table 1-1 shows the limits of the bow area definition and Table 1-2 the stern area definition. It can be noted that the longitudinal extent of the bow area is quite similar in most of the rule sets but the vertical extent varies somewhat. This applies also for the stern area where the largest difference between different rules is whether the aft shoulder area is included in the midbody or the stern area. In the Finnish-Swedish ice class rules it is included in the midbody area as the midbody area is stronger than the stern area.

3.3 Calculation of plate thickness, frame section modulus and shear area

After an insight about the hull areas exists, the next task is to establish the form of scantling equations. Here especially the parametres each set uses is of importance. In Appendix 2 the parametres used in each rule set to determine the ice pressure and plate thickness are given. The analysis shows that the common parametres in each rule set for the plate thickness are the frame spacing s, displacement Δ and yield strength σ_Y – and the influence of the yield strength is the same in all rule sets. Thus the value of yield strength was fixed in the subsequent calculations as $\sigma_Y = 235$ MPa. Other parametres for the plate thickness which exist in some rules but not in all were the propulsion power and hull shape. Thus it may be written

$$t = f\left[p(P,\Delta,\text{hull}\cdot\text{shape}), h(P,\Delta,\text{hull}\cdot\text{shape}), s, \sigma_Y, \text{frame}\cdot\text{orientation}, \text{hull}\cdot\text{shape}\right] + t_c$$

where the dependency of the ice pressure p and ice pressure vertical extent h on the propulsion power P, displacement Δ and the hull shape is indicated. The t_c is the corrosion allowance. Here, however, net scantlings are used in comparisons and thus the corrosion allowance is neglected. As mentioned, only the parametres of displacement, frame spacing s and yield strength of the steel are included in all the rule sets. There are four parametres common in all rules:

$$(s, \Delta, \sigma_Y, \text{frame}\cdot\text{orientation})$$

and, as mentioned earlier the influence of the yield strength of steel is the same in all rules. The frame spacing will be used as the main parameter for plate thickness and calculations will be done by varying the frame spacing between 0.3 m and 1.0 m. The displacement is treated by using three different displacements in the calculations (5000 t, 20 000 t and 160 000 t) and the results of each of these is shown versus the frame spacing. Further two frame orientations were used; vertical and horizontal framing systems. As there are four hull areas (bow, bow intermediate, midbody and stern) to check, 24 different sets of results, made for the frame spacing range mentioned, is the outcome.

The other parametres which are included in some rules but not in all were treated so that for each (s,Δ, frame orientation) combination, a combination of hull angles (representing the hull shape) and power giving a minimum and maximum value for the scantling considered (here first plate thickness t) was found. These combinations were found naturally within certain limits of angles and powers. This limit is taken for propulsion power as the power giving the vessel roughly an open water speed of 13 and 25 knots. The use of rough naval architectural rules-of-thumb gives now the propulsion power range of

$$P_D = 6\cdot\Delta^{2/3} ... 30\cdot\Delta^{2/3}$$

in units of kW and t. The variation in the hull angles is somewhat more difficult. It was decided here to use a variation of the waterline angle and buttock line angle and vary these in limits (the angle γ used in IASC rules is the complement angle of φ)

$$\alpha = 25^o \ldots 50^o$$
$$\varphi = 25^o \ldots 50^o.$$

The other angles (frame angle β, frame normal angle i.e. the frame angle on the vertical plane containing the hull normal β_n) follow from these as

$$\tan\beta = \tan\gamma\cdot\tan\alpha$$
$$\tan\beta_n = \tan\beta\cdot\cos\alpha$$

For plate thickness and also for frames, the net scantlings are used if the difference is stated. Finally, if the frame span l is needed in the plate thickness calculations (only in one or two rule sets this is the case), a value of l = 3.0 m is used.

The situation for frame section modulus and frame shear area is slightly more difficult. For frames the common parametres are displacement, frame span and yield strength while the list of other parametres includes information about the grillage made of frames and stringers. Thus the section modulus and shear area requirements can be written as

$$Z = f\left[p(P,\Delta,\text{hull}\cdot\text{shape}),h(P,\Delta,\text{hull}\cdot\text{shape}),l,\sigma_Y,\text{frame}\cdot\text{orientation},\text{hull}\cdot\text{shape},\text{grillage}\cdot\text{set}-\text{up}\right]$$

$$A = f\left[p(P,\Delta,\text{hull}\cdot\text{shape}),h(P,\Delta,\text{hull}\cdot\text{shape}),l,\sigma_Y,\text{frame}\cdot\text{orientation},\text{hull}\cdot\text{shape},\text{grillage}\cdot\text{set}-\text{up}\right]$$

where the grillage set-up refers to assumptions about lay-out of vertical and horizontal frames and end conditions. Here again the influence of the yield strength is similar in all rules and a fixed value of σ_Y=235 MPa is used. The frame spacing have some influence which is not exactly similar in all rule sets. It was decided to ignore this difference and use a frame spacing s = 0.4 m in all frame calculations. The different ways of treating the grillage result in a wider range between the maximum and minimum.

Another problem in comparing the frames is that the IASC and Russian 1999 rules use the plastic section modulus. The ratio between the plastic and elastic section modulus depends, among other things, on the web height of the frame. This ratio for bulb-sections with plate of 15 mm thickness and frame spacing of 600 mm is given in Fig. 1. In order to reach a rough basis for comparisons, a fixed ratio could be used (a ratio of 1.35 is suggested in the comparisons).

Finally, as for the plate thickness, any corrosion and wastage allowance will be ignored. This allowance appears in the rules as a multiplicative factor greater than one. Here a value of one is used throughout. It should be mentioned that this is not exactly correct as when the section modulus is calculated, the plate thickness including the corrosion allowance t_c is used.

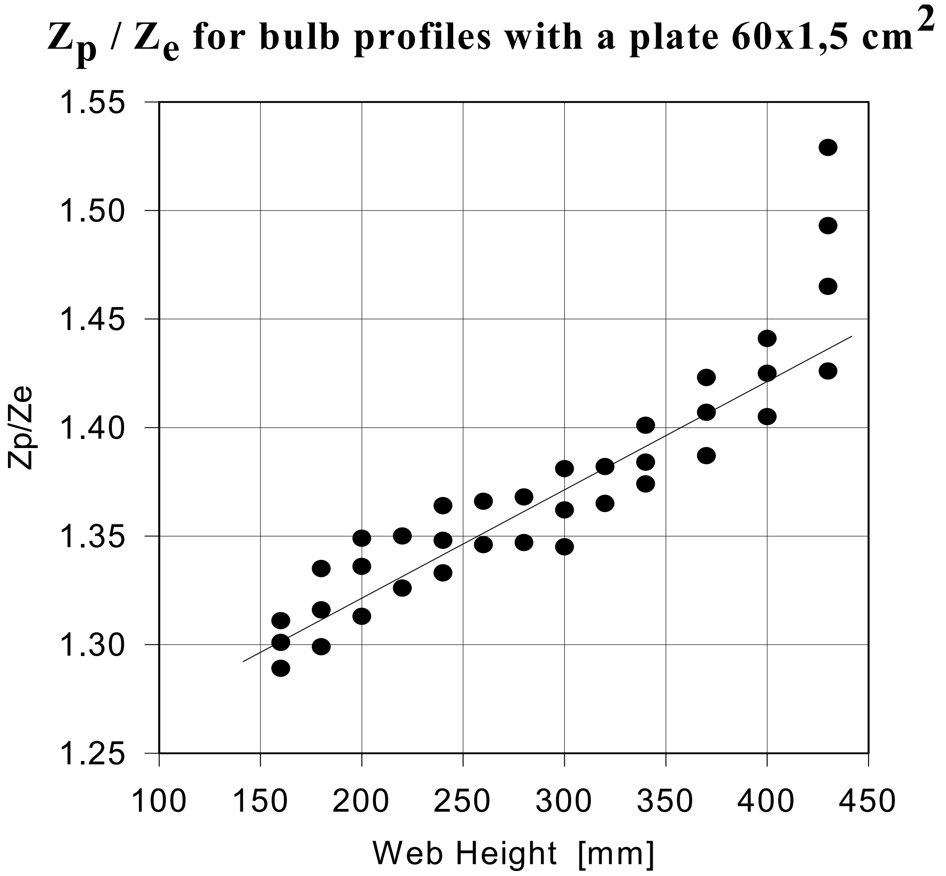

Fig. 1. The ratio between plastic and elastic section modulus for bulb sections. The line drawn is not a regression line but a line to illustrate the trend.

As mentioned above, following this plan to present the results, for each structural element scantling value, 24 cases is the result. These cases are illustrated in Fig. 2.

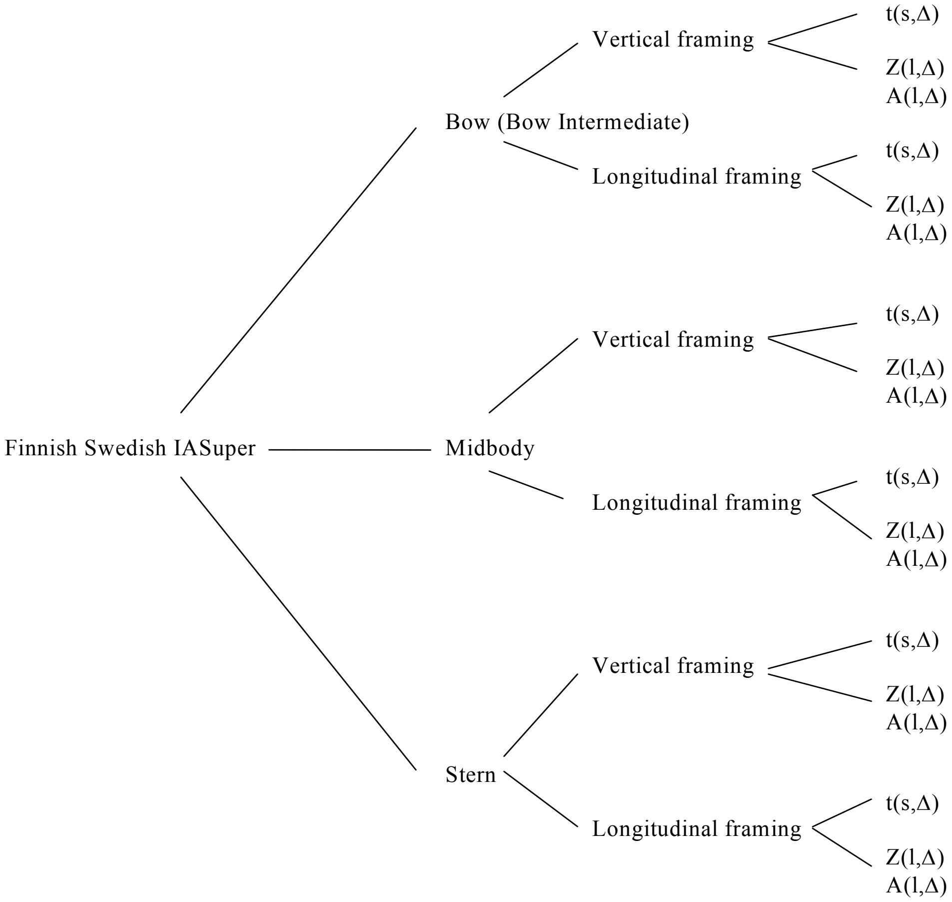

Fig. 2. A schematic presentation of all the calculation cases for each ice class showing also the free parametres.

3.4 Assumptions made for each set of rules

Finnish-Swedish Ice Class Rules

The calculations are straightforward once the displacement, propulsion power, frame spacing and frame span is set. There are, however, some restrictions and requirements in the rules which are not followed here. One such requirement is in §4.4.4 where the thickness of the web of frames is required to be at least 9 mm or half of the plate thickness. This requirement is not considered in the calculations as only the section modulus value as a whole is used. Another requirement which is ignored is the frame spacing of longitudinal frames. In §4.4.3 it is required that the frame spacing of longitudinal frames is at maximum 0.35 m in classes I A Super and I A and never more than 0.45 m. There is also a requirement to fit brackets in all longitudinal frames (§4.4.4.1). The hull shape does not influence the ice loading nor the scantlings. The ice load height is set as a class factor.

American Bureau of Shipping

The design ice pressure of the bow contains a hull shape factor F_{b1} which is a function of the waterline angle α and the frame angle β. Instead of varying the hull angles, it is assumed that the maximum value of the coefficient is 1.25 and the minimum value is 0.8 i.e.

$$\max\ F_{b1} = 1.25$$
$$\min\ F_{b1} = 0.80.$$

Similar shape dependent factor (F_i) is included in the other hull area pressures and similar limits as above are chosen for this factor also. These factors influence also the load height. In calculating the vertical frame section modulus, it is assumed conservatively that $j = 0$ i.e. that there are no supporting stringers. ABS has also a requirement that the thickness of the web of the frames must be at least 8 to 10 mm, depending on the ice class.

Canadian Arctic Shipping Pollution Prevention Regulations

The ice loading depends only on the vessel power and displacement but the hull shape influences the results through the frame spacing and the angle between the shell plating and web of the frame. In the CAC rules the frame direction is described by an angle the framing makes with horizontal direction, here only 0^o (horizontal framing) and 90^o (vertical framing) are used. The waterline angle influences the frame spacing in vertical framing and the frame angle in horizontal framing. These are taken into account within the limits stated above. The angle the frames make with the plating is, however, ignored. In measuring the frame span, a reduction based on the brackets is allowed; here it is assumed that no brackets are installed and thus l=LB=LS. Two misprints were detected in the rules. One is in Table 7 (p. 37) where there is a jump when the argument VP/LS becomes 4.0. Here this table is estimated with the function

$$R = -0.38 \cdot \left(\frac{VP}{LS}\right)^{0.66} + 1.0$$

Another misprint is in §19.2 where it stands $\frac{2-s}{VP}$ instead of the obviously correct expression $2 - \frac{s}{VP}$. Finally, it should be mentioned that the section modulus stipulated in the CAC rules is the plastic section modulus.

Det Norske Veritas

In the DNV Arctic rules the ice pressure p_o (the same as ice strength) and load height h_o (40 % of the ice thickness) are class factors. There is an equation for design ice pressure (D403) but the simpler one based on the ice strength is used in the rules in the plate and frame equations. In the plate and frame equations there are two tabulated constants. These are estimated with equations as

$$m_p = 2.68 \cdot \left(\frac{b}{s}\right)^{-0.6}$$

$$m_e = 12.9 \cdot \left(\frac{h_o}{l}\right)^{-0.5}$$

Here it should be noted that with DNV Arctic rules there is a problem with the frame section moduli. The requirement for the vertical frames in the 2001 version of rules becomes large. This is a result of a misprint. The section modulus requirement for vertical frames is (F401)

$$Z = \frac{520 \cdot l^2 \cdot s^{1-\alpha} \cdot p_o \cdot \frac{h_o}{l} \cdot \left(2 - \frac{h_o}{l}\right)}{8 \cdot \sigma_Y \cdot \sin\beta \cdot h_o^2} = 65 \frac{\sqrt{s} \cdot p_o \cdot (2l - h_o)}{\sigma_Y \cdot h_o}$$

where β is the angle of web with shell plating taken as 90° and frames as simply supported. Also the corrosion allowance factor w_k is taken as one. The factor α is a constant depending on the size of the loaded area being in most cases here 0.5. The misprint is in the exponent of h_0. This should be α instead of 2. Thus the correct equation is

$$Z = \frac{520 \cdot l^2 \cdot s^{1-\alpha} \cdot p_o \cdot \frac{h_o}{l} \cdot \left(2 - \frac{h_o}{l}\right)}{8 \cdot \sigma_Y \cdot \sin\beta \cdot h_o^\alpha} = 65 \frac{\sqrt{s} \cdot p_o \cdot \sqrt{h_o} \cdot (2l - h_o)}{\sigma_Y}.$$

Similar equation for the horizontal frames is

$$Z = \frac{41 \cdot h_o^{1-\alpha} \cdot l^{2-\alpha} \cdot p_o}{\sigma_Y \cdot \sin\beta} = \sqrt{h_o} \cdot l\sqrt{l} \cdot \frac{41 \cdot p_o}{\sigma_Y}.$$

The longitudinal frame section modulus requirement does not contain the frame spacing. This omission is slightly surprising and thus the section modulus requirements of DNV could be investigated somewhat deeper than is done here.

Germanischer Lloyd

The GL Arctic rules set the ice pressure and load height as class factors. As the scantling equations are lucid and relatively simple, no major assumptions in the calculations are needed. The only assumption needed is the location of the load patch relative to the frame span in vertical framing. Here it was assumed that the load acts centrically i.e. $d = l/2$. The section modulus stipulated is the plastic section modulus – and here occurs a major deviation from other rules. In §3.3.2.6 it is stated that in determining the plastic section modulus, the area of the web transferring shear must not be taken into account. This means that when the requirement for shear area is calculated, this area must then be removed in calculating the section modulus. In principle this leads to an optimizing exercise where the ratio of the web giving at the same time maximum section modulus and maximum shear area is to be determined. This line of thought is not followed here.

International Association of Classification Societies (PC-classes)

For the bow in the PC-classes the ice pressure, load width and load height depend on hull angles (normal frame angle $\beta_n = \beta'$ and waterline angle α). In determining the variation based on the hull angles, it was decided to determine the maximum and minimum of the factor $(fa)_i$ and calculate then the other loading variables with the angles giving the maximum and minimum value. In varying the hull angles mentioned above (Chapter 3.3) the bow was assumed to be wedge shaped. As there are opposing trends in the loading variables versus the hull angles, other possibilities to determine the range exist. One is to find the hull angle combinations giving the maximum and minimum plate thickness, section modulus and shear area. It was decided that this gives, however, too large and unrealistic variation. The frame scantlings were calculated assuming

$$a_1 = \frac{A_m}{A_{mFIT}} = 1 \quad \text{and} \quad kz = \frac{zp}{Zp} = 1$$

Further, the frames were assumed to be normal to the shell plating and simply supported. No brackets were assumed i.e. the frame span is the whole span between stringers or webframes in vertical and horizontal framing system, respectively. In the IASC rules there is a possibility to have an oblique framing system. Here again, the angle Ω was assumed to be either 0° or 90° i.e. framing system is assumed to be either horizontal or vertical. The section modulus requirement is for a plastic section modulus. Finally, the IASC rules contain many stability checks and it is assumed that these are checked individually.

Lloyd's Register of Shipping

LR has both Baltic and Arctic ice classes. Both sets are used here as the Baltic classes are different from the Finnish-Swedish ice classes. The Baltic and Arctic classes include a power requirement which is 'necessary to provide an independent icebreaking capability' (Pt. 3, Ch. 9, §7.3.3). The expression for the necessary power P_l includes ship breadth and length. These were related to displacement and estimated, based on average ratios between the main particulars, to be

$$B \approx 0.83 \cdot \sqrt[3]{\Delta}$$
$$L \approx 5.1 \cdot \sqrt[3]{\Delta}$$

where the displacement is given in tons and length/breadth in meters. The constants in the power expression are taken as

$$C_1 \cdot C_2 \cdot C_3 \cdot C_4 = 0.85$$

The factor K in the frame section modulus equation is assumed to be K = 1 i.e. the ice load acts centrically on the frame span. It should be noted that the LR Baltic rules do not contain explicitly any ice loading terms and in the Arctic classes the design ice pressure is decreasing towards higher ice classes (5.89 MPa in AC1 to 3.92 MPa in AC3).

USSR Register of Shipping (1986)

In the RS86 rules the ice pressure and load height are dependent on displacement and power and additionally on the hull angles. Here again a search using the hull angles to determine the maximum and minimum pressure is made. Even if different classes contain requirements for hull shape (mainly ULA), these limits have not been followed. The maximum and minimum load height is determined with the hull angle combination giving the maximum and minimum ice pressure. The ice pressure and load height depend also on the section location x/L from the bow. The factor depending on this ratio in the ice pressure expression is chosen to be 0.323 and in the expression for load height to be 0.788. There are expressions for the frame section modulus for side framing with and without web frames – the former expression is used here. Finally, the factor describing the framing grillage, $k\varphi_1$, is taken as a min-max range of 14.3,…,28.4. This range is rather large and it results in a quite large variation in frame section modulus. The section modulus referred to in these rules can be assumed to be the plastic section modulus, even if this is not mentioned in the rules explicitly.

Russian Maritime Register of Shipping (1999)

Similarly as in the older rules, the ice pressure and load height depend on hull angles and section position in 1999 rules. The angle variation is treated in the same way as in the older Russian rules. The section factor in the ice pressure expression is taken as 0.323 and in the load height expression as 0.788. The midship frames are assumed to be vertical. The plate thickness requirement contains a rather large corrosion allowance, up to 5 mm in higher ice classes. It could be argued that this should be taken into account in comparing the classes but for the sake of uniformity, this was not done. The frame requirement for section modulus contains many factors stemming from grillage (end conditions etc.) formulations. These are taken as $k_f = 1$, $E = 1$, $k = 3$ and $k_4 = 1$. The section modulus used in these rules can be assumed to be the plastic one as it is termed the 'ultimate section modulus'.

4. RESULTS OF THE CALCULATIONS

The calculations result in a mass of numbers as each class has at least three hull areas, three displacements, vertical and horizontal framing systems and up to three different scantling values (t, Z, A). Thus for each ice class there is some 18 or – if the bow intermediate area is included – 24 different calculations. One of these is presented in the Table 2 and all the cases calculated are given in Appendix 3. It is clear that some system to compare these results must be generated. Before going into this, two samples of results for bow plate thickness in vertical framing system are shown (Figs. 3 and 4).

Table 2. An example of the basic results of calculations, here for the FSICR ice class IA Super, bow area, both vertical and horizontal framing and the three displacements used.

```
FINNISH-SWEDISH ICE CLASS RULES, Ice Class IASuper,     Bow Area

                         Vertical Framing           Horizontal Framing
  DISP     s     Hc     Pmin    Pmax    tmin    tmax   Pmin    Pmax    tmin    tmax
   [t]    [m]    [m]   [MPa]   [MPa]    [mm]    [mm]  [MPa]   [MPa]    [mm]    [mm]
  5000.   .30    .35    1.79    2.40    13.7    15.9   1.79    2.40    15.6    18.1
  5000.   .35    .35    1.79    2.40    15.4    17.9   1.77    2.37    17.5    20.3
  5000.   .40    .35    1.79    2.40    17.0    19.7   1.74    2.35    19.4    22.5
  5000.   .45    .35    1.79    2.40    18.5    21.5   1.72    2.32    21.1    24.5
  5000.   .50    .35    1.79    2.40    20.0    23.1   1.70    2.29    22.7    26.4
  5000.   .55    .35    1.79    2.40    21.3    24.7   1.68    2.26    24.3    28.1
  5000.   .60    .35    1.79    2.40    22.6    26.2   1.66    2.24    25.7    29.8
  5000.   .65    .35    1.78    2.39    23.8    27.6   1.64    2.21    27.1    31.4
  5000.   .70    .35    1.77    2.37    24.9    28.9   1.62    2.18    28.4    32.9
  5000.   .75    .35    1.76    2.36    26.0    30.2   1.60    2.16    29.6    34.4
  5000.   .80    .35    1.74    2.35    27.0    31.4   1.58    2.13    30.8    35.7
  5000.   .85    .35    1.73    2.33    28.0    32.5   1.56    2.10    31.9    37.0
  5000.   .90    .35    1.72    2.32    29.0    33.6   1.54    2.07    33.0    38.3
  5000.   .95    .35    1.71    2.31    29.9    34.7   1.52    2.05    34.0    39.4
  5000.  1.00    .35    1.70    2.29    30.8    35.7   1.50    2.02    35.0    40.6

 20000.   .30    .35    2.87    3.61    17.4    19.5   2.87    3.61    19.8    22.2
 20000.   .35    .35    2.87    3.61    19.5    21.9   2.84    3.57    22.2    24.9
 20000.   .40    .35    2.87    3.61    21.6    24.2   2.80    3.53    24.5    27.5
 20000.   .45    .35    2.87    3.61    23.5    26.3   2.77    3.48    26.7    30.0
 20000.   .50    .35    2.87    3.61    25.3    28.4   2.74    3.44    28.8    32.3
 20000.   .55    .35    2.87    3.61    27.0    30.3   2.70    3.40    30.8    34.5
 20000.   .60    .35    2.87    3.61    28.7    32.2   2.67    3.36    32.6    36.6
 20000.   .65    .35    2.85    3.59    30.2    33.8   2.64    3.32    34.3    38.5
 20000.   .70    .35    2.84    3.57    31.6    35.4   2.61    3.28    36.0    40.4
 20000.   .75    .35    2.82    3.55    33.0    37.0   2.57    3.24    37.6    42.1
 20000.   .80    .35    2.80    3.53    34.3    38.4   2.54    3.20    39.1    43.8
 20000.   .85    .35    2.79    3.50    35.5    39.8   2.51    3.16    40.5    45.4
 20000.   .90    .35    2.77    3.48    36.7    41.2   2.48    3.12    41.8    46.9
 20000.   .95    .35    2.75    3.46    37.9    42.5   2.44    3.07    43.1    48.3
 20000.  1.00    .35    2.74    3.44    39.0    43.7   2.41    3.03    44.3    49.7

160000.   .30    .35    4.69    6.90    22.2    26.9   4.69    6.90    25.3    30.7
160000.   .35    .35    4.69    6.90    25.0    30.3   4.63    6.82    28.4    34.4
160000.   .40    .35    4.69    6.90    27.6    33.4   4.58    6.74    31.4    38.1
160000.   .45    .35    4.69    6.90    30.0    36.4   4.53    6.66    34.2    41.5
160000.   .50    .35    4.69    6.90    32.3    39.2   4.47    6.58    36.8    44.7
160000.   .55    .35    4.69    6.90    34.5    41.9   4.42    6.51    39.3    47.7
160000.   .60    .35    4.69    6.90    36.7    44.5   4.37    6.43    41.7    50.5
160000.   .65    .35    4.66    6.86    38.6    46.8   4.32    6.35    43.9    53.3
160000.   .70    .35    4.63    6.82    40.4    49.0   4.26    6.27    46.0    55.8
```

```
160000.  .75    .35    4.61    6.78    42.1    51.1    4.21    6.19    48.0    58.3
160000.  .80    .35    4.58    6.74    43.8    53.1    4.16    6.11    49.9    60.6
160000.  .85    .35    4.55    6.70    45.4    55.1    4.10    6.04    51.7    62.8
160000.  .90    .35    4.53    6.66    47.0    57.0    4.05    5.96    53.5    64.9
160000.  .95    .35    4.50    6.62    48.4    58.8    4.00    5.88    55.1    66.8
160000. 1.00    .35    4.47    6.58    49.9    60.5    3.94    5.80    56.7    68.7
```

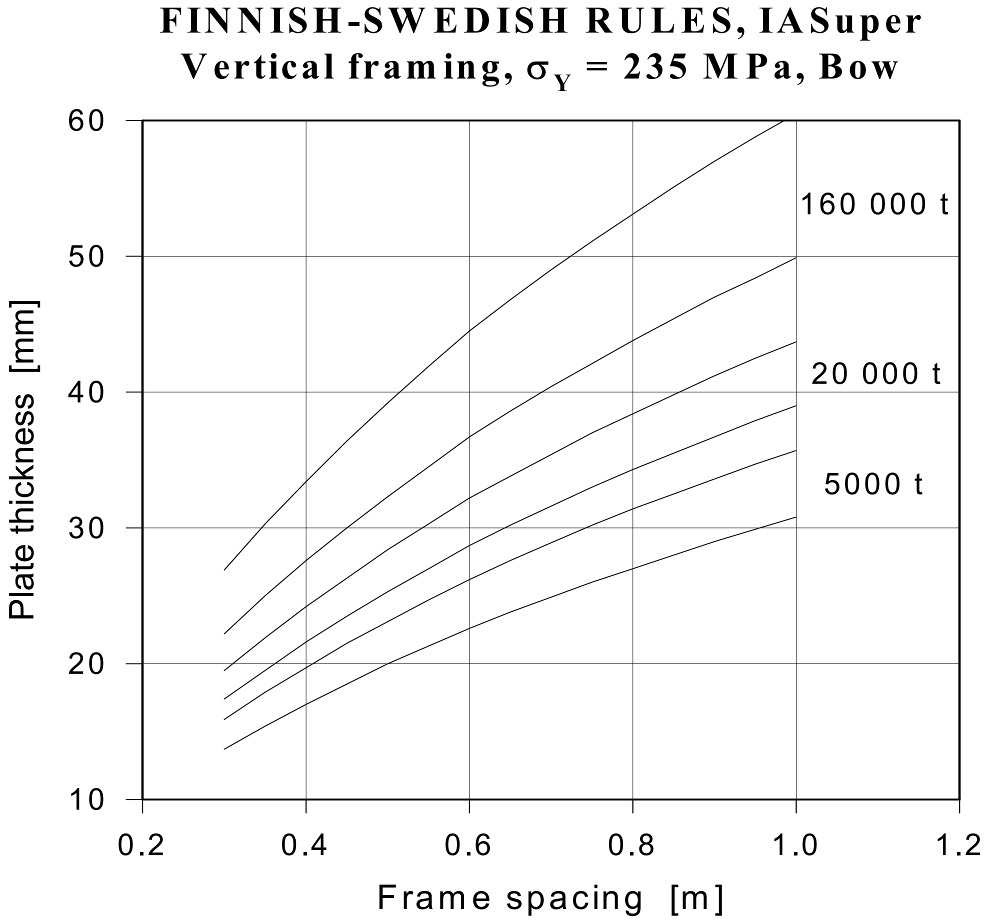

Fig. 3. The plate thickness variation for the Finnish-Swedish ice class I A Super in the bow area.

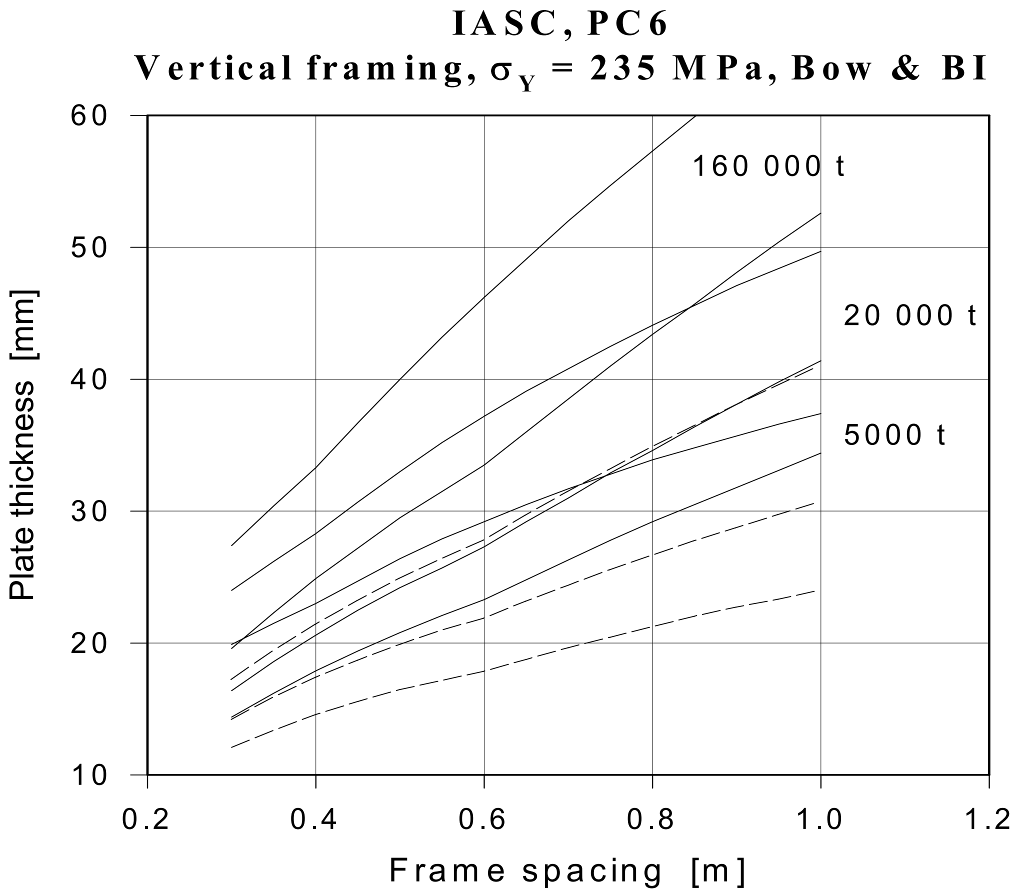

Fig. 4. The IACS PC6 class plate thickness at the bow and intermediate area. For the intermediate area (dashed lines) no displacement variation exists.

It is not practical to compare all the figures like Fig. 3 and Fig. 4, so the numbers are to be collected in more succinct tables. First tables of each calculation case (scantling, hull area and frame orientation as parametres) are collected. Here only the variation of the result is shown and if more detailed information is needed, the basic results in Appendix 3 must be consulted. An example of this kind of tables is shown below and all the tables are given in Appendix 4.

Table 3. The variation with frame spacing (s=0.3 m … 1.0 m) of plate thickness at the bow area of vertically framed shell structure.

Rule System	**Notation**	**Plate thickness t [mm] Bow area Transverse framing**			
			Δ=5000 t	**Δ=20 000 t**	**Δ=160 000 t**
Finnish-Swedish Ice Class Rules 1985 Annex I	I A Super	min	13.7 – 30.8	17.4 – 39.0	22.2 – 49.9
		max	15.9 – 35.7	19.5 – 43.7	26.9 – 60.5
	I A	min	13.2 –29.0	16.7 – 36.8	21.4 – 47.0
		max	15.3 –33.6	18.8 – 41.2	26.0 – 57.0
	I B	min	12.6 – 27.0	16.0 – 34.2	20.4 – 43.7
		max	14.6 – 31.3	17.9 – 38.3	24.7 – 53.0
	I C	min	12.1 – 25.6	15.4 – 32.4	19.7 – 41.5
		max	14.1 – 29.7	17.3 – 36.4	23.9 – 50.3
American Bureau of Shipping 2002 Pt 6, Ch.1, Sec. 1	A1	min	12.7 – 42.2	15.0 – 49.9	20.1 – 66.9
		max	18.6 – 62.0	22.0 – 73.3	29.5 – 98.2
	A0	min	12.6 – 42.1	14.2 – 47.3	17.4 – 58.1

		max	15.8 – 52.6	17.7 – 59.1	21.8 – 72.6
	B0	min	10.7 – 35.6	12.3 – 40.9	15.1 –50.4
		max	13.4 – 44.5	15.3 – 51.1	18.9 – 63.0
	C0	min	9.6 – 31.9	11.0 – 36.6	13.5 – 45.0
		max	11.9 – 39.8	13.7 – 45.7	16.9 – 56.3
Arctic Shipping Pollution Prevention Regulations 1995	CAC3	min	30.9 – 56.4	31.8 – 58.1	36.4 – 66.5
		max	37.0 – 67.5	38.4 – 70.2	45.4 – 82.9
	CAC4	min	25.2 – 46.1	26.0 – 47.5	29.7 – 54.3
		max	30.2 – 55.1	31.4 – 57.3	37.1 – 67.7
Det Norske Veritas 2001 Pt. 5, Ch. 1, Sec. 4	ICE-05		28.1 – 44.4		
	ICE-10		35.1 – 56.7		
	POLAR-10		39.2 – 63.4		
Germanischer Lloyd 2002 Pt. 1, Sec. 15-D	Arc 1		25.4 – 84.8		
	Arc 2		30.9 – 103.0		
Polar Classes (IACS) 26 April 2001 PS1	PC6	min	14.7 – 32.0	16.9 – 39.8	19.7 – 50.8
		max	19.4 – 34.4	23.2 – 45.0	26.2 – 58.8
	PC7	min	13.6 – 28.5	15.8 – 35.9	18.8 – 47.2
		max	17.4 – 29.4	21.5 – 40.2	24.5 – 52.7
Lloyd’s Register of Shipping July 2001 Pt. 5, Ch. 9, Secs. 6-9	1AS	min	12.7 – 42.3	16.2 – 54.1	17.0 – 56.6
		max	15.3 – 51.0	18.7 – 62.0	18.7 – 62.2
	1A	min	12.4 – 41.5	15.9 – 53.0	17.0 – 56.6
		max	15.7 – 52.2	18.3 – 61.0	18.3 – 61.0
	1B	min	11.8 – 39.4	15.1 – 50.3	16.9 – 56.4
		max	16.0 – 53.2	17.4 – 57.9	17.4 – 57.9
	1C	min	10.9 – 36.4	14.5 – 48.2	16.1 – 53.5
		max	16.1 – 53.5	16.1 – 53.5	16.1 – 53.5
	AC1	min	21.6 – 71.9	22.7 – 75.8	23.7 – 79.0
		max	23.2 – 77.3	26.6 – 88.8	32.0 – 106.8
	AC1,5	min	27.1 – 90.2	28.5 – 95.0	29.7 – 99.1
		max	28.0 – 93.2	30.6 – 101.9	34.4 – 114.8
USSR Register of Shipping 1986 Pt. II, Ch. 26	ULA	min	20.1 – 67.1	27.0 – 90.0	32.1 – 107.0
		max	21.5 – 71.6	29.7 – 99.1	33.8 – 112.8
	UL	min	14.4 – 47.9	19.3 – 64.2	22.9 – 76.4
		max	16.2 – 54.0	21.6 – 71.8	24.5 – 81.6
	L1	min	12.4 – 41.4	16.6 – 55.5	19.8 – 65.9
		max	14.3 – 47.6	18.9 – 63.0	21.4 – 71.3
	L2	min	11.4 – 37.9	15.0 – 50.1	17.9 – 59.6
		max	13.2 – 44.1	17.4 – 57.9	19.6 – 65.4
	L3	min	10.5 – 35.2	13.9 – 46.3	16.4 – 54.5
		max	12.3 – 40.9	16.2 – 53.8	18.3 – 60.9
Russian Maritime Register of Shipping 1999 Pt. II, Ch. 3.10	LU7	min	21.3 – 51.9	25.4 – 68.0	31.0 – 86.3
		max	22.4 – 57.4	26.4 – 73.4	32.1 – 92.3
	LU5	min	13.2 – 31.6	15.8 – 41.7	19.2 – 53.1
		max	13.9 – 35.1	16.4 – 45.1	19.9 – 56.9
	LU4	min	10.5 – 24.0	12.7 – 32.4	15.3 – 41.7

		max	11.2 – 27.0	13.3 – 35.4	16.3 – 45.1
	LU3	min	9.0 – 20.1	11.0 – 27.4	13.6 – 35.5
		max	9.6 – 22.7	11.6 – 30.1	14.1 – 38.5
	LU2	min	8.0 – 17.6	9.8 – 24.1	12.1 – 31.3
		max	8.6 – 19.9	10.3 – 26.6	12.6 – 34.1

Finally, the results can be collected together to facilitate the comparison for each set of ice classes where an equivalency is considered. These sets of classes are four in total here. These are:

FSICR IASuper
LR 1AS
PC6
RS86 UL
RMRS99 LU5

FSICR IA
LR 1A
PC7
RS86 L1
RMRS99 LU4

FSICR IB
LR 1B
RS86 L2
RMRS99 LU3

FSICR IC
LR 1C
RS86 L3
RMRS99 LU2

The results for these classes are collected in Appendices 5 to 8. This concludes the presentation of the calculation results.

5. CONCLUSION ABOUT THE EQUIVALENCIES

5.1 Definition of equivalency

The equivalency between two ice classes must in principle be decided based on the resulting safety level in the ice conditions on the sea area in question. The safety level pertains to a certain sea area and also to certain icebreaker assistance infrastructure. Thus the decision about the equivalency rests on the maritime authorities of the port state. Certain ice classes could be equivalent in view of navigation in some sea area but not in some other sea area because of differing navigation and assistance policy. Here the point of view is on Baltic navigation and the question is if some other ice classes should be considered as equivalent with the ice classes in the Finnish-Swedish ice class rules. Thus, apart from the hull strength, the power requirements must be fulfilled. This is not considered, however, here.

If the scantlings of a certain ice class are always greater than those given by FSICR, this class is naturally granted an equivalence with the corresponding FSICR ice class. This case is rare and it has been indicated that slightly smaller scantlings in certain cases may be tolerated. This applies especially for the plate thickness, where large plastic reserve usually exists. It must be, however, emphasized that strong frames is not a substitute for weak plating. Here the question of how much undersized the plating may be in order to not get too much damage is investigated.

This question may be investigated by calculating the ratio of elastic plate thickness i.e. plate thickness t_E which reaches the first yield with certain ice pressure p, frame spacing s, load height h and yield strength σ_Y. An approximate expression for this plate thickness for vertical framing system may be taken from the FSICR plate thickness equation

$$t_E = \frac{2}{3} \cdot s \cdot \sqrt{f_1\left(\frac{h}{s}\right) \cdot \frac{p}{\sigma_Y}} ,$$

where the constant is

$$f_1\left(\frac{h}{s}\right) = 1.3 - \frac{4.2}{\left(\frac{h}{s} + 1.8\right)^2} .$$

Similar approximate expression for the same geometry and loading for the plate thickness t_P which gets a permanent deflection of w_P with the same loading may be taken from Ranki (1986). This expression has been used in analyzing the plate ice damages (Kujala 1991, Hayward 2001). Thus the plate thickness t_P which gets a permanent deflection of w_P is

$$t_P = s \cdot \sqrt{\frac{p}{2\sigma_Y\left[\left(3 + 2\frac{s}{h}\right) \cdot \frac{w_P}{t_p} + 2 \cdot \frac{s}{h} + 1\right]}} , \quad \text{when } \frac{w_P}{t_P} \le 1 \text{ and}$$

$$t_p = s \cdot \sqrt{\frac{p}{8\sigma_Y\left(1 + \frac{s}{h}\right) \cdot \frac{w_P}{t_P}}} , \quad \text{when } \frac{w_P}{t_P} \ge 1 .$$

If it is assumed that the load height h equals the frame spacing s, then the equations simplify to

$$t_E = s \cdot \sqrt{f_1 \cdot \frac{p}{\sigma_Y}}\text{, where } f_1 = 0.764$$

$$t_P = s \cdot \sqrt{\frac{1}{2\left(5\frac{w_P}{t_P}+3\right)} \cdot \frac{p}{\sigma_Y}}\text{, when } \frac{w_P}{t_p} \le 1 \text{ and}$$

$$t_P = \frac{s}{4} \cdot \sqrt{\frac{1}{\frac{w_P}{t_P}} \cdot \frac{p}{\sigma_Y}}\text{, when } \frac{w_P}{t_P} \ge 1.$$

The ratio between the plastic plate thickness and the elastic one can be calculated using the above equations. The results are the following expressions:

$$\frac{t_P}{t_E} = \frac{2}{3} \cdot \frac{1}{\sqrt{2\left(5\frac{w_P}{t_P}+3\right) \cdot f_1}}\text{, when } \frac{w_P}{t_p} \le 1 \text{ and}$$

$$\frac{t_P}{t_E} = \frac{3}{8} \cdot \frac{1}{\sqrt{f_1 \cdot \frac{w_P}{t_P}}}\text{, when } \frac{w_P}{t_P} \ge 1.$$

The above ratio is plotted if Fig. 5. If e.g. it is considered that a permanent deflection equal to the plate thickness ($w_P = t$) is allowable for the purposes of determining an equivalence, a 57 % reduction in the plate thickness is the result. If the limit is just the onset of the permanent deflection ($w_P = 0$), then the allowable reduction is 30 % i.e. if the elastic plate thickness is 12 mm the plastic one is 8.4 mm. This onset of plastic permanent deflection may be used as a guideline in deciding about the allowable limits for equivalency.

For frames no such easy expressions may be derived as the yielding of frames involves also stability considerations. Thus only a fixed ratio (1.35) between the elastic and plastic section modulus may be used but otherwise the frames should fulfill – and not only approximately - the class requirements in order that the classes are to be equivalent.

The whole reasoning above rests on the assumption that the load is given exactly. This is not the case in reality as the ice load has a strong statistical nature. Thus even if the scantling equations are based on elastic theory, loads exceeding the elastic limit are encountered. These loads do not lead to failures because of the plastic reserve. This plastic reserve is even enhanced in the Finnish-Swedish rules by requiring brackets on longitudinal frames. All in all the Fig. 5 shows that if the onset of permanent deflection is used as the limit in granting the equivalency, there exists still a thickness reserve of about 40 % to large indents.

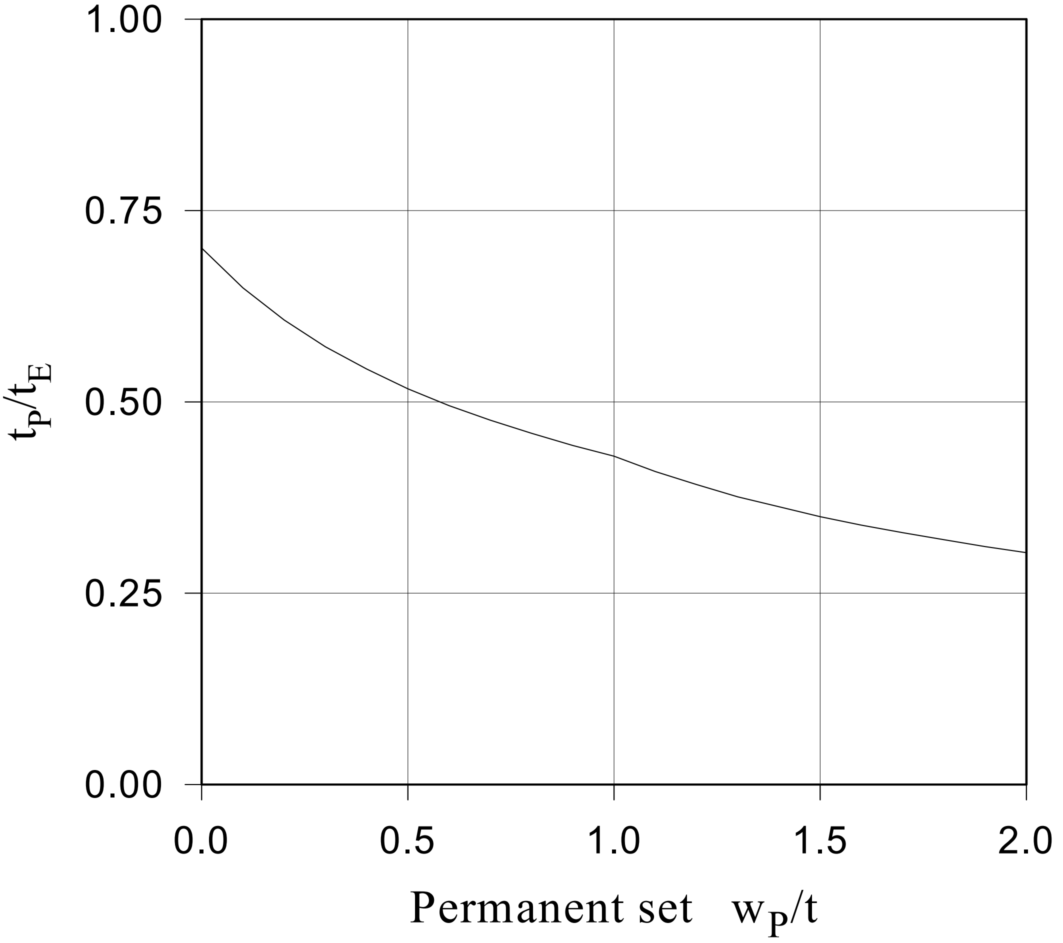

Fig. 5. The ratio between the plate thickness receiving a permanent deflection of w_P/t_P and the plate thickness reaching the first yield with the same loading and geometry.

5.2 Comparison for each class

5.2.1 Ice class IA Super

The comparison between scantlings given in Appendix 5 shows that Lloyd's Register ice class 1AS plate thickness is slightly less than that of FSICR IA Super in smaller frame spacings (s>0.4 m) especially in horizontal framing system but becomes noticeably thicker in larger spacings. The vertical frames are similar in each rule set for bow area but the longitudinal frame section modulus and shear area are noticeably smaller in LR as compared with FSICR for larger vessels and other hull areas than the bow.

The plate thickness in PC6 class is thinner than that of FSICR IA Super, especially in the bow intermediate area and the difference gets larger with increasing ship displacement. Vertical frames in PC6 are stronger than those of IA Super but the longitudinal frames are weaker in PC6 for other areas than the bow. Here it should be remembered that in calculating the PC-classes, no brackets were assumed on frames. As the FSICR require brackets especially on the longitudinal frames, the difference between FSICR and IASC rules diminishes.

The plate thickness of Russian ice classes UL and LU5 are comparable to I A Super even if the plate thickness is somewhat smaller in the Russian classes. This is augmented by a somewhat large corrosion allowance. The frames are stronger in the Russian classes.

5.2.2 Ice class IA

The comparison between the FSICR IA and LR 1A, PC7 and the Russian classes L1 and LU4 is exactly similar to the previous comparison. The plate thickness in the bow intermediate area in PC7 is somewhat smaller than that of in class IA, especially for larger ships and horizontal framing. The horizontal frames of smaller ships in PC7 are weak, especially as it should be remembered that the section modulus is the plastic one. The plate thickness in class LU4 is somewhat thinner that that of I A in the other areas than the bow area.

5.2.3 Ice class IB

There is not much difference in plate thickness of LR 1B and FSICR IB and even the horizontal frames are comparable – a slight difference occurs in larger displacements, however. The Russian ice class L2 scantlings are very close to those of FSICR IB but in ice class LU3 the plate thickness is noticeably smaller than in ice class IB. The frames in the Russian ice classes L2 and LU3 are strong; the only exception being the vertical frames in midbody and stern areas of L2 where the minimum scantlings are somewhat smaller than in FSICR IB.

5.2.4 Ice class IC

The plate thickness in LR 1C is now somewhat thinner than that of the ice class IC in FSICR whikle the frames are comparable. The increase in scantlings versus the displacement is not as steep in LR 1C than in FSICR IC and thus the difference between these classes increases with increasing displacement. The plate thickness in the Russian ice classes is somewhat thinner than that of FSICR IC and the vertical frames in L3 are somewhat smaller than the ones in IC.

5.3 Comparison of the Finnish-Swedish classes and other classes

In order to complete the comparisons, the four classes used above are compared with the FSICR classes. The comparison is presented in form of tables, Tables 4 – 19. These tables form the conclusion of this report on which the decisions about the equivalencies can be made. The percentages presented in the following tables must be viewed as approximate.

Table 4. The rule formulation comparison between FSICR and LR.

	Finnish-Swedish rules	Lloyd's Register rules
Minimum bow draught	$T = (2 + 0.00025\Delta)h_0$	$T = (1.5 + 0.1\sqrt[3]{\Delta})h_0$
Ice belt extent	0.4 to 0.6 m above LWL 0.5 to 0.75 m below BWL	0.4 to 0.6 m above LWL 0.5 to 0.75 m below BWL
Midship area	Extends aft from flat side at both forward and aft shoulders	Extends aft from flat side at both forward and aft shoulders
Influence of P and Δ	Through a factor $k = \sqrt{P \cdot \Delta}$	Through a factor $\gamma \geq 1$ defining excess power
Plate thickness Bow transverse framing	$t = 0.667 \cdot s \cdot \sqrt{\frac{f(h/s) \cdot p_{ice}}{\sigma_Y}}$	$t = 0.4 \cdot s \cdot \gamma \cdot \sqrt{\frac{4.7}{\sigma_Y}}$

Bow longitudinal framing	$t = 0.667 \cdot s \cdot \sqrt{\frac{p_{ice}}{f(h/s) \cdot \sigma_Y}}$	$t = 0.41 \cdot s \cdot \gamma \cdot \sqrt{\frac{4.7}{\sigma_Y}}$
Frame section modulus Bow – transverse	$Z = \frac{p_{ice} \cdot s \cdot l \cdot h}{f(h/l) \cdot \sigma_Y}$	$Z = 58.75 \frac{s \cdot \gamma^2 \cdot (3l^2 - h^2)}{\sigma_Y \cdot l}$
Bow – longitudinal	$Z = \frac{f(h/s) \cdot p_{ice} \cdot s \cdot l^2}{\sigma_Y}$	$Z = 78.02 \frac{s \cdot \gamma^2 \cdot l^2}{\sigma_Y}$

Table 5a. The plate thickness comparison between FSICR and LR; smaller (s<0.45 m) frame spacings.

	Transverse framing	Longitudinal framing
Bow	LR 5 % (small ships) to 20 % (large ships) thinner	LR 5 % (small ships) to 25 % (large ships) thinner
Midship	LR 5 % (small ships) to 20 % (large ships) thinner	LR 10 % (small ships) to 30 % (large ships) thinner
Stern	LR 5 % (small ships) to 20 % (large ships) thinner	LR 10 % (small ships) to 30 % (large ships) thinner

Table 5b. The plate thickness comparison between FSICR and LR; smaller (s>0.45 m) frame spacings.

	Transverse framing	Longitudinal framing
Bow	LR up to 40 % thicker	LR up to 30 % thicker
Midship	LR up to 35 % thicker	LR up to 25 % thicker
Stern	LR up to 35 % thicker	LR up to 25 % thicker

Table 6. The frame section modulus comparison between FSICR and LR.

	Transverse framing	Longitudinal framing
Bow	LR about 50 % larger	LR about 20 % (small ships) to 40 % (large ships) larger
Midship	LR about 30 % (IC) to 50 % (IA Super) larger	LR from equal (small ships) to 20 % (large ships) smaller
Stern	LR about 20 % larger	LR 5 % (small ships) to 40 % (large ships) smaller

Table 7. The frame shear area comparison between FSICR and LR.

	Transverse framing	Longitudinal framing
Bow	FSICR NA	Comparable
Midship	FSICR NA	LR about 25 % smaller for short spans, equal for longer spans
Stern	FSICR NA	LR about 25 % smaller for short spans, equal for longer spans

Table 8. The rule formulation comparison between FSICR and IASC

	Finnish-Swedish rules	International Association of Classification Societies rules
Minimum bow draught	$T = (2 + 0.00025\Delta)h_0$	NA
Ice belt extent	0.4 to 0.6 m above LWL 0.5 to 0.75 m below BWL	1.2 to 2.0 m above LWL 1.5 m below BWL (bow intermediate area)
Midship area	Extends aft from flat side at both forward and aft shoulders	Extends aft from flat side at forward shoulder. Stern area length fixed (0.15L)
Influence of P and Δ	Through a factor $k = \sqrt{P \cdot \Delta}$	Power is not included, displacement through shape factors
Plate thickness Bow transverse framing	$t = 0.667 \cdot s \cdot \sqrt{\frac{f(h/s) \cdot p_{ice}}{\sigma_Y}}$	$t = \frac{0.5 \cdot s}{1 + \frac{s}{2h}} \cdot \sqrt{\frac{p_{ice}}{\sigma_Y}}$
Bow longitudinal framing	$t = 0.667 \cdot s \cdot \sqrt{\frac{p_{ice}}{f(h/s) \cdot \sigma_Y}}$	$t = \frac{0.65 \cdot s}{1 + \frac{s}{2h}} \cdot \sqrt{\frac{p_{ice}}{\sigma_Y}}$
Frame section modulus Bow – transverse	$Z = \frac{p_{ice} \cdot s \cdot l \cdot h}{f(h/l) \cdot \sigma_Y}$	$Z = C \cdot \frac{s \cdot h \cdot l \cdot (1 - \frac{h}{2l}) \cdot p_{ice}}{\sigma_Y}$
Bow – longitudinal	$Z = \frac{f(h/s) \cdot p_{ice} \cdot s \cdot l^2}{\sigma_Y}$	$Z = C \cdot \frac{(1 - 0.3\frac{s}{h})(1 - \frac{h}{4s}) \cdot l^2 \cdot p_{ice}}{\sigma_Y}$

Table 9. The plate thickness comparison between FSICR and IASC PC.

	Transverse framing	Longitudinal framing
Bow intermediate	PC from 10 % (small ships) to 20 % (large ships) thinner	PC from 5 % (small s) to 20 % (large s) thinner
Midship	PC about 15 % (small s) to 25 % (large s) thinner	PC about 10 % thinner
Stern	PC about 10 % (small s) to 25 % (large s) thinner	Comparable

Table 10. The frame section modulus comparison between FSICR and IASC PC. Note that the IASC requirement is a plastic section modulus.

	Transverse framing	Longitudinal framing
Bow Intermediate	PC much (up to 300 %) stronger	PC about 20 % smaller (small ships) to 20 % larger (large ships)
Midship	PC much (up to 300 %) stronger	PC from 40 % smaller (small ships) to 30 % smaller (larger ships)
Stern	PC much (up to 300 %) stronger	PC from 50 % smaller (small ships) to 20 % smaller (larger ships)

Table 11. The frame shear area comparison between FSICR and IASC PC.

	Transverse framing	Longitudinal framing
Bow Intermediate	FSICR NA	PC from 50 % larger (small ships) to 200 % (large ships) larger
Midship	FSICR NA	PC from 20 % (small ships) smaller to equal (large ships)
Stern	FSICR NA	Comparable or larger (longer spans)

Table 12. The rule formulation comparison between FSICR and RS86.

	Finnish-Swedish rules	Russian Register of Shipping 1986 rules
Minimum bow draught	$T = (2 + 0.00025\Delta)h_0$	NA
Ice belt extent	0.4 to 0.6 m above LWL 0.5 to 0.75 m below BWL	0.75 m to L/160 above LWL 1.2 m below BWL
Midship area	Extends aft from flat side at both forward and aft shoulders	Extends aft from flat side at both forward and aft shoulders
Influence of P and Δ	Through a factor $k = \sqrt{P \cdot \Delta}$	Excess power and displacement influence ice pressure

Plate thickness Bow transverse framing	$t = 0.667 \cdot s \cdot \sqrt{\frac{f(h/s) \cdot p_{ice}}{\sigma_Y}}$	$t = 18.4 \cdot s \cdot \sqrt{\frac{p_{ice}}{\sigma_Y}}$
Bow longitudinal framing	$t = 0.667 \cdot s \cdot \sqrt{\frac{p_{ice}}{f(h/s) \cdot \sigma_Y}}$	$t = 18.4 \cdot s \cdot \sqrt{\frac{p_{ice}}{\sigma_Y}}$
Frame section modulus Bow – transverse	$Z = \frac{p_{ice} \cdot s \cdot l \cdot h}{f(h/l) \cdot \sigma_Y}$	$Z = C \cdot \frac{s \cdot h \cdot l \cdot (1 - 0.7 \cdot \frac{h}{l}) \cdot p_{ice}}{\sigma_Y}$
Bow – longitudinal	$Z = \frac{f(h/s) \cdot p_{ice} \cdot s \cdot l^2}{\sigma_Y}$	$Z = 65 \cdot \frac{s \cdot l^2 \cdot p_{ice}}{\sigma_Y}$

Table 13. The plate thickness comparison between FSICR and RS86.

	Transverse framing	Longitudinal framing
Bow	Comparable, only for larger ships, smaller spacings and lower ice classes RS86 20 % thinner	RS86 equal (higher ice classes) to 30 % (lower ice classes and smaller spans) thinner
Midship	RS86 equal (higher ice classes) to 15 % (lower ice classes) thinner	RS86 equal (higher ice classes) to 30 % (lower ice classesand smaller spans) thinner
Stern	RS86 equal (higher ice classes) to 15 % (lower ice classes) thinner	RS equal (higher ice classes) to 30 % (lower ice classes and smaller spans) thinner

Table 14. The frame section modulus comparison between FSICR and RS86.

	Transverse framing	Longitudinal framing
Bow	RS86 up to three times larger	RS86 several times larger
Midship	Comparable, but RS86 50 % smaller with some parameter combinations	RS86 from 50 % larger (small ships) to comparable (large ships)
Stern	Comparable, but RS86 50 % smaller with some parameter combinations	RS86 from 40 % smaller (small ships) to 15 % (large ships) smaller

Table 15. The frame shear area comparison between FSICR and RS86.

	Transverse framing	Longitudinal framing
Bow	FSICR and RS86 NA	RS86 NA
Midship	FSICR and RS86 NA	RS86 NA
Stern	FSICR and RS86 NA	RS86 NA

Table 16. The rule formulation comparison between FSICR and RMRS99.

	Finnish-Swedish rules	Russian Register of Shipping 1999 rules
Minimum bow draught	$T = (2 + 0.00025\Delta)h_0$	NA
Ice belt extent	0.4 to 0.6 m above LWL 0.5 to 0.75 m below BWL	0.75 m to 1.4 m above LWL 0.55 m below BWL
Midship area	Extends aft from flat side at both forward and aft shoulders	Extends aft from flat side at both forward and aft shoulders
Influence of P and Δ	Through a factor $k = \sqrt{P \cdot \Delta}$	Displacement influences ice pressure
Plate thickness Bow transverse framing	$t = 0.667 \cdot s \cdot \sqrt{\frac{f(h/s) \cdot p_{ice}}{\sigma_Y}}$	$t = \frac{15.8 \cdot s}{1 + \frac{s}{2h}} \cdot \sqrt{\frac{p_{ice}}{\sigma_Y}}$
Bow longitudinal framing	$t = 0.667 \cdot s \cdot \sqrt{\frac{p_{ice}}{f(h/s) \cdot \sigma_Y}}$	$t = \frac{15.8 \cdot s}{1 + \frac{s}{2l}} \cdot \sqrt{\frac{p_{ice}}{\sigma_Y}}$
Frame section modulus Bow – transverse	$Z = \frac{p_{ice} \cdot s \cdot l \cdot h}{f(h/l) \cdot \sigma_Y}$	$Z = C \cdot \frac{s \cdot h \cdot l \cdot (1 - \frac{h}{2l}) \cdot p_{ice}}{\sigma_Y}$
Bow – longitudinal	$Z = \frac{f(h/s) \cdot p_{ice} \cdot s \cdot l^2}{\sigma_Y}$	$Z = C \cdot \frac{s \cdot l^2 \cdot h \cdot (1 - \frac{h}{4s}) \cdot (1 - \frac{0.3s}{h}) \cdot p_{ice}}{\sigma_Y}$

Table 17. The plate thickness comparison between FSICR and RMRS99.

	Transverse framing	Longitudinal framing
Bow	RMRS99 from equal (small ships) to 15 % (large ships, higher ice class) or 35 % (large ships, lower ice class) thinner	RMRS99 from 10 % (small ships) thinner to 20 % (large ships, higher ice class) or 50 % (large ships, lower ice class) thinner
Midship	RMRS99 about 15 % thinner	RMRS99 from 10 % (small ships) thinner to 15 % (large ships, higher ice class and small spacing) or 30 % (large ships, lower ice class and small spacing) thinner
Stern	RMRS99 about 20 % thinner	RMRS99 from 10 % (small ships and small spacing) thinner to 20 % (large ships and small spacing)

Table 18. The frame section modulus comparison between FSICR and RMRS99.

	Transverse framing	Longitudinal framing
Bow	RMRS99 several times larger	RMRS99 several times larger
Midship	RMRS99 several times larger	RMRS99 several times larger
Stern	RMRS99 several times larger	RMRS99 several times larger

Table 19. The frame shear are comparison between FSICR and RMRS99.

	Transverse framing	Longitudinal framing
Bow	FSICR NA	In lower ice classes comparable, in higher RMRS up to 200 % larger
Midship	FSICR NA	In lower ice classes comparable, in higher RMRS up to 200 % larger
Stern	FSICR NA	In lower ice classes comparable, in higher RMRS up to 200 % larger

6. CONCLUSION

The aim of the present report is to make and present a basis for deciding about the equivalence between certain ice classes and the Finnish-Swedish ice classes. A calculation scheme for this purpose was developed and scantling values calculated. Once the calculation method is developed, the problem in deciding about the equivalencies is that of presentation of the results. This was approached here by presenting a range of values for plate thickness, frame section modulus and shear area.

The calculations revealed differences some rule sets which should be clarified separately. Most notable of these differences are in the description of the load patch. In many rules the load has quite large vertical extent. Only in the Finnish-Swedish rules the load height is relatively small. This results in differences in the longitudinal framing. There has been several damages related to the longitudinal framing system in the Baltic and thus the strength level in the FSICR seems at the moment adequate. Another more implicit difference is design point definition. The ice loading is statistical and thus the design point should be defined as a return period, exposure time or perhaps mileage in ice. This definition should also be reflected in the design limit. This kind of considerations have not been done and this forms one of the avenues for future development. Overall the numbers created and shown in this report should form a basis for deciding about the equivalencies. The decision itself is to be made by the maritime authorities of each port state and this report gives just guidance for the decision.

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