RULES FOR THE SURVEY AND CONSTRUCTION OF STEEL SHIPS

Part I Polar Class Ships and Ice Class Ships

RULES

2009 AMENDMENT NO.1

Rule No.45 30th October 2009

Resolved by Technical Committee on 24th June 2009

Approved by Board of Directors on 28th July 2009

Rule No.45 30th October 2009
AMENDMENT TO THE RULES FOR THE SURVEY AND CONSTRUCTION OF STEEL SHIPS

"Rules for the survey and construction of steel ships" has been partly amended as follows:

Part I POLAR CLASS SHIPS AND ICE CLASS SHIPS

Chapter 1 GENERAL

1.1 General

1.1.1 Application

Sub-paragraph -3 has been amended as follows.

3 Where a ship is intended to be registered as an ice class vessel (hereinafter referred to as "ice class ship" in this Part) for navigation of the Northern Baltic <u>complying with the *Finnish-Swedish Ice Class Rules* 2008 or in the Canadian Arctic complying with the *Arctic Shipping Pollution Prevention Regulations*,</u> the materials, hull structures, equipment and machinery of the ship are to be in accordance with the requirements in **Chapter 1** and **Chapter 5** of this Part in addition to those in other Parts.

Chapter 2 MATERIALS AND WELDING

2.1 Material

Paragraph 2.1.2 has been amended as follows.

2.1.2 Material Classes and Grades

1 Material classes and grades used for the hull structure are given in **Table I2.1-1** to **Table I2.1-4**.
2 In addition, material classes for weather and sea exposed structural members and for members attached to the weather and sea exposed shell plating of polar class ships are given in **Table I2.2**.
3 For polar class ships designed base on a designated design temperature, the steels used for hull structures are to comply with the requirements in **1.1.12, Part C**.
4 The steel grade of rolled steels with a thickness of 50*mm* or more and/or a minimum upper yield stress of 390N/mm^2 or more is deemed appropriate by the Society.

Table I2.1 has been deleted and Table I2.1-1 to Table I2.1-4 have been added as follows.

~~Table I2.1 Material Classes for Structural Members~~

~~Structural Members~~	~~Material Class~~	
	~~Within 0.4*L* amidships~~	~~Outside 0.4*L* amidships~~
~~Secondary:~~ ~~A1. Longitudinal bulkhead strakes, other than that belonging to the Primary category~~ ~~A2. Deck plating exposed to weather, other than that belonging to the Primary or Special category~~ ~~A3. Side plating~~	~~I~~	~~*A/AH*[(9)]~~
~~Primary:~~ ~~B1. Bottom plating, including keel plate~~ ~~B2. Strength deck plating, excluding that belonging to the Special category~~ ~~B3. Continuous longitudinal members above strength deck, excluding hatch coamings~~ ~~B4. Uppermost strake in longitudinal bulkhead~~ ~~B5. Vertical strake (hatch side girder) and uppermost sloped strake in top wing tank~~	~~II~~	~~*A/AH*[(9)]~~
~~Special:~~ ~~C1. Sheer strake at strength deck [(1),(8)]~~ ~~C2. Stringer plate in strength deck [(1),(8)]~~ ~~C3. Deck strake at longitudinal bulkhead [(2),(8)]~~ ~~C4. Strength deck plating at outboard corners of cargo hatch openings in container carriers and other ships with similar hatch openings configuration [(3)]~~ ~~C5. Strength deck plating at corners of cargo hatch openings in bulk carriers, ore carriers, combination carriers and other ships with similar hatch openings configuration [(4)]~~ ~~C6. Bilge strake [(5),(6),(8)]~~ ~~C7. Longitudinal hatch coamings of length greater than 0.15*L* [(7)]~~ ~~C8. End brackets and deck house transition of longitudinal cargo hatch openings [(7)]~~	~~III~~	~~II~~ ~~I outside 0.6*L* amidships~~

~~Notes:~~

~~(1) Not to be less than grade *E/EH* within 0.4 *L* amidships in ships with length exceeding 250 *m*.~~
~~(2) Excluding deck plating in way of inner-skin bulkhead of double hull ships.~~
~~(3) Not to be less than class III within the length of the cargo region.~~
~~(4) Not to be less than class III within 0.6 *L* amidships and class II within the remaining length of the cargo region.~~

~~(5) May be of class II in ships with a double bottom over the full breadth and with length less than 150 *m*.~~

~~(6) Not to be less than grade *D*/*DH* within 0.4 *L* amidships in ships with length exceeding 250 *m*.~~

~~(7) Not to be less than *D*/*DH*.~~

~~(8) Single strakes required to be of class III or of grade *E*/*EH* and within 0.4 *L* amidships are to have breadths not less than 5*L*+800 *mm*, need not be greater than 1,800 *mm*, unless limited by the geometry of the ship's design.~~

~~(9) *A* means *KA*, *AH* means *KA*32 or *KA*36~~

Table I2.1-1 Material Classes for Structural Members in general

Structural Member Category	Material Class/Grade
SECONDARY: A1. Longitudinal bulkhead strakes, other than that belonging to the Primary category A2. Deck plating exposed to weather, other than that belonging to the Primary or Special category A3. Side plating	-Class I within 0.4L amidships -Grade *A*/*AH* [(2)] outside 0.4L amidships
PRIMARY: B1. Bottom plating, including keel plate B2. Strength deck plating, excluding that belonging to the Special category B3. Continuous longitudinal members above strength deck, excluding hatch coamings B4. Uppermost strake in longitudinal bulkhead B5. Vertical strake (hatch side girder) and uppermost sloped strake in top wing tank	-Class II within 0.4L amidships -Grade *A*/*AH* [(2)] outside 0.4L amidships
SPECIAL C1. Sheer strake at strength deck [(1)] C2. Stringer plate in strength deck [(1)] C3. Deck strake at longitudinal bulkhead, excluding deck plating in way of inner-skin bulkhead of double-hull ships[(1)]	-Class III within 0.4L amidships -Class II outside 0.4L amidships -Class I outside 0.6L amidships
C4. Strength deck plating at outboard corners of cargo hatch openings in container carriers and other ships with similar hatch opening configuration	-Class III within 0.4L amidships -Class II outside 0.4L amidships -Class I outside 0.6L amidships -Min. Class III within cargo region
C5. Strength deck plating at corners of cargo hatch openings in bulk carriers, ore carriers, combination carriers and other ships with similar hatch opening configuration	-Class III within 0.6L amidships -Class II within rest of cargo region
C6. Bilge strake in ships with double bottom over the full breadth and length less than 150*m*[(1)]	-Class II within 0.6L amidships -Class I outside 0.6L amidships
C7. Bilge strake in other ships [(1)]	-Class III within 0.4L amidships -Class II outside 0.4L amidships -Class I outside 0.6L amidships
C8. Longitudinal hatch coamings of length greater than 0.15L C9. End brackets and deck house transition of longitudinal cargo hatch openings	-Class III within 0.4L amidships -Class II outside 0.4L amidships -Class I outside 0.6L amidships -Not to be less than Grade *D*/*DH* [(3)]

Notes:

(1) Single strakes required to be of class III within 0.4L amidships are to have breadths not less than 5L+800 *mm*, need not be greater than 1,800 *mm*, unless limited by the geometry of the ship's design.

(2) *A* means *KA*, *AH* means *KA*32 or *KA*36

(3) *D* means *KD*, *DH* means *KD*32 or *KD*36

Table I2.1-2 Minimum Material Grades for ships with length exceeding 150 *m* and single strength deck

Structural Member Category	Material Grade
Longitudinal strength members of strength deck plating	Grade *B*/*AH*(1) within 0.4*L* amidships
Continuous longituginal strength members above strength deck	Grade *B*/*AH*(1) within 0.4*L* amidships
Single side strakes for ships without inner continuous longituginal bulkhead(s) between bottom and the strength deck	Grade *B*/*AH*(1) within cargo region

Notes:

(1) *B* means *KB*, *AH* means *KA*32 or *KA*36

Table I2.1-3 Minimum Material Grades for ships with length exceeding 250 *m*

Structural Member Category	Material Grade
Shear strake at strength deck(1)	Grade *E*/*EH*(2) within 0.4*L* amidships
Stringer plate in strength deck(1)	Grade *E*/*EH*(2) within 0.4*L* amidships
Bilge strake(1)	Grade *D*/*DH*(3) within 0.4*L* amidships

Notes:

(1) Single strakes required to be of Grade *E*/*EH* and within 0.4*L* amidships are to have breadths not less than 5*L*+800 *mm*, need not be greater than 1,800 *mm*, unless limited by the geometry of the ship's design.

(2) *E* means *KE*, *EH* means *KE*32 or *KE*36

(3) *D* means *KD*, *DH* means *KD*32 or *KD*36

Table I2.1-4 Minimum Material Grades for ships of *BC-A* and *BC-B*

Structural Member Category	Material Grade
Lower bracket of ordinary side frame(1)(2)	Grade *D*/*DH*(3)
Side shell strakes included totally or partially between the two points located to 0.125*l* above the intersection of side shell and bilge hopper sloping plate or inner bottom plate(2)	Grade *D*/*DH*(3)

Notes:

(1) The term "lower bracket" means webs of lower brackets and webs of the lower part of side frames up to the point of 0.125*l* above the intersection of side shell and bilge hopper sloping plate or inner bottom plate.

(2) The span of the side frame, *l*, is defined as the distance between the supporting structures.

(3) *D* means *KD*, *DH* means *KD*32 or *KD*36

Table I2.2 has been amended as follows.

Table I2.2 Material Classes for Structural Members of Polar Class Ships

Structural Members	Material Class
Shell plating within the Bow and Bow Intermediate Icebelt hull areas (B, B_{Ii})	II
All weather and sea exposed Secondary and Primary, as defined in **Table I2.1-1**, structural members outside 0.4 *L* amidships	I
Plating materials for stem and stern frames, rudder hone, rudder, propeller nozzle, shaft brackets, ice skeg, ice knife and other appendages subject to ice impact loads	II
All inboard framing members attached to the weather and sea-exposed plating including any contiguous inboard member within 600 *mm* of the shell plating	I
Weather-exposed plating and attached framing in cargo holds of ships which by nature of their trade have their cargo hold hatches open during cold weather operations	I
All weather and sea exposed Special, as defined in **Table I2.1-1**, structural members within 0.2*L* from *FP*	II

Paragraph 2.1.3 has been amended as follows.

2.1.3 Steel Grade

1 Steel grades for all plating and attached framing of hull structures and appendages situated below the level of 0.3*m* below the *LIWL*, are to be obtained from **Table I2.3** based on the Material Classes for Structural members in **Table I2.1-1 to Table I2.1-4** and **Table I2.2** above, regardless of polar classes.

2 Steel grades for all weather exposed plating of hull structures and appendages situated above the level of 0.3 *m* below the *LIWL* are to be not less than that given in **Table I2.4** based on the Material Class for Structural Members in **Table I2.1-1 to Table I2.1-4** and **Table I2.2** above, regardless of polar class.

3 Steel grades for all inboard framing members attached to weather exposed plating are not to be less than that given in **Table I2.5**. This applies to all inboard framing members as well as to other contiguous inboard members (*e.g*. bulkheads, decks) within 600 *mm* of the exposed plating.

Chapter 5 ICE CLASS SHIPS

5.1 General

5.1.1 Application

Sub-paragraph -2 has been amended as follows.

1 The requirements in this Chapter apply to hull structure, equipment and machinery, etc. of ice class ships.
2 The requirements in this Chapter are framed for the ice strengthening of ships which are intended to navigate in the Northern Baltic complying with the *Finnish-Swedish Ice Class Rules* ~~2002~~ 2008 or in the Canadian Arctic complying with the *Arctic Shipping Pollution Prevention Regulations*.

5.1.2 Maximum and Minimum Draught

Sub-paragraph -6 has been amended as follows.

6 The minimum forward draught is not to be less than that obtained from the following formula~~,~~ ~~but need not exceed $4h_0$.~~

$(2.0 + 0.00025\Delta)h_0 (m)$ but need not exceed $4h_0$

where

Δ : The displacement of the ship at the maximum draught amidships on the *UIWL*.

h_0 : Constant given in **Table I5.1** according to the respective ice class

Table I5.1 Value of Constant h_0

Ice Class	h_0
I*A Super*	1.0
I*A*	0.8
I*B*	0.6
I*C*	0.4
I*D*	0.4

5.2 Design Ice Pressures

5.2.1 Design Ice Pressures

Sub-paragraph -1 has been amended as follows.

1 Design ice pressure (P) is not to be less than that obtained from the following formula:

$C_d\, C_{\cancel{1}p}\, C_a\, p_0\ (MPa)$

where

$$C_d = \frac{ak+b}{1000}$$

$$k = \frac{\sqrt{\Delta H}}{1000}$$

Δ : Displacement (t) of the ship on the maximum draught specified in **5.1.2-6**

H : Engine output (kW)

a and b : As given in **Table I5.2** according to the region under consideration and the value of k.

$C_{\cancel{1}p}$: As given in **Table I5.3** according to the ice class and the region under consideration.

p_0 : The nominal ice pressure; the value 5.6 MPa is to be used.

C_a : As given by the following formula. However, C_a need not to exceed 1.0 and where C_a is less than 0.6, C_a is to be taken as 0.6.

$$C_a = \frac{47-5l_a}{44}$$

l_a : To be taken as specified in **Table I5.4** according to the structural member under consideration.

Table I5.3 has been amended as follows.

Table I5.3 Coefficient $C_{\cancel{1}p}$

Ice Class	Forward region	Midship region	Aft region
I*A Super*	1.00	1.00	0.75
I*A*	1.00	0.85	0.65
I*B*	1.00	0.70	0.45
I*C*	1.00	0.50	0.25
I*D*	1.00	-	-

5.3 Hull Structures and Equipment

5.3.1 Shell Plating

Sub-paragraph -2 has been amended as follows.

2 The thickness of shell plating in the ice belt is not to be less than that obtained from the following formula according to the type of framing.

For the transverse framing: $667s\sqrt{\dfrac{f_1 p_{PL}}{\sigma_y}} + t_c \quad (mm)$

For the longitudinal framing: $667s\sqrt{\dfrac{p_{PL}}{f_2 \sigma_y}} + t_c \quad (mm)$

where

s : Frame spacing (m)

p_{PL} : $0.75p$ (MPa)
p : As specified in **5.2.1-1**
f_1 : As given in the following formula. Where, however, f_1 is greater than 1.0, f_1 is to be taken as 1.0.

$$1.3 - \frac{4.2}{(h/s + 1.8)^2}$$

f_2 : As given in the following formula depending on the value of h/s

where $h/s < 1.0$: $0.6 + \frac{0.4}{h/s}$

where $1.0 \le h/s < 1.8$: $1.4 - 0.4\,(h/s)$

h : As specified in **5.2.1-2**

σ_y : Yield stress of the materials (N/mm^2)~~: For mild steel σ_y is to be taken as 235 N/mm^2~~ , for which the following values are to be used
235 N/mm^2 for normal-strength hull structural steel
315 N/mm^2 for high-strength hull structural steel
However, if steels with different yield stresses than those given above are used, the value is to be at the discretion of the Society.

t_c :2 mm: If special surface coating, by experience shown capable to withstand the abrasion of ice, is applied and maintained, lower values may be approved.

Section 5.4 has been amended as follows.

5.4 ~~Propulsion Systems~~ Fundamental Requirements of Machinery

5.4.1 Materials

1 Materials for Machinery Parts exposed to Seawater

Materials exposed to seawater, such as propeller blades, propeller hub and blade bolts are to have an elongation of not less than 15% for the $U14A$ test specimens given in **Part K**. Materials other than bronze and austenitic steel are to have an average impact energy value of 20 J at -10 °C for the $U4$ test specimens given in **Part K**.

2 Materials for Machinery Parts exposed to Seawater Temperatures

Materials exposed to seawater temperatures are to be of steel or other ductile material approved by the Society. The materials are to have an average impact energy value of 20 J at -10 °C for the U4 test specimens given in **Part K**.

5.4.~~1~~2 Engine Output

1 The engine output (H) is not to be less than the greater of two outputs determined by the following formula for the maximum draught amidships referred to as the $UIWL$ and the minimum draught referred to as the $LIWL$, and in no case less than 1,000 kW for ice class ships with IA, IB, IC and ID, and not less than 2,800 kW for ice class ships with IA *Super*.

$$H = K_e \frac{(R_{CH}/1000)^{3/2}}{D_P}$$

H : Engine output (kW)
K_e : Constant given in **Table I5.11**
D_p : Diameter (m) of the propeller

R_{CH} : The resistance (N) of the ship in a channel with brash ice and a consolidated layer

$$R_{CH} = C_1 + C_2 + C_3 C_\mu (H_F + H_M)^2 (B + C_\psi H_F) + C_4 L_{PAR} H_F^2 + C_5 (LT / B^2)^3 (A_{wf} / L)$$

L : Length (m) of the ship between the perpendiculars on the *UIWL*

B : Maximum breadth (m) of the ship on the *UIWL*

T : Actual ice class draughts (m) of the ship, in general being a draught amidships of length L_f corresponding to the *UIWL* according to **1.2.4-1** and a draught amidships of length L_f corresponding to the *LIWL* according to **1.2.4-2**.

In any case, $(LT / B^2)^3$ is not to be taken as less than 5 and not to be taken as more than 20.

L_{PAR} : Length (m) of the parallel midship body, measured horizontally between the fore and aft ends of the flat side on the waterline at the actual ice class draught, see **Fig. I5.4**

L_{BOW} : Length (m) of the bow, measured horizontally between the fore end of the flat side on the waterline at the actual ice class draught and the fore perpendicular at the *UIWL*, see **Fig. I5.4.**

A_{wf} : Area (m^2) of the waterline of the bow at the actual ice class draught, see **Fig. I5.4.**

$\psi = \arctan(\tan \varphi_2 / \sin \alpha)$ (deg)

φ_1, φ_2, α : The angle (deg) between the ship and the water plane at the actual ice class draught, see **Fig. I5.4**. ~~Where the value of φ_1 and φ_2 is greater than 90 *degrees*, 90 *degrees* is to be used in the calculations.~~ <u>If the ship has a bulbous bow then φ_1 is taken as 90 *degrees*.</u>

C_1 and C_2 : Coefficient taken into account a consolidated upper layer of the brash ice and are to be taken as the followings.

(1) For I*A Super* ice class ships

$$C_1 = f_1 B L_{PAR} / (2T / B + 1) + (1 + 0.021\varphi_1)(f_2 B + f_3 L_{BOW} + f_4 B L_{BOW})$$

$$C_2 = (1 + 0.063\varphi_1)(g_1 + g_2 B) + g_3 (1 + 1.2T / B) B^2 / \sqrt{L}$$

(2) For I*A*, I*B*, I*C* and I*D* ice class ships

$C_1 = 0$

$C_2 = 0$

C_3, C_4 and C_5 : Value given in **Table I5.12**

C_μ : Value given by the following formula, but in no case less than 0.45

$$C_\mu = 0.15 \cos \varphi_2 + \sin \psi \sin \alpha$$

C_ψ : Value given by the following formula, but taken as 0 where $\psi \le 45°$

$$C_\psi = 0.047\psi - 2.115$$

f_1, f_2, f_3, f_4, g_1, g_2 and g_3 : Value given in **Table I5.12**

H_M : Thickness (m) of the brash ice in a channel as given by the followings.

(1) For I*A Super* and I*A* ice class ships $H_M = 1.0$

(2) For I*B* ice class ships $H_M = 0.8$

(3) For I*C* ice class ships $H_M = 0.6$

(4) For I*D* ice class ships $H_M = 0.5$

H_F : Thickness (m) of the brash ice layer displaced by the bow as given by the following formula.

$$H_F = 0.26 + (H_M B)^{0.5}$$

Fig. I5.4Dimensions

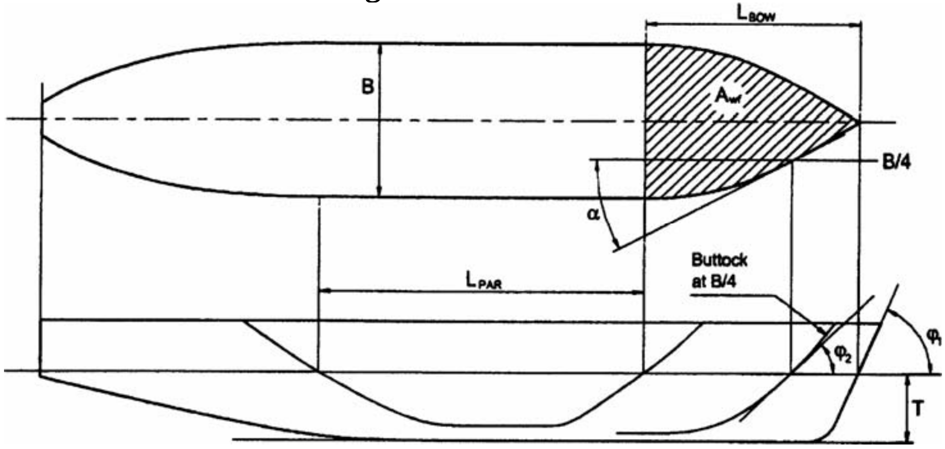


Table I5.11 Value of Constant K_e

Propeller type or machinery	CPP or Electric or Hydraulic propulsion machinery	FPP
1 Propeller	2.03	2.26
2 Propellers	1.44	1.60
3 Propellers	1.18	1.31

Table I5.12 Value of $f_1, f_2, f_3, f_4, g_1, g_2, g_3, C_3, C_4, C_5$

f_1:	23.0 (N/m^2)	g_1:	1,530 (N)	C_3:	845 (N/m^3)
f_2:	45.8 (N/m)	g_2:	170 (N/m)	C_4:	42 (N/m^3)
f_3:	14.7 (N/m)	g_3:	400 ($N/m^{1.5}$)	C_5:	825 (N/m)
f_4:	29.0 (N/m^2)				

2 Special Requirements for Existing Ships

For I*A Super* and I*A* ice class ships which are at beginning stage of construction before 1 September 2003, the engine output (H) is to comply with the requirements specified in **-1** above or equivalent requirements by ~~1 January 2005 or~~ 1 January in the year when 20 *years* have elapsed since the year the ship was delivered~~, whichever comes the latest~~. When, for an existing ship, values for some of the hull form parameters required for the calculation method specified in **-1** above are difficult to obtain, the following alternative formulae may be used. The dimensions of the ship, defined below, are measured on the *UIWL* as defined in **1.2.4-1**.

$$H = K_e \frac{(R_{CH}/1000)^{3/2}}{D_P}$$

H : Engine output (kW)

K_e : Constant given in **Table I5.11**

D_P : Diameter of the propeller (m)

R_{CH} : The resistance of the ship in a channel with brash ice and a consolidated layer (N)

$$R_{CH} = C_1 + C_2 + C_3(H_F + H_M)^2(B + 0.658H_F) + C_4LH_F^2 + C_5(LT/B^2)^3(B/4)$$

L : Length (m) of the ship between the perpendiculars

B : Maximum breadth (m) of the ship

T : Actual ice class draught (m) of the ship

However, $(LT/B^2)^3$ is not to be taken as less than 5 and not to be taken as more than 20.

C_1 and C_2 : Coefficient taken into account a consolidated upper layer of the brash ice and are to be taken as the followings.

(1) For I*A Super* ice class ships and ice class ships with a bulbous bow

$$C_1 = f_1 BL/(2T/B+1) + 2.89(f_2 B + f_3 L + f_4 BL)$$

$$C_2 = 6.67(g_1 + g_2 B) + g_3(1+1.2T/B)B^2/\sqrt{L}$$

(2) For I*A Super* ice class ships and ice class ships without a bulbous bow

$$C_1 = f_1 BL/(2T/B+1) + 1.84(f_2 B + f_3 L + f_4 BL)$$

$$C_2 = 3.52(g_1 + g_2 B) + g_3(1+1.2T/B)B^2/\sqrt{L}$$

(3) For I*A* ice class ships

$C_1 = 0$ and $C_2 = 0$

$f_1, f_2, f_3, f_4, g_1, g_2, g_3, C_3, C_4$, and C_5 : Value given in **Table I5.13**

H_M : Thickness (m) of the brash ice in a channel as given by the followings.

$$H_M = 1.0$$

H_F : Thickness (m) of the brash ice layer displaced by the bow as given by the following formula.

$$H_F = 0.26 + (H_M B)^{0.5}$$

Table I5.13 Value of $f_1, f_2, f_3, f_4, g_1, g_2, g_3, C_3, C_4, C_5$

f_1:	10.3 (N/m^2)	g_1:	1,530 (N)	C_3:	845 (N/m^3)
f_2:	45.8 (N/m)	g_2:	170 (N/m)	C_4:	42 (N/m^3)
f_3:	2.94 (N/m)	g_3:	400 ($N/m^{1.5}$)	C_5:	825 (N/m)
f_4:	5.8 (N/m^2)				

3 For ships having features of which, there is ground to assume that they will improve the performance of the ship when navigation in ice or ships parameter values of which defined in **-1** above are beyond the range given in **Table I5.14**, an engine output less than that required in **-1** may be approved, provided that it gives a minimum speed of 5 *knots* in the following brash ice channels.

(1) For I*A Super* ice class ships: 1.0 *m* of the brash ice and a 0.1 *m* thick consolidated layer of ice

(2) For I*A* ice class ships: 1.0 *m* of the brash ice

(3) For I*B* ice class ships: 0.8 *m* of the brash ice

(4) For I*C* ice class ships: 0.6 *m* of the brash ice

(5) For I*D* ice class ships: 0.5 *m* of the brash ice

Table I5.14 The Range of Parameters

Parameter	Minimum	Maximum
α (deg)	15	55
φ_1 (deg)	25	90
φ_2 (deg)	10	90
L (m)	65.0	250.0
B (m)	11.0	40.0
T (m)	4.0	15.0
L_{BOW} / L	0.15	0.40
L_{PAR} / L	0.25	0.75
D_P / T	0.45	0.75
$A_{wf} / (LB)$	0.09	0.27

~~5.4.2 Ice Torque~~

~~**1** Dimensions of propellers, shafting and gearing are to be determined taking into account the impact when a propeller blade hits ice. The ensuing load is hereinafter called the ice torque.~~

~~**2** The ice torque (M) is to be less than the value determined by the following formula when the ice torque is used for the calculation of propeller in **5.4.3** and reduction gears in **5.4.5**:~~

$$\cancel{mD_p^2 \quad (kN\text{-}m)}$$

~~where:~~

~~D_p : Diameter of propeller (m)~~

~~m : Constant given in **Table I5.15**~~

~~**3** If the propeller is not fully submerged when the ship is in ballast condition, the ice torque for ice class ships with IA is to be used for ice class ships with IB, IC and ID.~~

~~**Table I5.15 Value of Constant m**~~

~~Ice Class~~	~~m~~
~~IA *Super*~~	~~21.09~~
~~IA~~	~~15.70~~
~~IB~~	~~13.05~~
~~IC~~	~~11.97~~
~~ID~~	~~11.97~~

~~5.4.3 Propellers~~

~~**1** As for the materials of the propellers, the elongation of the materials used is not to be less than 19% for $U14A$ test specimen specified in **Part K**, and absorbed energy for the Charpy impact test is not to be less than 21 J at -10°C for $U4$ test specimen specified in **Part K**.~~

~~**2** Width and thickness of the propeller at each blade section specified below are to be determined as follows, the blade thickness at $0.125D_P$ radius, however, is not to be less than the value determined by the formula in **7.2.1, Part D**.~~

~~(1) For solid propellers~~

~~at the radius $0.125D_P$:~~

$$\cancel{wt^2 = \frac{26490}{\sigma_b\left(0.65 + 0.7\,P/D_P\right)}\left(27.2\frac{H_S}{ZR} + 2.24M\right)}$$

~~at the radius $0.3D_P$:~~

$$wt^2 = \frac{9320}{\sigma_b\left(0.65+0.7P/D_P\right)}\left(27.2\frac{H_S}{ZR}+2.85M\right)$$

~~(2) For controllable pitch propellers~~

~~at the radius $0.175D_P$:~~

$$wt^2 = \frac{21090}{\sigma_b\left(0.65+0.7P/D_P\right)}\left(27.2\frac{H_S}{ZR}+2.34M\right)$$

~~at the radius $0.3D_P$:~~

$$wt^2 = \frac{9320}{\sigma_b\left(0.65+0.7P/D_P\right)}\left(27.2\frac{H_S}{ZR}+2.85M\right)$$

~~w : Length (cm) of the expanded cylindrical section of the blade, at the radius in question~~

~~t : The corresponding maximum blade thickness (cm)~~

~~p : Propeller pitch (m) at the radius in question. For controllable pitch propeller, 70% of the nominal pitch is to be used.~~

~~D_P : Diameter (m) of propeller~~

~~H_S : Shaft engine output (kW)~~

~~Z : Number of blades~~

~~R : Number of revolution (rpm) at the maximum continuous engine output of main engine~~

~~σ_b : Specified minimum tensile strength (N/mm^2) of the propeller blade material~~

~~**3** The blade tip thickness at the radius $0.5D_P$ is not less than the value determined by the following formula:~~

~~(1) I*A Super* ice class ships~~ $(20+2D_p)\sqrt{\frac{490}{\sigma_b}}$ ~~(mm)~~

~~(2) Ice class ships other than I*A Super*~~ $(15+2D_p)\sqrt{\frac{490}{\sigma_b}}$ ~~(mm)~~

~~where~~

~~D_p and σ_b : As specified in **-2**~~

~~**4** The blade thickness of other sections is to conform to a smooth curve connecting the section thickness as determined by the above **-2** and **-3**.~~

~~**5** The thickness of blade edges is to be less than 50% of the blade tip thickness determined by the above **-3** For solid propellers, the measured points are the position equal to 1.25 *times* the required blade tip thickness in the above **-3** from leading and following edges, respectively. For controllable pitch propellers, this applies only to the leading edge.~~

~~**6** The strength of mechanisms in the boss of a controllable pitch propeller is to be 1.5 *times* that of the blade, when a load is applied at the radius $0.45D_P$ in the weakest direction of the blade.~~

~~5.4.4 Shaftings~~

~~**1** The diameter of the propeller shaft at the stern tube bearing is not to be less than obtained from the following formula:~~

$$10.8\sqrt[3]{\frac{\sigma_b wt^2}{\sigma_y}}\ (mm)$$

~~where:~~

~~w : Actual length (cm) of the expanded section of the blade at the radius $0.125D_P$~~

~~t : Actual maximum blade thickness (cm) at the radius $0.125D_P$~~

~~σ_b : Specified minimum tensile strength (N/mm^2) of the propeller blade material~~

~~σ_y : Specified minimum yield point (N/mm^2) of the propeller shaft material~~

~~**2** If the shaft diameter of the propeller boss is greater than $0.25D_P$, the diameter of the propeller shaft at stern tube bearing is not to be less than that obtained from the following formula:~~

$$\cancel{11.5\sqrt[3]{\frac{\sigma_b w t^2}{\sigma_y}}\ (mm)}$$

~~where:~~

~~w : Actual length (cm) of expanded section of the blade at the radius $0.175D_P$~~

~~t : Actual maximum blade thickness (cm) at the radius $0.175D_P$~~

~~σ_b and σ_y : As specified in **-1**~~

~~**3** If the shaft diameter derived from the above **-1** or **-2** is less than the required diameter specified in **6.2.4, Part D**, the latter is to be used.~~

~~**4** For *IA Super* ice class ships, the diameters of intermediate shafts and thrust shafts in external bearings are not to be less than 1.1 *times* the required value, specified in **6.2.2** and **6.2.3, Part D**, respectively.~~

~~5.4.5 Reduction Gearing~~

~~**1** Where the reduction gearing is fitted between the main engine and the propeller shafting, the external load magnification coefficient K_1 specified in **5.3.3, Part D**, is to be substituted by the value determined by the following formula:~~

$$\cancel{\frac{1}{\frac{1}{K_1}+\frac{1}{1+J_1/J_h}\frac{M}{M_0}}}$$

~~where:~~

~~K_1 : Coefficient specified in **5.3.3, Part D**~~

~~M : Ice torque ($kN\text{-}m$) specified in **5.4.2.**~~

~~M_0 : Mean torque of the propeller shaft determined by the following formula.~~

$$\cancel{M_0 = 9.55 H_S / R\ (kN\text{-}m)}$$

~~H_S : Shaft engine output (kW)~~

~~R : Number of revolution (rpm) at the maximum continuous engine output of engine~~

~~J_1: Total mass moment of inertia of the output shaft of the reduction gearing, propeller and propulsion shafting, where including propeller with an additional mass of 30% for water.~~

~~J_h: Total mass moment of inertia the main engine, flywheel and reduction gearing except output shaft. Where the revolutions of the engine differ from those of the propeller, equivalent mass moment of inertia corrected by the gear ratio is to be used.~~

~~5.4.6 Starting Arrangements~~

~~**1** The capacity of the air reservoirs is to be sufficient to provide without reloading not less than 12 consecutive starts of the propulsion engines if this has to be reversed for going astern, or 6 consecutive starts if the propulsion engine do not have to be reversed for going astern.~~

~~**2** If the air reservoirs serve any other purposes than starting the propulsion engines, they are to have additional capacity sufficient for these purposes.~~

~~**3** The capacity of the air compressors are to be sufficient for charging the air reservoirs from atmospheric to full pressure in one hour. For *IA Super* ice class ships that required its propulsion engines to be reversed for going astern, the compressors are to be able to charge the air reservoirs in half an hour.~~

~~**5.4.7 Sea Inlet and Cooling Water Systems**~~

~~**1** The cooling water system is to be designed to ensure a supply of cooling water when navigating in ice.~~

~~**2** To satisfy the preceding **-1**, at least one cooling sea water inlet chest is to be arranged as follows. However, I*D* ice class ships may not comply with the requirements in **(2)**, **(3)** and **(5)**:~~

~~(1) The sea inlet is to be situated near the centre line of the ship and well aft if possible.~~

~~(2) As a guidance for design the volume of sea chest is to be about $1m^3$ for every $750kW$ engine output of the ship including the out put of auxiliary engines necessary for the ship's service.~~

~~(3) The sea chest is to be sufficiently high to allow ice to accumulate above the inlet pipe.~~

~~(4) A pipe for discharge cooling water, allowing full capacity discharge, is to be connected to sea chest.~~

~~(5) The area through grating holes is not to be less than 4 *times* the inlet pipe sectional area.~~

~~**3** Where more than two sea chests are arranged, requirements of the preceding **-2(2)** and **(3)** above may be suitably considered. In this case, these sea chests are to be arranged for alternating intake and discharge of cooling water, as well as the requirements in the preceding **(1)**, **(4)** and **(5)** are complied with.~~

~~**4** Heating coils may be installed in the upper part of the chest or chests.~~

5.4.~~8~~3 Rudders and Steering Arrangements

1 The rudder scantlings of rudder post, rudder stock, pintles, steering gear etc. are to comply with requirements in **Chapter 3** of this Part and **Chapter 15, Part D**. In this case, the maximum service speed of the ship to be used in these calculations is not to be taken less than that given in the **Table I5.1~~6~~5**.

2 For I*A Super* and I*A* ice class ships, the rudder stock and the upper edge of the rudder are to be protected against ice pressure by an ice knife or equivalent means.

3 For I*A Super* and I*A* ice class ships, the rudders and steering arrangements are to be designed as follows to endure the loads that work on the rudders by the ice when backing into an ice ridge.

(1) Relief valves for hydraulic pressure are to be effective.

(2) The components of the steering gear are to be dimensioned to stand the yield torque of the rudder stock.

(3) Where possible, rudder stoppers working on the blade or rudder stock are to be fitted.

Table I5.1~~6~~5 Minimum Speed

Class	Speed (*kt*)
I*A Super*	20
I*A*	18
I*B*	16
I*C*	14
I*D*	14

Section 5.5 has been added as follows.

5.5 Design Loads of Propulsion Units

5.5.1 General

1 In the design of the propeller, propulsion shafting system and power transmission system, the following are to be taken into account.

(1) Maximum backward blade force
(2) Maximum forward blade force
(3) Maximum blade spindle torque
(4) Maximum propeller ice torque
(5) Maximum propeller ice thrust
(6) Design torque on propulsion shafting system
(7) Maximum thrust on propulsion shafting system
(8) Blade failure load

2 The loads specified in **-1** above are to comply with the following:

(1) The ice loads cover open and ducted-type propellers situated at the stern of ships having controllable pitch or fixed pitch blades. Ice loads on bow propellers and pulling type propellers are to receive special consideration and ice loads due to ice impact on the bodies of azimuthing thrusters are not covered by this Chapter.
(2) The given loads in this chapter are expected, single occurrence, maximum values for the whole ships service life for normal operation conditions. The loads do not cover off-design operational conditions, for example when a stopped propeller is dragged through ice.
(3) The loads are total loads (unless otherwise stated) during interaction and are to be applied separately (unless otherwise stated) and are intended for component strength calculations only.

3 Design Loads of Propellers

(1) The loads given are intended for component strength calculations only and are total loads including ice-induced loads and hydrodynamic loads during propeller/ice interaction.
(2) The F_b and F_f specified in **5.5.2** and **5.5.3** originate from different propeller/ice interaction phenomena, and do not occur simultaneously. Hence, they are to be applied separately to one blade.
(3) If the propeller is not fully submerged when the ship is in the ballast condition, the propulsion system is to be designed according to Ice Class I*A* for Ice Classes I*B* and I*C*.

5.5.2 Maximum Backward Blade Force

1 The maximum backward blade force which bends a propeller blade backwards when a propeller mills an ice block while rotating ahead is to be given by the following formulae:

(1) For open propellers:

when $D \le D_{limit} = 0.85(H_{ice})^{1.4}$ (m)

$$F_b = 27\left(\frac{n}{60}D\right)^{0.7}\left(\frac{EAR}{Z}\right)^{0.3} D^2 \quad (kN)$$

when $D > D_{\mathrm{limit}} = 0.85(H_{ice})^{1.4}$ (m)

$$F_b = 23(H_{ice})^{1.4}\left(\frac{n}{60}D\right)^{0.7}\left(\frac{EAR}{Z}\right)^{0.3} D \quad (kN)$$

(2) For ducted propellers :

when $D \le D_{limit} = 4H_{ice}$ (m)

$$F_b = 9.5\left(\frac{n}{60}D\right)^{0.7}\left(\frac{EAR}{Z}\right)^{0.3} D^2 \quad (kN)$$

when $D > D_{limit} = 4H_{ice}$ (m)

$$F_b = 66(H_{ice})^{1.4}\left(\frac{n}{60}D\right)^{0.7}\left(\frac{EAR}{Z}\right)^{0.3} D^{0.6} \quad (kN)$$

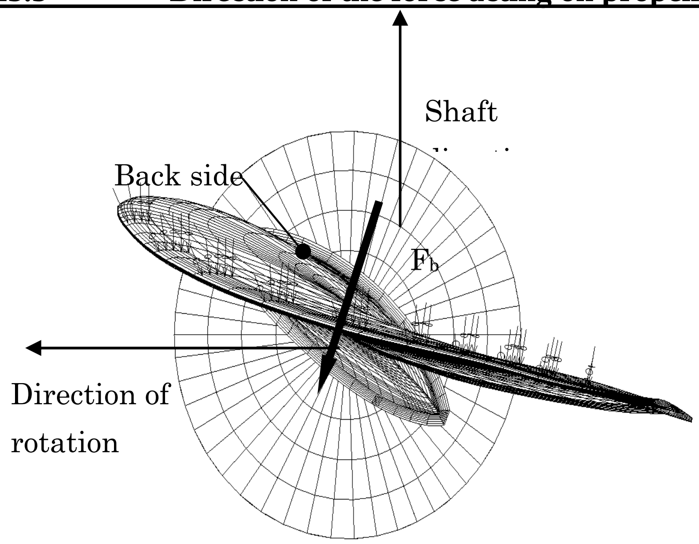
where

F_b: Maximum backward blade force for the ship's service life (kN)
Direction of the backward blade force resultant taken perpendicular to chord line at radius $0.7R$. (*See* Fig. **I5.5**)
H_{ice}: Ice thickness (m) specified in **Table I5.16**.
D : Propeller diameter (m)
EAR : Expanded blade area ratio
d : external diameter of propeller hub (at propeller plane) (m)
Z : number of propeller blades
n : Nominal rotational propeller speed (rpm) at maximum continuous revolutions in free running condition for controllable pitch propellers and 85% of the nominal rotational propeller speed at maximum continuous revolutions in free running condition for fixed pitch propellers

Table I5.16 The thickness of the ice block H_{ice}

	I*A Super*	I*A*	I*B*	I*C*
Thickness of the design maximum ice block entering the propeller H_{ice} (m)	1.75	1.5	1.2	1.0

Fig.I5.5 Direction of the force acting on propeller blades



2 The maximum backward blade force F_b is to be applied as a uniform pressure distribution to an area of the blade for the following load cases:

(1) In the case of open propellers:

(a) The F_b specified in **-1(1)** above is to be applied to an area from $0.6R$ to the tip and from the blade leading edge to a value 0.2 of the chord length. (See Load Case 1 in **Table I4.2**)

(b) A load equal to 50% of the F_b specified in **-1(1)** above is to be applied to the propeller tip area outside of $0.9R$. (See Load Case 2 in **Table I4.2**)

(c) In the case of reversible propellers, a load equal to 60 % of the F_b specified in **-1(1)** above is to be applied to an area from 0.6R to the tip and from the blade trailing edge to a value 0.2 of the chord length. (See load case 5 in **Table I4.2**)

(2) In the case of ducted propellers:

(a) The F_b specified in **-1(2)** above is to be applied to an area from 0.6R to the tip and from the blade leading edge to a value 0.2 of the chord length. (See Load Case 1 in **Table I4.3**)

(b) In the case of reversible propellers, a load equal to 60 % of the F_b specified in **-1(2)** above is to be applied to an area from 0.6R to the tip and from the blade trailing edge to a value 0.2 of the chord length. (See load case 5 in **Table I4.3**)

5.5.3 Maximum Forward Blade Force

1 The maximum forward blade force which bends a propeller blade forwards when a propeller interacts with an ice block while rotating ahead is to be given by the following formulae:

(1) For open propellers:

when $D \le D_{limit} = \dfrac{2}{(1-d/D)} H_{ice}$ (m)

$$F_f = 250\left(\frac{EAR}{Z}\right)D^2 \ (kN)$$

when $D > D_{limit} = \dfrac{2}{(1-d/D)} H_{ice}$ (m)

$$F_f = 500 H_{ice}\left(\frac{EAR}{Z}\right)\left(\frac{1}{1-d/D}\right)D \ (kN)$$

(2) For ducted propellers:

when $D \le D_{limit} = \dfrac{2}{(1-d/D)} H_{ice}$ (m)

$$F_f = 250\left(\frac{EAR}{Z}\right)D^2 \ (kN)$$

when $D > D_{limit} = \dfrac{2}{(1-d/D)} H_{ice}$ (m)

$$F_f = 500 H_{ice}\left(\frac{EAR}{Z}\right)\left(\frac{1}{1-d/D}\right)D \ (kN)$$

where

F_f: The maximum forward blade force for the ship's service life (kN)
Direction of the forward blade force resultant taken perpendicular to chord line at radius 0.7R.

H_{ice}, D, EAR, d and Z : As specified in **5.5.2**

2 The maximum forward blade force F_f is to be applied as a uniform pressure distribution to an area of the blade for the following load cases:

(1) In the case of open propellers:

(a) The F_f specified in **-1(1)** above is to be applied to an area from 0.6R to the tip and from the blade leading edge to a value 0.2 of the chord length. (See Load Case 3 in **Table I4.2**)

(b) A load equal to 50 % of the F_f specified in **-1(1)** above is to be applied to the propeller tip area outside of $0.9R$. (See Load Case 4 in **Table I4.2**)

(c) In the case of reversible propellers, a load equal to 60 % of the F_f specified in **-1(1)** above is to be applied to an area from $0.6R$ to the tip and from the blade trailing edge to a value 0.2 of the chord length. (See Load Case 5 in **Table I4.2**)

(2) In the case of ducted propellers:

(a) The F_f specified in **-1(2)** above is to be applied to an area from $0.6R$ to the tip and from the blade leading edge to a value 0.5 of the chord length. (See Load Case 3 in **Table I4.3**)

(b) In the case of reversible propellers, a load equal to 60 % of the F_f specified in **-1(2)** above is to be applied to an area from $0.6R$ to the tip and from the blade trailing edge to a value 0.2 of the chord length. (See Load Case 5 in **Table I4.3**)

5.5.4 Maximum Blade Spindle Torque

The spindle torque around the spindle axis of the blade fitting is to be calculated both for the load cases specified in **5.5.2** and **5.5.3** for F_b and F_f. In cases where these spindle torque values are less than the default value obtained from the following formula, the default value is to be used.

$$Q_{s\max} = 0.25 F C_{0.7} \quad (kNm)$$

where

$C_{0.7}$: Length (m) of the blade chord at radius $0.7R$

F: Either F_b determined in **5.5.2-1** or F_f determined in **5.5.3-1,** whichever has the greater absolute value (kN).

5.5.5 Frequent Distributions for Propellers Blade Loads

1 A Weibull-type distribution (probability that F_{ice} exceeds $(F_{ice})_{max}$), as given in Figure **I5.6**, is to be used for the fatigue design of blades.

$$P\left(\frac{F_{ice}}{(F_{ice})_{max}} \geq \frac{F}{(F_{ice})_{max}}\right) = e^{\left(-\left(\frac{F}{(F_{ice})_{max}}\right)^{k} \ln(N_{ice})\right)}$$

where

F_{ice} : Random variable for ice loads (kN) on the blade, and meet the requirements $0 \leq F_{ice} \leq (F_{ice})_{max}$

$(F_{ice})_{max}$: Maximum ice load for the ship's service life (kN)

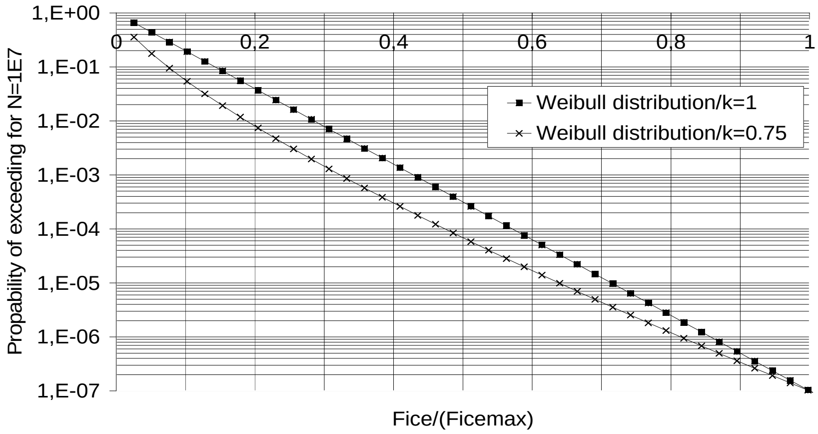
k : Shape parameter for Weibull-type distribution The following definitions apply:

Open propeller: $k = 0.75$

Ducted propeller: $k = 1.0$

N_{ice} : Total number of ice loads on a propeller blade for the ship's service life

Fig.I5.6 The Weibull-type distribution (probability that F_{ice} exceeds $(F_{ice})_{max}$) that is used for fatigue designs



2 Number of ice loads

(1) The number of load cycles per propeller blade in the load spectrum shall be determined according to the formula:

$$N_{ice} = k_1 k_2 k_3 k_4 N_{class} \frac{n}{60}$$

where

N_{class} : Reference number of loads for ice classes, as specified in **Table I5.17**

k_1 : Propeller location factor, as specified in **Table I5.18**

k_2 : Propeller type factor, as specified in **Table I5.19**

k_3 : Propulsion type factor, as specified in **Table I5.20**

Table I5.17 Reference number of loads for ice classes N_{class}

Class	I*A Super*	I*A*	I*B*	I*C*
impacts in life / n	$9 \cdot 10^6$	$6 \cdot 10^6$	$3.4 \cdot 10^6$	$2.1 \cdot 10^6$

Table I5.18 Propeller location factor k_1

factor	Centre propeller	Wing propeller
k_1	1	1.35

Table I5.19 Propeller type factor k_2

factor	open propeller	ducted propeller
k_2	1	1.1

Table I5.20 Propulsion type factor k_3

factor	fixed	azimuthing
k_3	1	1.2

k_4 : The submersion factor k_4 is determined from the equation.

$$k_4 = \begin{cases} 0.8 - f & : f < 0 \\ 0.8 - 0.4f & : 0 \le f \le 1 \\ 0.6 - 0.2f & : 1 < f \le 2.5 \\ 0.1 & : f > 2.5 \end{cases}$$

where

$$f = \frac{h_0 - H_{ice}}{D/2} - 1$$

h_0 : The depth of the propeller centreline at the lower ice waterline (*LIWL*) of the ship (m)

H_{ice} and D : As specified in **5.5.2**

(2) In the case of components that are subject to loads resulting from propeller/ice interaction with all of the propeller blades, the number of load cycles (N_{ice}) is to be multiplied by the number of propeller blades (Z).

5.5.6 Maximum Propeller Ice Thrust

The maximum propeller ice thrust applied to a propeller is to be given by the following formulae:

(1) Maximum backward propeller ice thrust

$T_b = 1.1\ F_b\ (kN)$

(2) Maximum forward propeller ice thrust

$T_f = 1.1\ F_f\ (kN)$

where

F_b : Maximum backward blade force for the ship's service life, as specified in **5.5.2-1**

F_f : Maximum forward blade force for the ship's service life, as specified in **5.5.3-1**

T_b : Maximum backward propeller ice thrust (kN)

T_f : Maximum forward propeller ice thrus (kN)

5.5.7 Design Thrust along Propulsion Shaft Lines

The design thrust along the propeller shaft line is to be given by the following formulae:

(1) Maximum shaft thrust forwards:

$T_r = T + 2.2T_f$ (kN)

(2) Maximum shaft thrust backwards:

$T_r = 1.5T_b$ (kN)

where:

T_b and T_f: Maximum propeller ice thrust (kN) determined in **5.5.6**

T: Propeller bollard thrust (kN). If not known, T is to be taken as specified in **Table I5.21**

Table I5.21 Value of *T*

Propeller type	T
Controllable pitch propellers (open)	$1.25\ T_n$
Controllable pitch propellers (ducted)	$1.1\ T_n$
Fixed pitch propellers driven by turbine or electric motor	T_n
Fixed pitch propellers driven by diesel engine (open)	$0.85\ T_n$
Fixed pitch propellers driven by diesel engine (ducted)	$0.75\ T_n$

Notes:

T_n : Nominal propeller thrust (kN) at maximum continuous revolutions in free running open water conditions

5.5.8 Maximum Propeller Ice Torque

The maximum propeller ice torque applied to the propeller is to be given by the following formulae:

(1) For open propellers:

when $D \le D_{limit} = 1.8H_{ice}$ (m)

$$Q_{max} = 10.9\left(1-\frac{d}{D}\right)\left(\frac{P_{0.7}}{D}\right)^{0.16}\left(\frac{n}{60}D\right)^{0.17} D^3 \ (kNm)$$

when $D > D_{limit} = 1.8H_{ice}$ (m)

$$Q_{max} = 20.7\left(H_{ice}\right)^{1.1}\left(1-\frac{d}{D}\right)\left(\frac{P_{0.7}}{D}\right)^{0.16}\left(\frac{n}{60}D\right)^{0.17} D^{1.9} \ (kNm)$$

(2) For ducted propellers:

when $D \le D_{limit} = 1.8H_{ice}$ (m)

$$Q_{max} = 7.7\left(1-\frac{d}{D}\right)\left(\frac{P_{0.7}}{D}\right)^{0.16}\left(\frac{n}{60}D\right)^{0.17} D^3 \ (kNm)$$

when $D > D_{limit} = 1.8H_{ice}$ (m)

$$Q_{max} = 14.6\left(H_{ice}\right)^{1.1}\left(1-\frac{d}{D}\right)\left(\frac{P_{0.7}}{D}\right)^{0.16}\left(\frac{n}{60}D\right)^{0.17} D^{1.9} \ (kNm)$$

where:

H_{ice}, D and d: As specified in **5.5.2**

$P_{0.7}$: Propeller pitch (m) at $0.7R$
In the case of controllable pitch propellers, $P_{0.7}$ is to correspond to maximum continuous revolutions at the bollard condition. If not known, $P_{0.7}$ is to be taken as 0.7 $P_{0.7n}$, where $P_{0.7n}$ is the propeller pitch at maximum continuous revolutions at a free running condition.

n : Rotational propeller speed (rpm) at the bollard condition
If not known, n is to be taken as specified in **Table I5.22**.

Table I5.22 Rotational propeller speed *n*

Propeller type	n
Controllable pitch propellers	n_n
Fixed pitch propellers driven by turbine or electric motor	n_n
Fixed pitch propellers driven by diesel engine	$0.85n_n$

Notes:

n_n: Nominal rotational speed (rpm) at maximum continuous revolutions at the free running condition

5.5.9 Design Torque on Propulsion Shafting System

1 The propeller ice excitation torque for shaft line transient torsional vibration dynamic analysis is to comply with the following requirements:

(1) The excitation torque is to be described by a sequence of blade impacts which are of half sine shape and occur at the blade. The total ice torque is to be obtained by summing the torques of single ice blade ice impacts taking into account the phase shift. The single ice blade impact is given by the following formulae: (See **Fig. I5.7**)

(a) when $0 \le \phi \le \alpha_i$ (deg)

$$Q(\phi) = C_q Q_{max} \sin(\phi(180/\alpha_i))$$

(b) when $\alpha_i \le \phi \le 360$ (deg)

$$Q(\phi) = 0$$

where

Q_{max}: Maximum torque on the propeller as specified in **5.5.8**

C_q : As specified in **Table I5.23**

a_i : Duration of propeller blade/ice interaction expressed in rotation angle as specified in **Table I5.23**

Table I5.23 Values of C_q and a_i

Torque excitation	Propeller-ice interaction	C_q	a_i
Case 1	Single ice block	0.75	90
Case 2	Single ice block	1.0	135
Case 3	Two ice blocks (phase shift 360/2/Z deg.)	0.5	45

Note:

Total ice torque is obtained by summing the torque of single blades, taking into account the phase shift 360/Z deg.. In addition, at the beginning and at the end of the milling sequence, a linear ramp functions for 270 degrees of rotation angle is to be used.

(2) The number of propeller revolutions and the number of impacts during the milling sequence are to be given by the following formulae. For bow propellers, the number of propeller revolutions and the number of impacts during the milling sequence are subject to special consideration.

(a) The number of propeller revolutions:

$$N_Q = 2H_{ice}$$

(b) The number of impacts:

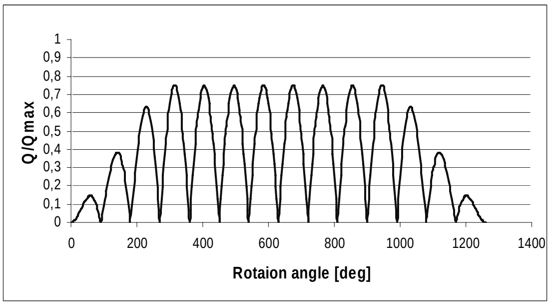
$$ZN_Q$$

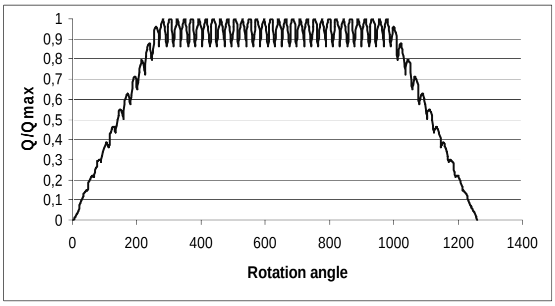
Where

H_{ice} : As specified in **Table I5.16**

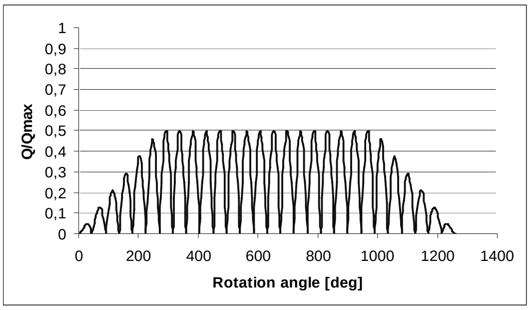
Z : Number of propeller blades

Fig.I5.7 Example of the shape of the propeller ice torque excitation (Four bladed propeller)





(a) Case 1 Single blade impact(α_i=90°) (b) Case 2 Single blade impact(α_i=135°)



(c) Case 3 Double blade impact（α_i=45°）

2 Design torque along propeller shaft line

(1) If there is not a predominant torsional resonance within the designed operating rotational speed range extended 20% above the maximum and 20% below the minimum operating speeds, the following estimation of the maximum torque can be used:

$$Q_r = Q_{emax} + Q_{max}\frac{I}{I_t} \quad (kNm)$$

Q_{emax}: maximum engine torque（kNm）

If the maximum torque, Q_{emax}, is not known, it is to be taken as specified in **Table I5.24**

I : equivalent mass moment of inertia of all parts on the engine side of the component under consideration（kgm^2）

I_t : equivalent mass moment of inertia of the whole propulsion system（kgm^2）

Table I5.24 Maximum engine torque Q_{emax}

Propeller type	Q_{emax}
Propellers driven by electric motor	Q_{motor}
CP propellers not driven by electric motor	Q_n
FP propellers driven by turbine	Q_n
FP propellers driven by diesel engine	$0.75\ Q_n$

Notes:

Q_{motor} : Electric motor peak torque（kNm）

Q_n : Nominal torque at MCR in free running condition（kNm）

Q_r : Maximum response torque along the propeller shaft line（kNm）

(2) If there is a first blade order torsional resonance within the designed operating rotational speed range extended 20 % above the maximum and 20 % below the minimum operating speeds, the design torque (Q_r) of the shaft component is to be determined by means of torsional vibration analysis of the propulsion line.

5.5.10 Blade Failure Loads

1 The blade failure load is to be given by the following formula:

$$F_{ex} = \frac{300ct^2\sigma_{ref}}{0.8D - 2r} \quad (kN)$$

where

σ_{ref} : The reference stress is to be given by the following formula:

$$\sigma_{ref} = 0.6\sigma_{0.2} + 0.4\sigma_u \quad (MPa)$$

where

σ_u : Tensile stress of blade material (MPa)

$\sigma_{0.2}$: Yield stress or 0.2 % proof strength of blade material (MPa)

c : Chord length of blade section (m)

F_{ex} : ultimate blade load resulting from blade loss through plastic bending (kN)

r : blade section radius (m)

t : Maximum blade section thickness (m)

2 The force specified in **-1** above is to be acting at 0.8R in the weakest direction of the blade and at a spindle arm of 2/3 the distance of the axis of blade rotation of the leading or trailing edge, whichever is greater.

Section 5.6 has been added as follows.

5.6 Design of Propellers and Propulsion Shafting Systems

5.6.1 General

With respect to the design of the propeller and the propulsion shafting system, the following are to be taken into account:

(1) Propeller and propulsion shafting systems are to have sufficient strength for the loads specified in **5.5**.

(2) The blade failure load given in **5.5.10** is not to damage the propulsion shafting system other than the propeller blade itself.

(3) Propeller and propulsion shafting systems are to have sufficient fatigue strength.

5.6.2 Propeller Blade Stresses

1 Propeller blade stresses are to be calculated for the design loads given in **5.5.2** and **5.5.3** using Finite Element Analysis.

In the case of a relative radius r/R<0.5, the blade stresses for all propellers at their root areas may be calculated by the formula given below. Root area dimensions based on this formula can be accepted even if FEM analysis shows greater stresses at the root area.

$$\sigma_{st} = C_1 \frac{M_{BL}}{100ct^2} \quad (MPa)$$

where

C_1 : $\dfrac{\text{stress obtained with FEM analysis result}}{\text{stress obtained with beam equation}}$

If the actual value is not available, C_1 should be taken as 1.6.

where

M_{BL}: Blade bending moment (kNm), in the case of a relative radius r/R<0.5, the following:

$M_{BL} = (0.75 - r/R)RF$

F: Maximum of F_b and F_f, whichever is greater.

2 The calculated blade stress σ_{st} specified in **-1** above is to comply with the following:

$$\frac{\sigma_{ref2}}{\sigma_{st}} \geq 1.5$$

where

σ_{st}: Maximum stress resulting from F_b or F_f (MPa)

σ_u: Tensile stress of blade material (MPa)

σ_{ref2}: Reference stress (MPa), whichever is less

$\sigma_{ref2} = 0.7\sigma_u$,or $\sigma_{ref2} = 0.6\sigma_{0.2}+0.4\sigma_u$

3 Fatigue design of propeller blades

(1) The fatigue design of a propeller blade is based on the estimated load distribution for the service life of the ship and the S-N curve for the blade material. An equivalent stress that produces the same fatigue damage as the expected load distribution is to be calculated and the acceptability criterion for fatigue is to be fulfilled as given in this section. The equivalent stress is normalized for 100 million cycles. If the following criterion is fulfilled, the fatigue calculations specified in this section are not required.

$$\sigma_{\exp} \geq B_1 \sigma_{ref2}{}^{B_2} \log(N_{ice})^{B_3}$$

where

The coefficients B_1, B_2 and B_3 are as given in the **Table I5.25**.

Table I5.25 The coefficients B_1, B_2 and B_3

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

(2) For the calculation of equivalent stress, two types of S-N curves are to be used.

(a) Two-slope S-N curve (slopes 4.5 and 10), see **Fig. I5.8**.

(b) One-slope S-N curve(the slope can be chosen), see **Fig. I5.9**.

(3) The type of the S-N curve shall be selected to correspond to the material properties of the blade. If the S-N curve is not known, a two-slope S-N curve is to be used.

Fig.I5.8 Two-slope S-N curve

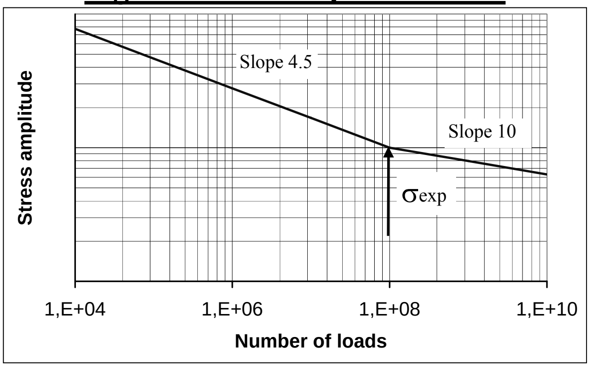
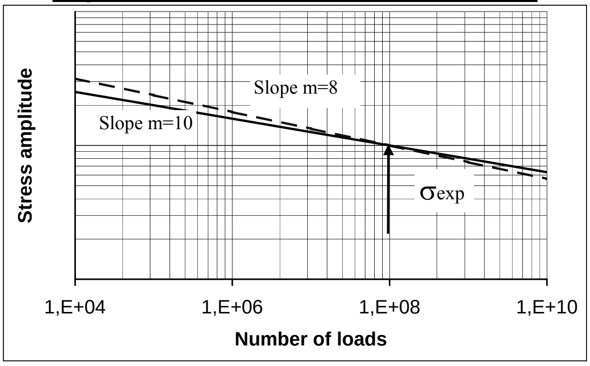


Fig.I5.9 Constant-slope S-N curve



(4) The equivalent fatigue stress for 100 million stress cycles which produces the same fatigue damage as the load distribution is:

$$\sigma_{fat} = \rho(\sigma_{ice})_{max}$$

where

ρ: Depending on the applicable S-N curve, ρ is to be given by either **(5)** or **(6)**.

$$(\sigma_{ice})_{max} = 0.5\left((\sigma_{ice})_{fmax} - (\sigma_{ice})_{bmax}\right)$$

$(\sigma_{ice})_{max}$: The mean value of the principal stress amplitudes resulting from forward and backward blade forces at the location being studied.

$(\sigma_{ice})_{fmax}$: The principal stress resulting from forward load

$(\sigma_{ice})_{bmax}$: The principal stress resulting from backward load

(5) The calculation of the parameter ρ for a two-slope S-N curve is as follows:

Parameter ρ relates the maximum ice load to the distribution of ice loads according to the following regression formulae:

$$\rho = C_1(\sigma_{ice})_{max}^{\ \ C2}\,\sigma_{fl}^{\ C3}\,\lg(N_{ice})^{C4}$$

where

$$\sigma_{fl} = \gamma_{\varepsilon}\gamma_{v}\gamma_{m}\sigma_{\exp}$$

σ_{fl} : Characteristic fatigue strength for blade material (*MPa*)

γ_{ε} : The reduction factor for scatter and test specimen size effect

γ_{v} : The reduction factor for variable amplitude loading

γ_{m} : The reduction factor for mean stress

$\sigma_{\exp}$: The mean fatigue strength of the blade material at 10^8 cycles to failure in seawater (*MPa*)

The following values are to be used as reduction factors if actual values are not available: $\gamma_{\varepsilon} = 0.67$, $\gamma_{v} = 0.75$, $\gamma_{m} = 0.75$

The coefficients C_1, C_2, C_3, and C_4 are given in **Table I5.26**.

Table I5.26 The coefficients C_1, C_2, C_3 and C_4

Coefficients	Open propeller	Ducted propeller
C_1	0.000711	0.000509
C_2	0.0645	0.0533
C_3	-0.0565	-0.0459
C_4	2.220	2.584

(6) The calculation of the parameter for a constant-slope S-N curve

In the case of materials with a constant-slope S-N curve - see **Fig. I5.9** – the ρ factor is to be calculated using the following formula:

$$\rho = \left(G \frac{N_{ice}}{N_R} \right)^{1/m} \left(\ln(N_{ice}) \right)^{-1/k}$$

where

k is the shape parameter of the Weibull distribution, it is as follows:

(a) $k = 1.0$ for ducted propellers

(b) $k = 0.75$ for open propellers

N_R: The reference number of load cycles ($= 10^8$)

m: slope for S-N curve in log/log scale

G: Values for the parameter G are given in **Table I5.27**. Linear interpolation may be used to calculate the G value for m/k ratios other than those given in **Table I5.27**.

Table I5.27 Value for the *G* parameter for different *m/k* ratios

m/k	*G*	*m/k*	*G*	*m/k*	*G*
3	6	5.5	287.9	8	40320
3.5	11.6	6	720	8.5	119292
4	24	6.5	1871	9	362880
4.5	52.3	7	5040	9.5	1.133E6
5	120	7.5	14034	10	3.623E6

4 Acceptability criterion for fatigue

The equivalent fatigue stress at all locations on a blade has to fulfill the following acceptability criterion:

$$\frac{\sigma_{fl}}{\sigma_{fat}} \geq 1.5$$

5.6.3 Propeller bossing and CP mechanism

1 The blade bolts, the CP mechanism, the propeller boss, and the fitting of the propeller to the propeller shaft are to be designed to withstand maximum and fatigue design loads, as defined in **5.5**. The safety factor is as follows.

(1) The safety factor against yielding is to be greater than 1.3

(2) The safety factor against fatigue is to be greater than 1.5

2 The safety factor for loads resulting from loss of a propeller blade through plastic bending as defined in **5.5.10** is to be greater than 1.0 against yielding.

5.6.4 Propulsion shaft line

1 The shafts and shafting components, such as the thrust and stern tube bearings, couplings, flanges and sealings, shall be designed to withstand the propeller/ice interaction axial, bending and torsion loads. The safety factor is to be at least 1.3.

2 The ultimate load resulting from total blade failure as defined in Section **5.5.10** is not to cause yielding in shafts and shaft components. The loading is to consist of the combined axial, bending, and torsion loads, wherever this is significant. The minimum safety factor against yielding is to be 1.0 for bending and torsional stresses.

5.6.5 Azimuthing Main Propulsors

With respect to the design of azimuthing main propulsors, the following are to be taken into account in addition to the requirements specified in **5.6.1**:

(1) Loading cases which are extraordinary for propulsion units are to be taken into account. The estimation of loading cases is to reflect the operational realities of the ship and the thrusters.
(2) The steering mechanism, the fitting of the unit and body of the thruster are to be designed to withstand the loss of a blade without damage.
(3) The plastic bending of a blade is to be considered in the propeller blade position, which causes the maximum load on the considered component.
(4) Azimuth thrusters are to be designed for the estimated loads specified in **3.5.10**.
(5) The thickness of an ice sheet is to be taken as the thickness of the maximum ice block entering the propeller, as defined in **Table I5.16**

5.6.6 Vibrations

The propulsion system shall be designed in such a way that the complete dynamic system is free from dominant torsional, axial, and bending resonances within the designed running speed range, extended by 20 % above and below the maximum and minimum operating rotational speeds. If this condition cannot be fulfilled, a detailed vibration analysis has to be carried out in order to determine that the acceptable strength of the components can be achieved.

Section 5.7 has been added as follows.

5.7 Alternative design

5.7.1 Alternative design

As an alternative to **5.5** and **5.6**, a comprehensive design study may be carried out.

Section 5.8 has been added as follows.

5.8 Miscellaneous Machinery Requirements

5.8.1 Starting Arrangements

1 The capacity of air reservoirs is to be sufficient to provide, without reloading, not less than 12 consecutive starts of the propulsion engines if these have to be reversed for going astern, or 6 consecutive starts if such propulsion engines do not have to be reversed for going astern.

2 If the air reservoirs serve any other purposes than starting propulsion engines, they are to have additional capacity sufficient for such purposes.

3 The capacity of air compressors is to be sufficient for charging the air reservoirs from atmospheric to full pressure in one hour. In the case of I*A Super* ice class ships that require their propulsion engines to be reversed for going astern, the compressors are to be able to charge the air reservoirs in half an hour.

5.8.2 Sea Inlet and Cooling Water Systems

1 Cooling water systems are to be designed to ensure a supply of cooling water when navigating in ice.

2 To satisfy **-1** above, at least one cooling sea water inlet chest is to be arranged as follows. However, I*D* ice class ships may not comply with the requirements given in **(2)**, **(3)** and **(5)**:

(1) Sea inlets are to be situated near the centre line of ships and well aft if possible.

(2) As guidance for design, the volume of sea chests is to be about $1m^3$ for every $750kW$ of engine output of ships including the output of auxiliary engines necessary for the ship service.

(3) Sea chests are to be sufficiently high to allow ice to accumulate above inlet pipes.

(4) Pipes for discharging cooling water, allowing full capacity discharge, are to be connected to sea chests.

(5) Areas through grating holes are not to be less than 4 *times* inlet pipe sectional areas.

3 In cases where more than two sea chests are arranged, it is not necessary to satisfy the requirements given in **-2(2)** and **(3)** above. In such cases, sea chests are to be arranged for alternating the intake and discharge of cooling water as well as complying with the requirements given **-2(1)**, **(4)** and **(5)** above.

4 Heating coils may be installed in the upper parts of sea chests.

5 Arrangements for using ballast water for cooling purposes may be useful as a reserve in the ballast condition, but cannot be accepted as a substitute for the sea inlet chests described above.

EFFECTIVE DATE AND APPLICATION

1. The effective date of the amendments is 1 January 2010.
2. Notwithstanding the amendments to the Rule, the current requirements may apply to ships for which the date of contract for construction is before the effective date.

GUIDANCE FOR THE SURVEY AND CONSTRUCTION OF STEEL SHIPS

Part I Polar Class Ships and Ice Class Ships

GUIDANCE

2009 AMENDMENT NO.1

Notice No.62 30th October 2009
Resolved by Technical Committee on 24th June 2009

Notice No.62 30th October 2009
AMENDMENT TO THE GUIDANCE FOR THE SURVEY AND CONSTRUCTION OF STEEL SHIPS

"Guidance for the survey and construction of steel ships" has been partly amended as follows:

Part I POLAR CLASS SHIPS AND ICE CLASS SHIPS

I1 GENERAL APPLICATION

I1.2 Definitions

I1.2.3 Classification of Ice Strengthening

Sub-paragraph -1 has been amended as follows.

1 The correspondence of ice classes specified in **1.2.3, Part I of the Rules** with those in the *Finnish-Swedish Ice Class Rules* ~~2002~~ 2008 is as given in **Table I1.2.3-1**.

Table I1.2.3-1 has been amended as follows.

Table I1.2.3-1 The correspondence of ice classes between the Rules and the Finnish-Swedish Ice Class Rules ~~2002~~ 2008

Ice Class of the *Finnish-Swedish Ice Class Rules* ~~2002~~2008	Ice Class of the Rules
I*A Super*	NS*(Class I*A Super* Ice Strengthening) NS (Class I*A Super* Ice Strengthening)
I*A*	NS*(Class I*A* Ice Strengthening) NS (Class I*A* Ice Strengthening)
I*B*	NS*(Class I*B* Ice Strengthening) NS (Class I*B* Ice Strengthening)
I*C*	NS*(Class I*C* Ice Strengthening) NS (Class I*C* Ice Strengthening)
II	NS*(Class I*D* Ice Strengthening) NS (Class I*D* Ice Strengthening) NS* NS

I5 ICE CLASS SHIPS

Section I5.4 has been renumbered to Section I5.6, and Section I5.6 has been amended as follows.

I5.~~4~~6 ~~Propulsion Systems~~ Design of Propellers and Propulsion Shafting Systems

I5.4.~~3~~6 Propeller bossing and CP mechanism

~~1 The diameter of blade fixing bolts of controllable pitch propellers and built-up propellers is not to be less than the value obtained from the following formula:~~

$$\cancel{d = 1.5\sqrt{\frac{1}{\sigma_0 n}\left(\frac{\left(A + \pi M \times 10^5\right)K_3}{L} + F_c\right)}}$$

~~where:~~

~~σ_0 : Specified yield point or 0.2% proof stress (N/mm^2) of bolt material. However, if $\sigma_0 < 0.69\sigma_B + 110.5$, it is to be taken as $0.69\sigma_B + 110.5$ and, if $\sigma_0 > 662.5$ N/mm^2, it is to be taken as 662.5 N/mm^2.~~

~~M : Ice torque ($kN\text{-}m$) specified in **5.4.2-2, Part I** of the Rules.~~

~~Other symbols used herein are the same as those specified in **7.2.2-2, Part D of the Rules**.~~

~~2~~ Where the propeller is force-fitted on the propeller shaft without key, the lower limit of pull-up length is to be determined according to **7.3.1-1, Part D of the Rules**, substituting F_V' given by following formula for F_V and the thrust T is to be determined according to maximum thrust T_r given by **5.5.7, Part I of the Rules**:

$$\cancel{F_V' = F_V + 4.46\frac{M}{R_0}\times 10^5 \quad (N)}$$

$$F_V' = F_V + 4.46\frac{Q_{max}}{R_0}\times 10^5 \quad (N)$$

where:

~~M~~ Q_{max}: ~~Ice torque~~ Maximum propeller ice torque ($kN\text{-}m$) specified in ~~**5.4.2-2**~~ **5.5.8, Part I of the Rules**.

R_0 : Radius (mm) of the propeller shaft cone part at the mid-length

F_V : Tangential force (N) acting on contact surface specified in **7.3.1-1, Part D of the Rules**.

Section I5.7 has been added as follows.

I5.7 Alternative designs

I5.7.1 Alternative designs

The examination specified in **5.7, Part I of the Rules,** may be according to the following (1) to (3).

(1) The study has to be based on ice conditions given for the different ice classes specified in **5.5, Part I of the Rules**. It has to include both fatigue and maximum load design calculations and fulfill the pyramid strength principle, as given in **5.5.1, Part I of the Rules.**

(2) Loading

Loads on propeller blades and propulsion systems are to be based on acceptable estimations of hydrodynamic and ice loads.

(3) Design levels

(a) Analysis is to indicate that all components transmitting random (occasional) forces, excluding propeller blade, are not subjected to stress levels in excess of the yield stress of the component material, within a reasonable safety margin.

(b) Cumulative fatigue damage calculations are to indicate reasonable safety factors. Due account is to be taken of material properties, stress raisers, and fatigue enhancements.

(c) Vibration analysis is to be carried out and is to indicate that complete dynamic systems are free from harmful torsional resonances resulting from propeller/ice interaction.

EFFECTIVE DATE AND APPLICATION

1. The effective date of the amendments is 1 January 2010.

2. Notwithstanding the amendments to the Guidance, the current requirements may apply to ships for which the date of contract for construction is before the effective date.