PART

6

CHAPTER 1 Strengthening for Navigation in Ice

Foreword *(1998)*

This Chapter provides requirements for optional ice strengthening classes. Section 6-1-1 contains general ice strengthening classes including ice classes for vessels intended for independent navigation in multi-year ice. Section 6-1-2 represents *1985 Finnish Swedish Ice Class Rules*, as amended.

The requirements in this Section are applicable to vessels of any length and are in addition to those in other Sections of these Rules or *Rules for Building and Classing Steel Vessels Under 90 Meters (295 Feet) in Length*, as appropriate.

Vessels intended for navigation in the Canadian Arctic are to comply with the requirements of the *Canadian Arctic Shipping Pollution Prevention Regulations*. The Bureau can issue an Arctic Pollution Prevention Certificate when authorized by the Canadian flag administration.

It is the responsibility of the owner to determine which ice class is most suitable for the intended service.

(2008) In association with the implementation of the IACS Unified Requirements for Polar Class Ships on 1 March 2008, the ABS *Guide for Building and Classing Vessels Intended for Navigation in Polar Waters, 2008* was published separately. For vessels intended to receive a Polar Ice Class the requirements of the Guide and 6-1-1/1.3 of this Chapter are applicable.

PART
6

CHAPTER 1 Strengthening for Navigation in Ice

SECTION 1 General Ice Classes *(1998)*

1 General

1.1 Application

Vessels to be distinguished in the *Record* by **Ice Class** followed by ice class **A5** through **A1**, **A0** through **C0** or **D0** as specified in 6-1-1/3.1 are to meet the applicable requirements of this Chapter.

Non-self-propelled vessels are to comply with the requirements in 6-1-1/33. Vessels requiring ice breaker assistance are to comply with the additional requirements in 6-1-1/39.1. Vessels serving as a leading ice breaker are to comply with the additional requirements in 6-1-1/39.3.

1.3 Polar Ice Classes *(1 March 2008)*

Vessels intended to operate in Polar waters are to fully comply with the requirements as specified in ABS *Guide for Building and Classing Vessels Intended for navigation in Polar Waters.* Provided all requirements as specified in the Guide are met, the vessels will be distinguished in the *Record* by **Ice Class** followed by ice class **PC 7** through **PC 1**.

1.5 Ice Breaker Class

In accordance with 1-1-3/3, the classification ✠ **A1 Ice Breaker** is to be assigned to vessels of ice class **A2** through **A5** built to the requirements of Section 6-1-1 of this Chapter and other relevant sections of the Rules for independent navigation in Polar Waters with Multi-year Ice. These vessels are to be distinguished in the *Record* by the notation **Ice Breaker** followed by an appropriate **Ice Class** notation in 6-1-1/3.1 (e.g., ✠ **A1 Ice Breaker, Ice Class A5**).

3 Selection of Ice Class

3.1 Ice Class *(1 March 2008)*

The requirements in this Section are intended primarily for vessels intended for independent navigation in first-year ice, except that ice classes **A5** through **A2** are intended to be used as Ice Breakers in Polar waters. The ice classes are as follows

Ice Class A5 (See Note 1)	**Ice Class A0**
Ice Class A4 (See Note 1)	**Ice Class B0**
Ice Class A3 (See Note 1)	**Ice Class C0**
Ice Class A2 (See Notes 1 & 2)	**Ice Class D0**
Ice Class A1 (See Note 2)	

Notes:

1 Applicable for vessels intended for use as an Ice Breaker only. The region and periods for navigation in ice are not only for first-year ice but also for multi-year ice. See 6-1-1/Table 1

2 **Ice Class A2**, in addition to a class for **Ice Breaker**, and **Ice Class A1** are for vessels intended for independent navigation in first year ice in non-Polar waters.

3.3 Guide for Selection

For the guidance of the Owner in selecting the most suitable ice class, the regions, periods and ice conditions suitable for respective ice classes are shown in 6-1-1/Table 1. The conditions of first-year ice are shown in 6-1-1/Table 2.

TABLE 1
Regions and Periods for Navigation in Ice for Selecting Ice Class *(1 March 2008)*

Ice Class	*Navigating independently or when escorted by an icebreaker of the following ice classes*	*Polar Waters with Multi-year Ice*			*Year around navigation in water with first-year ice with the ice conditions given in 6-1-1/Table 2*
		Central Arctic basin (1)	*Arctic offshore shelf* (2)	*Antarctic ice covered waters*	
A5	Independently	Year around	Year around	Year around	Extreme
		Note 3	Note 3	Note 3	Extreme
A4	Independently	July through November	Year around	Year around	Extreme
		Note 3	Note 3	Note 3	Extreme
A3	Independently	Short term, short distance entries during July through September	July through December	February through May	Extreme
A2, A1	Escorted by **Ice Breaker, Ice Class A3** or Higher Ice Breaker Ice Class Vessel	Note 3	Note 3	Note 3	Extreme
A2	Independently	—	August through October	March through April	Extreme
A1, A0	Escorted by **A2** or Higher Ice Class Vessel	—	Note 3	Note 3	Extreme
A1	Independently	—	Note 3	—	Very Severe
B0	Escorted by **A3** or Higher Ice Class Vessel	—	Note 3	Note 3	Extreme
A0, B0, C0	Escorted by **A1** or Higher Ice Class Vessel	—	Note 3	—	Very Severe
A0	Independently	—	—	—	Severe
B0	Independently	—	—	—	Medium
C0	Independently	—	—	—	Light
D0	Independently	—	—	—	Very Light

Notes

1. "Central Arctic Basin" means all of the multi-year ice covered waters of the Arctic Ocean and Arctic seas to the north from the boundary of the stable Arctic pack ice zone.
2. "Arctic Offshore Shelf" means Arctic waters within landfast and shear ice zones off the shores of continents, archipelagoes, and Greenland.
3. Polar Ice classes, **PC 7**, **PC 6**, **PC 5**, **PC 4**, **PC 3**, **PC 2** and **PC 1**, whichever is applicable. See the ABS *Guide for Building and Classing Vessels Intended Operate in Polar Waters.*
4. The shaded columns shaded are applicable for **Ice Breakers**.

TABLE 2
Ice Conditions of First-Year Ice Versus Concentration and Thickness of Ice Cover

Thickness of First-Year Ice Cover in m (ft)	*Concentration of Ice* [1]			
	Very Close and Consolidated Ice, Fast Ice (from 10/10 to 9/10 or from 8/8 to 7/8)	*Close Ice (from 9/10 to 6/10 or from 7/8 to 5/8)*	*Open Ice (from 6/10 to 3/10 or from 5/8 to 2/8) and Fresh Channel*[2] *in Fast Ice (more than 6/10 or 5/8)*	*Very Open Ice (less than 3/10 or 2/8), Fresh Channel*[2] *in Fast Ice (6/10 or 5/8 and less) and Brash Ice*
1.0 (3.3) and above	Extreme	Extreme	Very severe	Severe
from 0.6 (2) to 1.0 (3.3)	Extreme	Very severe	Severe	Medium
from 0.3 (1) to 0.6 (2)	Very severe	Severe	Medium	Light
less than 0.3 (1)	Severe	Medium	Light	Very light

Notes

1 These ratios of mean area density of Ice in a given area are from the "World Meteorological Organization Sea Ice Nomenclature", Appendix B.7, and give the ratio of area of Ice concentration to the total area of sea surface within some large geographic locales.

2 Provided the channel is wider than the ship

5 Definitions

5.1 Ice Belt

The *Ice Belt* is that part of the shell plating and hull appendages defined in 6-1-1/7 for self propelled vessels and in 6-1-1/33.5 for non-self propelled vessels.

5.3 Upper Ice Waterline

The *Upper Ice Waterline* is the deepest waterline at which the vessel is intended to operate in ice. The upper ice waterline is to be clearly indicated on the shell expansion drawing.

5.5 Lower Ice Waterline

The *Lower Ice Waterline* is the lightest waterline at which the vessel is intended to operate in ice. Generally, it is to be located so that propellers are fully submerged. The lower ice waterline is to be clearly indicated on the shell expansion drawing.

5.7 Displacement

The *Displacement*, *D*, is the molded displacement in metric tons (long tons) at the upper ice waterline. For the purposes of this section, the displacement may be calculated using a specific gravity of 1.00.

5.9 Length

The *Length, L* is the length at the upper ice waterline.

7 Extent and Length of Ice Belt Areas

The ice belt for self-propelled vessels is subdivided into the following areas:

- *For ice class* ***A5*** *through* ***A1***

  Bow, intermediate, lower intermediate, midbody, lower midbody, stern and upper areas.

- *For ice class* ***A0*** *through* ***C0***

  Bow, midbody and stern areas.

- *For ice class* ***D0***

  Bow area.

For ice class **A0** through **D0**, the lowest extent of the bow area need not extend below a line drawn between *Q* m (ft) below the lower ice waterline at the stem and *B* m (ft) below the lower ice waterline at the stern. (See 6-1-1/Table 3 for values of *Q* and *B*.) The extent and length of each area is shown in 6-1-1/Figure 1 and 6-1-1/Table 3.

TABLE 3
Dimensions of Ice Belt Areas, m (ft)

Ice Class	*A*	*B*	*C*	*D*	*E*	*F**	*G*	*H*	*I*	*K*	*S*	*Q*
A5	1.8 (6.0)	4.0 (13.1)	0.75*D*	1.5 + 0.01*L* (5 + 0.01*L*)	2.0 (6.5)	0.4*L*	0.1L	3.0 (10.0)	0.33*F*	0.15*L*	0.20*L*	
A4	1.6 (5.3)	3.0 (10)	0.75*D*	1.2 + 0.01*L* (4 + 0.01*L*)	1.0 (3.3)	0.4*L*	0.05L	2.0 (6.5)	0.33*F*	0.10*L*	0.20*L*	
A3	1.4 (4.6)	2.0 (6.5)	0.5*D*	0.9 + 0.0075*L* (3 + 0.0075*L*)	1.0 (3.3)	0.4*L*	0.05L	1.5 (5.0)	0.33*F*	0.10*L*	0.20*L*	
A2	1.2 (4.0)	1.5 (3.3)	0.5*D*	0.6 + 0.005*L* (2.0 + 0.005*L*)	1.0 (3.3)	0.4*L*	0	1.2 (4.0)	0.33*F*	0.05*L*	0.15*L*	
A1	1.0 (3.3)	0.8 (2.6)	0.5*D*	0.3 + 0.005*L* (1 + 0.005*L*)	1.0 (3.3)	0.4*L*	0	1.0 (3.3)	0.33*F*	0.05*L*	0.15*L*	
A0	0.8 (2.6)	0.6 (2.0)	0.5*D*	0.2 + 0.004*L* (0.7 + 0.004*L*)	0	0.3*L*	0	0	0	0	0.10*L*	10.0 (33.0)
B0	0.6 (2.0)	0.5 (1.6)	0	0.1 + 0.003*L* (0.3 + 0.003*L*)	0	0.3*L*	0	0	0	0	0.10*L*	9.0 (30.0)
C0	0.6 (2.0)	0.5 (1.6)	0	0.0025L	0	0.3*L*	0	0	0	0	0.10*L*	6.6 (22.0)
D0	0.5 (1.6)	0.5 (1.6)	0	0.002L	0	0.3*L*	0	0	0	0	0	4.5 (15.0)

* For ships with upper ice waterline parallel to centerline, *F* is to be as shown in 6-1-1/Figure 1d. In any case, the bow area is to extend aft not less than to a section at:

$M = 0.2L$ abaft the fore-end of the lower ice waterline, or

$N = 0.05L$ abaft point where the molded stem line crosses the baseline, whichever is located aft.

FIGURE 1
Ice Belt Areas

FIGURE 1a
Ice Class A5 through A1

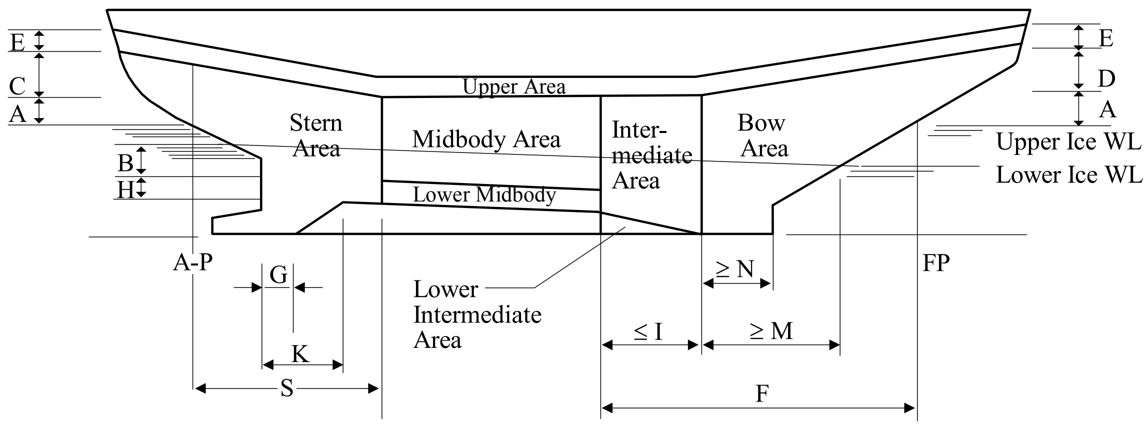


FIGURE 1b
Ice Class A0 through C0

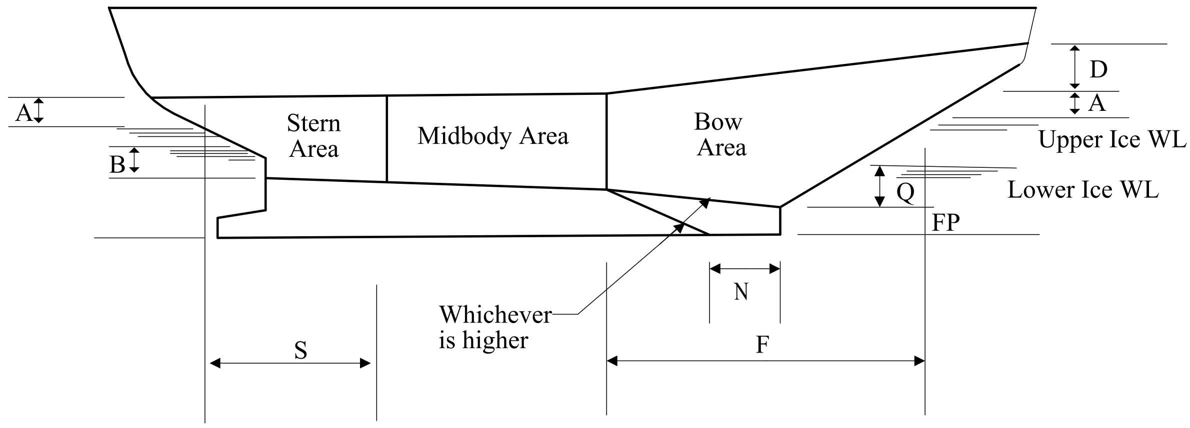


FIGURE 1c
Ice Class D0

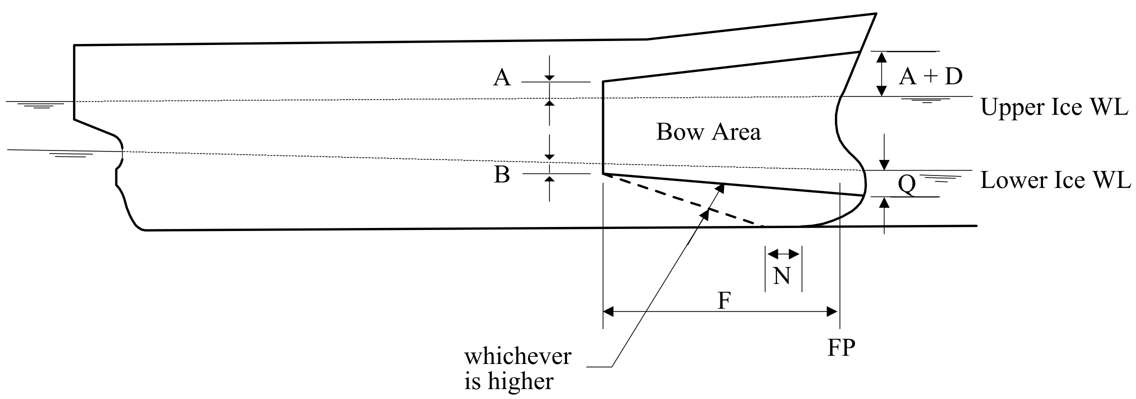
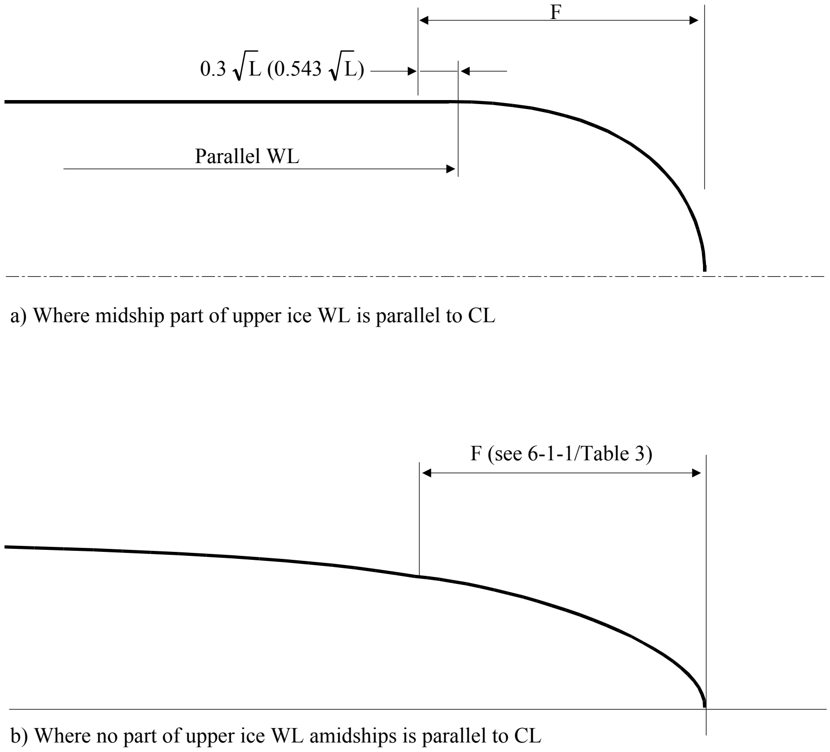


FIGURE 1d
Definition of F



9 Design Ice Loads

9.1 Design Ice Pressure on the Bow Area

The design ice pressure on the bow area is to be not less than that obtained from the following equations:

$P_b = P_o F_b$

P_b = design ice pressure on the bow area, in N/mm^2 (kgf/mm^2, ksi)

- *For ice classes* ***A5*** *through* ***A1***

  $P_o = A(N/k)^{0.2} (D/n)^{0.15}$

- *For ice classes* ***A0****,* ***B0****,* ***C0*** *and* ***D0***

  $P_o = B(D/n)^{0.2}$

where

A, B	=	coefficients, as given in 6-1-1/Table 4
N	=	total maximum continuous power delivered to the propellers, in kW (mhp, hp)
D	=	displacement, as defined in 6-1-1/5.7
k	=	746 (1000, 986)
n	=	1000 (1000, 984)
F_b	=	$(F_{b1}) (F_{b2})$

F_{b1} = coefficient is given in 6-1-1/Figure 2. It is to be determined for each bow section at the upper and lower ice waterlines depending on α_b and β_b and the maximum value obtained is to be used; if the values of coefficient F_{b1} obtained for the different sections and at different ice waterlines vary by more than 15%, different coefficients F_{b1} and, correspondingly, different design ice pressures may be used for the appropriate parts of the bow area.

F_{b1} is not to be taken less than 0.80, but need not be taken as more than 1.25 for vessels with conventional bows; for vessels fitted with bulbous bows, the F_{b1} coefficient within the bulb area is to be as given in 6-1-1/Table 4

F_{b2} = $1 + i\,(1.3 + 0.001D)^{-2}$

i = coefficient given in 6-1-1/Table 4

α_b = angle between the centerline and a tangent to the ice waterline being considered at the bow section being considered

β_b = angle between the vertical and tangent to the bow section at the level of the ice waterline being considered.

TABLE 4
Bow Area Ice Pressure Coefficients

Ice Classes	*A* N/mm^2 *(kgf/mm², ksi)*	*B* N/mm^2 *(kgf/mm², ksi)*	*i*	F_{b1} *
A5	3.70 (0.377, 0.537)	—	5	—
A4	3.08 (0.314, 0.447)	—	4.5	—
A3	2.26 (0.23, 0.328)	—	4	—
A2	1.54 (0.157, 0.224)	—	3	—
A1	0.905 (0.092, 0.132)	—	2.5	1.45
A0	—	0.997 (0.102, 0.142)	2	1.35
B0	—	0.750 (0.076, 0.109)	0	1.25
C0	—	0.60 (0.061, 0.086)	0	1.25
D0	—	0.50 (0.051,0.071)	0	1.25

* Within the bulbous bow area

9.3 Design Ice Pressures on Other Ice Belt Areas

Design ice pressures on other parts of the ice belt are to be obtained from the following equations:

- *For the intermediate area*

  $P_i = P_o F_i$

- *For the midbody*

  $P_m = K_m P_o$ or $P_m = K_m P_b$, whichever is less

- *For the stern*

  $P_s = K_s P_b$

- *For the lower intermediate area*

  $P_{li} = 0.8\,P_i$

- *For lower midbody area*

  $P_{lm} = 0.7\,P_m$

- *For the upper area*

  $P_u = 0.3\,P_b$

P_i, P_m, P_s, P_{li}, P_{lm} and P_u = design ice pressures on corresponding area, in N/mm^2 (kgf/mm^2, ksi)

K_s = coefficient, as given in 6-1-1/Table 5

K_m = coefficient, as given in 6-1-1/Table 5 or by $2(3 + 4\sin\beta_m)^{-1}$, whichever is less

F_i = coefficient, as given in 6-1-1/Figure 3. It is to be determined for each section of the intermediate area depending on α_i and β_i and the maximum value obtained is to be used. F_i is not to be less than $0.7F_b$ and need not be taken as more than F_b.

α_i and β_i are defined in similar manner as α_b and β_b but for each section of the intermediate area.

β_m = as defined for β_b (see 6-1-1/9.1), but for the section at amidship.

TABLE 5
Ice Pressure Coefficients in Other Areas

Ice Class	K_s	K_m
A5	0.75	0.60
A4	0.70	0.60
A3	0.65	0.58
A2	0.60	0.55
A1	0.50	0.50
A0	0.35	0.45
B0	0.22	0.35
C0	0.11	0.22

FIGURE 2
Coefficients F_{b1} Versus angles α_b and β_b

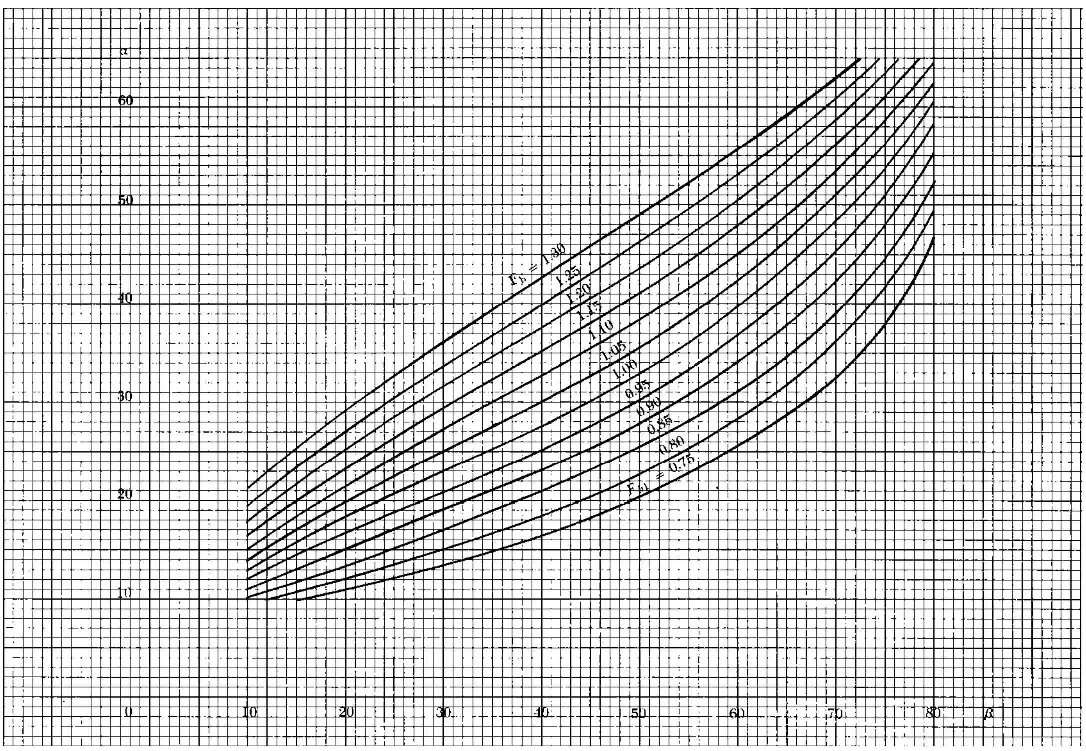
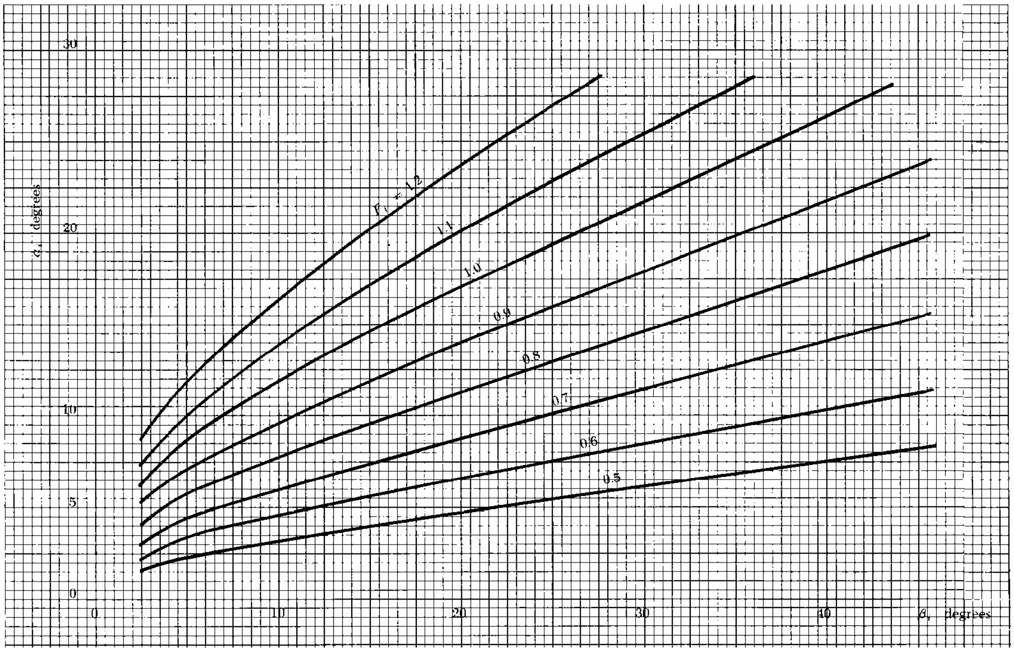


FIGURE 3
Coefficients F_i Versus Angles α_i and β_i



9.5 Extent of Design Ice Load

In a vertical direction, the design ice pressure is considered to be uniformly distributed on the side structure. The vertical extent of the design ice pressure is to be obtained from the following equations:

- *For the bow*

  $b_b = 0.61 + b_o F_{b1}$ m

  $b_b = 2 + b_o F_{b1}$ ft

- *For the intermediate area*

  $b_i = 0.61 + 0.7 b_o$ m

  $b_i = 2 + 0.7 b_o$ ft

- *For the midbody*

  $b_m = 0.65 + 0.5 b_o$ m

  $b_m = 2.13 + 0.5 b_o$ ft

- *For the stern*

  $b_s = b_i$

  $b_o = R\,(N/k)^{0.25}\,(D/n)^{0.2}$

where b_b, b_i, b_m and b_s are the vertical extent of the design ice pressure, in m (ft)

R = coefficient, as given in 6-1-1/Table 6

F_{b1} = coefficient, as given in 6-1-1/9.1

For **A1** to **C0** ice class vessels fitted with bulbous bows, the extent b_b within the bulbous area of the ice belt is to be 30% more.

N, D, k and n are as defined in 6-1-1/9.1.

TABLE 6
Extent of Ice Load Coefficients

Ice Class	*R, m (ft)*
A5	0.040 (0.131)
A4	0.038 (0.125)
A3	0.035 (0.115)
A2	0.030 (0.098)
A1	0.025 (0.082)
A0	0.020 (0.066)
B0	0
C0	0
D0	0

11 Longitudinal Strength

Special consideration is to be given to ice-induced hull girder bending for vessels of ice classes **A2** and above.

13 Shell Plating

13.1 Ice Belt with Transverse Framing

The thickness of the ice belt shell plating is to be not less than that obtained from the following equation:

$$t = 0.60s\,(P/Y)^{1/2} + Ct \quad \text{mm}$$

$$t = 0.60s\,(P/Y)^{1/2} + Ct_o \quad \text{in.}$$

where

t = thickness of the shell plating, in mm (in.)

s = distance measured along the shell between adjacent frames, in mm (in.)

P = design ice pressure in appropriate region, as given in 6-1-1/9, in N/mm^2 (kgf/mm^2, ksi)

Y = minimum yield strength of the material, in N/mm^2 (kgf/mm^2, ksi)

C = 1 for the bow, intermediate and lower intermediate areas

= 0.80 for the midbody and lower midbody areas

= 0.65 for the stern area

= 0.50 for the upper area

t_o = as given in 6-1-1/Table 7

In no case is the thickness of the bow, intermediate, mid and stern areas of the ice belt plating to be less than given in 6-1-1/Table 7.

TABLE 7
Minimum Thickness and Abrasion Allowance of Ice Belt Plating

Ice Class	*Minimum Thickness*	t_o* *mm (in.)*
A5	22 (0.87)	6 (0.236)
A4	20 (0.79)	6 (0.236)
A3	18 (0.71)	6 (0.236)
A2	16 (0.63)	5 (0.20)
A1	14 (0.55)	4 (0.16)
A0	12 (0.47)	3 (0.118)
B0	10 (0.39)	3 (0.118)
C0	8 (0.315)	3 (0.118)
D0	8 (0.315)	1 (0.04)

* Values of t_o may be reduced down to $0.3t_o$, if an abrasive-resistant coating is used for the ice belt plating. Special approval of this will be based on necessary evidence including submission of results of operational experience in ice.

13.3 Ice Belt with Longitudinal Framing

The thickness of ice belt shell plating is to be not less than that obtained from the following equation:

$t = 0.7s\,(P/Y)^{1/2} + Ct_o$ mm

$t = 0.7s\,(P/Y)^{1/2} + Ct_o$ in.

where

s = distance between longitudinal frames, in mm (in.)

t, P, Y, t_o,C are as defined in 6-1-1/13.1.

The thickness of ice belt plating is also to be not less than the thickness given in 6-1-1/Table 7, plus 1 mm (0.04 in.).

13.5 Bottom Plating

The thickness of plating at and below the lower turn of the bilge for ice classes **A5** to **A1** is to be not less than that obtained from the following equation:

$t = s\,(KP/Y)^{1/2} + 2$ mm

$t = s\,(KP/Y)^{1/2} + 0.08$ in.

where

t = thickness of the bottom plating, in mm (in.)

s = frame spacing, in mm (in.)

K = coefficient, as given in 6-1-1/Table 8

P = design ice pressure, as expressed in 6-1-1/9.1 and 6-1-1/9.3

Y = minimum yield strength, as defined in 6-1-1/13.1

TABLE 8
Coefficient K

Ice Classes	*Bow Area*	*Intermediate and Stern Area*	*Midbody Area*
A5	0.32	0.23	0.15
A4	0.29	0.19	0.13
A3	0.26	0.15	0.11
A2	0.23	0.11	0.10
A1	0.21	0.09	0.09

13.7 Changes in Plating Thickness

Plating thickness in the transverse direction from the ice belt to the bottom and in the longitudinal direction within the ice belt is to be gradually tapered.

15 Transverse Framing

15.1 Definitions

15.1.1 Main Frames

Main Frames are the hold, tween deck and peak frames referred to in Section 3-2-5.

15.1.2 Intermediate Frames

Intermediate Frames are the additional frames fitted within the ice belt between the main frames, to comply with 6-1-1/15.3.

15.1.3 Standard Frame Spacing

Standard Frame Spacing is the frame spacing specified by 3-2-5/1.7 and is measured along the centerline.

15.3 Ice Belt Frame Spacing

Except for the midbody and stern areas of ice class **C0**, spacing between any adjacent frames measured along the centerline is in general not to exceed one half of the standard frame spacing defined in 6-1-1/15.1.3. A larger spacing between any adjacent frames may be approved if the intermediate frames have end fixity similar to that of the main frames. In no case is the spacing between any adjacent frames measured along side plating to exceed 0.75 of the standard frame spacing given in 6-1-1/15.1.3.

15.5 Main and Intermediate Frames

15.5.1 Section Modulus

The section modulus, SM, of each transverse main and intermediate frame in association with the width of plating, s, to which it is attached is to be not less than that obtained from the following equation:

$$SM = Ks\ell b(P/Y) \quad \text{cm}^3$$

$$SM = 0.144Ks\ell b(P/Y) \quad \text{in}^3$$

where

K = $(160 - 100b/\ell)K_1K_2$

s = distance between adjacent frames, in mm (in.), measured along the lowest ice waterline in way of the compartment being considered

ℓ = span of the main frame, in m (ft), measured along the frame between decks or between deck and inner bottom

b = vertical extent of the design ice pressure, as defined in 6-1-1/9.5, in m (ft)

P = the design ice pressure, as defined in 6-1-1/9

Y = minimum yield strength of the material, in N/mm^2 (kgf/mm^2, ksi)

For framing system with web frames and supporting stringers in accordance with 6-1-1/15.9, coefficient K_1 is to be obtained from the equation:

$K_1 = 2/(3 + j)$

where j = number of the supporting stringers.

For framing system without web frames and supporting stringers, coefficient K_1 is to be as given in 6-1-1/Table 9a.

K_2 = 1.1 for the midship area of the ice belt for ice classes **A1** through **C0**

= 1 elsewhere

The web thickness, t, of the main and intermediate frames is to be not less than:

$t = 0.013h + 6$ mm

$t = 0.013h + 0.24$ in.

where h is the depth of the main and intermediate frame, in mm (in.).

In no case is the web thickness t to be less than the following:

Ice class **A5** through **A2**	10 mm (0.39 in.)
Ice class **A1** and **A0**	9 mm (0.35 in.)
Ice class **B0**	8.5 mm (0.34 in.)
Ice class **C0** and **D0**	8.0 mm (0.31 in.)

15.5.2 Upper End of Frames

Main and intermediate frames are to extend up to the first deck or platform above the ice belt. They are to be welded and bracketed to the deck beams or to the deck longitudinals, as shown in 6-1-1/Figure 4a and 6-1-1/Figure 4b.

For ice classes **A2** through **D0**, where the lowest or only deck, or the lowest platform, is situated above the ice belt so that the distance between the deck, or platform, and the upper boundary of the ice belt exceeds "*d*" meters (feet), given in 6-1-1/Table 9b, the upper ends of intermediate frames in the midbody and stern areas (**A2** through **C0**) or bow area (**D0**) may terminate at a deep stringer situated at least 0.6 m (2 ft) above the ice belt.

For ice classes **A0**, **B0**, **C0** and **D0** in tween deck spaces, where the tween deck is 0.5 m (1.6 ft) or more above the upper ice waterline but within the ice belt, the upper ends of intermediate frames may terminate for ice class **A0** at a stringer situated at least 0.5 m (1.6 ft) above the ice belt, and for ice classes **B0**, **C0** and **D0** at an intercostal longitudinal at least 0.5 m (1.6 ft) above the ice belt.

The upper ends of the frames terminated at a deep stringer are to be welded and bracketed to it as shown in 6-1-1/Figure 4c.

The intermediate frames terminated at an intercostal stringer or longitudinal are to be welded to it as shown in 6-1-1/Figure 4d.

TABLE 9a
Coefficient K_1 for the Framing System without Webs and Supporting Stringers

Termination of the upper & lower ends of the main & intermediate frames	*At the upper deck (or platform) of the adjacent upward spaces*	*Other*
At bottom structures or at the lower deck of the adjacent downward spaces (hold, tween deck, tank, etc.)	0.9	1
Other	1	1.15

TABLE 9b
Distance, m (ft)

Ice Class	*Where Web Frames are Fitted*	*No Web Frames are Fitted*
A2	5.2 (17)	—
A1	4.0 (13)	—
A0	3.0 (10)	—
B0	2.1 (7)	3 (10)
C0	1.2 (4)	1.8 (6)
D0	1.2 (4)	1.8 (6)

15.5.3 Lower End of Frames

Main and intermediate frames are to extend down to the inner bottom or to the double bottom margin plate. For ice classes **A2**, **A1** and **A0**, the intermediate frames may terminate at a deck 1.0 m (3.3 ft) below the ice belt. For ice classes **B0**, **C0** and **D0**, the intermediate frames may terminate at a stringer or intercostal longitudinal situated at least 1.0 m (3.3 ft) below the ice belt. The main and intermediate frames are to be attached and bracketed either to the inner bottom or to the double bottom margin plate or to the deck beams, or deck or to the stringer as shown in 6-1-1/Figure 5.

For vessels not having a double bottom, the intermediate frames are to extend down to a point below the top of the bottom transverses and are to terminate at an intercostal longitudinal. For ice classes **A0**, **B0**, **C0** and **D0**, the intermediate frames need not extend below the top of the floors, provided they terminate on an intercostal longitudinal not less than 0.8 m (2.6 ft) below the ice belt. The intermediate frames are to be attached to the bottom intercostal longitudinals.

15.5.4 Connection to Stringers and Decks

Main and intermediate frames are to be attached and bracketed to each supporting (deep) stringer, deck and deck beam within the ice belt.

15.7 Web Frames

The section modulus, *SM*, of each web frame, in association with the plating to which it is attached, is to be not less than that obtained from the following equation:

$$SM = Ks_1 \ell b(P/Y) \quad \text{cm}^3$$

$$SM = 0.144 Ks_1 \ell b(P/Y) \quad \text{in}^3$$

where

K = $(96 - 36b/\ell)K_1K_2K_3$

K_1 = $1.06 - 0.0024i^2$, but not less than 0.4

i = number of the main and intermediate frames between adjacent web frames

K_2 = 1 for the bow, intermediate and stern areas of the ice belt

= 1.2 for the midship area of the ice belt for ice classes **A1** through **C0**

= 1.1 for the midship area of the ice belt for ice classes **A5** through **A2**

K_3 = 1 if there is one supporting (deep) stringer

= 0.90 if there are two supporting (deep) stringers

= 0.85 if there are three or more supporting (deep) stringers

s_1 = distance between the web frames, in mm (in.), measured along lower ice waterline in way of the compartment being considered

ℓ = span, in m (ft), measured in a straight line along the hold web frame from the line of the inner bottom (extended to the side of the vessel) to the lowest deck of the hold, or for the tween deck web frame measured between the decks as shown in 6-1-1/Figure 4a or 6-1-1/Figure 4b and 6-1-1/Figure 5

b = as defined in 6-1-1/9.5, in m (ft)

P = as defined in 6-1-1/9, in N/mm^2 (kgf/mm^2, ksi)

Y = as defined in 6-1-1/13.1, in N/mm^2 (kgf/mm^2, ksi)

In determining the section modulus, the effective width of the plating is to be the distance between the webs or 0.125ℓ, whichever is less.

Thickness of the web plate, t, is to be not less than that obtained from the following equation:

$$t = 0.01h + 8 \quad \text{mm}$$

$$t = 0.01h + 0.32 \quad \text{in.}$$

where h is the depth of the web frame; t need not exceed 18 mm (0.71 in.) for ice classes **A5** through **A2** and 15 mm (0.59 in.) for other ice classes.

The web frames are to be attached and bracketed to the solid floors and the beams at each ice deck.

15.9 Ice Stringers

15.9.1 Arrangements

Deep continuous or intercostal stringers are to be fitted within the ice belt throughout the length of the vessel, except that for ice class **C0** and **D0** vessels, the ice stringers need be fitted only in the bow area of the ice belt. The spacing between adjacent stringers or between the stringer and a deck or the double bottom measured along the shell is to be not more than indicated in 6-1-1/Table 10. One of the ice stringers is to be fitted about 200 to 400 mm (8 to 16 in.) below the upper ice waterline, if there is no deck in this area. For ice classes **A5** through **A0**, another stringer is to be fitted about 100 to 300 mm (4 to 12 in.) below the lower ice waterline, if there is no deck or similar support in this area.

FIGURE 4
Upper End Terminations of Frames

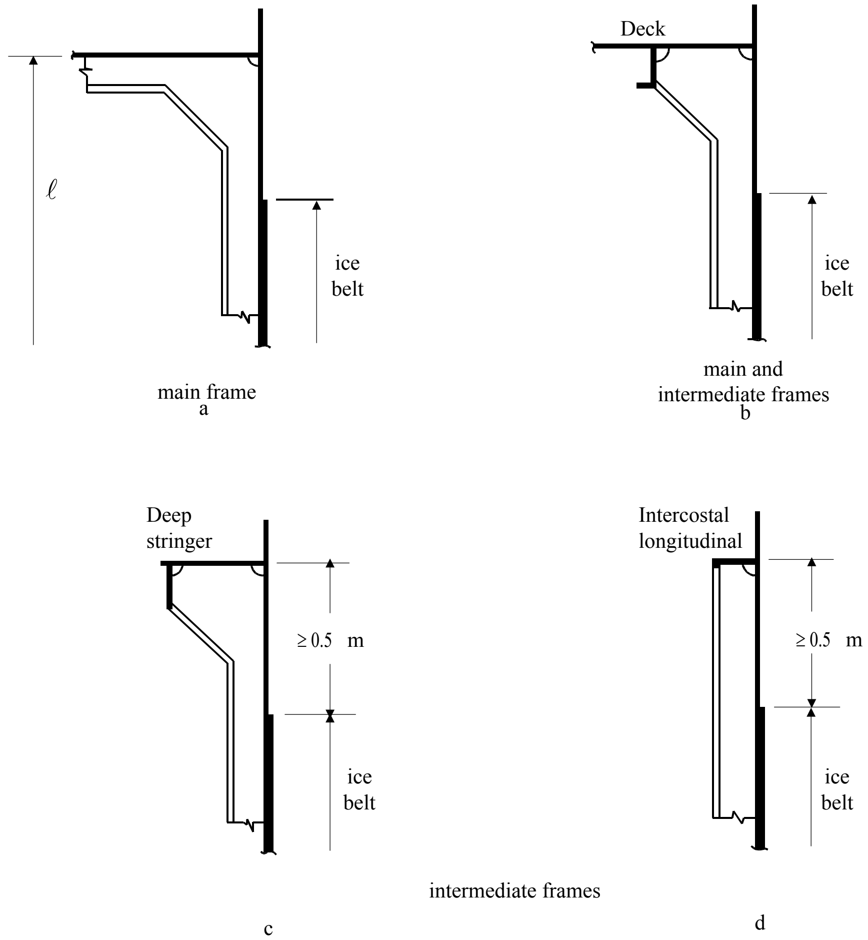


FIGURE 5
Lower End Terminations of Frames

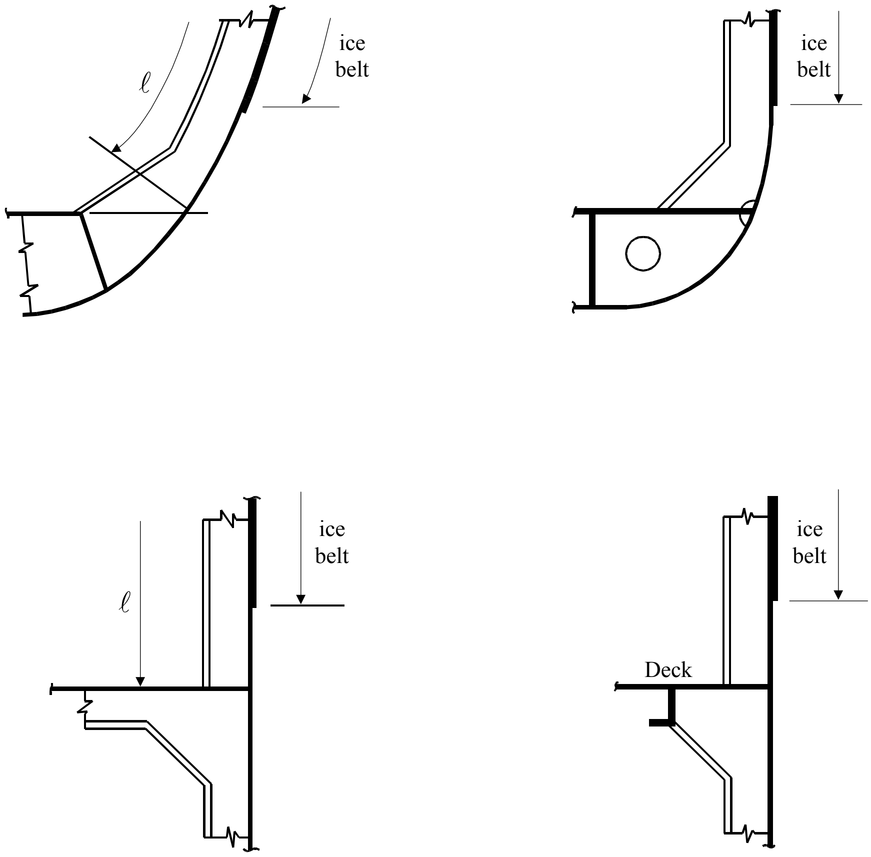


TABLE 10
Maximum Stringer Spacing, m (ft)

Ice Class	*For Framing without Web Frames*	*System with Web Frames*
A5 through **A2**	1.5 (5)	2.1 (7)
A1 through **D0**	1.5 (5)	2.7 (9)

15.9.2 Scantlings and Connections

Where web frames are not fitted, the ice stringers may be intercostal between frames and their scantlings are to be not less than those for the main frames. They are to be welded to the main and intermediate frames. Where web frames are fitted, the shear area of the deep ice stringer within one frame space from the web frame is to be not less than that of the web frames. The depth of the ice stringer at the midspan between the web frames is to be not less than twice the depth of the main frame. The face, or flange, area of the deep stringer is to be not less than that of the web frame. The deep stringer referred to in 6-1-1/15.5.2, at which the upper ends of frames are terminated, is to have the scantlings as required in 6-1-1/15.9. The web plate and the flange, or face, of intercostal ice stringers are to be attached to those of the main and intermediate frames. The web plate and the face, or flange, of deep ice stringers are to be attached to those of the web frames. The main and intermediate frames are to be bracketed to the bulkheads, so that the shear area at the bulkhead is twice that of the ice stringer web.

Stiffeners or tripping brackets are to be fitted as required in 3-2-6/3.7 and 3-2-6/3.9.

17 Longitudinal Framing

17.1 General

For vessels of ice classes **A5**, **A4** and **A3**, longitudinal framing within the bow area of the ice belt is to be specially considered.

17.3 Spacing of Longitudinals

The spacing measured along the shell between adjacent longitudinals and between the longitudinal and the double bottom or a deck within the ice belt is not to exceed one half of the spacing as given in 3-2-5/1.7.

17.5 Section Modulus

The section modulus, *SM*, of each longitudinal, in association with the width of plating, *s*, to which it is attached, is to be not less than that obtained from the following equation:

$$SM = 70s\ell^2 K_o(P/Y) \quad \text{cm}^3$$

$$SM = 10s\ell^2 K_o(P/Y) \quad \text{in}^3$$

where

s = spacing of longitudinals, as defined in 6-1-1/17.3, in mm (in.)

ℓ = span, in m (ft), of the longitudinals measured at the lower ice waterline

K_o = $(2.44/\ell)^{1/2}$ (ℓ in m)

= $(8/\ell)^{1/2}$ (ℓ in ft), but not less than 0.4

P = design ice pressure, as defined in 6-1-1/9

Y = minimum yield stress of the material, in N/mm^2 (kgf/mm^2, ksi)

The longitudinals are to be attached and bracketed to the webs and to the bulkheads to provide a shear area at least twice the net shear area of the longitudinal.

17.7 Web Frames

The section modulus, *SM*, of the web frame, in association with the plating to which it is attached, is to be not less than that obtained from the following equation:

$$SM = K_o K s_1 \ell b(P/Y) \quad \text{cm}^3$$

$$SM = 0.144 K_o K s_1 \ell b(P/Y) \quad \text{in}^3$$

where

K_o = as defined in 6-1-1/17.5

K = 165 without struts

= 100 with one horizontal strut

= 80 with two struts

= 70 with three struts

s_1 = as defined in 6-1-1/15.7, in mm (in.)

ℓ = as defined in 6-1-1/15.7, in m (ft)

b = as defined in 6-1-1/9.5 for particular area of the ice belt, in m (ft)

P = as defined in 6-1-1/9 for particular area of the ice belt

Y = as defined in 6-1-1/13.1

In determining the section modulus, the effective width of plating is to be the distance between the webs or 0.125ℓ, whichever is less.

The net sectional area of the web plate including effective end brackets, where applicable, is to be not less than that obtained from the following equation:

$$A = K_1 SM/\ell \quad \text{cm}^2$$

$$A = 8.33K_1 SM/\ell \quad \text{in}^2$$

where

K_1	=	0.009	without struts
	=	0.015	with one or more struts

Plate thickness is to be not less than given in 6-1-1/15.7.

17.9 Struts

Where one or more struts are fitted as an effective supporting system for the ice belt structure, they are to be located within the ice belt and spaced so as to divide the supported web into spans of approximately equal length. Inboard ends of the struts are to be supported sufficiently by longitudinal bulkhead transverses having a section modulus not less than 0.9 of that required by 6-1-1/17.7. The sectional area of the strut is to be obtained from the following equation:

$$A = (bs_1/K)(P/Y)K_o \quad \text{cm}^2\ (\text{in}^2)$$

where

b	=	as defined in 6-1-1/9.5 for particular area of the ice belt, in m (ft)	
s_1	=	as defined in 6-1-1/15.7, in mm (in.)	
K	=	$0.04 - 0.0175(\ell/r)$	for SI & MKS units
	=	$0.0333 - 0.00175(\ell/r)$	for US units
ℓ	=	unsupported span of the strut, m (ft)	
r	=	least radius of gyration, cm (in.)	
P	=	as defined in 6-1-1/9 for particular area of the ice belt	
Y	=	as defined in 6-1-1/13.1	
K_o	=	as defined in 6-1-1/17.5	

19 Alternative Framing Arrangements

Where framing arrangements differing from those given in 6-1-1/15 and 6-1-1/17 are used for the ice belt structures, special approval of the framing members will be based on submitted stress analysis of the structure.

21 Peak Frames

Main and intermediate frames in forepeaks are to extend down to the floors or the bottom transverses or the stem. The section modulus of each peak frame is to be as given in 6-1-1/15.5.1 where ℓ, in m (ft), is measured between deep ice stringers and $K_1 = 1$. The spacing between the deep ice stringers or platforms measured along the shell is to be not more than 1.5 m (5 ft) for forepeaks of ice classes **A5** through **A2**. For the afterpeaks of ice classes **A1** through **B0**, the distance is to be not more than 2.1 m (7 ft).

For ice classes **A5** through **A2**, transverse peak frames are to be fitted so that the angle between the web of the transverse frame and the shell plating, γ, is not less than 40 degrees at any waterline within the ice belt. If this angle is less than 60 degrees, the section modulus of the transverse peak frames is to be increased by the factor.

$K = 2 \cos \gamma$ where 40 degrees $\leq \gamma \leq$ 60 degrees

For all ice classes except **C0** and **D0**, the intermediate frames are to extend down to the bottom structure and up to the first deck above the ice belt. Intermediate frames in the forepeak for ice class **C0** and **D0** may terminate at the first stringer above the ice belt.

23 Double Bottom

23.1 Inner Bottom

An inner bottom is to be fitted between the peaks in all vessels of ice classes **A5** to **A3** and in **A2** ice class vessels of lengths of 61 m (200 ft) and over.

23.3 Transversely Framed Bottom

For ice classes **A5** through **A1**, solid floors are to be fitted at each web frame along the length of the vessel, and, in addition, at each main frame within the bow, lower intermediate and lower stern areas of the ice belt. Spacing of the solid floors is to be not more than required by 3-2-4/5 or the appropriate sections of Part 5, as applicable. Open floors or bilge brackets extending to longitudinals or side girders are to be fitted at each intermediate frame that extends to the inner bottom. The distance between bottom side girders is to be not more than 2.4 m (8 ft) for the bow area of ice classes **A5** through **A3** and 3.0 m (10 ft) elsewhere for ice classes **A5** through **A1**. Spacing of the side girders is to be not more than required by 3-2-4/3.7.

23.5 Longitudinally Framed Bottom

For ice classes **A5** through **A1**, solid bottom transverses or solid floors are to be fitted at each web frame along the length of the vessel, but at not more than 1.8 m (6 ft) within the bow, lower intermediate and lower stern areas of the ice belt. Spacing of the solid floors is to be not more than required by 3-2-4/5 or the appropriate sections of Part 5, as applicable. Special consideration will be given to wider spacings.

Open floors or bilge brackets extending to the outboard longitudinals are to be fitted throughout at each frame that extends to the inner bottom, except ice classes **B0**, **C0** and **D0**, where only the bow area is to comply with this requirement. The spacing of the bottom longitudinals within the bow, lower intermediate and lower stern areas of the ice belt is to be not more than 0.6 m (2 ft) for ice classes **A5** through **A3** and 0.7 m (2.3 ft) for ice classes **A2** through **A0**.

25 Ice Decks

25.1 General

The following requirements apply to decks or parts of decks situated within the ice belt. For vessels not having decks in the ice belt and for vessels of ice classes **A5** through **A2** having only one deck in the ice belt, the following requirements apply also to decks or parts of decks above and below the ice belt to which the main and intermediate frames extend. Where there are three or more decks within the ice belt, the deck or parts of the deck situated within the upper area of the ice belt, defined in 6-1-1/7, need not comply with these requirements.

25.3 Deck Plating

The thickness of the stringer plate is to be not less than:

$$t = k(s^2 b\ P)^{1/3} \quad \text{mm (in.)}$$

where

k = 0.12 (0.257, 0.0523)

s = distance between the deck beams, in mm (in.)

b = as defined in 6-1-1/9.5, in m (ft), for the particular area of the ice belt

P = as defined in 6-1-1/9.1 or 6-1-1/9.3, for the particular area of the ice belt

The width of the stringer plate is to be not less than five times the depth of the main frame for ice classes **A5** and **A4** and four times the main frame depth for **A3** to **A0** ice classes. For ice classes **A5** through **A0**, the thickness of the deck plating is to be not less than 0.75 times the required thickness of the stringer plate.

25.5 Deck Transverses and Deck Beams

25.5.1 Transversely Framed Decks

Partial beams or brackets are to be fitted at every intermediate frame for ice classes **A5** to **A1**. These partial beams or brackets are to be extended from the frames to a deck longitudinal or deck girder. The length of these partial beams or brackets is to be not less than the width of the stringer plate.

25.5.2 Longitudinally Framed Decks

Deck transverses are to be fitted at every web frame and, in addition, not less than at every second main frame for ice classes **A5** to **A2**, at every third main frame for ice classes **A1** to **A0** and at every fourth main frame for ice class **B0**.

Partial beams or brackets are to be fitted at all other main frames and at every intermediate frame for ice classes **A5** to **A0**, and at all other main frames for ice classes **B0**, **C0** and **D0**. The partial beams or brackets are to be extended from the frames to a deck longitudinal or deck girder situated not less than 1.5s from the inboard edge of the frames, where s is as defined in 6-1-1/25.3

25.5.3 Scantlings

The sectional area of the beams and deck transverses is to be not less than:

$$A = K_1 sb(P/Y)\cos\beta \quad \text{cm}^2$$

$$A = 1.2K_1 sb(P/Y)\cos\beta \quad \text{in}^2$$

The moment of inertia of the beams is to be not less than:

$$MI = kK_2 s\ell^2 bP\cos\beta \quad \text{cm}^4\ (\text{in}^4)$$

where

k = 1.0 (9.81, 0.1191)

P = as defined in 6-1-1/9.1 or 6-1-1/9.3, in N/mm^2 (kgf/mm^2, ksi), for the particular area of the ice belt

b = as defined in 6-1-1/9.5, in m (ft), for the particular area of the ice belt

s = distance between the beams, in mm (in.)

ℓ = the span of the beam, measured in m (ft), between the inboard edge of the frame and the deck longitudinal or deck girder supporting the beam

Y = as defined in 6-1-1/13.1

β = as defined in 6-1-1/9.1 and 6-1-1/9.3, in degrees, for the particular area of the ice belt

K_1 = 8.5 for ice classes **A5** to **A1**

= 6.6 for ice classes **A0**, **B0**, **C0** and **D0**

K_2 = 0.24 for ice classes **A5** to **A1**

= 0.13 for ice classes **A0**, **B0**, **C0** and **D0**

The sectional area and the moment of inertia of the partial beams and of the brackets are to be not less than required above. The beams and the partial beams are to be bracketed to the deck longitudinals or deck girders. Beams or partial beams or brackets fitted at the web frames are to be reinforced so that their section modulus, *SM* is to be not less than:

$SM = K_3 SM_{wf} \ell_{wf} / \ell$ cm^3 (in^3)

where SM_{wf} and ℓ_{wf} are the section modulus and the span of the web frame, as defined in 6-1-1/15.7, respectively.

K_3 = 0.8 for ice classes **A5** through **A1**

= 0.5 for ice classes **A0**, **B0**, **C0** and **D0**

25.7 Decks with Wide Openings

Within the intermediate and midbody areas of the ice belt, the cross sectional area of the deck outside the line of openings is to be not less than:

$A = Kb\ell(P/Y)\cdot 10^3$ cm^2

$A = 14.4Kb\ell(P/Y)$ in^2

where

K = 8.2 for ice classes **A5** to **A1**

= 6.2 for ice classes **A0** and **B0**

b = as defined in 6-1-1/9.5, in m (ft), for the particular area of the ice belt

ℓ = the length of the opening, in m (ft), but need not be taken as more than $0.1L$

P = as defined in 6-1-1/9.3, for the particular area of the ice belt

Y = as defined in 6-1-1/13.1

L = as defined in 6-1-1/5.9, in m (ft)

27 Bulkheads

27.1 General

For ice classes **A5** to **A1**, those parts of transverse bulkheads situated within the ice belt are not to be vertically corrugated.

27.3 Scantlings

For ice classes **A5** to **A0**, the thickness of that part of the bulkhead adjacent to the side shell and within the ice belt is to be not less than the thickness of the adjacent frames or of the stringers connected to the bulkhead, whichever is greater. The width of these parts of the bulkhead is to be not less than shown in 6-1-1/Table 11. These parts of the bulkhead adjacent to the shell within the ice belt are to be fitted with stiffeners normal to the shell plating. The stiffeners are to be welded to a vertical bulkhead stiffener and welded and bracketed to the side longitudinals. Where the shell is transversely framed, brackets are to be welded to the shell and extended and attached to adjacent frames.

TABLE 11
Minimum Width of Reinforced Bulkhead Plating

Ice Class	*Area of the Ice Belt*			
	Peak Bulkheads m (ft)	*Bow and Intermediate Areas m (ft)*	*Midbody Area m (ft)*	*Stern Area m (ft)*
A5 through **A2**	1.6 (5.2)	1.4 (4.6)	1.2 (4.0)	1.4 (4.6)
A1 and **A0**	1.2 (4.0)	1.2 (4.0)	1.0 (3.3)	1.0 (3.3)

29 Stem and Stern Frame

29.1 General

The requirements of Section 3-2-13 of the Rules are to be complied with. The stem and stern frame for ice classes **A5** through **A1**, and for ice class **A0**, vessels of displacements more than 50,000 tonnes (49,200 Lt) are to be constructed of rolled bar, cast or forged steel. Shaped plate stem may be used elsewhere. All joints and connections are to fully develop the strength of the stem and stern frame. All rudders are to be protected against ice impacts for going astern.

29.3 Stem

29.3.1 Solid Stem

The cross sectional area of a stem made of rolled bar, cast or forged steel from the center vertical keel to $0.01L$ above the ice belt is to be not less than:

$$A = K_1 D^{1/3} (L - 61) + A_o \quad \text{cm}^2$$

$$A = 0.0473 K_1 D^{1/3} (L - 200) + A_o \quad \text{in}^2$$

where

K_1 and A_o = as given in 6-1-1/Table 12

D = as defined in 6-1-1/5.7

L = as defined in 6-1-1/5.9, in m (ft), but is not to be taken less than 61 m (200 ft)

For vessels of displacements less than 2,500 tonnes (2,460 Lt) the cross sectional area given by the above equation may be reduced 10%. The cross sectional area of the stem above the ice belt may be reduced gradually to the value given in Section 3-2-13.

TABLE 12
Solid Stem Bar Coefficients

Ice Class	A_o *cm²* (*in²*)	K_1
A5	750 (116.2)	0.28
A4	750 (116.2)	0.28
A3	700 (108.5)	0.27
A2	500 (77.5)	0.24
A1	200 (31.0)	0.18
A0	62 (9.6)	0.13
B0	50 (7.8)	0.705
C0	45 (7.0)	0.095
D0	45 (7.0)	0.095

29.3.2 Shaped Plate Stem

Thickness of shaped plate stems within the bow area of the ice belt is to be not less than

$$t = 0.8s(P/Y)^{1/2} + t_o \quad \text{but not less than } 0.04R.$$

where

t = required thickness of plate stem, in mm (in.)

s = distance between frames, brackets (breast hooks) or stiffeners, in mm (in.)

P, Y and t_o are as defined in 6-1-1/13.1.

R = the inside radius of the stem at the given section, in mm (in.). Need not be taken greater than 800 mm (31.5 in.) for ice class **A1** and 625 mm (24.6 in.) for ice classes **A0** through **D0**

At any section, the fore and aft length of the stem plate is to be not less than $15t$.

29.3.3 Arrangement

The outer surface of connections of the shell plating to the stem is to be flush. The stem is to be supported by floors, webs, frames, breasthooks or brackets spaced not more than 610 mm (24 in.). In addition, shaped plate stems are to be supported in the centerline by a plate, web or bulkhead having the same thickness as the center vertical keel and a width not less than 610 mm (24 in.).

29.5 Stern Frame

The stern post is to be of size obtained from 3-2-13/3.5 through 3-2-13/3.11, with all thicknesses increased by coefficient K, as given in 6-1-1/Table 13. In addition, factors C_f and C_c in 3-2-13/3.5 are to be multiplied by K^2.

TABLE 13
Stern Post Coefficient

Ice Class	*K*
A5	2.0
A4	1.9
A3	1.8
A2	1.6
A1	1.4
A0	1.2
B0	1.12
C0	1.07
D0	1.05

31 Power of Propulsion Machinery

31.1 Minimum Power

For ice classes **A5** through **C0**, the total ahead horsepower delivered to the propellers, N, is to be not less than the lesser of the values obtained from the following two equations:

i) $N = kA(B)^{0.8}(L)^{0.4}(1 + me^{-5D \times 10^{-6}})$ kW (mhp, hp)

ii) $N = k(C + KD \times n/1000)$

where

B	=	the maximum breadth of the vessel, in m (ft), at the upper ice waterline
L	=	the length of the vessel, in m (ft), as defined in 6-1-1/5.9
e	=	base of natural logarithms
D	=	as defined in 6-1-1/5.7
n	=	1 (1.016)
k	=	0.735 (1, 0.986)

A, m, C and K are as given in 6-1-1/Table 14.

For ice classes **A5** to **A2**, only equation *i)* is to be used.

For vessels with unconventional features, the power delivered to the propellers may also be less than given in equation *i)*, if the particular vessel is able to progress continuously in any ice condition corresponding to its ice class. Special approval of this will be based on necessary evidence including the submission of results of full-scale and model tests. Special consideration will be given when the value of N determined from the equations in 6-1-1/31.1 is less than N_o in 6-1-1/Table 14.

TABLE 14
Power Coefficients

The power given may be reduced up to 10% for vessels fitted with controllable pitch propellers

Ice Class	*A* *SI & MKS (US units)*	*m*	*C*	*K*	N_o *kW (mhp, hp)*
A5	360 (86.6)	1.3	—	—	44,740 (60,840, 60,000)
A4	270 (64.9)	1.0	—	—	22,370 (30,420, 30,000)
A3	200 (48.1)	0.8	—	—	13,420 (18,250, 18,000)
A2	136 (32.7)	0.6	—	—	6,710 (9,125, 9,000)
A1	107 (25.7)	0.6	1500	400	3,730 (5,070, 5,000)
A0	93 (22.4)	0.6	1000	350	1,490 (2,030, 2,000)
B0	79 (19.0)	0.6	500	300	746 (1,040, 1,000)
C0	64 (15.4)	0.6	0	250	373 (507, 500)

31.3 Astern Power

The astern power delivered to the propellers for ice classes **A5**, **A4**, and **A3** is to be not less than 85% of that required in 6-1-1/31.1 and for ice classes **A2** to **C0** not less than 70% of that required in 6-1-1/31.1. For ice class **D0**, see 4-1-1/7.5, as applicable.

33 Non-self-propelled Vessels

33.1 General

Barges designed for being towed and/or pushed in broken ice and built to the requirements of this section and related sections of the ABS *Rules for Building and Classing of Steel Barges* will be designated by ice classes **A0**, **B0**, **C0** and **D0**. Non-self propelled vessels other than barges covered by these Rules will be subject to special consideration.

33.3 Ice Classes

For the guidance of the Owner, the ice conditions considered appropriate for towing or pushing barges are shown below:

Ice Class	*Towed/Pushed*	*Towed by ice class **A1** vessel**	*Towed by ice class **A2** vessel**
A0	severe	very severe	extreme
B0	medium	severe	
C0	light	medium	
D0	very light	light	

* Breadth of towed barge not to exceed the breadth of towing vessels.

Barges intended to be pushed in "very severe" or "extreme" ice conditions will be subject to special consideration.

33.5 Ice Belt

The ice belt is divided into three parts: bow, midbody and aft areas, except that for class **D0**, the ice belt applies to bow area only. For barges designed for tow by either end, bow area requirements apply to both ends. For such barges, the midbody and two bow areas of the ice belt are to be used. The bow area of the ice belt is to extend forward from the section $0.025L$ aft of either the point where the rake reaches the bottom or where the lightest ice waterline reaches its greatest breadth, whichever is greater. The aft area of the ice belt is to extend aft of the section $0.025L$ forward of the point where the lightest ice waterline reaches its greatest breadth. The midbody area of the ice belt extends between the bow and aft areas.

Upper boundary of the ice belt throughout the length of the barge is to be not less than 0.75 m (30 in.) above the deepest ice waterline for ice class **A0** and not less than 0.6 m (24 in.) above the deepest ice waterline for ice classes **B0** and **C0** and not less than 0.5 m (20 in.) above the deepest ice waterline for ice class **D0**. The lower boundary of the ice belt is to be not less than 0.6 m (24 in.) below the lightest ice waterline for the midbody and aft areas of ice class **A0**. In the bow area of ice class **A0**, the ice belt is to extend to the bottom of the side shell and is to include the bottom shell in way of the rake. For ice classes **B0**, **C0** and **D0**, the lower boundary of the ice belt is to be not less than 0.5 m (20 in.) below the lightest ice waterline throughout the length of the barge.

33.7 Design Ice Loads

The design ice pressure on the bow area, P_{bow}, is to be as given for P_b in 6-1-1/9.1, where F_{b1} = 1.25 for vertical structures and F_{b1} = 1 for the rakes. The design ice pressures on the midship and aft areas, P_{mid} and P_{aft} are to be

$$P_{mid} = K_m P_{bow}$$

$$P_{aft} = K_s P_{bow}$$

where K_m and K_s are as given in 6-1-1/Table 5.

The vertical extent of the design ice pressure for all of the ice belt areas is to be:

0.61 m (24 in.) for ice class **A0**

0.51 m (20 in.) for ice class **B0**

0.45 m (18 in.) for ice class **C0**

0.40 m (16 in.) for ice class **D0**

33.9 Structural Arrangements

The thickness of the shell plating within the ice belt areas is to be as required by 6-1-1/13.1 or 6-1-1/13.3. Structural arrangements and scantlings of the ice belt framing members are to be as required by 6-1-1/15, 6-1-1/17 and 6-1-1/21. Decks and bulkheads situated within the ice belt and, where there are no decks within the ice belt, the deck above and below the ice belt to which the main and intermediate frames are extended are to comply with the requirements of 6-1-1/25 and 6-1-1/27.

35 Hull Structural Materials

35.1 General

All hull structural materials are to be in accordance with the requirements of Part 2, Chapter 1. In addition, material grades for ice belt structures and exposed shell and main strength deck structures are to be selected based on the design service temperature and material class, as defined as follows.

35.3 Design Service Temperature

The design service temperature is to be taken in accordance with 6-1-1/Table 15. Design service temperature for insulated members will be specially considered upon submission of substantiating data.

TABLE 15
Design Service Temperature, degrees C (degrees F) *(1998)*

		Ice Class			
Zones		**A5** *through* **A2**	**A1** *and* **A0**	**B0** *and* **C0**	**D0**
a.	Ice Belt Structures (other than Area c)				
	1. external plating	-40 (-40)	-30 (-22)	-20 (-4)	-10 (14)
	2. framing [1] for all items above	-30 (-22)	-20 (-4)	-10 (14)	0 (32)
b.	Above Ice Belt [3]				
	1. external plating	-40 (-40)	-30 (-22)	-20 (-4)	-10 (14)
	2. framing [1] for external plating	-30 (-22)	-20 (-4)	-10 (14)	0 (32)
	3. plating [2] and framing in enclosed spaces				
	i) Heated space	0 (32)	0 (32)	0 (32)	0 (32)
	ii) Unheated space	-20 (-4)	-10 (14)	0 (32)	0 (32)
c.	More than 0.3 m (1 ft) below the lower ice waterline.	0 (32)	0 (32)	0 (32)	0 (32)

Notes:

1 Includes bulkheads and decks attached to the external plating within 600 mm (23.5 in.) from the plating.

2 Excludes those portions covered by Note 1 above.

3 Above Area c for class **D0** excluding the bow area.

35.5 Material Class of Structural Members

The material class of hull structural members is to be in accordance with 6-1-1/Table 16.

TABLE 16
Material Class of Structural Members *(2010)*

Material class given in this table refers to the classes in 6-1-1/Table 17 or in 6-1-1/35.9, as applicable.

Structural Members		*Ice Classes*	
		***A0** and above*	***B0** and below*
a.	Within Ice Belt (other than Area c)		
	1. Bottom and side shell plating-bow, intermediate and lower intermediate areas	III	I
	2. Bottom and side shell plating-other ice belt areas	II	I
	3. Framing (1) – bow and intermediate areas	II	I
	4. Framing (1) – other ice belt areas	I	I
	5. Stem, ice knife, propeller nozzle, shaft bracket, rudder, stern frame and rudder horn	III	I
	6. Other structures	I	I
b.	Above Ice Belt		
	1. Sheer strake and deck stringer		
	i) within 0.4*L* amidships	III	III
	ii) outside 0.4*L* amidships	II	II
	2. Side shell (4) and strength deck plating (2),(3)(5)	I	I
	3. Other structures (2),(3)	I	I
c.	More than 0.3 m (1 ft) below the lower ice waterline.	No additional requirements for ice class. See 3-1-2/Table 2	

Notes:

1 Includes bulkheads and decks attached to the external plating within 600 mm (23.5 in.) from the plating.

2 Excludes those portions covered by Note 1 above.

3 Above Area c for class **D0** excluding the bow area.

4 *(2010)* Single side strakes for ships exceeding 150 m (492 ft) without inner continuous longitudinal bulkheads between bottom and the single strength deck are not to be less than grade B/AH within cargo region in ships.

5 *(2010)* Not to be less than grade B/AH within 0.4*L* amidships in ships with length exceeding 150 m (492 ft) and single strength deck.

35.7 Criteria for ABS Grade Steels

For those rolled steel products in 2-1-2/Table 5 or 2-1-3/Table 5, the appropriate grade to be used for respective material class and thickness is shown in 6-1-1/Table 17a through 6-1-1/Table 17c. Where 3-1-2/3 results in a higher grade, such higher grade is to be used.

TABLE 17a
Material Grades – Class I

	Design Service Temperature				
Thickness in mm (in.)	*0°C (32°F)*	*-10°C (14°F)*	*-20°C (-4°F)*	*-30°C (-22°F)*	*-40°C (-40°F)*
$t < 12.5$ ($t < 0.50$)	A,AH	A,AH	A,AH	A,AH	B (2),AH
$12.5 < t \le 20$ ($0.50 < t \le 0.79$)	A,AH	A,AH	A,AH	B,AH	D,DH
$20 < t \le 25$ ($0.79 < t \le 0.98$)	A,AH	A,AH	B,AH	D,DH	D (1),DH (1)
$25 < t \le 30$ ($0.98 < t \le 1.18$)	A,AH	A,AH	D,DH	D,DH	E,EH
$30 < t \le 35$ ($1.18 < t \le 1.38$)	A,AH	B,AH	D,DH	D,DH	E,EH
$35 < t \le 40$ ($1.38 < t \le 1.57$)	A,AH	D,DH	D,DH	D,DH	E,EH
$40 < t \le 51$ ($1.57 < t \le 2.00$)	B,AH	D,DH	D,DH	D,DH	E,EH

Notes:

1 To be normalized.

2 May be “A” if fully killed.

TABLE 17b
Material Grades – Class II

	Design Service Temperature				
Thickness in mm (in.)	*0°C (32°F)*	*-10°C (14°F)*	*-20°C (-4°F)*	*-30°C (-22°F)*	*-40°C (-40°F)*
$t \le 12.5$ ($t \le 0.50$)	A,AH	A,AH	A,AH	B [(2)],AH	D,DH
$12.5 < t \le 20$ ($0.50 < t \le 0.79$)	A,AH	A,AH	B,AH	D,DH	D [(1)],DH [(1)]
$20 < t \le 25$ ($0.79 < t \le 0.98$)	A,AH	B,AH	D,DH	D [(1)],DH [(1)]	E,EH
$25 < t \le 30$ ($0.98 < t \le 1.18$)	A,AH	B,AH	D,DH	E,EH	E,EH
$30 < t \le 35$ ($1.18 < t \le 1.38$)	B,AH	D,DH	D,DH	E,EH	E,EH
$35 < t \le 40$ ($1.38 < t \le 1.57$)	B,AH	D,DH	D,DH	E,EH	E,EH
$40 < t \le 51$ ($1.57 < t \le 2.00$)	D,DH	D,DH	D,DH	E,EH	E,EH

Notes:

1 To be normalized.

2 May be A if fully killed.

TABLE 17c
Material Grade – Class III

	Design Service Temperature				
Thickness in mm (in.)	*0°C (32°F)*	*-10°C (14°F)*	*-20°C (-4°F)*	*-30°C (-22°F)*	*-40°C (-40°F)*
$t < 12.5$ ($t < 0.50$)	A,AH	A,AH	B [(2)],AH	D,DH	D [(1)],DH [(1)]
$12.5 < t \le 20$ ($0.50 < t \le 0.79$)	A,AH	B,AH	D,DH [(1)]	D [(1)],DH [(1)]	E,EH
$20 < t \le 25$ ($0.79 < t \le 0.98$)	B,AH	D,DH	D [(1)],DH [(1)]	E,EH	E,EH
$25 < t \le 30$ ($0.98 < t \le 1.18$)	B,AH	D,DH	E,EH	E.EH	E,EH
$30 < t \le 35$ ($1.18 < t \le 1.38$)	D,DH	D,DH	E,EH	E,EH	—
$35 < t \le 40$ ($1.38 < t \le 1.57$)	D,DH	D,DH	E,EH	E,EH	
$40 < t \le 51$ ($1.57 < t \le 2.00$)	D,DH	D,DH	E,EH	E,EH	

Notes:

1 To be normalized.

2 May be A if fully killed.

35.9 Criteria for Other Steels

35.9.1 Yield Strength Below 410 N/mm^2, (42 kgf/mm^2, 60 ksi)

Where steels other than those in 2-1-2/Table 5 or 2-1-3/Table 5 are intended, their specifications are to be submitted for approval. These steels are to comply with the following impact test requirements:

Yield Strength		
N/mm^2	*(kgf/mm^2)*	*(ksi)*
235-305	(24-31)	(34-44)
315-400	(32-41)	(45.5-58)

CVN (Longitudinal)		
J	*(kgf-m)*	*(ft-lbf)*
27	(2.8)	(20)
34	(3.5)	(25)

At the following temperatures:

Class I – design service temperature

Class II – 10°C (18°F) below design service temperature

Class III – 20°C (36°F) below design service temperature

35.9.2 Yield Strength 410-690 N/mm² (42-70 kgf/mm², 60-100 ksi)

Where steels of this strength level are intended, their specifications are to be submitted for approval. These steels are to comply with the impact test requirements of 34 J (3.5 kgf-m, 25 ft-1bf) at the following temperatures:

Design Service Temperature	*Test Temperature*
0°C (32°F)	-30°C (-22°F)
-10°C (14°F)	-40°C (-40°F)
-20°C (-4°F)	-40°C (-40°F)
-30°C (-22°F)	-50°C (-58°F)
-40°C (-40°F)	-60°C (-76°F)

35.9.3 Alternative Requirements

As an alternative to the requirements in 6-1-1/35.9.1 and 6-1-1/35.9.2, higher strength steels may comply with the following:

i) For transverse specimens, $^{2}/_{3}$ of energy values shown in 6-1-1/35.9.1

ii) For longitudinal specimens, lateral expansion is not to be less than 0.5 mm (0.02 in.). For transverse specimens, lateral expansion is not to be less than 0.38 mm (0.015 in.).

iii) Nil-ductility temperature (NDT), as determined by drop weight tests, is to be 5°C (9°F) below the temperature specified in 6-1-1/35.9.1.

35.11 Weld Metal

35.11.1 ABS Hull Steels

When the ABS ordinary and higher strength hull steels of 2-1-2/Table 5 or 2-1-3/Table 5 are applied in accordance with 6-1-1/Table 17a through 6-1-1/Table 17c, approved filler metals appropriate to the grades shown in Part 2, Appendix 3 may be used.

35.11.2 Criteria for Other Steels

For the welding of hull steels other than the ABS grades in 6-1-1/Table 17, weld metal is to exhibit a Charpy V-Notch toughness value at least equivalent to the transverse base metal requirements ($^{2}/_{3}$ of longitudinal base metal requirements).

35.13 Inspection

In addition to the nondestructive inspection requirements of the other sections of the Rules, all intersections of full penetration welds within the ice belt structure, except the upper area of ice class vessels **A2** to **A5**, are to be inspected by radiographic or ultrasonic methods and are to meet the Class A requirements of the ABS *Rules for Nondestructive Inspection of Hull Welds*. Additional inspections may also be required by the Surveyor for other locations.

37 Weld Design *(1997)*

Weld design of hull construction is to comply with Section 3-2-19. Special attention is to be paid to welds in structures attached to side shell, such as transverse bulkheads, decks, frames, web frames and side shell stringers, within the ice belt, which are to be of double continuous weld.

39 Towing Arrangements

39.1 Bow

Every ice class vessel intended to be escorted by a higher ice class leading vessel, as given in 6-1-1/Table 1, is to be fitted with a tow chock pipe and a tow bitt on the bow. The chock and the bitt are to be properly connected to the stem frame. The portions of the decks at which the chock and the bitt are attached are to meet requirements of 6-1-1/25. The shell plating and framing below and 1.5 m (5 ft) around the chock are to be as required by 6-1-1/13 and 6-1-1/15 for the bow area of the ice belt for ice classes **A0**, **B0**, **C0** and **D0** and for the intermediate area of the ice belt for ice classes **A4** through **A1** and where coefficient C = 0.5. The stem frame below the connections with the chock is to be as required by 6-1-1/29.3 for the portion of the stem within the ice belt.

Where a bulbous bow is fitted, the bulb is not to extend beyond the fore end of the lower ice waterline specified by 6-1-1/5.5.

39.3 Stern

Vessels of ice classes **A5** through **A1** intended to be used as leading vessels assisting passage of a lower ice class vessel as specified by 6-1-1/Table 1 are to be equipped with a towing system. Both the arrangement of the towing system and the shape of the stern are to be suitable for towing the assisted vessel in immediate contact. The portion of the upper deck at which the towed vessel can contact is to be as required by 6-1-1/25. The shell plating and framing adjacent to this portion of the upper deck are to be as required by 6-1-1/13 and 6-1-1/15 for the stern area of the ice belt.

41 Propeller Nozzles

41.1 General

This Subsection applies to fixed nozzles. Special consideration will be given to steering nozzles for ice classes **A5** through **A0**. For ice classes **A5** through **A0**, the nozzles are to be supported at least at the upper and lower ends. For ice classes **B0**, **C0** and **D0**, the nozzles supported only at the upper ends are to be attached to the hull for a width of not less than $^1/_6$ of the outer circumference of the nozzle. The strength, rigidity and resistance to buckling of the nozzle are to be adequate for the design ice forces given in 6-1-1/41.3. All of the critical loading cases are to be considered. In no case under the design ice forces are the normal and axial displacements of the inside ring to exceed 10% of the clearance between the inside plating of the nozzle and the propeller blade tips, or 0.5% of the inside ring diameter, whichever is less. Nozzles are to be protected by stern structures as much as possible against direct impacts with large ice features.

41.3 Design Ice Forces

The design ice forces are to be not less than those obtained from the following equations:

$$F_n = K_1 K_2 (D\, d_1)^{1/2} \quad \text{kN (tf, Ltf)}$$

$$F_f = K_3 K_4 [D\, (d_1 - d_2)]^{1/2} \quad \text{kN (tf, Ltf)}$$

where

F_n = the design ice force applied normal to the outside surface of the nozzle in the most critical location

K_2	=	1	for the external sides of a single nozzle of a single screw vessel
	=	1.1	for the outboard external sides of the outermost nozzles of vessels with two or more screws
	=	0.25	for the external sides of nozzles situated between the outermost ones and for the internal sides of any nozzles
	=	0.8	for bottoms of the nozzles

D = ship displacement, in tonnes (long tons), as specified in 6-1-1/5.7

d_1 = maximum outer diameter of the nozzle, in m (ft)

d_2 = minimum internal diameter of the nozzle, in m (ft)

F_f = the design ice force applied to the ends of the nozzle, parallel to the propeller axis, in the most critical locations

K_4 = 1 for aft end face of the nozzle having no rudder behind

= 0.7 for the aft end face of the nozzle with a rudder behind

= 0.6 for the fore end face of the nozzle

K_1 and K_3 are as given in 6-1-1/Table 18.

Values of K_2 and K_4 less than above will be approved, provided the stern and bottom hull structures effectively protect the nozzle against large ice fragments.

TABLE 18
Design Ice Force Coefficient

Ice Class	K_1	K_3
	SI units (MKS, US)	*SI units (MKS, US)*
A5	55 (5.6, 3.1)	294 (30.0, 16.4)
A4	53 (5.4, 3.0)	286 (29.2, 16.0)
A3	49 (5.0, 2.7)	243 (24.8, 13.6)
A2	43 (4.4, 2.4)	188 (19.2, 10.0)
A1	32 (3.3, 1.8)	110 (11.2, 6.1)
A0	20 (2.1, 1.1)	59 (6.0, 3.3)
B0	13 (1.3, 0.7)	35 (3.6, 2.0)
C0	9 (0.9, 0.5)	22 (2.2, 1.2)
D0	7 (0.7, 0.4)	18 (1.8, 1.0)

41.5 Plate Thickness

The plate thickness of both inner and outer surfaces of the nozzle is to be not less than required by 6-1-1/13.1 for the stern ice belt area with coefficient $C = 0.3$. A value of $C = 0$ will be considered for a high abrasion-resistant coating of the nozzle. In this case, the results of operational experience information, required in the note to 6-1-1/Table 7, are to be submitted.

43 Rudder and Steering Arrangements

43.1 General *(1993)*

43.1.1 All Ice Classes, Multiple Rudders

Where two or more rudders are provided, they are to be mechanically independent.

43.1.2 Ice Classes **A5** through **A0** *(2003)*

43.1.2(a) Pintles. Rudders are to have at least two pintles.

43.1.2(b) Locking. Rudders are to be protected by strong and effective external rudder stops and provided with mechanical means of locking the rudder parallel to the centerline for use in the astern condition.

43.1.3 Ice Classes **A5** through **B0** *(2003)*

43.1.3(a) Ice Knife. Rudders are to be protected by ice knives or other similar structures located abaft the rudder. Clearance between the ice knife and the rudder is not to exceed 100 mm (4 in.)

43.3 Rudder Stocks, Couplings and Pintles *(1993)*

43.3.1 Ice Classes **A5** through **A1** *(2003)*

In addition to the requirements in Section 3-2-14, the rudder stocks, couplings and pintles are to meet the ice strengthening requirements, using equations in Section 3-2-14 in association with V_i, A_i and r_i, as defined below, in lieu of V, A, A_1, A_2, r, r_1, and r_2.

V_i = the greater of V, as defined in Section 3-2-14, or the minimum design speed in 6-1-1/Table 19

A_i = that part of the total projected area, A, A_1 or A_2, as defined by Section 3-2-14, that is abaft the rudder stock centerline

r_i = distance from the centerline of the rudder stock to the centroid of A_i

43.3.2 Ice Classes **A0** through **D0** *(2003)*

For ice classes **A0** through **D0**, rudder stocks, pintles, gudgeons and other bolting arrangements to the stern frames are to meet the requirements in Section 3-2-14 in association with V_i, as specified in 6-1-1/43.3.1.

TABLE 19
Design Speed for Rudders, Couplings and Pintles *(2003)*

Ice Class	*Minimum Design Speed, knots*
A5	29
A4	29
A3	28
A2	26
A1	23
A0	20
B0	18
C0	16
D0	14

43.3.3 Ice Classes **A5** through **A0**

The stresses in these members with the load F applied as follows are not to exceed the shear yielding strength which may be taken as 0.577 times the specified yield point of the material.

$$F = 2K_3(Dt)^{1/2} \quad \text{kN (tf, Ltf)}$$

where

K_3 = as given in 6-1-1/Table 18

D = ship displacement, in tonnes (long tons), as specified in 6-1-1/5.7

t = thickness of the rudder, in m (ft), measured at the level of F and at 10% of the rudder length from the trailing edge.

F is to be applied to the after edge of the rudder in a direction parallel to the centerline of the vessel at all locations below the ice waterline within the middle 40% of the rudder height to determine the most severe requirements. Alternatively, F may be spread over any 60% of the rudder height as a uniform load. No other force need be considered simultaneously with F.

43.5 Double Plate Rudder

For double plate rudders, the minimum thickness of plates is to be not less than required by 6-1-1/41.5

45 Bossings

The bossings are to be designed to withstand the design ice forces F_n, as specified by 6-1-1/41.3, where d_1 is the diameter of the bossing. The bossing plating thickness is to be not less than required by 6-1-1/13.3 for the stern ice belt area, where s is the distance between stiffeners.

47 Machinery Arrangements

47.1 General

All machinery is to be suitable for operation under the environmental conditions to which it will be exposed in service and is to include all necessary special provisions for that purpose.

47.3 Governmental Authority

Attention is directed to the appropriate governmental authorities in the intended regions of operation for additional requirements in consideration of operation in ice such as fuel capacity, refueling capability, water capacity, radio communications requirements, etc.

47.5 Propulsion Arrangements

In addition to the regular governor, all propulsion engines and turbines are to be fitted with a separate overspeed device so adjusted that the speed cannot exceed the maximum rated speed by more than 20%.

47.7 Electric Propulsion

Propulsion motors are to be fitted with automatic protection against excessive torque, overloading and temperature. This protection is to automatically limit these parameters, but is not to cause loss of propulsion power.

47.9 Boilers

Vessels propelled by steam machinery are to be fitted with at least two boilers of equal capacity.

47.11 Protection Against Excessive Torques

For vessels of all classes, if torsionally flexible couplings or torque-limiting devices are fitted in the propulsion system, positive means are to be provided for transmitting full torque to the propeller in the event of failure of the flexible element. Ratings for flexible couplings are to be in accordance with 6-1-1/59. In addition, for vessels of classes **A5** through **A2**, couplings of the elastomer-in-shear type are not to be fitted in those portions of the propulsion system which are subject to shock loading from the propeller.

47.13 Vibration Analysis

Special consideration is to be given to ice-induced vibrations of the power train system for ice classes **A1** and above.

47.15 Sea Chests

For vessels of Ice Class **A0**, **B0**, **C0** and **D0**, at least one sea chest for supplying water for cooling and fire-fighting purposes is to be connected to the cooling-water discharge by a branch pipe having the same cross sectional area as the main pipe-line, in order to stay free from ice and slush ice. As far as practicable, the sea inlet chest is to be situated well aft, adjacent to the keel.

47.17 Cooling Water Arrangements

The following apply to vessels of ice classes **A5** through **A1**.

47.17.1 Sea Bay or Tank

The suctions for cooling water for all machinery essential to the propulsion of the vessel and for fire-fighting purposes are to be taken from a sea bay or tank located as close as practicable to the keel. The sea bay or tank is to be supplied with water from at least two independent sea suctions with at least one on each side of the hull. The area of each sea suction opening is to be not less than six times the total cross-sectional area of all pump suctions connected to the sea bay.

47.17.2 Sea Suctions

Suitable strainers are to be provided between the sea suctions and the sea bay. Valves are to be provided to permit isolation of the strainers, both from the sea suctions and from the sea bay. The cross-sectional area of such valves and strainers and associated piping for each sea suction is not to be less than the total cross-sectional area of all pump suctions connected to the sea bay.

47.17.3 Sea Water Pumps

Each sea water pump serving machinery essential to the propulsion of the vessel is to draw sea water directly from the sea bay. Design flow velocity in any suction line is not to exceed 2 m (6.6 ft) per second.

47.17.4 Cooling Water Recirculation

The discharge line from the cooling system is to be provided with suitable piping, valves and fittings to permit the discharge flow to be recirculated. The recirculation piping is to connect with the suction piping at a point on the seaward side of the strainer sea shut-off valves. Piping, valves and fittings for the recirculation line are to be of at least the same cross-sectional area as the overboard discharge line.

47.19 Starting-air System *(1996)*

For vessels of Ice Class **A5** through **A1**, in addition to the applicable requirements of 4-6-5/9, starting-air systems are to comply with the following.

i) At least two independently driven starting-air compressors are to be provided. The total capacity of the compressors is to be sufficient to charge the air receiver from empty to maximum pressure in not more than 30 minutes.

ii) The smallest of the starting air compressors is to have not less than two-thirds the capacity of the largest.

49 Materials for Propellers and Propulsion Shafting

Propeller materials are to be in accordance with the applicable requirements of 4-3-3/3 and 2-3-14/5.

In addition to the applicable requirements of 4-3-2/3, the material used in propulsion shafting is to have a Charpy V-notch impact value of not less than 20.5 J (2.1 kgf-m, 15 ft-lbf) at a temperature of -10°C (14°F) for all ice classes, except ice class **D0**. The propulsion shafts and couplings are to be made of steel.

51 Determination of Ice Torque for Propulsion Systems

The Ice Torque M for determining the dimensions of propellers and gears is to be in accordance with 6-1-1/Table 20 and associated notes. It is expected that a dynamic analysis of ice loads be carried out on classes **A5** through **A2**. The use of ice torques based on these analyses will be subject to special consideration.

53 Propellers

53.1 Propeller Arrangements

Propeller arrangements, the shape of the stern and the propeller protecting structures are to be adequate for the intended service. Special consideration is to be given to the propeller protection when moving astern. For **A5** through **A1** ice class vessels, the following condition is to be complied with.

$$0.5B_x - b_x \geq kd$$

where

B_x = breadth of the lower ice waterline, as defined in 6-1-1/5.5, at the hull section in way of the propeller tips, in m (ft)

b_x = distance from the vessel centerline to the outermost propeller blade tip, in m (ft)

k = 0.25 for unducted propellers

= 0.10 for ducted propellers

d = propeller diameter, in m (ft)

TABLE 20
Value of Ice Torque M

Location of Propeller	*Centerline*	*Off Centerline*
Propellers protected by nozzle		
Nozzle protected (see Note 1)		
class **A5**-**B0**	$0.75M_1$ (see Note 2)	$0.85M_1$ (see Note 2)
class **C0**-**D0**	$0.85M_1$	$0.9M_1$
Nozzle unprotected		
class **A5**-**C0**	$0.9M_1$ (see Note 3)	$0.9M_1$ (see Note 3)
class **D0**	$0.9M_1$	$0.9M_1$
Open propellers		
class **A5**-**A2**	M_{12}	$1.1M_{12}$ (see Note 4)
class **A1**-**D0**	M_1	M_1

M_1 = mD^2, in kN-m (tf-m, Ltf-ft)

M_2 = kN/R, in kN-m (tf-m, Ltf-ft)

M_{12} = the greater of M_1 or M_2

m, k = value from 6-1-1/Table 21

D = propeller diameter, in m (ft)

N = power at the maximum continuous rating, in kW (metric hp, British hp)

R = RPM at the maximum continuous rating

Notes

1 These requirements apply where the nozzle is well protected by ice knives, fins or other adequate stern arrangement from large ice fragments entering into nozzle from forward or backward motion of the vessel. These reductions are subject to special consideration.

2 To be not less than required for the second lower ice class.

3 To be not less than required for the next lower ice class.

4 Need not be greater than required for next higher ice class.

TABLE 21
Values of m and k

Ice Class	*m SI units*	*MKS units*	*US units*	*k SI units*	*MKS units*	*US units*
A5	37.3	3.80	1.14	20.8	1.56	5.11
A4	35.4	3.60	1.08	19.1	1.43	4.68
A3	30.4	3.10	0.93	16.4	1.23	4.03
A2	25.5	2.60	0.78	14.0	1.05	3.44
A1	20.6	2.10	0.63	—	—	—
A0	15.7	1.60	0.48	—	—	—
B0	13.0	1.33	0.40	—	—	—
C0	12.1	1.23	0.37	—	—	—
D0	11.1	1.13	0.34	—	—	—

53.3 Propeller Section

53.3.1 Width and Thickness

The thickness T and width W of propeller blade sections are to be obtained from the following equations:

- *At the 0.25 radius for solid propellers*

$$WT^2 = [a_1/U(0.65 + 0.7P_{0.25})]\,[(a_2CN/nR) + a_3M] \quad \text{cm}^3\ (\text{in}^3)$$

- *At the 0.35 radius for solid propellers with hubs larger than 0.25 propeller diameter*

$$WT^2 = [a_4/U(0.65 + 0.7P_{0.35})]\,[(a_2CN/nR) + a_5M] \quad \text{cm}^3\ (\text{in}^3)$$

- *At the 0.35 radius for controllable-pitch propellers*

$$WT^2 = [a_4/U(0.65 + 0.49P_{nominal})]\,[(a_2CN/nR)+a_5M] \quad \text{cm}^3\ (\text{in}^3)$$

- *At the 0.6 radius for solid propellers*

$$WT^2 = [a_6/U(0.65 + 0.7P_{0.6})]\,[(a_2CN/nR) + a_7M] \quad \text{cm}^3\ (\text{in}^3)$$

- *At the 0.6 radius for controllable-pitch propellers*

$$WT^2 = [a_6/U(0.65 + 0.49P_{nominal})]\,[(a_2CN/nR) + a_7M] \quad \text{cm}^3\ (\text{in}^3)$$

where

a_1 = 2650 (270, 27000)

a_2 = 272 (200, 176)

a_3 = 22.4 (220, 59.134)

a_4 = 2108 (215, 21500)

a_5 = 23.5 (230, 61.822)

a_6 = 932 (95, 9500)

a_7 = 28.6 (280, 75.261)

W = expanded width of a cylindrical section at the appropriate radius, cm (in.)

T = maximum thickness at the appropriate radius from propeller drawing, cm (in.)

U = tensile strength of propeller material, N/mm^2 (kgf/mm^2, psi)

P = pitch at the appropriate radius divided by the propeller diameter (for controllable-pitch propellers, the nominal value of pitch is to be used)

C = 1 for $N \le$ 7,460 kW (10,140 mhp, 10,000 hp)

= $0.667 + \dfrac{N}{22380}$ for 7,460 kW < N < 29,840 kW

= $0.667 + \dfrac{N}{30420}$ for 10,140 mhp < N < 40,560 mhp

= $0.667 + \dfrac{N}{30000}$ for 10,000 hp < N < 40,000 hp

= 2 for $N \ge$ 29,840 kW (40,560 mhp, 40,000 hp)

N = as defined in 6-1-1/9.1, per propeller

n = number of blades

R = rpm at the maximum continuous rating

M = ice torque, as defined in 6-1-1/51

53.3.2 Blade Tip Thickness *(1999)*

The minimum blade thickness t_a, in mm (in.), at the tip of the blade (D/2) is to be determined from the following equations:

- *For Classes **A5** through **A1***

$$t_a = (a_1 + a_2D)\sqrt{a_3 / U} \quad \text{mm (in.)}$$

- *For Classes **A0**, **B0**, **C0** and **D0***

$$t_a = (a_4 + a_2D)\sqrt{a_3 / U} \quad \text{mm (in.)}$$

where

a_1 = 20 (20, 0.787)

a_2 = 2 (2, 0.024)

a_3 = 490 (50, 71000)

a_4 = 15 (15, 0.591)

D = propeller diameter, m (ft)

U = tensile strength of the propeller material, N/mm^2 (kgf/mm^2, psi)

53.3.3 Blade Bolts

For built-up or controllable-pitch propellers, the cross sectional area of the bolts at the root of the thread is to be determined by the following equation:

$$\alpha = 0.082UWT^2/U_bnr$$

where

α = area of each bolt at root of thread, in mm^2 (in^2)

U = tensile strength of the propeller material, N/mm^2 (kgf/mm^2, psi)

U_b = tensile strength of the bolt material, N/mm^2 (kgf/mm^2, psi)

n = number of bolts on one side of blade (if n is not the same on both sides of the blade, the smaller number is to be used.)

r = radius of bolt pitch circle, in mm (in.)

W and T are as defined in 6-1-1/55, in mm (in.).

53.5 Additional Requirements

53.5.1 Rule Required Thickness

Where the blade thickness derived from the equations in 6-1-1/53.1 is less than the required thickness detailed in 4-3-3/5.1 through 4-3-3/5.7, the latter is to be used.

53.5.2 Other Sections

The thicknesses of propeller sections at radii intermediate to those specified are to be determined from fair curves connecting the required section thicknesses.

53.5.3 Blade Edges *(1999)*

The thickness of blade edges is not to be less than 50% of the required tip thickness t_a, measured at a point $1.25t_a$ from the leading edge for controllable-pitch propellers, and from each edge for solid propellers.

53.5.4 Controllable-pitch Propellers

The strength of the internal mechanisms of controllable-pitch propellers is to be at least 1.5 times that of the blade in the weakest direction of the blade for a load applied on the blade at the 0.9 radius and at an offset from the blade spindle axis equal to two-thirds the distance from the spindle axis to the leading or trailing edge (whichever is greater, as measured at the 0.9 radius).

53.5.5 Highly Skewed Propellers

Where highly skewed propellers are utilized, stress calculations considering both the ahead and astern operating conditions as well as the above ice loads are to be submitted for review.

53.7 Friction Fitting of Propeller Hubs and Shaft Couplings

Friction fitting of propeller hubs, shaft couplings or other torque transmitting components in those portions of the shaft line subject to shock loading from the propeller, is to have a factor of safety against slip considering both propulsion torque and ice torque of at least 2.4. Detailed stress and fitting calculations for all friction-fitted components are to be submitted for review. See 4-3-3/5.15.2(c).

55 Propulsion Shafting Diameters

The diameters of the propulsion shafts are to be not less than that obtained from the following equation:

$$d = k_o k_1 (WT^2 U/Y)^{1/3} \quad \text{cm (in.)}$$

where

d = diameter of the shaft being considered, measured at its aft bearing, cm (in.)

k_o = 1.05 for single-screw vessels of ice classes **A5**-**A3**

= 1.00 otherwise

k_1 = as given in 6-1-1/Table 22

W, T = actual values of the propeller blade width and thickness, defined in 6-1-1/53.3, and measured at the blade section at the 0.25 radius for solid propellers with the propeller hub not larger than 0.25D and at the 0.35 radius otherwise; in cm (in.)

U = tensile strength of the propeller material, N/mm^2 (kgf/mm^2, psi)

Y = yield strength of the shaft steel, N/mm^2 (kgf/mm^2, psi)

TABLE 22
Propulsion Shaft Diameter Factor k_1

	Solid Propellers with Hubs	
	Not Larger than 0.25D	*Larger than 0.25D and CPP's*
Tail shaft	1.08	1.15
Tube shaft	1.03	1.10
Intermediate shaft(s)	0.87	0.95
Thrust shaft	0.95	1.01

57 Reduction Gears *(2006)*

Pinions, gears and gear shafts are to be designed to withstand an increase in torque over that normally required for ice-free service. The following corrected ice torque (T_i) is to be utilized in Section 4-3-1.

$$T_i = T + C[MI_H R^2/(I_L + I_H R^2)]$$

where

T_i	=	ice corrected torque, N-m (kgf-cm, lbf-in)
T	=	torque corresponding to maximum continuous power, N-m (kgf-cm, lbf-in)
M	=	ice torque, as defined in 6-1-1/51, kN-m (tf-m, Ltf-ft)
I_H	=	sum of mass moment of inertia of machinery components rotating at higher rpm (drive side)
R	=	gear ratio (pinion rpm/gear wheel rpm)
I_L	=	sum of mass moment of inertia of machinery components rotating at lower rpm (driven side) including propeller with an addition of 30% for water
C	=	1000 (100,000, 26800)

I_H and I_L are to be expressed in the same units.

For calculations in Appendix 4-3-1A1, for diesel engine propulsion, $K_{Aice} = T_i/T$. If $K_{Aice} > K_A$ per 4-3-1A1/11, apply K_{Aice}. If $K_{Aice} < K_A$ per 4-3-1A1/11, apply K_A.

59 Flexible Couplings

Torsionally flexible couplings are to be selected so that the ice-corrected torque, as determined in 6-1-1/57, does not exceed the coupling manufacturer's recommended rating for continuous operation. When the rotating speed of the coupling differs from that of the propeller, the ice-corrected torque is to be suitably adjusted for the gear ratio. If a torque-limiting device is installed between the propeller and the flexible coupling, the maximum input torque to the torque-limiting device may be taken as the basis for selecting the coupling, in lieu of the ice-corrected torque. Flexible couplings which may be subject to damage from overheating are to be provided with temperature-monitoring devices or equivalent means of overload protection with alarms at each engine control station.

PART

6

CHAPTER 1 Strengthening for Navigation in Ice

SECTION 2 Baltic Ice Classes

1 General

1.1 Application

Vessels to be distinguished in the *Record* by **Ice Class** followed by ice class **I AA** through **I C**, as specified in 6-1-2/3.1 are to meet the applicable requirements of this Section.

All vessels so designated are to be self-propelled and equipped with a radio telephone (VHF).

1.3 Northern Baltic Waters *(1 September 2003)*

The ice strengthening requirements in this Section are in agreement with the *Finnish-Swedish Ice Class Rules 1985*, as amended, developed for vessels trading in the Northern Baltic in winter.

3 Assignment of Ice Class

3.1 Ice Class *(1 September 2003)*

The requirements in this Section are intended primarily for vessels operating in the Northern Baltic in winter and are assigned to ice classes as follows:

- **Ice Class I AA:** vessels whose structural strength in essential areas affecting their ability to navigate in ice essentially exceeds the requirements of Ice Class **I A** and which as regards hull form and engine output are capable of navigation under difficult ice conditions;
- **Ice Class I A, I B, I C:** according to ice strengthening and engine output, vessels which meet the requirements for navigation in ice as regards structural strength and engine output and are strengthened for navigation in ice;

The administrations of Sweden and Finland (hereafter called the Administrations) provide icebreaker assistance to vessels bound for their ports in winter. Depending on the ice conditions, restrictions by the administrations may apply to the size and ice class of the vessel.

3.3 General Suitability for Operating in Ice

Where no specific requirements are given, vessels are assumed to be normal seagoing cargo vessels of conventional proportions, hull form and propulsion arrangement. A vessel having very unconventional proportions, hull form or propulsion arrangement, or any other characteristics, may have a lower ice class assigned by the Administrations.

3.5 General Suitability for Winter Conditions

These requirements are primarily for the vessel's capability to advance in ice. When designing structures, equipment and arrangements essential for the safety and operation of the vessel, other problems that may be encountered are to be taken into account.

In particular, the functioning of hydraulic systems, the freezing of water piping and tanks, starting of emergency diesels, low temperature strength of materials, etc. are to be considered in conjunction with the expected air temperature which will be well below 0°C (32°F) for much of the time and may occasionally go down to about -30°C (-22°F).

5 Definitions

5.1 Ice Belt

The *Ice Belt* is the area over which the shell plating is required to be reinforced for navigation in ice, see 6-1-2/13.1 and 6-1-2/Figure 3.

5.3 Upper and lower Ice Waterlines *(1 July 2009)*

The upper ice waterline (UIWL) is to be the highest waterline at which the vessel is intended to operate in ice. The line may be a broken line.

The lower ice waterline (LIWL) is to be the lowest waterline at which the vessel is intended to operate in ice.

5.5 Main Frame

Main Frames are real, or in the case of longitudinal framing, imaginary transverse frames, whose spacing corresponds to that of the vessel clear of the ice strengthening area, or of the vessel if it were not ice-strengthened.

5.7 Propulsion Machinery Output

The *Propulsion Machinery Output*, P, is the maximum output in kW that the machinery can continuously deliver. If the output is restricted by technical means or by any regulations applicable to the vessel, P is to be taken as the restricted output.

7 Maximum and Minimum Draft Fore and Aft *(1 July 2009)*

The maximum and minimum ice class drafts at fore and aft perpendiculars are to be determined in accordance with the upper and lower ice waterlines.

Restrictions on drafts when operating in ice shall be documented and kept onboard readily available to the master. The maximum and minimum ice class drafts fore, amidships and aft are to be indicated in the classification certificate. For vessels built on or after 1 July 2007, if the summer load line in fresh water is located at a higher level than the UIWL, the vessel's sides are to be provided with a warning triangle and with an ice class draft mark at the maximum permissible ice class draft amidships (see Appendix 6-1-2A1).

Vessels built before 1 July 2007 are to be provided with such a marking, if the UIWL is below the summer load line, not later than the first scheduled dry docking after 1 July 2007. The draft and trim, limited by the UIWL, must not be exceeded when the vessel is navigating in ice. The salinity of the sea water along the intended route shall be taken into account when loading the vessel.

The vessel is to always be loaded down at least to the LIWL when navigating in ice. Any ballast tank, situated above the LIWL and needed to load down the vessel to this waterline, is to be equipped with devices to prevent the water from freezing. In determining the LIWL, regard is to be paid to the need for ensuring a reasonable degree of ice-going capability in ballast. The propeller is to be fully submerged, if possible entirely below the ice. The forward draft is to be at least:

$$d_f = (2 + 0.00025\Delta)h_o \quad \text{m}$$

$$d_f = (2 + 0.000254\Delta)h_o \quad \text{ft}$$

but need not exceed $4h_o$

where

Δ = displacement of the vessel, in metric tons (long tons), at the upper ice waterline (UIWL) amidships, as defined in 6-1-2/5.3

h_o = ice thickness, in m (ft), as defined in 6-1-2/11.5

9 Power of Propulsion Machinery *(1 September 2003)*

The minimum required engine output power P is to be determined in accordance with 6-1-2/9.1.2 and stated in the Classification certificate.

9.1 Propulsion Machinery Output, Ice Classes I AA, 1 A, I B and I C* *(1 September 2003)*

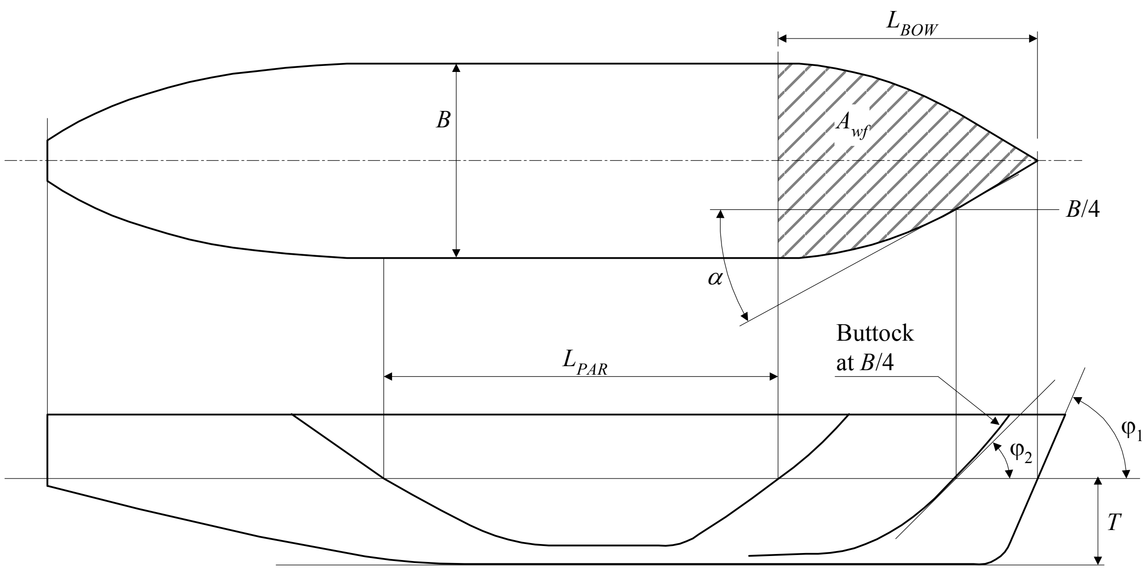
*(*NOTE: For reference purposes, the propulsion machinery output requirements for* ***I AA, I A, I B*** *and* ***I C*** *in the1985 Finnish-Swedish Ice Class Rules were amended as follows for vessels with the keel laid or which are at a similar stage of construction on or after 1 September 2003.)*

9.1.1 Definitions

The dimensions of the vessel are defined below in 6-1-2/Figure 1, and are measured on the maximum ice class draft.

L	=	length of the vessel between perpendiculars at the maximum draft, T, corresponding to the fresh water load line, m (m, ft)
L_{BOW}	=	length of the bow, m (m, ft)
L_{PAR}	=	length of the parallel midship body, m (m, ft)
B	=	maximum breadth of the vessel, m (m, ft)
T	=	actual ice class drafts of the vessel in accordance with 6-1-2/9.1.2. Drafts to be used are the maximum draft amidships corresponding to LWL and the minimum draft corresponding to BWL, m (m, ft)
A_{WL}	=	area of waterline of the bow, m^2 (m^2, ft^2)
H_F	=	thickness of the brash ice layer displaced by the bow, m (m, ft)
H_M	=	thickness of the brash ice in mid channel, m (m, ft)
α	=	the angle of the waterline at B/4, deg
φ_1	=	the rake of the stem at the centerline, deg
φ_2	=	the rake at the bow, at B/4, deg
D_P	=	diameter of the propeller, m (m, ft)

FIGURE 1
Vessels' Dimensions



9.1.2 Power Calculation

To be entitled to ice class **I AA**, **I A**, **I B** or **I C**, a vessel the keel of which is laid or which is at a similar stage of construction on or after 1 September 2003 is to comply with the following requirements regarding its engine output. The engine output is to be not less than determined by the formula below and in no case less than 1000 kW (1360 mhp; 1341 hp) for Ice Class **I A, I B** and **I C**, and not less than 2800 kW (3807 mhp; 3754 hp) for Ice Class **I AA**.

$$P = K_C \frac{(R_{CH}/1000)^{3/2}}{D_p} \quad \text{kW (mhp, hp)}$$

where K_C is to be taken as follows:

Propeller Type or Propulsion Machinery	*Controllable Pitch Propeller or Electric or Hydraulic Propulsion Machinery*			*Fixed Pitch Propeller*		
	SI Units	*MKS Units*	*US Units*	*SI Units*	*MKS Units*	*US Units*
1 propeller	2.03	84.76	83.79	2.26	94.37	93.29
2 propellers	1.44	60.13	59.44	1.6	66.81	66.04
3 propellers	1.18	49.27	48.71	1.31	54.70	54.07

R_{CH} is the resistance of the vessel in a channel with brash ice and a consolidated layer.

$$R_{CH} = C_1 + C_2 + C_3\, C_\mu (H_F + H_M)^2 (B + C_\varnothing H_F) + C_4 L_{PAR} H_F^2 + C_5 \left[\frac{LT}{B^2}\right]^3 \frac{A_{WL}}{L} \quad \text{N (kgf, lbf)}$$

where

C_μ = $0.15\cos\varphi_2 + \sin\psi\sin\alpha$, C_μ is to be taken equal or larger than 0.45

$C_\varnothing$ = $0.047\psi - 2.115$, and $C_\varnothing = 0$ if $\psi \le 45°$

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

H_F = $0.85 + (H_M B)^{0.5}$ ft

H_M = 1.0 m (3.28 ft) for Ice Class **I A** and **I AA**

= 0.8 m (2.62 ft) for Ice Class **I B**

= 0.6 m (1.97 ft) for Ice Class **I C**

The coefficients C_1 and C_2 take into account a consolidated upper layer of the brash ice and can be taken as zero for Ice Class **I A, I B and I C**.

For Ice Class **I AA**:

$$C_1 = f_1 \frac{BL_{PAR}}{(2T/B)+1} + (1 + 0.021\varphi_1)(f_2 B + f_3 L_{BOW} + f_4 B L_{BOW}) \quad \text{N (kgf, lbf)}$$

$$C_2 = (1 + 0.063\varphi_1)(g_1 + g_2 B) + g_3 (1 + 1.2T/B)\frac{B^2}{\sqrt{L}} \quad \text{N (kgf, lbf)}$$

For a vessel with a bulbous bow, φ_1 is to be taken as 90°.

	SI units	*MKS units*	*US units*
f_1	23 N/m^2	2.35 kgf/m^2	0.48 lbf/ft^2
f_2	45.8 N/m	4.67 kgf/m	3.138 lbf/ft
f_3	14.7 N/m	1.50 kgf/m	1.007 lbf/ft
f_4	29 N/m^2	2.96 kgf/m^2	0.61 lbf/ft^2
g_1	1530 N	156.02 kgf	343.96 lbf
g_2	170 N/m	17.34 kgf/m	11.649 lbf/ft
g_3	400 N/m$^{1.5}$	40.79 kgf/m$^{1.5}$	15.132 lbf/ft$^{1.5}$
C_3	845 N/m^3	86.2 kgf/m^3	5.38 lbf/ft^3
C_4	42 N/m^3	4.28 kgf/m^3	0.267 lbf/ft^3
C_5	825 N/m	84.1 kgf/m	56.5 lbf/ft

ψ = $\arctan[\tan \varphi_2/\sin \alpha]$ deg.

The following is to apply:

$$20 \geq \left[\frac{LT}{B^2}\right]^3 \geq 5$$

9.1.3 Other Methods of Determining K_C and R_{CH}

The Administration may for an individual vessel, in lieu of the K_C or R_{CH} values defined in 6-1-2/9.1 above, approve the use of K_C and R_{CH} values based on more exact calculations or values based on model test. Such an approval will be given on the understanding that it can be revoked if experience with the vessel's performance in practice motivates this.

The design requirement for ice classes is a minimum speed of 5 knots in the following brash ice channels:

I AA H_M = 1.0 m (3.28 ft) and a 0.1 m (0.328 ft) thick consolidated layer of ice

I A H_M = 1.0 m (3.28 ft)

I B H_M = 0.8 m (2.62 ft)

I C H_M = 0.6 m (1.97 ft)

11 Hull Structural Design

11.1 Application *(1 September 2003)*

The requirements for the hull scantlings are based on certain assumptions concerning the nature of the ice load on the structure. These assumptions are from full scale observations made in the Northern Baltic.

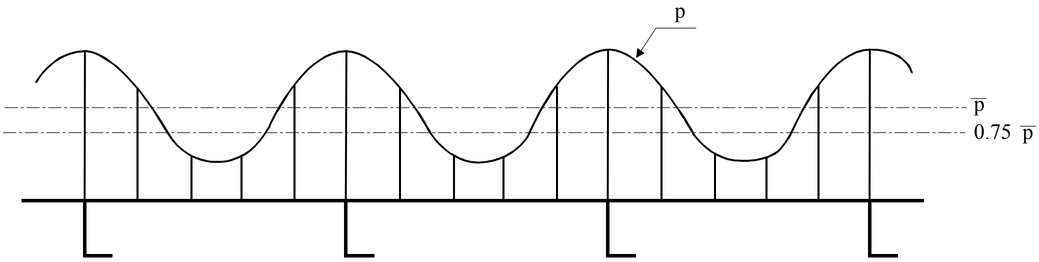
The local ice pressure on small areas can reach high values. This pressure may be well in excess of the normal uniaxial crushing strength of sea ice since the stress field is multi-axial.

It has also been observed that the ice pressure on a frame can be greater than on the shell plating at mid-spacing between frames. This is due to the different flexural stiffness of the frames and shell plating. The load distribution on the side structure is assumed to be as shown in 6-1-2/Figure 2.

As an alternative to the requirements of this Section, the hull structure may be obtained by direct engineering analysis subject to approval by the Administration.

Where the scantlings given by these requirements are less than those required by the Rules for a vessel unstrengthened for navigation in ice, the greater requirements are to apply.

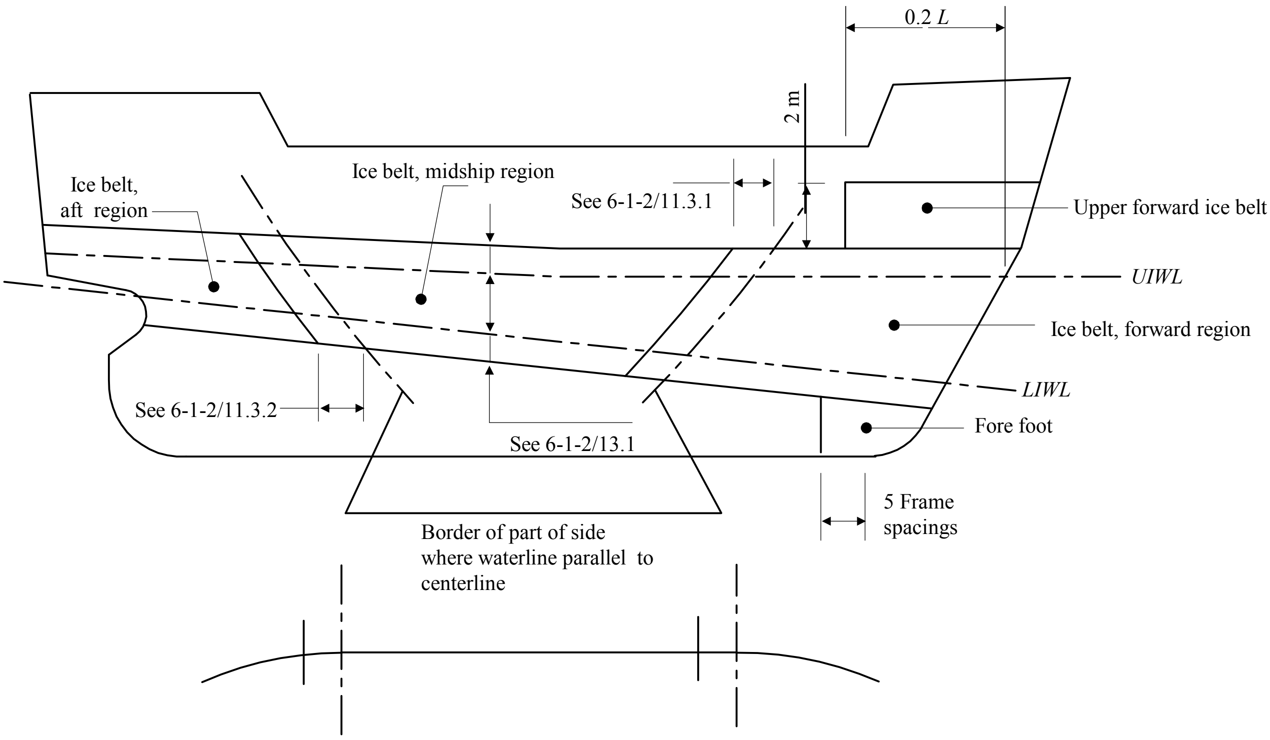
FIGURE 2
Ice Load Distribution on Ship's Side



11.3 Ice Strengthening Regions

For the application of this Section the vessel's ice belt is divided forward and aft into the following regions, see also 6-1-2/Figure 2.

FIGURE 3
Ice Strengthening Regions *(1 July 2009)*



11.3.1 Forward

From the stem to a line through the ice belt parallel to and 0.04*L* aft of the forward horizontal line of tangency of the parallel midbody, i.e., the forward end of the buttock line within the ice belt bounding the maximum beam. For ice classes **I AA** and **I A**, the overlap over the forward line of tangency need not exceed 6 m (19.7 ft); for ice classes **I B** and **I C**, this overlap need not exceed 5 m (16.4 ft).

11.3.2 Midship

From the aft boundary of the forward region to a line parallel to and 0.04*L* aft of the aft horizontal line of tangency of the parallel midbody, i.e., the aft end of the buttock line within the ice belt bounding the maximum beam. For ice classes **I AA** and **I A**, the overlap over the borderline need not exceed 6 m (19.7 ft); for ice classes **I B** and **I C**, this overlap need not exceed 5 m (16.4 ft).

11.3.3 Aft

From the aft boundary of the midship region to the stern.

11.5 Vertical Extent of Design Ice Pressure

An ice strengthened vessel is assumed to operate in open sea conditions with level ice thickness not exceeding h_o. The design height, h, of the area actually under ice pressure at any particular time is, however, assumed to be only a fraction of the ice thickness. The values for h_o and h are given in the following table:

Ice Class	h_o *m (ft)*	h *m (ft)*
I AA	1.0 (3.28)	0.35 (1.15)
I A	0.8 (2.62)	0.30 (0.98)
I B	0.6 (1.97)	0.25 (0.82)
I C	0.4 (1.31)	0.22 (0.72)

11.7 Design Ice Pressure *(1 July 2009)*

The design ice pressure is to be not less than given by the following equation:

$$p = c_d \cdot c_1 \cdot c_a \cdot p_o \quad \text{N/mm}^2 \text{ (kgf/mm}^2\text{, psi)}$$

where

c_d = a factor for the influence of the size and propulsion machinery output of the vessel

= $(ak + b)/1000$

k = $\sqrt{n\Delta P}/1000$

a and b are given in the following table:

	Region			
	Forward		*Midship & Aft*	
	$k \le 12$	$k > 12$	$k \le 12$	$k > 12$
a	30	6	8	2
b	230	518	214	286

n = 1.0 (1.0, 1.016)

Δ = displacement of the vessel, in metric tons (long tons), at the upper ice waterline (UIWL) amidships, as defined in 6-1-2/5.3

P = the actual continuous propulsion machinery output, in kW, as defined in 6-1-2/5.11

c_1 = factor for the probability that the design ice pressure occurs in a certain region of the hull for the particular ice class

The value of c_1 is given in the following table:

	Region		
Ice Class	*Forward*	*Midship*	*Aft*
I AA	1.0	1.0	0.75
I A	1.0	0.85	0.65
I B	1.0	0.70	0.45
I C	1.0	0.50	0.25

c_a = a factor for the probability that the full length of the area under consideration will be under pressure at the same time

c_a = $(47 - 5\ell_a)/44$, maximum 1.0, minimum 0.6 SI & MKS units

c_a = $(47 - 1.52\ell_a)/44$, maximum 1.0, minimum 0.6 US units

ℓ_a is as given in the following table:

Structure	*Type of framing*	ℓ_a *m (ft)*
Shell	Transverse	Frame spacing
	Longitudinal	2 times spacing of frame
Frames	Transverse	Frame spacing
	Longitudinal	Span of frame
Ice stringer		Span of stringer
Web frame		2 times spacing of web frames

p_o = the nominal ice pressure; the value 5.6 N/mm^2 (0.571 kgf/mm^2, 812 psi) is to be used

13 Shell Plating

13.1 Vertical Extent of Ice Strengthening

The vertical extension of the ice strengthening or the ice belt is given in the following table:

Ice class	*Above LWL m (ft)*	*Below BWL m (ft)*
I AA	0.6 (1.97)	0.75 (2.46)
I A	0.5 (1.64)	0.6 (1.97)
I B	0.4 (1.31)	0.5 (1.64)
I C	0.4 (1.31)	0.5 (1.64)

In addition, the following areas are to be strengthened:

13.1.1 Fore Foot

For ice class **I AA**, the shell plating below the ice belt from the stem to a position five main frame spaces abaft the point where the bow profile departs from the keel line is to be at least the thickness required for the ice belt in the midship region.

13.1.2 Upper Forward Ice Belt *(1 September 2003)*

For ice class **I AA** and **I A**, on vessels with an open water service speed equal to or exceeding 18 knots, the shell plating from the upper limit of the ice belt to 2 m (6.56 ft) above it and from the stem to a position at least 0.2*L* abaft the forward perpendicular is to be at least the thickness required for the ice belt in the midship region.

Side lights, side scuttles etc., are not to be situated in the ice belt. If the weather deck in any part of the vessel is situated below the upper limit of the ice belt, i.e., in way of the well of a raised quarter decker, the bulwark is to be given at least the same strength as is required for the shell in the ice belt. The strength of the construction of the freeing ports is to meet the requirements for the bulwark.

13.3 Ice Belt Plating Thickness *(2010)*

With transverse framing, the thickness of the shell plating is to be not less than given by the following equation:

$$t = a\,s\,\sqrt{f_1 P_{PL} / \sigma_y} + t_c \quad \text{mm (in.)}$$

With longitudinal framing, the thickness of the shell plating is to be not less than given by the following equation:

$$t = a\,s\,\sqrt{P_{PL} / f_2 \sigma_y} + t_c \quad \text{mm (in.)}$$

where

s	=	frame spacing, in m (ft)
P_{PL}	=	0.75 p, in N/mm^2 (kgf/mm^2, psi)
p	=	as given in 6-1-2/11.7
f_1	=	$1.3 - 4.2/[(h/s) + 1.8]^2$; maximum 1.0
f_2	=	$0.6 + 0.4/(h/s)$; when $h/s \le 1$
	=	$1.4 - 0.4\,(h/s)$; when $1 \le h/s < 1.8$
h	=	as given in 6-1-2/11.5, in m (ft)
σ_y	=	yield strength of the material, in N/mm^2 (kgf/mm^2, psi)
a	=	667 (8)

Use of steels with yield strengths greater than 390 N/mm^2 (40 kgf/mm^2, 56565 psi) are subject to special consideration.

t_c	=	increment for abrasion and corrosion, in mm (in.); normally, t_c is to be 2 mm (0.08 in.); however, if a special surface coating by experience is shown capable to withstand the abrasion of ice and is applied and maintained effective, lower values may be approved.

15 Framing

15.1 General

15.1.1 End Attachments

Within the ice strengthened area, all frames are to be effectively attached to all supporting structure by brackets (see 6-1-2/15.7). Frames are to be connected to transverse structure on both sides of the cut-out slots, i.e., the free edge of a slot is to be connected to the frame by a lug.

15.1.2 Frames

For Ice Class **I AA** throughout, for ice class **I A** in the forward and midship regions and for ice classes **I B** and **I C** in the forward region, the following is to apply.

15.1.2(a) Slanted frames. Frames not at right angles to the shell are to be supported against tripping by brackets, intercostals, stringers or similar at a distance preferably not exceeding 1300 mm (51 in.)

15.1.2(b) Welding. Frames are to be attached to the shell by double continuous welding. Scallops are to be avoided, except where frames cross shell plate butts.

15.1.2(c) Web Thickness. The web thickness of the frames is to be at least one half of the thickness of the shell plating, but not less than 9 mm (0.35 in.). Where a deck, tanktop or bulkhead replaces a frame, this thickness is to apply for a depth corresponding to the depth of the adjacent frame.

15.3 Vertical Extent of Ice Strengthening *(1 September 2003)*

The vertical extent of the ice strengthening of framing is to be at least as given in the following table:

Ice Class	*Region*	*Above LWL m (ft)*	*Below BWL m (ft)*
I AA	From stem to 0.3 *L* abaft stem	1.2 (3.94)	to double bottom or below top of floors
	Abaft 0.3 *L* from stem	1.2 (3.94)	1.6 (5.25)
	Midship	1.2 (3.94)	1.6 (5.25)
	Aft	1.2 (3.94)	1.2 (3.94)
I A, I B, I C	From stem to 0.3 *L* abaft stem	1.0 (3.28)	1.6 (5.25)
	Abaft 0.3 *L* from stem	1.0 (3.28)	1.3 (4.27)
	Midship	1.0 (3.28)	1.3 (4.27)
	Aft	1.0 (3.28)	1.0 (3.28)

Where an upper forward ice belt is required, see 6-1-2/13.1, the ice strengthening of the framing is to be extended at least to the top of this ice belt.

Where the ice strengthening would go beyond a deck or a tanktop by not more than 250 mm (9.8 in.), it may be terminated at that deck or tanktop.

15.5 Transverse Framing *(1 September 2003)*

15.5.1 Section Modulus

The section modulus, *SM,* of a main or intermediate frame is to be not less than that obtained from the equation:

$$SM = n[(psh\ell)/m_t\sigma_y] \quad \text{cm}^3 \text{ (in}^3\text{)}$$

where

n = 10^6 (1728)

σ_y = yield strength, as defined in 6-1-2/13.3, in N/mm^2 (kgf/mm^2, psi)

p = ice pressure, as given in 6-1-2/11.7, in N/mm^2 (kgf/mm^2, psi)

s = frame spacing, in m (ft)

h = height of load area, as given in 6-1-2/11.5, in m (ft)

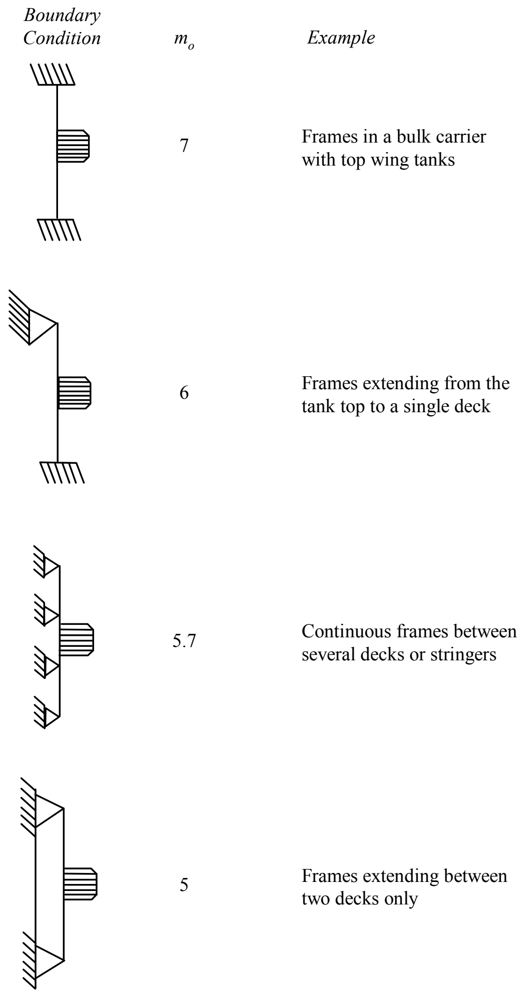
ℓ = span of the frame, in m (ft)

m_t = $7m_o/[7 - 5(h/\ell)]$

m_o values are given in 6-1-2/Figure 4a.

The boundary conditions shown are for the main and intermediate frames. Possible different conditions for the main frames are assumed to have been taken care of by interaction between the frames and are reflected in the m_o values. The load is considered applied at mid span. Where less than 15% of the span, ℓ, of the frame is situated within the ice-strengthening zone for frames as defined in 6-1-2/15.3, ordinary frame scantlings may be used.

FIGURE 4a
Web Frame Model



15.5.2 Upper End of Transverse Frames

The upper end of an ice-strengthened part of a main frame and of an intermediate ice frame is to be attached to a deck or ice stringer, see 6-1-2/17.

Where an intermediate ice frame terminates above a deck or ice stringer that is situated at or above the upper limit of the ice belt, see 6-1-2/13.1, the part above the deck or stringer may have scantlings as required for an unstrengthened vessel and the upper end of the frame may be connected to the adjacent main frames by a header of the same scantlings as the main frame. Such an intermediate frame can also be extended to the deck above and if this is situated more than 1.8 m (5.9 ft) above the ice belt, the intermediate frame need not be attached to that deck, except in the Forward Region.

15.5.3 Lower End of Transverse Framing

The lower end of an ice-strengthened part of a main frame and of an intermediate ice frame is to be attached to a deck, tanktop or ice stringer, see 6-1-2/17.

Where an intermediate ice frame terminates below a deck, tanktop or ice stringer which is situated at or below the lower limit of the ice belt, see 6-1-2/13.1, the lower end of the frame may be connected to the adjacent main frames by a header of the same scantlings as the main frame.

15.7 Longitudinal Framing

The section modulus, *SM,* of a longitudinal frame is to be not less than that obtained from the equation:

$$SM = n(f_3 f_4 ps\ell^2/m_1\ \sigma_y) \quad \text{cm}^3\ (\text{in}^3)$$

The shear area, *A*, is to be not less than that obtained from the equation:

$$A = k\ (\sqrt{3}\ \ f_3\, ps\ell/\sigma_y) \quad \text{cm}^2\ (\text{in}^2)$$

This is applicable only if the longitudinal frames are attached to the supporting structure by brackets* as required in 6-1-2/15.1.

f_3 = factor for the load distribution to adjacent frames

$f_3 = (1 - 0.2h/s)\ (h/s)$

f_4 = factor for the concentration of load to point of support;

$f_4 = 0.6$

p = ice pressure, as given in 6-1-2/11.7, in N/mm^2 (kgf/mm^2, psi)

h = height of load area, as given in 6-1-2/11.5, in m (ft)

s = frame spacing, in m (ft); the frame spacing is not to exceed 0.35 m (1.15 ft) for ice class **I AA** or **I A**, and is in no case to exceed 0.45 m (1.48 ft) *

n = 10^6 (1728)

k = 5×10^3 (72)

ℓ = span of frame, in m (ft)

m_1 = boundary condition factor; m_1 = 13.3 for a continuous beam.

σ_y = yield strength, as defined in 6-1-2/13.3, in N/mm^2 (kgf/mm^2, psi)

* *Alternatively, full compliance with the requirements as specified in the "Tentative Guidelines for Application of Direct Calculation Methods for Longitudinally Framed Hull Structure" issued by the Finnish Maritime Administration is considered to satisfy the Rule requirements.*

17 Ice Stringers

17.1 Stringers within the Ice Belt *(1 September 2003)*

The section modulus, *SM*, of a stringer within the ice belt, (see 6-1-2/13.1) is to be not less than that obtained from the equation:

$$SM = n(f_5\, ph\ell^2/m_s\ \sigma_y) \quad \text{cm}^3\ (\text{in}^3)$$

The shear area, *A,* is to be not less than that obtained from the equation:

$$A = k\ (\sqrt{3}\, f_6 ph\ell/\sigma_y) \quad \text{cm}^2\ (\text{in}^2)$$

where

p = ice pressure, as given in 6-1-2/11.7, in N/mm^2 (kgf/mm^2, psi)

h = height of load area, as given in 6-1-2/11.5, in m (ft)

n = 10^6 (1728)

The product ($p \times h$) is not to be taken as less than 0.3 SI units (0.0306 MKS units, 142.8 US units)

k = 5×10^3 (72)

ℓ = span of stringer, in m (ft)

m_s = boundary condition factor; m_s = 13.3 for a continuous beam

f_5 = factor for distribution of the load on the transverse frames;

= 0.9 may be used for normal construction, but f_5 may also be obtained from the following equation:

$f_5 = [1 - (d/118)]/[1 + (d/13)]$

d = $(\ell/\ell_f)^3\ (\ell/s_f)\ (I_f/I)$

ℓ_f = span of transverse frames, in m (ft)

s_f = frame spacing, in m (ft)

I = moment of inertia of stringer, in cm^4 (in^4)

I_f = moment of inertia of transverse frames, in cm^4 (in^4)

f_6 = factor for distribution of the load on the transverse frames; f_6 = 0.9 may be used for normal construction, but f_6 may also be obtained from the following equation:

$$f_6 = \frac{1 + \dfrac{d}{16}n}{1 + \dfrac{d}{13}}$$

n = number of transverse frames supported by the stringer

σ_y = yield strength, as defined in 6-1-2/13.3, in N/mm^2 (kgf/mm^2, psi)

17.3 Stringers Outside the Ice Belt

The section modulus, *SM,* of a stringer outside the ice belt that supports ice strengthened frames is to be not less than that obtained from the equation:

$$SM = \frac{f_7 \cdot p \cdot h \cdot \ell^2}{m_s \cdot \sigma_y}\left(1 - \frac{h_s}{\ell_s}\right) n \quad cm^3\ (in^3)$$

The shear area, *A,* is to be not less than that obtained from the equation:

$$A = \frac{\sqrt{3} f_8 \cdot p \cdot h \cdot \ell}{\sigma_y}\left(1 - \frac{h_s}{\ell_s}\right) k \quad cm^2\ (in^2)$$

where

p = ice pressure, as given in 6-1-2/11.7, in N/mm^2 (kgf/mm^2, psi)

h = height of load area, as given in 6-1-2/11.5, in m (ft)

n = 10^6 (1728)

The product ($p \times h$) is to be not taken as less than 0.3 SI units (0.0306 MKS units, 142.8 US units).

k = 5×10^3 (72)

ℓ = span of stringer, in m (ft)

m_s = boundary condition factor; m_s = 13.3 for a continuous beam

ℓ_s = the distance to the adjacent ice stringer, in m (ft)

h_s = the distance to the ice belt, in m (ft)

f_7 = factor for the load distribution on transverse frames.

$f_7 = (f_5 + 1)/2$

f_5 = as given in 6-1-2/17.1

f_8 = factor for the load distribution on transverse frames

$f_8 = (f_6 + 1)/2$

f_6 = as given in 6-1-2/17.1

σ_y = yield strength, as defined in 6-1-2/13.3, in N/mm^2 (kgf/mm^2, psi)

17.5 Deck Strips *(1 September 2003)*

The deck strips abreast of hatches serving as ice stringers are to comply with the section modulus and shear area requirements in 6-1-2/17.1 and 6-1-2/17.3, respectively. In the case of very long hatches, the product ($p \times h$) may be taken as less than 0.3 SI units (0.0306 MKS units, 142.8 US units), but in no case less than 0.2 SI units (0.0204 MKS units, 95.2 US units).

In designing weather deck hatch covers and their fittings, special attention is to be paid to the deflection of the vessel's sides due to ice pressure in way of very long hatch openings.

19 Web Frames

19.1 Design Ice Load

The design load, F, on a web frame from an ice stringer or from longitudinal framing may be obtained from the following equation:

$$F = n f_6 phS \quad \text{kN (tf, Ltf)}$$

where

n = 10^3 (0.0643)

f_6 = as given in 6-1-2/17.1 for loads from ice stringers and, for longitudinals, $f_6 = 1.0$

p = ice pressure, as given in 6-1-2/11.7, in N/mm^2 (kgf/mm^2, psi); in calculating c_a however, ℓ_a is to be taken as $2S$

h = height of ice load area, as given in 6-1-2/11.5, in m (ft)

The product ($p \times h$) is not to be taken as less than 0.3 SI units (0.0306 MKS units, 142.8 US units).

S = distance between web frames, in m (ft)

19.3 Section Modulus and Shear Area *(1 September 2003)*

When a web frame can be represented by the structural model shown in 6-1-2/Figure 4b, the section modulus and shear area may be obtained from the following equations:

- *Shear area*

$$A = (\sqrt{3})n(k_1)(F)(\alpha)/\sigma_y \quad \text{cm}^2 \text{ (in}^2\text{)}$$

where

k_1 = $1 + (1/2)(\ell_f/\ell)^3 - (3/2)(\ell_f/\ell)^2$ or

k_1 = $(3/2)(\ell_f/\ell)^2 - (1/2)(\ell_f/\ell)^3$ whichever is greater

For the lower part of the web frame, the smallest value of ℓ_f within the ice belt is to be used. For the upper part, the greatest value of ℓ_f within the ice belt is to be used.

n = 10 (2240)

α = as given in the Table below

σ_y = yield strength, as defined in 6-1-2/13.3, in N/mm^2 (kgf/mm^2, psi)

F = as in 6-1-2/19.1

- *Section modulus*

$$SM = nk_2F\ell/\sigma_y \sqrt{1-(\gamma A/A_a)^2} \quad \text{cm}^3 \ (\text{in}^3)$$

where

k_2 = $(1/2)(\ell_f/\ell)^3 - (3/2)(\ell_f/\ell)^2 + (\ell_f/\ell)$

γ = as given in the Table below

A = required shear area obtained using

$k_1 = 1 + (1/2)(\ell_f/\ell)^3 - (3/2)(\ell_f/\ell)^2$

A_a = actual cross sectional area of the web frame, in cm^2 (in^2)

n = 1000 (26880)

- *Factors α and γ*

A_f = cross section area of free flange, in cm^2 (in^2)

A_w = cross section area of web plate, in cm^2 (in^2)

A_f/A_w	0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
α	1.5	1.23	1.16	1.11	1.09	1.07	1.06	1.05	1.05	1.04	1.04
γ	0	0.44	0.62	0.71	0.76	0.80	0.83	0.85	0.87	0.88	0.89

For web frame configurations and boundary conditions other than as given above, a direct stress calculation is to be carried out.

The concentrated load on the web frame is to be as given in 6-1-2/19.1. The point of application is in each case to be chosen in relation to the arrangement of stringers and longitudinal frames so as to obtain the maximum shear forces and bending moments.

The allowable stresses are as follows:

- *Shear Stress*

$$\tau \le \sigma_y/\sqrt{3}$$

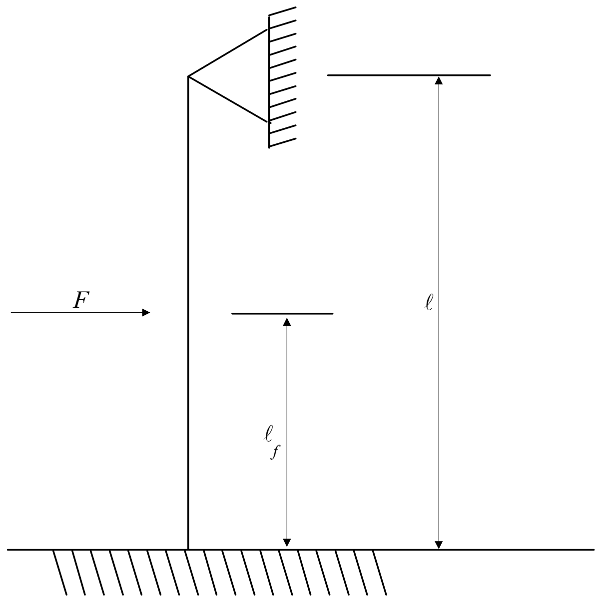
- *Bending Stress*

$$\sigma_b \le \sigma_y$$

- *Equivalent Stress*

$$\sigma_c = \sqrt{\sigma_b^{\,2} + 3\tau^2} \le \sigma_y$$

FIGURE 4b
Web Frame Model



21 Bow

21.1 Stem

The stem may be made of rolled, cast or forged steel or of shaped steel plates. A sharp edged stem, see 6-1-2/Figure 5, improves the maneuverability of the vessel in ice and is recommended particularly for smaller vessels with a length of less than 150 m (492.1 ft).

The thickness of a shaped plate stem and, in the case of a blunt bow, any part of the shell that forms an angle of 30 degrees or more with the center line in the horizontal plane, is to be obtained from the equation in 6-1-2/13.3 where

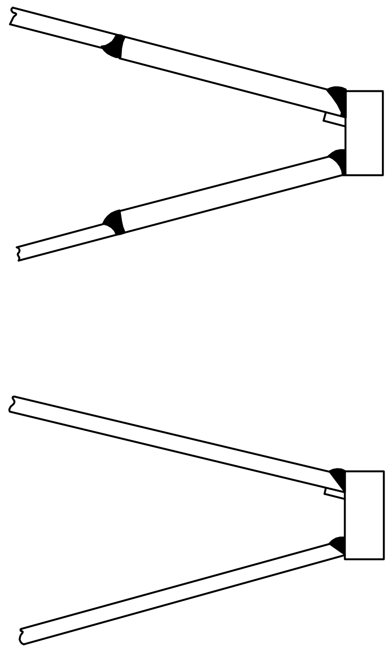
s = spacing of elements supporting the plate, in m (ft)

P_{PL} = p, in N/mm^2 (kgf/mm^2, psi), see 6-1-2/11.7

ℓ_a = spacing of vertical supporting elements, in m (ft)

The stem and that part of a blunt bow defined above is to be supported by floors, breasthooks or brackets spaced not more than 0.6 m (1.97 ft) apart and of a thickness at least half the shell plate thickness. This reinforcement of the stem is to extend from the keel to a point 0.75 m (2.46 ft) above *LWL*, or where an upper forward ice belt is required, see 6-1-2/13.1, to the upper limit of this upper forward ice belt.

FIGURE 5
Ice Stems



21.3 Arrangements for Towing

A mooring pipe with an opening not less than 250 mm (10 in.) by 300 mm (12 in.), a length of at least 150 mm (6 in.) and an inner surface radius of at least 100 mm (4 in.) is to be fitted in the bow bulwark at the centerline.

A bitt or other means for securing a towline, dimensioned to stand the breaking force of the towline of the vessel is also to be fitted. The deck in way of the bitt is to be suitably reinforced.

On vessels with a displacement not exceeding 30,000 metric tons (29,527 long tons), that part of the bow that extends to a height of at least 5 m (16.4 ft) above the *LWL* and at least 3 m (9.84 ft) aft of the stem is to be strengthened to take the stresses caused by fork towing. For this purpose, intermediate frames are to be fitted and the framing is to be supported by stringers or decks.

It is to be noted that, for vessels with a displacement not exceeding 30,000 metric tons (29,527 long tons), fork towing in many situations is the most efficient way of assisting in ice. Vessels with a bulb protruding more than 2.5 m (8.2 ft) forward of the forward perpendicular are often difficult to tow in this manner. The administrations reserve the right to deny assistance to such vessels if the situation so warrants.

23 Stern

An extremely narrow clearance between the propeller blade tip and the stern frame is to be avoided as this causes very high loads on the blade tips.

On twin and triple screw vessels, the ice strengthening of the shell and framing is to extend to the double bottom for 1.5 meters (4.92 ft) forward and aft of the side propellers.

Shafting and stern tubes of side propellers are to be normally enclosed within plated bossing. If detached struts are used, their design, strength and attachment to the hull is to be duly considered for ice loading.

A wide transom stern extending below the *LWL* will seriously impede the essential capability of the vessel to back in ice. Therefore a transom stern is not to be extended below the *LWL*, if this can be avoided. If unavoidable, the part of the transom stern situated within the ice belt is to be strengthened as for the midship region.

25 Bilge Keels

Bilge keels are prone to ice damage. The connection of bilge keels to the hull is to be so designed as to minimize the risk of damage to the hull in the case of a bilge keel being ripped off.

To limit damage when a bilge keel may be partly ripped off, it is recommended that bilge keels be fitted in several shorter independent lengths. The bilge keels are to comply with 3-2-2/13, except that the doubler may be either discontinuous with the bilge keel or continuous.

Special attention is to be given to details at the ends of the bilge keels. In general, the bilge keels are to terminate on an internal structural member in gradual *S* tapers and the shell doubler is to terminate in a reduced width taper with the end radiused.

27 Rudder and Steering Arrangements

27.1 Minimum Design Speed *(1993)*

The scantlings of rudder post, rudder stock, pintles, steering gear etc., as well as the capacity of the steering gear are to comply with Section 3-2-14 of the Rules. Where the design ahead speed of the vessel, as defined in 3-2-14/3.1, is less than the minimum speed indicated in the table below, the latter speed is to be used in lieu of *V* in Section 3-2-14.

Class	*Minimum Speed*
I AA	20 knots
I A	18 knots
I B	16 knots
I C	14 knots

For use with the minimum ahead speeds in the above table, k_c may be taken as 80% of that specified in Section 3-2-14. Also, k_1 for rudders situated behind nozzles need not be taken as greater than 1.0.

27.3 Double Plated Rudders

For double plated rudders, the minimum thickness of plates and horizontal and vertical webs in the ice-belt region is to be determined as for shell plating in the aft region in accordance with 6-1-2/13.

27.5 Rudder and Rudder Stock Protection

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

27.7 Overload Design

For ice classes **I AA** and **I A**, due regard is to be given to the excessive loads caused by the rudder being forced out of the midship position when backing into an ice ridge. Also, relief valves for hydraulic pressure are to be effective. The components of the steering gear are to be dimensioned to withstand the yield torque of the rudder stock. Where possible, rudder stops working on the blade or rudder stock are to be fitted.

29 Propulsion Machinery *(2010)*

29.1 Scope

Requirements 6-1-2/29 apply to propulsion machinery covering open- and ducted-type propellers with controllable pitch or fixed pitch design for the ice classes **I AA**, **I A**, **I B** and **I C**. The given loads are the expected ice loads for the whole ship's service life under normal operational conditions, including loads resulting from the changing rotational direction of FP propellers. However, these loads do not cover off-design operational conditions, for example when a stopped propeller is dragged through ice. The requirements also apply to azimuthing and fixed thrusters for main propulsion, considering loads resulting from propeller-ice interaction. However, the load models do not include propeller/ice interaction loads when ice enters the propeller of a turned azimuthing thruster from the side (radially) or load case when ice block hits on the propeller hub of a pulling propeller. Ice loads resulting from ice impacts on the body of thrusters have to be estimated, but ice load formulae are not available.

29.3 Symbols

c = chord length of blade section, m (ft)

$c_{0.7}$ = chord length of blade section at $0.7R$ propeller radius, m (ft)

CP = controllable pitch

D = propeller diameter, m (ft)

d = external diameter of propeller hub, m (ft)

D_{limit} = limit value for propeller diameter, m (ft)

EAR = expanded blade area ratio

F_b = maximum backward blade force for the ship's service life, kN (kgf, lbf)

F_{ex} = ultimate blade load resulting from blade loss through plastic bending, kN (kgf, lbf)

F_f = maximum forward blade force for the ship's service life, kN (kgf, lbf)

F_{ice} = ice load, kN (kgf, lbf)

$(F_{ice})_{max}$ = maximum ice load for the ship's service life, kN (kgf, lbf)

FP = fixed pitch

h_0 = depth of the propeller centerline from the winter waterline, m (ft)

H_{ice} = thickness of maximum design ice block entering to propeller, m (ft)

I = equivalent mass moment of inertia of all parts on engine side of component under consideration, kg-m^2 (lb-ft^2)

I_t = equivalent mass moment of inertia of the whole propulsion system, kg-m^2 (lb-ft^2)

k = shape parameter for Weibull distribution

$LIWL$ = lower ballast waterline in ice, m (ft)

m = slope for SN curve in log/log scale

M_{BL} = blade bending moment, kN-m (kgf-m, lbf-ft)

MCR = maximum continuous rating

n = propeller rotational speed, rev/s

n_n = nominal propeller rotational speed at MCR in free running condition, rev/s

N_{class} = reference number of impacts per propeller rotational speed per ice class

N_{ice} = total number of ice loads on propeller blade for the ship's service life

N_R = reference number of load for equivalent fatigue stress (10^8 cycles)

N_Q = number of propeller revolutions during a milling sequence

$P_{0.7}$ = propeller pitch at 0.7R radius, m (ft)

$P_{0.7n}$ = propeller pitch at 0.7R radius at MCR in free running condition, m (ft)

$P_{0.7b}$ = propeller pitch at 0.7R radius at MCR in bollard condition, m (ft)

Q = torque, kN-m (kgf-m, lbf-ft)

Q_{emax} = maximum engine torque, kN-m (kgf-m, lbf-ft)

Q_{max} = maximum torque on the propeller resulting from propeller-ice interaction, kN-m (kgf-m, lbf-ft)

Q_{motor} = electric motor peak torque, kN-m (kgf-m, lbf-ft)

Q_n = nominal torque at MCR in free running condition, kN-m (kgf-m, lbf-ft)

Q_r = maximum response torque along the propeller shaft line, kN-m (kgf-m, lbf-ft)

Q_{smax} = maximum spindle torque of the blade for the ship's service life, kN-m (kgf-m, lbf-ft)

R = propeller radius, m (ft)

r = blade section radius, m (ft)

T = propeller thrust, kN (kgf, lbf)

T_b = maximum backward propeller ice thrust for the ship's service life, kN (kgf, lbf)

T_f = maximum forward propeller ice thrust for the ship's service life, kN (kgf, lbf)

T_n = propeller thrust at MCR in free running condition, kN (kgf, lbf)

T_r = maximum response thrust along the shaft line, kN (kgf, lbf)

t = maximum blade section thickness, m (ft)

Z = number of propeller blades

α_i = duration of propeller blade/ice interaction expressed in rotation angle, deg

γ_ε = reduction factor for fatigue; scatter and test specimen size effect

γ_v = reduction factor for fatigue; variable amplitude loading effect

γ_m = reduction factor for fatigue; mean stress effect

ρ = reduction factor for fatigue correlating the maximum stress amplitude to the equivalent fatigue stress for 10^8 stress cycles

$\sigma_{0.2}$ = proof yield strength of blade material, MPa (kgf/cm^2, psi)

σ_{exp} = mean fatigue strength of blade material at 10^8 cycles to failure in sea water, MPa (kgf/cm^2, psi)

σ_{fat} = equivalent fatigue ice load stress amplitude for 10^8 stress cycles, MPa (kgf/cm^2, psi)

σ_{fl} = characteristic fatigue strength for blade material, MPa (kgf/cm^2, psi)

σ_{ref} = reference stress $\sigma_{ref} = 0.6\sigma_{0.2} + 0.4\sigma_u$, MPa (kgf/cm^2, psi)

σ_{ref2} = reference stress $\sigma_{ref2} = 0.7\sigma_u$ or $\sigma_{ref2} = 0.6\sigma_{0.2} + 0.4\sigma_u$, whichever is less, MPa (kgf/cm^2, psi)

σ_{st} = maximum stress resulting from F_b or F_f, MPa (kgf/cm^2, psi)

σ_u = ultimate tensile strength of blade material, MPa (kgf/cm^2, psi)

$(\sigma_{ice})_{bmax}$ = principal stress caused by the maximum backward propeller ice load, MPa (kgf/cm^2, psi)

$(\sigma_{ice})_{fmax}$ = principal stress caused by the maximum forward propeller ice load, MPa (kgf/cm^2, psi)

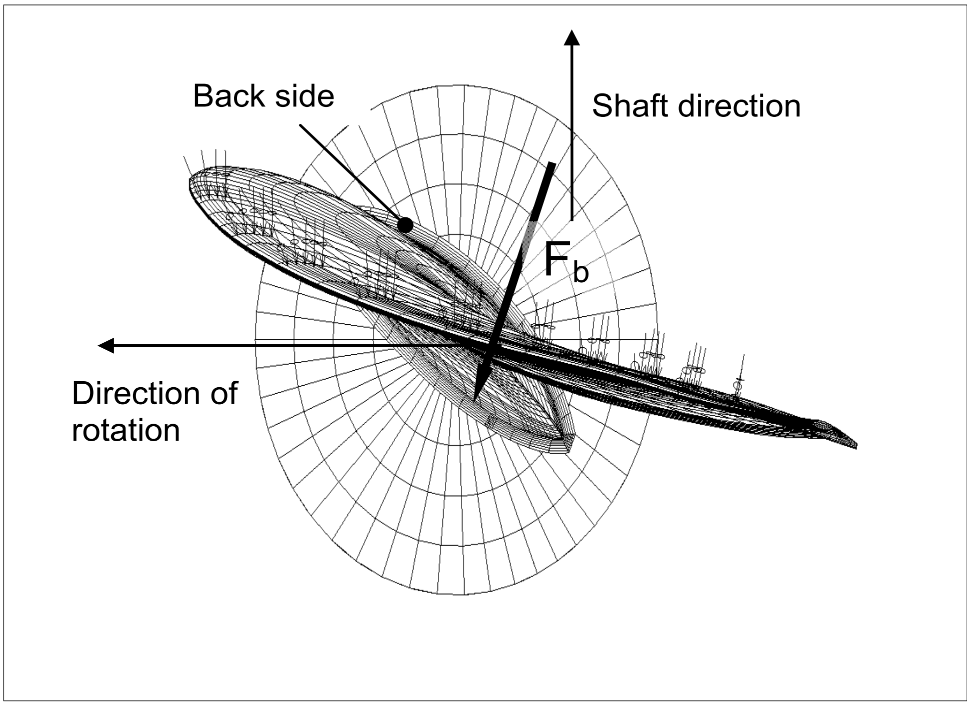
$(\sigma_{ice})_{max}$ = maximum ice load stress amplitude, MPa (kgf/cm^2, psi)

TABLE 1
Definition of Loads *(2010)*

	Definition	*Use of the load in design process*
F_b	The maximum lifetime backward force on a propeller blade resulting from propeller/ice interaction, including hydrodynamic loads on that blade. The direction of the force is perpendicular to 0.7 *r*/*R* chord line. See 6-1-2/Figure 6	Design force for strength calculation of the propeller blade.
F_f	The maximum lifetime forward force on a propeller blade resulting from propeller/ice interaction, including hydrodynamic loads on that blade. The direction of the force is perpendicular to 0.7 *r*/*R* chord line.	Design force for calculation of strength of the propeller blade.
Q_{smax}	The maximum lifetime spindle torque on a propeller blade resulting from propeller/ice interaction, including hydrodynamic loads on that blade.	In designing the propeller strength, the spindle torque is automatically taken into account because the propeller load is acting on the blade as distributed pressure on the leading edge or tip area.
T_b	The maximum lifetime thrust on propeller (all blades) resulting from propeller/ice interaction. The direction of the thrust is the propeller shaft direction and the force is opposite to the hydrodynamic thrust.	Is used for estimation of the response thrust T_r. T^β can be used as an estimate of excitation for axial vibration calculations. However, axial vibration calculations are not required in the Rules.
T_f	The maximum lifetime thrust on propeller (all blades) resulting from propeller/ice interaction. The direction of the thrust is the propeller shaft direction acting in the direction of hydrodynamic thrust.	Is used for estimation of the response thrust T_r. T_f can be used as an estimate of excitation for axial vibration calculations. However, axial vibration calculations are not required in the Rules.
Q_{max}	The maximum ice-induced torque resulting from propeller/ice interaction on one propeller blade, including hydrodynamic loads on that blade.	Is used for estimation of the response torque (Q_r) along the propulsion shaft line and as excitation for torsional vibration calculations.
F_{ex}	Ultimate blade load resulting from blade loss through plastic bending. The force that is needed to cause total failure of the blade so that plastic hinge is caused to the root area. The force is acting on 0.8 *r*/*R*. Spindle arm is to be taken as $^2/_3$ of the distance between the axis of blade rotation and leading/trailing edge (whichever is the greater) at the 0.8*R* radius.	Blade failure load is used to dimension the blade bolts, pitch control mechanism, propeller shaft, propeller shaft bearing and trust bearing. The objective is to guarantee that total propeller blade failure should not cause damage to other components.
Q_r	Maximum response torque along the propeller shaft line, taking into account the dynamic behavior of the shaft line for ice excitation (torsional vibration) and hydrodynamic mean torque on propeller.	Design torque for propeller shaft line components.
T_r	Maximum response thrust along shaft line, taking into account the dynamic behavior of the shaft line for ice excitation (axial vibration) and hydrodynamic mean thrust on propeller.	Design thrust for propeller shaft line components.
Q_g	Fatigue torque at reduction gear for N_g load cycles.	Design torque for reduction gear.

FIGURE 6
Direction of the Backward Blade Force Resultant Taken Perpendicular to Chord Line at $0.7r/R$ *(2010)*

Ice contact pressure at leading edge is shown with small arrows.



29.5 Design Ice Conditions

In estimating the ice loads of the propeller for ice classes, different types of operation as given in 6-1-2/Table 2 were taken into account. For the estimation of design ice loads, a maximum ice block size is determined. The maximum design ice block entering the propeller is a rectangular ice block with the dimensions $H_{ice} \times 2H_{ice} \times 3H_{ice}$. The thickness of the ice block (H_{ice}) is given in 6-1-2/Table 3.

TABLE 2
Types of Ice Operation *(2010)*

Ice Class	*Operation of the Ship*
I AA	Operation in ice channels and in level ice The ship may proceed by ramming
I A, I B, I C	Operation in ice channels

TABLE 3
Thickness of the Ice Block (H_{ice}) *(2010)*

	I AA	**I A**	**I B**	**I C**
Thickness of the design maximum ice block entering the propeller (H_{ice})	1.75 m (5.74 ft)	1.5 m (4.92 ft)	1.2 m (3.94 ft)	1.0 m (3.28 ft)

29.7 Materials

29.7.1 Materials Exposed to Sea Water

Materials of components exposed to sea water, such as propeller blades, propeller hubs, and thruster body, are to have an elongation of not less than 15% on a test specimen, the gauge length of which is five times the diameter. A Charpy V impact test is to be carried out for materials other than bronze and austenitic steel. An average impact energy value of 20 J (2.04 kgf-m, 14.75 lbf-ft) taken from three tests is to be obtained at minus 10°C (14°F).

29.7.2 Materials Exposed to Sea Water Temperature

Materials exposed to sea water temperature are to be of ductile material. An average impact energy value of 20 J (2.04 kgf-m, 14.75 lbf-ft) taken from three tests is to be obtained at minus 10°C (14°F). This requirement applies to blade bolts, CP mechanisms, shaft bolts, strut-pod connecting bolts etc. This does not apply to surface hardened components, such as bearings and gear teeth.

29.9 Design Loads

The given loads are intended for component strength calculations only and are total loads including ice-induced loads and hydrodynamic loads during propeller/ice interaction.

The values of the parameters in the formulae in this section are to be given in the units shown in the symbol list.

If the propeller is not fully submerged when the ship is in ballast condition, the propulsion system shall be designed according to ice class **I A** for ice classes **I B** and **I C**.

29.9.1 Design Loads on Propeller Blades

F_b is the maximum force experienced during the lifetime of the ship that bends a propeller blade backwards when the propeller mills an ice block while rotating ahead. F_f is the maximum force experienced during the lifetime of the ship that bends a propeller blade forwards when the propeller mills an ice block while rotating ahead. These forces originate from different propeller/ice interaction phenomena, not acting simultaneously. Hence, they are to be applied to one blade separately.

29.9.1(a) Maximum backward blade force, F_b, for open propellers:

$$F_b = k \cdot [n \cdot D]^{0.7} \cdot \left[\frac{EAR}{Z}\right]^{0.3} \cdot D^2 \quad \text{kN (kgf, lbf)} \qquad \text{when } D \le D_{limit}$$

k = 27 (2753.23, 245.48)

$$F_b = k \cdot [n \cdot D]^{0.7} \cdot \left[\frac{EAR}{Z}\right]^{0.3} \cdot D \cdot H_{ice}^{1.4} \quad \text{kN (kgf, lbf)} \qquad \text{when } D > D_{limit}$$

k = 23 (2345.35, 130.01)

where

D_{limit} = $0.85 \cdot H_{ice}^{1.4}$ m (ft)

n = nominal rotational speed (at MCR in free running condition) for a CP propeller and 85% of the nominal rotational speed (at MCR in free running condition) for an FP propeller.

29.9.1(b) Maximum forward blade force, F_f, for open propellers:

$$F_f = k \cdot \left[\frac{EAR}{Z}\right] \cdot D^2 \quad \text{kN (kgf, lbf)} \qquad \text{when } D \le D_{limit}$$

k = 250 (2549.9, 5221.36)

$$F_f = k \cdot \left[\frac{EAR}{Z}\right] \cdot D \cdot \frac{1}{\left(1 - \frac{d}{D}\right)} \cdot H_{ice} \quad \text{kN (kgf, lbf)} \qquad \text{when } D > D_{limit}$$

k = 500 (50985.81, 10442.72)

where

$$D_{limit} = \frac{2}{\left(1 - \frac{d}{D}\right)} \cdot H_{ice} \quad \text{m (ft)}$$

29.9.1(c) Loaded area on the blade for open propellers. Load cases 1-4 have to be covered, as given in 6-1-2/Table 4 below, for CP and FP propellers. In order to obtain blade ice loads for a reversing propeller, load case 5 also has to be covered for FP propellers.

29.9.1(d) Maximum backward blade ice force, F_b, for ducted propellers:

$$F_b = k \cdot [n \cdot D]^{0.7} \cdot \left[\frac{EAR}{Z}\right]^{0.3} \cdot D^2 \quad \text{kN (kgf, lbf)} \qquad \text{when } D \le D_{limit}$$

k = 9.5 (968.73, 86.37)

$$F_b = k \cdot [n \cdot D]^{0.7} \cdot \left[\frac{EAR}{Z}\right]^{0.3} \cdot D^{0.6} \cdot H_{ice}^{1.4} \quad \text{kN (kgf, lbf)} \qquad \text{when } D > D_{limit}$$

k = 66 (6730.13, 600.06)

where

D_{limit} = $4 \cdot H_{ice}$ m (ft)

n = nominal rotational speed (at MCR in free running condition) for a CP propeller and 85% of the nominal rotational speed (at MCR in free running condition) for an FP propeller.

29.9.1(e) Maximum forward blade ice force, F_f, for ducted propellers:

$$F_f = k \cdot \left[\frac{EAR}{Z}\right] \cdot D^2 \quad \text{kN (kgf, lbf)} \qquad \text{when } D \le D_{limit}$$

k = 250 (25492.91, 5221.35)

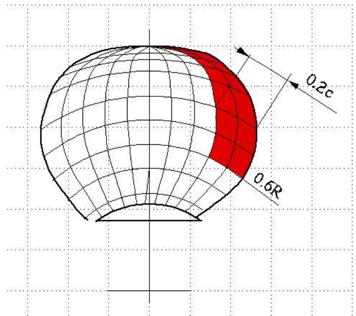
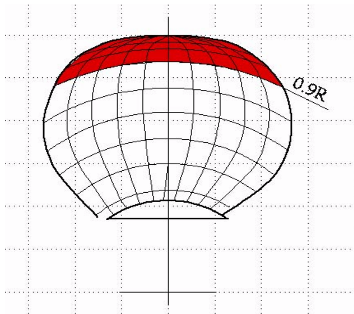
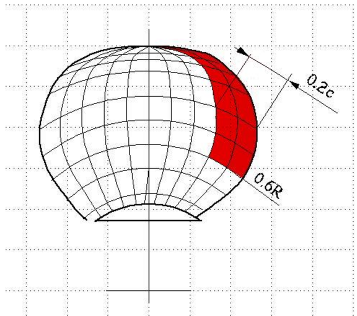
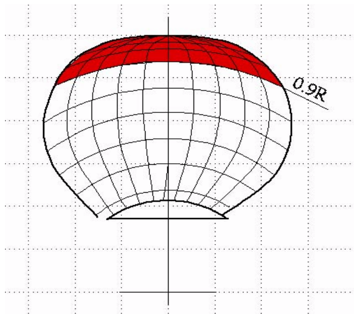
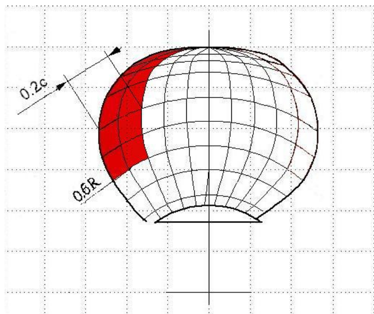
$$F_f = k \cdot \left[\frac{EAR}{Z}\right] \cdot D \cdot \frac{1}{\left(1 - \frac{d}{D}\right)} \cdot H_{ice} \quad \text{kN (kgf, lbf)} \qquad \text{when } D > D_{limit}$$

k = 500 (50985.91, 10442.72)

where

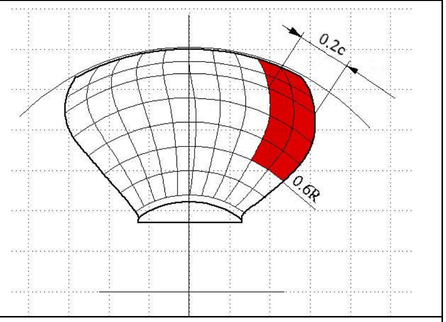
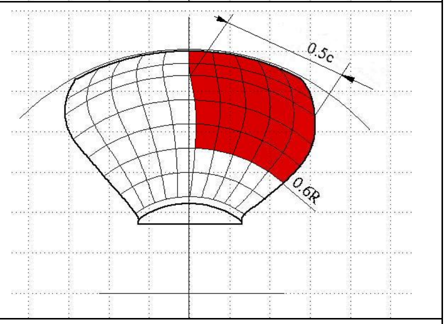
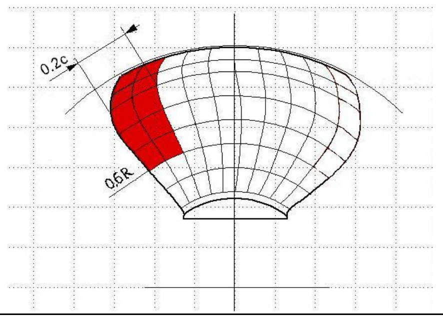
$$D_{limit} = \frac{2}{\left(1 - \frac{d}{D}\right)} \cdot H_{ice} \quad \text{m (ft)}$$

TABLE 4
Load Cases for Open Propellers *(2010)*

	Force	*Loaded Area*	*Right-handed Propeller Blade Seen from Behind*
Load case 1	F_b	Uniform pressure applied on the back of the blade (suction side) to an area from 0.6R to the tip and from the leading edge to 0.2 times the chord length.	
Load case 2	50% of F_b	Uniform pressure applied on the back of the blade (suction side) on the propeller tip area outside 0.9R radius.	
Load case 3	F_f	Uniform pressure applied on the blade face (pressure side) to an area from 0.6R to the tip and from the leading edge to 0.2 times the chord length.	
Load case 4	50% of F_f	Uniform pressure applied on propeller face (pressure side) on the propeller tip area outside 0.9R radius.	
Load case 5	60% of F_f or F_b, whichever is greater	Uniform pressure applied on propeller face (pressure side) to an area from 0.6R to the tip and from the trailing edge to 0.2 times the chord length	

29.9.1(f) Loaded area on the blade for ducted propellers. Load cases 1 and 3 have to be covered as given in 6-1-2/Table 5 for all propellers, and an additional load case (load case 5) for an FP propeller, to cover ice loads when the propeller is reversed.

TABLE 5
Load Cases for Ducted Propellers *(2010)*

	Force	*Loaded Area*	*Right-handed Propeller Blade Seen from Behind*
Load case 1	F_b	Uniform pressure applied on the back of the blade (suction side) to an area from 0.6R to the tip and from the leading edge to 0.2 times the chord length.	
Load case 3	F_f	Uniform pressure applied on the blade face (pressure side) to an area from 0.6R to the tip and from the leading edge to 0.5 times the chord length.	
Load case 5	60% of F_f or F_b, whichever is greater	Uniform pressure applied on propeller face (pressure side) to an area from 0.6R to the tip and from the trailing edge to 0.2 times the chord length.	

29.9.1(g) Maximum blade spindle torque, Q_{smax}, for open and ducted propellers. The spindle torque, Q_{smax}, around the axis of the blade fitting is to be determined both for the maximum backward blade force, F_b, and forward blade force, F_f, which are applied as in 6-1-2/Table 4 and 6-1-2/Table 5. If the above method gives a value which is less than the default value given by the formula below, the default value is to be used.

Default value $Q_{smax} = 0.25 \cdot F \cdot c_{0.7}$ kN-m (kgf-m, lbf-ft)

where

$c_{0.7}$ = length of the blade section at 0.7R radius

F = either F_b or F_f, whichever has the greater absolute value

29.9.1(h) Load distributions for blade loads. The Weibull-type distribution (probability of exceeding), as given in 6-1-2/Figure 7, is used for the fatigue design of the blade.

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

where

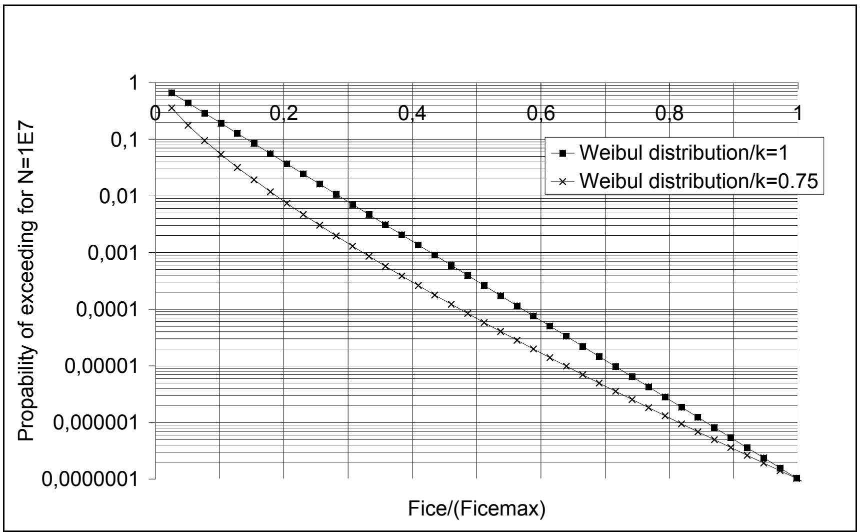
K = shape parameter of the spectrum

N_{ice} = number of load cycles in the spectrum

F_{ice} = random variable for ice loads on the blade, $0 \leq F_{ice} \leq (F_{ice})_{max}$

The shape parameter k = 0.75 is to be used for the ice force distribution of an open propeller and the shape parameter k = 1.0 for that of a ducted propeller blade.

FIGURE 7
The Weibull-type Distribution (Probability of Exceeding) That is Used for Fatigue Design *(2010)*



i) *Number of ice loads.* The number of load cycles per propeller blade in the load spectrum is to be determined according to the formula:

$$N_{ice} = k_1k_2k_3k_4N_{class}n$$

where

Reference number of loads for ice classes N_{class}:

Class	**I AA**	**I A**	**I B**	**I C**
Impacts in life/n	9×10^6	6×10^6	3.4×10^6	2.1×10^6

Propeller location factor k_1:

Single Propeller		*Twin Propeller*
Location	*Centerline*	*Twin Wing*
k_1	1	1.35

Propeller type factor k_2:

Type	*Open*	*Ducted*
k_2	1	1.1

Propulsion type factor k_3:

Type	*Fixed*	*Azimuthing*
k_3	1	1.2

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

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

Where the immersion function f is:

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

where h_o is the depth of the propeller centerline at the lower ballast waterline in ice (LIWL) of the vessel.

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

29.9.2 Axial Design Loads for Open and Ducted Propellers

29.9.2(a) Maximum ice thrust on propeller T_f and T_b for open and ducted propellers. The maximum forward and backward ice thrusts are:

$T_f = 1.1 \cdot F_f$ kN (kgf, lbf)

$T_b = 1.1 \cdot F_b$ kN (kgf, lbf)

29.9.2(b) Design thrust along the propulsion shaft line for open and ducted propellers. The design thrust along the propeller shaft line is to be calculated with the formulae below. The greater value of the forward and backward direction loads is to be taken as the design load for both directions. The factors 2.2 and 1.5 take into account the dynamic magnification resulting from axial vibration.

In a forward direction:

$T_r = T + 2.2 \cdot T_f$ kN (kgf, lbf)

In a backward direction:

$T_r = 1.5 \cdot T_b$ kN (kgf, lbf)

If the hydrodynamic bollard thrust, T, is not known, T is to be taken as follows:

Propeller Type	T
CP propellers (open)	$1.25T_n$
CP propellers (ducted)	$1.1T_n$
FP propellers driven by turbine or electric motor	T_n
FP propellers driven by diesel engine (open)	$0.85T_n$
FP propellers driven by diesel engine (ducted)	$0.75T_n$

where T_n is the nominal propeller thrust at MCR in free running open water condition.

29.9.3 Torsional Design Loads

29.9.3(a) Design ice torque on propeller Q_{max} for open propellers. Q_{max} is the maximum torque on a propeller resulting from ice/propeller interaction.

$$Q_{max} = k \cdot \left[1 - \frac{d}{D}\right] \cdot \left[\frac{P_{0.7}}{D}\right]^{0.16} \cdot (nD)^{0.17} \cdot D^3 \quad \text{kN-m (kgf-m, lbf-ft)}$$

when $D \le D_{limit}$

$k = 10.9\ (1111.49,\ 186.02)$

$$Q_{max} = k \cdot \left[1 - \frac{d}{D}\right] \cdot \left[\frac{P_{0.7}}{D}\right]^{0.16} \cdot (nD)^{0.17} \cdot D^{1.9} \cdot H_{ice}^{1.1} \quad \text{kN-m (kgf-m, lbf-ft)}$$

when $D > D_{limit}$

$k = 20.7\ (2110.81,\ 353.26)$

where

D_{limit} = $1.8 \cdot H_{ice}$ m (ft)

Propeller Type	*Rotational Speed, n*
CP propellers	n_n
FP propellers driven by turbine or electric motor	n_n
FP propellers driven by diesel engine	$0.85n_n$

where n_n is the nominal rotational speed at MCR in free running condition.

For CP propellers, the propeller pitch, $P_{0.7}$ shall correspond to MCR in bollard condition. If not known, $P_{0.7}$ is to be taken as $0.7P_{0.7n}$, where $P_{0.7n}$ is the propeller pitch at MCR in free running condition.

29.9.3(b) Design ice torque on propeller Q_{max} for ducted propellers. Q_{max} is the maximum torque on a propeller resulting from ice/propeller interaction.

$$Q_{max} = k \cdot \left[1 - \frac{d}{D}\right] \cdot \left[\frac{P_{0.7}}{D}\right]^{0.16} \cdot (nD)^{0.17} \cdot D^3 \quad \text{kN-m (kgf-m, lbf-ft)}$$

when $D \le D_{limit}$

$k = 7.7\ (785.18,\ 131.41)$

$$Q_{max} = k \cdot \left[1 - \frac{d}{D}\right] \cdot \left[\frac{P_{0.7}}{D}\right]^{0.16} \cdot (nD)^{0.17} \cdot D^{1.9} \cdot H_{ice}^{1.1} \quad \text{kN-m (kgf-m, lbf-ft)}$$

when $D > D_{limit}$

$k = 14.6\ (1466.78,\ 249.16)$

where

D_{limit} = $1.8 \cdot H_{ice}$ m (ft)

n = rotational propeller speed in bollard condition. If not known, n is to be taken as follows:

Propeller Type	*Rotational Speed, n*
CP propellers	n_n
FP propellers driven by turbine or electric motor	n_n
FP propellers driven by diesel engine	$0.85n_n$

where n_n is the nominal rotational speed at MCR in free running condition.

For CP propellers, the propeller pitch, $P_{0.7}$ shall correspond to MCR in bollard condition. If not known, $P_{0.7}$ is to be taken as $0.7P_{0.7n}$, where $P_{0.7n}$ is the propeller pitch at MCR in free running condition.

29.9.3(c) Ice torque excitation for open and ducted propellers. The propeller ice torque excitation for shaft line transient torsional vibration analysis is to be described by a sequence of blade impacts which are of a half sine shape; see 6-1-2/Figure 8.

The torque resulting from a single blade ice impact as a function of the propeller rotation angle is then:

$$Q(\varphi) = C_q \cdot Q_{max} \cdot \sin[\varphi(180/\alpha_i)] \qquad \text{when } \varphi = 0 \ldots \alpha_i$$

$$Q(\varphi) = 0 \qquad \text{when } \varphi = \alpha_i \ldots 360$$

Where the C_q and α_i parameters are given in the table below. α_i is duration of propeller blade/ice interaction expressed in propeller rotation angle.

Torque Excitation	*Propeller/Ice Interaction*	C_q	α_i
Case 1	Single ice block	0.75	90
Case 2	Single ice block	1.0	135
Case 3	Two ice blocks (phase shift 45 deg.)	0.5	45

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

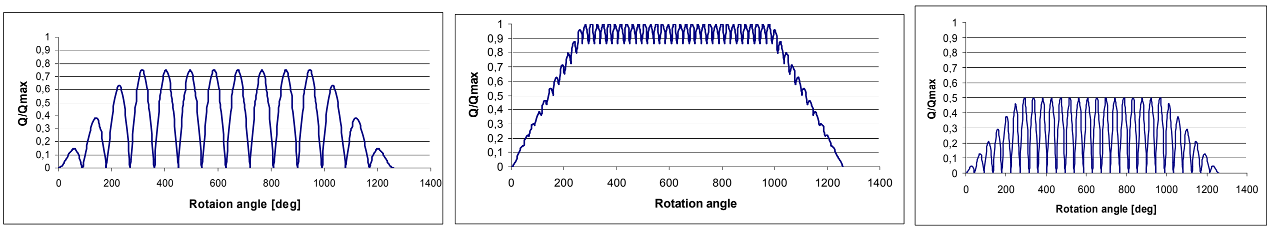
The number of propeller revolutions during a milling sequence is to be obtained with the formula:

$$N_Q = 2 \cdot H_{ice}$$

The number of impacts is $Z \cdot N_Q$ for blade order excitation.

FIGURE 8
Shape of the Propeller Ice Torque Excitation for 90- and 135-Degree Single-blade Impact Sequences and 45-Degree Double Blade Impact Sequence *(2010)*

(Figures apply for propellers with 4 blades.)



29.9.3(d) Design torque along propeller shaft line. If there is not any relevant 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 following estimation of the maximum torque can be used.

$$Q_r = Q_{emax} + Q_{max} \cdot \frac{I}{I_t} \quad \text{kN-m (kgf-m, lbf-ft)}$$

where

I = equivalent mass moment of inertia of all parts on engine side of component under consideration

I_t = equivalent mass moment of inertia of the whole propulsion system

where all the torques and the inertia moments shall be reduced to the rotation speed of the component being examined.

If the maximum torque, Q_{emax} is not known, it is to be taken as follows:

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	$0.75Q_n$

where Q_{motor} is the electric motor peak torque.

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.

29.9.4 Blade Failure Load

The ultimate load resulting from blade failure as a result of plastic bending around the blade root is to be calculated with the formula below. The ultimate load is acting on the blade at the 0.8*R* radius in the weakest direction of the blade. For calculation of the extreme spindle torque, the spindle arm is to be taken as $^2/_3$ of the distance between the axis of blade rotation and the leading/trailing edge (whichever is the greater) at the 0.8*R* radius.

$$F_{ex} = \frac{k \cdot c \cdot t^2 \cdot \sigma_{ref}}{0.8 \cdot D - 2 \cdot r} \quad \text{kN (kgf, lbf)}$$

k = 300 (3000.05, 43.20)

where

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

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

29.11 Design

29.11.1 Design Principle

The strength of the propulsion line is to be designed according to the pyramid strength principle. This means that the loss of the propeller blade is not to cause any significant damage to other propeller shaft line components.

29.11.2 Propeller Blade

29.11.2(a) Calculation of blade stresses. The blade stresses are to be calculated for the design loads given in 6-1-2/29.9.1. Finite element analyses are to be used for stress analysis for final approval for all propellers.

The following simplified formulae can be used in estimating the blade stresses for all propellers at the root area (r/R < 0.5). The root area dimensions will be accepted even if the FEM analysis would show greater stresses at the root area.

$$\sigma_{st} = C_1 \frac{M_{BL}}{k \cdot ct^2} \quad \text{MPa (kgf/cm}^2\text{, psi)}$$

$k = 10^2$ (10^4, 144)

where constant C_1 is the "actual stress"/"stress obtained with beam equation". If the actual value is not available, C_1 should be taken as 1.6.

$M_{BL} = (0.75 - r/R) \cdot R \cdot F$ for relative radius $r/R < 0.5$

F is the maximum of F_b and F_f, whichever is greater.

29.11.2(b) Acceptability criterion. The following criterion for calculated blade stresses has to be fulfilled.

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

where

σ_{st} = calculated stress for the design loads. If FE analysis is used in estimating the stresses, von Mises stresses shall be used

σ_{ref2} = reference stress, defined as:

= $0.7 \cdot \sigma_u$ or

= $0.6 \cdot \sigma_{0.2} + 0.4 \cdot \sigma_u$, whichever is less

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

If the following criterion is fulfilled, fatigue calculations according to this section are not required.

$$\sigma_{exp} \geq B1 \cdot \sigma_{ref2}^{B2} \cdot \log(N_{ice})^{B3}$$

where $B1$, $B2$, and $B3$ are coefficients for open and nozzle propellers are given in the table below.

	Open Propeller	*Nozzle Propeller*
$B1$	0.00270	0.00184
$B2$	1.007	1.007
$B3$	2.101	2.470

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

1. Two slope S-N curve (slopes 4.5 and 10), see 6-1-2/Figure 9.

2. One slope S-N curve (the slope can be chosen), see 6-1-2/Figure 10.

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 the two slope S-N curve is to be used.

FIGURE 9
Two-slope S-N Curve *(2010)*

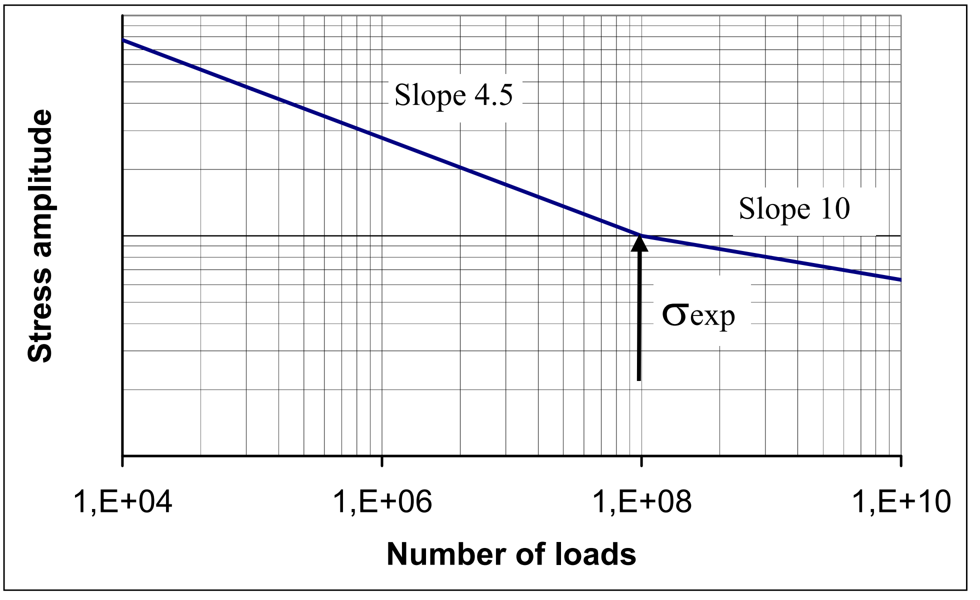
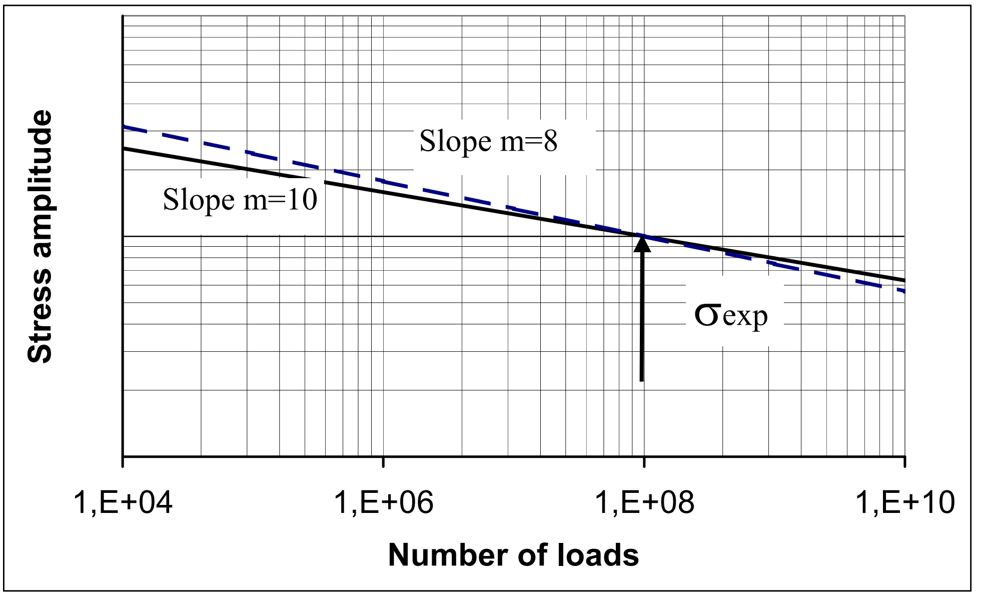


FIGURE 10
Constant-slope S-N Curve *(2010)*



i) *Equivalent fatigue stress.* The equivalent fatigue stress for 100 million stress cycles which produces the same fatigue damage as the load distribution is:

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

where

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

= $0.5 \cdot [(\sigma_{ice})_{f\max} - (\sigma_{ice})_{b\max}]$

$(\sigma_{ice})_{f\max}$ = principal stress resulting from forward load

$(\sigma_{ice})_{b\max}$ = principal stress resulting from backward load

In calculation of $(\sigma_{ice})_{\max}$, case 1 and case 3 (or case 2 and case 4) are considered as a pair for $(\sigma_{ice})_{f\max}$, and $(\sigma_{ice})_{b\max}$ calculations. Case 5 is excluded from the fatigue analysis.

ii) *Calculation of ρ parameter for two-slope S-N curve.* The parameter ρ relates the maximum ice load to the distribution of ice loads according to the regression formula:

$$\rho = C_1 \cdot (\sigma_{ice})_{\max}^{C_2} \cdot \sigma_{fl}^{C_3} \cdot \log(N_{ice})^{C_4}$$

where

σ_{fl} = $\gamma_\varepsilon \cdot \gamma_v \cdot \gamma_m \cdot \sigma_{exp}$

γ_ε = reduction factor for scatter and test specimen size effect

γ_v = reduction factor for variable amplitude loading

γ_m = reduction factor for mean stress

σ_{exp} = mean fatigue strength of the blade material at 10^8 cycles to failure in seawater

The following values are to be used for the reduction factors if actual values are not available: $\gamma_\varepsilon = 0.67$, $\gamma_v = 0.75$, and $\gamma_m = 0.75$.

The coefficients C_1, C_2, C_3, and C_4 are given in 6-1-2/Table 6, below.

TABLE 6
Coefficients *C* (2010)

	Open Propeller	*Ducted Propeller*
C_1	0.000711	0.000509
C_2	0.0645	0.0533
C_3	–0.0565	–0.0459
C_4	2.22	2.584

iii) *Calculation of ρ parameter for constant-slope S-N curve.* For materials with a constant-slope S-N curve, see 6-1-2/Figure 10, the ρ-factor is to be calculated with the following formula:

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

where

k = shape parameter of the Weibull distribution

= 1.0 for ducted propellers

= 0.75 for open propellers

N_R = reference number of load cycles (= 100 million)

Values for the G parameter are given in 6-1-2/Table 7. Linear interpolation may be used to calculate the G value for other m/k ratios than given in the 6-1-2/Table 7.

TABLE 7
Value for the G Parameter for Different m/k Ratios *(2010)*

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	1.133×10^6
5	120	7.5	14034	10	3.623×10^6

29.11.2(d) Acceptability criterion for fatigue. The equivalent fatigue stress at all locations on the blade has to fulfill the following acceptability criterion:

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

where

σ_{fl} = $\gamma_\varepsilon \cdot \gamma_v \cdot \gamma_m \cdot \sigma_{exp}$

γ_ε = reduction factor for scatter and test specimen size effect

γ_v = reduction factor for variable amplitude loading

γ_m = reduction factor for mean stress

σ_{exp} = mean fatigue strength of the blade material at 10^8 cycles to failure in seawater

The following values are to be used for the reduction factors if actual values are not available: $\gamma_\varepsilon = 0.67$, $\gamma_v = 0.75$, and $\gamma_m = 0.75$.

29.11.3 Propeller Bossing and CP Mechanism

The blade bolts, the CP mechanism, the propeller boss, and the fitting of the propeller to the propeller shaft shall be designed to withstand the maximum and fatigue design loads, as defined in 6-1-2/29.9. The safety factor against yielding shall be greater than 1.3 and that against fatigue greater than 1.5. In addition, the safety factor for loads resulting from loss of the propeller blade through plastic bending as defined in 6-1-2/29.9.4 is to be greater than 1.0 against yielding.

29.11.4 Propulsion Shaft Line

The shafts and shafting components, such as the thrust and stern tube bearings, couplings, flanges and sealings, are to be designed to withstand the propeller/ice interaction loads as given in 6-1-2/29.9. The safety factor is to be at least 1.3.

29.11.4(a) Shafts and shafting components. The ultimate load resulting from total blade failure as defined in 6-1-2/29.9.4 is not to cause yielding in shafts and shaft components. The loading shall 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.

29.11.5 Azimuthing Main Propulsors

In addition to the above requirements, special consideration shall be given to those loading cases which are extraordinary for propulsion units when compared with conventional propellers. The estimation of loading cases has to reflect the way of operation of the ship and the thrusters. In this respect, for example, the loads caused by the impacts of ice blocks on the propeller hub of a pulling propeller have to be considered. Furthermore, loads resulting from the thrusters operating at an oblique angle to the flow have to be considered. The steering mechanism, the fitting of the unit, and the body of the thruster shall be designed to withstand the loss of a blade without damage. The loss of a blade shall be considered for the propeller blade orientation which causes the maximum load on the component being studied. Typically, top-down blade orientation places the maximum bending loads on the thruster body.

Azimuth thrusters shall also be designed for estimated loads caused by thruster body/ice interaction. The thruster body has to stand the loads obtained when the maximum ice blocks, which are given in 6-2-1/29.3, strike the thruster body when the ship is at a typical ice operating speed. In addition, the design situation in which an ice sheet glides along the ship's hull and presses against the thruster body should be considered. The thickness of the sheet should be taken as the thickness of the maximum ice block entering the propeller, as defined in 6-2-1/29.3.

29.11.6 Vibrations

The propulsion system shall be designed in such a way that the complete dynamic system is free from harmful torsional, axial, and bending resonances at a 1-order blade frequency within the designed running speed range, extended by 20 percent 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.

29.13 Alternative Design

29.13.1 Scope

As an alternative to 6-1-2/29.9 and 6-1-2/29.11, a comprehensive design study may be carried out to the satisfaction of the Administration. The study has to be based on ice conditions given for different ice classes in 6-1-2/29.5. It has to include both fatigue and maximum load design calculations and fulfill the pyramid strength principle, as given in 6-1-2/29.11.1.

29.13.2 Loading

Loads on the propeller blade and propulsion system shall be based on an acceptable estimation of hydrodynamic and ice loads.

29.13.3 Design Levels

The 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, with a reasonable safety margin.

Cumulative fatigue damage calculations are to indicate a reasonable safety factor. Due account is to be taken of material properties, stress raisers, and fatigue enhancements.

Vibration analysis is to be carried out and is to indicate that the complete dynamic system is free from harmful torsional resonances resulting from propeller/ice interaction.

31 Additional Ice Strengthening Requirements

31.1 Starting Arrangements

The capacity of the air receivers required for reversible propulsion engines is to be sufficient for at least twelve consecutive starts and that for non-reversible propulsion engines is to be sufficient for six consecutive starts of each engine.

If the air receivers supply systems other than starting the propulsion engines, the additional capacity of the receivers is to be sufficient for continued operations of these systems after the capacity for the required number of consecutive engine starts has been used.

The capacity of the air compressors is to be sufficient for charging the air receivers from atmospheric to full pressure in one hour. For a vessel with ice class **I AA** that requires its propulsion engines to be reversed for astern operations, the compressors are to be able to charge the air receivers in half an hour.

31.3 Sea Inlet Chests for Cooling Water Systems and Fire Main *(1995)*

The sea water system is to be designed to ensure a supply of water for the cooling water system and for at least one of the fire pumps when navigating in ice. For this purpose, at least one sea water inlet chest is to be arranged as follows.

31.3.1

The sea inlet is to be situated near the centerline of the vessel and well aft, if possible.

31.3.2

The sea chest volume is to be on the order of 1 cubic meter (35.3 cubic foot) for every 750 kW (1033 mhp; 1019 hp) propulsion engine output including the ship's service auxiliary engine output.

31.3.3

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

31.3.4

A cooling water discharge pipeline having full capacity discharge is to be connected to the sea chest.

31.3.5

The open area of the strainer plates is to be not less than four times the inlet pipe sectional area.

Where it is impractical to meet the requirements of 6-1-2/31.3.2 and 6-1-2/31.3.3 above, two smaller sea chests may be arranged for alternating the intake and discharge of the cooling water, provided 6-1-2/31.3.1, 6-1-2/31.3.4 and 6-1-2/31.3.5 above are complied with.

Heating coils, if necessary, may be installed in the upper part of the chest or chests.

The use of ballast water for cooling purposes while in the ballast condition may be acceptable as an additional means but is not to be considered a permanent substitute for the above required sea inlet chest or chests.

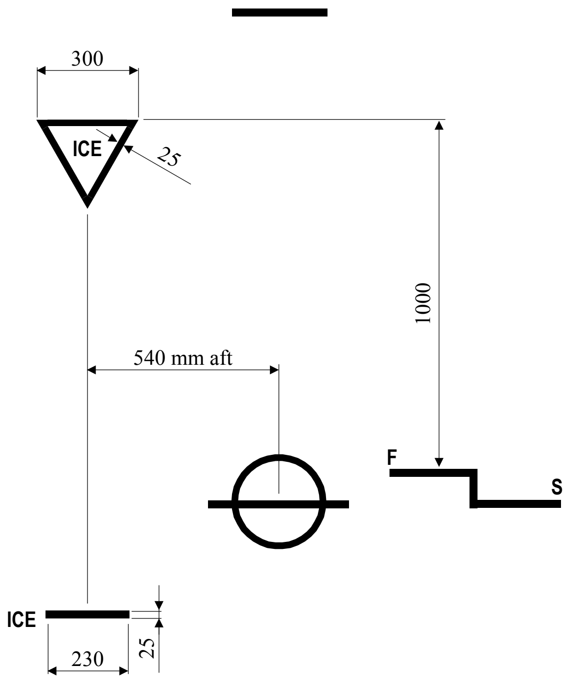
PART
6

CHAPTER 1 Strengthening for Navigation in Ice

SECTION 2 Appendix 1 – Ice Class Draft Marking *(1 July 2009)*

Subject to 6-1-2/7, the vessel's sides are to be provided with a warning triangle and with a draft mark at the maximum permissible ice class draft amidships (see 6-1-2A1/Figure 1). The purpose of the warning triangle is to provide information on the draft limitation of the vessel when it is sailing in ice for masters of icebreakers and for inspection personnel in ports.

FIGURE 1
Ice Class Draft Marking *(1 July 2009)*



Notes:

1 The upper edge of the warning triangle is to be located vertically above the "ICE" mark, 1000 mm higher than the Summer Load Line in fresh water but in no case higher than the deck line. The sides of the triangle are to be 300 mm in length.

2 The ice class draft mark is to be located 540 mm abaft the center of the load line ring or 540 mm abaft the vertical line of the timber load line mark, if applicable.

3 The marks and figures are to be cut out of 5 - 8 mm plate and then welded to the vessel's side. The marks and figures are to be painted in a red or yellow reflecting color in order to make the marks and figures plainly visible even in ice conditions.

4 The dimensions of all figures are to be the same as those used in the load line mark.