Requirements concerning

POLAR CLASS

CONTENTS

I1
(August 2006)
(Rev.1 Jan 2007)
(Corr.1 Oct 2007)

Polar Class Descriptions and Application

I1.1 Application

I1.1.1 The IACS Unified Requirements for Polar Ships apply to ships constructed of steel and intended for navigation in ice-infested polar waters, except ice breakers (see I1.1.3) *.

I1.1.2 Ships that comply with the IACS Unified Requirements I2 and I3 can be considered for a Polar Class notation as listed in Table 1. The requirements of IACS Unified Requirements I2 and I3 are in addition to the open water requirements of each member society. If the hull and machinery are constructed such as to comply with the requirements of different polar classes, then both the hull and machinery are to be assigned the lower of these classes in the classification certificate. Compliance of the hull or machinery with the requirements of a higher polar class is also to be indicated in the classification certificate or an appendix thereto.

I1.1.3 Ships that are also to receive an “Icebreaker” notation may have additional requirements and are to receive special consideration. “Icebreaker" refers to any ship having an operational profile that includes escort or ice management functions, having powering and dimensions that allow it to undertake aggressive operations in ice-covered waters, and having a class certificate endorsed with this notation.

I1.2 Polar Classes

I1.2.1 The Polar Class (PC) notations and descriptions are given in Table 1. It is the responsibility of the Owner to select an appropriate Polar Class. The descriptions in Table 1 are intended to guide owners, designers and administrations in selecting an appropriate Polar Class to match the requirements for the ship with its intended voyage or service.

I1.2.2 The Polar Class notation is used throughout the IACS Unified Requirements for Polar Ships to convey the differences between classes with respect to operational capability and strength.

---

* Note:

1. This UR is to be uniformly applied by IACS Societies on ships contracted for construction on and after 1 March 2008.

2. The “contracted for construction” date means the date on which the contract to build the vessel is signed between the prospective owner and the shipbuilder. For further details regarding the date of “contract for construction”, refer to IACS Procedural Requirement (PR) No. 29.

I1
(cont)

Table 1 - Polar Class Descriptions

Polar Class	Ice Description (based on WMO Sea Ice Nomenclature)
PC 1	Year-round operation in all Polar waters
PC 2	Year-round operation in moderate multi-year ice conditions
PC 3	Year-round operation in second-year ice which may include multi-year ice inclusions.
PC 4	Year-round operation in thick first-year ice which may include old ice inclusions
PC 5	Year-round operation in medium first-year ice which may include old ice inclusions
PC 6	Summer/autumn operation in medium first-year ice which may include old ice inclusions
PC 7	Summer/autumn operation in thin first-year ice which may include old ice inclusions

I1.3 Upper and Lower Ice Waterlines

I1.3.1 The upper and lower ice waterlines upon which the design of the vessel has been based is to be indicated in the classification certificate. The upper ice waterline (UIWL) is to be defined by the maximum draughts fore, amidships and aft. The lower ice waterline (LIWL) is to be defined by the minimum draughts fore, amidships and aft.

I1.3.2 The lower ice waterline is to be determined with due regard to the vessel's ice-going capability in the ballast loading conditions (e.g. propeller submergence).

End of Document

I2
(August 2006)
(Rev.1 Jan 2007)
(Corr.1 Oct 2007)

Structural Requirements for Polar Class Ships

I2.1 Application *

I2.1.1 These requirements are to be applied to polar class ships according to IACS UR I1.

I2.2 Hull Areas

I2.2.1 The hull of all polar class ships is divided into areas reflecting the magnitude of the loads that are expected to act upon them. In the longitudinal direction, there are four regions: Bow, Bow Intermediate, Midbody and Stern. The Bow Intermediate, Midbody and Stern regions are further divided in the vertical direction into the Bottom, Lower and Icebelt regions. The extent of each Hull Area is illustrated in Figure 1.

I2.2.2 The upper ice waterline (UIWL) and lower ice waterline (LIWL) are as defined in I1.3.

I2.2.3 Figure 1 notwithstanding, at no time is the boundary between the Bow and Bow Intermediate regions to be forward of the intersection point of the line of the stem and the ship baseline.

I2.2.4 Figure 1 notwithstanding, the aft boundary of the Bow region need not be more than 0.45 L aft of the forward perpendicular (FP).

I2.2.5 The boundary between the bottom and lower regions is to be taken at the point where the shell is inclined 7° from horizontal.

I2.2.6 If a ship is intended to operate astern in ice regions, the aft section of the ship is to be designed using the Bow and Bow Intermediate hull area requirements.

I2.3 Design Ice Loads

I2.3.1 General

(i) For ships of all Polar Classes, a glancing impact on the bow is the design scenario for determining the scantlings required to resist ice loads.

(ii) The design ice load is characterized by an average pressure (P_{avg}) uniformly distributed over a rectangular load patch of height (b) and width (w).

---

* Note:

1. This UR is to be uniformly applied by IACS Societies on ships contracted for construction on and after 1 March 2008.

2. The "contracted for construction" date means the date on which the contract to build the vessel is signed between the prospective owner and the shipbuilder. For further details regarding the date of "contract for construction", refer to IACS Procedural Requirement (PR) No. 29.

I2
(cont)

(iii) Within the Bow area of all polar classes, and within the Bow Intermediate Icebelt area of polar classes PC6 and PC7, the ice load parameters are functions of the actual bow shape. To determine the ice load parameters (P_{avg}, b and w), it is required to calculate the following ice load characteristics for sub-regions of the bow area; shape coefficient (fa_i), total glancing impact force (F_i), line load (Q_i) and pressure (P_i).

(iv) In other ice-strengthened areas, the ice load parameters (P_{avg}, b_{NonBow} and w_{NonBow}) are determined independently of the hull shape and based on a fixed load patch aspect ratio, AR = 3.6.

(v) Design ice forces calculated according to I2.3.2 are only valid for vessels with icebreaking forms. Design ice forces for any other bow forms are to be specially considered by the member society.

(vi) Ship structures that are not directly subjected to ice loads may still experience inertial loads of stowed cargo and equipment resulting from ship/ice interaction. These inertial loads, based on accelerations determined by each member society, are to be considered in the design of these structures.

I2.3.2 Glancing Impact Load Characteristics

(i) The parameters defining the glancing impact load characteristics are reflected in the Class Factors listed in Table 1.

Table 1 - Class Factors

Polar Class	Crushing Failure Class Factor (CF_C)	Flexural Failure Class Factor (CF_F)	Load Patch Dimensions Class Factor (CF_D)	Displacement Class Factor (CF_{DIS})	Longitudinal Strength Class Factor (CF_L)
PC1	17.69	68.60	2.01	250	7.46
PC2	9.89	46.80	1.75	210	5.46
PC3	6.06	21.17	1.53	180	4.17
PC4	4.50	13.48	1.42	130	3.15
PC5	3.10	9.00	1.31	70	2.50
PC6	2.40	5.49	1.17	40	2.37
PC7	1.80	4.06	1.11	22	1.81

I2.3.2.1 Bow Area

(i) In the Bow area, the force (F), line load (Q), pressure (P) and load patch aspect ratio (AR) associated with the glancing impact load scenario are functions of the hull angles measured at the upper ice waterline (UIWL). The influence of the hull angles is captured through calculation of a bow shape coefficient (fa). The hull angles are defined in Figure 2.

(ii) The waterline length of the bow region is generally to be divided into 4 sub-regions of equal length. The force (F), line load (Q), pressure (P) and load patch aspect ratio (AR) are to be calculated with respect to the mid-length position of each sub-region (each maximum of F, Q and P is to be used in the calculation of the ice load parameters P_{avg}, b and w).

I2 (cont)

(iii) The Bow area load characteristics are determined as follows:

(a) Shape coefficient, fa_i, is to be taken as

fa_i = minimum ($fa_{i,1}$; $fa_{i,2}$; $fa_{i,3}$) [Equation 1]

where $fa_{i,1} = (0.097 - 0.68\,(x/L - 0.15)^2) * \alpha_i \;/\; (\beta'_i)^{0.5}$ [Equation 2]

$fa_{i,2} = 1.2 * CF_F \;/\; (\sin(\beta'_i) * CF_C * D^{0.64})$ [Equation 3]

$fa_{i,3} = 0.60$ [Equation 4]

i = sub-region considered
L = ship length measured at the upper ice waterline (UIWL) [m]
x = distance from the forward perpendicular (FP) to station under consideration [m]
α = waterline angle [deg], see Figure 2
β' = normal frame angle [deg], see Figure 2
D = ship displacement [kt], not to be taken less than 5 kt
CF_C = Crushing Failure Class Factor from Table 1
CF_F = Flexural Failure Class Factor from Table 1

(b) Force, F:

$F_i = fa_i * CF_C * D^{0.64}$ [MN] [Equation 5]

where i = sub-region considered
fa_i = shape coefficient of sub-region i
CF_C = Crushing Failure Class Factor from Table 1
D = ship displacement [kt], not to be taken less than 5 kt

(c) Load patch aspect ratio, AR:

$AR_i = 7.46 * \sin(\beta'_i) \geq 1.3$ [Equation 6]

where i = sub-region considered
β'_i = normal frame angle of sub-region i [deg]

(d) Line load, Q:

$Q_i = F_i^{0.61} * CF_D / AR_i^{0.35}$ [MN/m] [Equation 7]

where i = sub-region considered
F_i = force of sub-region i [MN]
CF_D = Load Patch Dimensions Class Factor from Table 1
AR_i = load patch aspect ratio of sub-region i

(e) Pressure, P:

$P_i = F_i^{0.22} * CF_D^2 * AR_i^{0.3}$ [MPa] [Equation 8]

where i = sub-region considered
F_i = force of sub-region i [MN]

I2
(cont)

CF_D = load patch dimensions class factor from Table 1
AR_i = load patch aspect ratio of sub-region i

I2.3.2.2 Hull Areas Other Than the Bow

(i) In the hull areas other than the bow, the force (F_{NonBow}) and line load (Q_{NonBow}) used in the determination of the load patch dimensions (b_{NonBow}, w_{NonBow}) and design pressure (P_{avg}) are determined as follows:

(a) Force, F_{NonBow}:

$$F_{NonBow} = 0.36 * CF_C * DF \text{ [MN]} \qquad \text{[Equation 9]}$$

where CF_C = Crushing Force Class Factor from Table 1
DF = ship displacement factor
= $D^{0.64}$ if $D \leq CF_{DIS}$
= $CF_{DIS}^{0.64} + 0.10 (D - CF_{DIS})$ if $D > CF_{DIS}$
D = ship displacement [kt], not to be taken less than 10 kt
CF_{DIS} = Displacement Class Factor from Table 1

(b) Line Load, Q_{NonBow}:

$$Q_{NonBow} = 0.639 * F_{NonBow}^{0.61} * CF_D \text{ [MN/m]} \qquad \text{[Equation 10]}$$

where F_{NonBow} = force from Equation 9 [MN]
CF_D = Load Patch Dimensions Class Factor from Table 1

I2.3.3 Design Load Patch

(i) In the Bow area, and the Bow Intermediate Icebelt area for ships with class notation PC6 and PC7, the design load patch has dimensions of width, w_{Bow}, and height, b_{Bow}, defined as follows:

$$w_{Bow} = F_{Bow} / Q_{Bow} \text{ [m]} \qquad \text{[Equation 11]}$$

$$b_{Bow} = Q_{Bow} / P_{Bow} \text{ [m]} \qquad \text{[Equation 12]}$$

where F_{Bow} = maximum F_i in the Bow area [MN]
Q_{Bow} = maximum Q_i in the Bow area [MN/m]
P_{Bow} = maximum P_i in the Bow area [MPa]

(ii) In hull areas other than those covered by I2.3.3 (i), the design load patch has dimensions of width, w_{NonBow}, and height, b_{NonBow}, defined as follows:

$$w_{NonBow} = F_{NonBow} / Q_{NonBow} \text{ [m]} \qquad \text{[Equation 13]}$$

$$b_{NonBow} = w_{NonBow} / 3.6 \text{ [m]} \qquad \text{[Equation 14]}$$

where F_{NonBow} = force determined using Equation 9 [MN]
Q_{NonBow} = line load determined using Equation 10 [MN/m]

I2
(cont)

I2.3.4 Pressure Within the Design Load Patch

(i) The average pressure, P_{avg}, within a design load patch is determined as follows:

$$P_{avg} = F / (b * w) \text{ [MPa]} \qquad \text{[Equation 15]}$$

where $F = F_{Bow}$ or F_{NonBow} as appropriate for the hull area under consideration [MN]
$b = b_{Bow}$ or b_{NonBow} as appropriate for the hull area under consideration [m]
$w = w_{Bow}$ or w_{NonBow} as appropriate for the hull area under consideration [m]

(ii) Areas of higher, concentrated pressure exist within the load patch. In general, smaller areas have higher local pressures. Accordingly, the peak pressure factors listed in Table 2 are used to account for the pressure concentration on localized structural members.

Table 2 - Peak Pressure Factors

Structural Member		**Peak Pressure Factor (PPF_i)**
Plating	Transversely-Framed	$PPF_p = (1.8 - s) \geq 1.2$
	Longitudinally-Framed	$PPF_p = (2.2 - 1.2 * s) \geq 1.5$
Frames in Transverse Framing Systems	With Load Distributing Stringers	$PPF_t = (1.6 - s) \geq 1.0$
	With No Load Distributing Stringers	$PPF_t = (1.8 - s) \geq 1.2$
Load Carrying Stringers Side and Bottom Longitudinals Web Frames		$PPF_s = 1$, if $S_w \geq 0.5 * w$ $PPF_s = 2.0 - 2.0 * S_w / w$, if $S_w < (0.5 * w)$
where: s = frame or longitudinal spacing [m] S_w = web frame spacing [m] w = ice load patch width [m]		

I2.3.5 Hull Area Factors

(i) Associated with each hull area is an Area Factor that reflects the relative magnitude of the load expected in that area. The Area Factor (AF) for each hull area is listed in Table 3.

(ii) In the event that a structural member spans across the boundary of a hull area, the largest hull area factor is to be used in the scantling determination of the member.

(iii) Due to their increased manoeuvrability, ships having propulsion arrangements with azimuthing thruster(s) or “podded” propellers shall have specially considered Stern Icebelt (S_i) and Stern Lower (S_l) hull area factors.

I2 (cont)

Table 3 - Hull Area Factors (AF)

Hull Area		Area	Polar Class						
			PC1	PC2	PC3	PC4	PC5	PC6	PC7
Bow (B)	All	B	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Bow Intermediate (BI)	Icebelt	BI_i	0.90	0.85	0.85	0.80	0.80	1.00*	1.00*
	Lower	BI_l	0.70	0.65	0.65	0.60	0.55	0.55	0.50
	Bottom	BI_b	0.55	0.50	0.45	0.40	0.35	0.30	0.25
Midbody (M)	Icebelt	M_i	0.70	0.65	0.55	0.55	0.50	0.45	0.45
	Lower	M_l	0.50	0.45	0.40	0.35	0.30	0.25	0.25
	Bottom	M_b	0.30	0.30	0.25	**	**	**	**
Stern (S)	Icebelt	S_i	0.75	0.70	0.65	0.60	0.50	0.40	0.35
	Lower	S_l	0.45	0.40	0.35	0.30	0.25	0.25	0.25
	Bottom	S_b	0.35	0.30	0.30	0.25	0.15	**	**

Note to Table 3: * See I2.3.1 (iii).
** Indicates that strengthening for ice loads is not necessary.

I2.4 Shell Plate Requirements

I2.4.1 The required minimum shell plate thickness, t, is given by:

$t = t_{net} + t_s$ [mm] [Equation 16]

where t_{net} = plate thickness required to resist ice loads according to I2.4.2 [mm]
t_s = corrosion and abrasion allowance according to I2.11 [mm]

I2.4.2 The thickness of shell plating required to resist the design ice load, t_{net}, depends on the orientation of the framing.

In the case of transversely-framed plating ($\Omega \geq 70$ deg), including all bottom plating, i.e. plating in hull areas B_{Ib}, M_b and S_b, the net thickness is given by:

$t_{net} = 500 * s * ((AF * PPF_p * P_{avg}) / \sigma_y)^{0.5} / (1 + s / (2 * b))$ [mm] [Equation 17a]

In the case of longitudinally-framed plating ($\Omega \leq 20$ deg), when $b \geq s$, the net thickness is given by:

$t_{net} = 500 * s * ((AF * PPF_p * P_{avg}) / \sigma_y)^{0.5} / (1 + s / (2 * l))$ [mm] [Equation 17b]

In the case of longitudinally-framed plating ($\Omega \leq 20$ deg), when $b < s$, the net thickness is given by:

$t_{net} = 500 * s * ((AF * PPF_p * P_{avg}) / \sigma_y)^{0.5} * (2 * b / s - (b / s)^2)^{0.5} / (1 + s / (2 * l))$ [mm] [Equation 17c]

In the case of obliquely-framed plating (70 deg > Ω > 20 deg), linear interpolation is to be used.

where Ω = smallest angle between the chord of the waterline and the line of the first level framing as illustrated in Figure 3 [deg].

I2
(cont)

s = transverse frame spacing in transversely-framed ships or longitudinal frame spacing in longitudinally-framed ships [m]
AF = Hull Area Factor from Table 3
PPF_p = Peak Pressure Factor from Table 2
P_{avg} = average patch pressure according to Equation 15 [MPa]
σ_y = minimum upper yield stress of the material [N/mm^2]
b = height of design load patch [m], where b ≤ (*l* – s/4) in the case of [Equation 17a]
l = distance between frame supports, i.e. equal to the frame span as given in I2.5.5, but not reduced for any fitted end brackets [m]. When a load-distributing stringer is fitted, the length *l* need not be taken larger than the distance from the stringer to the most distant frame support.

I2.5 Framing - General

I2.5.1 Framing members of Polar class ships are to be designed to withstand the ice loads defined in I2.3.

I2.5.2 The term "framing member" refers to transverse and longitudinal local frames, load-carrying stringers and web frames in the areas of the hull exposed to ice pressure, see Figure 1. Where load-distributing stringers have been fitted, the arrangement and scantlings of these are to be in accordance with the requirements of each member society.

I2.5.3 The strength of a framing member is dependent upon the fixity that is provided at its supports. Fixity can be assumed where framing members are either continuous through the support or attached to a supporting section with a connection bracket. In other cases, simple support is to be assumed unless the connection can be demonstrated to provide significant rotational restraint. Fixity is to be ensured at the support of any framing which terminates within an ice-strengthened area.

I2.5.4 The details of framing member intersection with other framing members, including plated structures, as well as the details for securing the ends of framing members at supporting sections, are to be in accordance with the requirements of each member society.

I2.5.5 The design span of a framing member is to be determined on the basis of its moulded length. If brackets are fitted, the design span may be reduced in accordance with the usual practice of each member society. Brackets are to be configured to ensure stability in the elastic and post-yield response regions.

I2.5.6 When calculating the section modulus and shear area of a framing member, net thicknesses of the web, flange (if fitted) and attached shell plating are to be used. The shear area of a framing member may include that material contained over the full depth of the member, i.e. web area including portion of flange, if fitted, but excluding attached shell plating.

I2.5.7 The actual net effective shear area, A_w, of a framing member is given by:

$$A_w = h \; t_{wn} \sin\varphi_w / 100 \text{ [cm}^2\text{]} \qquad \text{[Equation 18]}$$

h = height of stiffener [mm], see Figure 4
t_{wn} = net web thickness [mm]
= $t_w - t_c$
t_w = as built web thickness [mm], see Figure 4

I2
(cont)

t_c = corrosion deduction [mm] to be subtracted from the web and flange thickness (as specified by each member society, but not less than t_s as required by I2.11.3).
φ_w = smallest angle between shell plate and stiffener web, measured at the midspan of the stiffener, see Figure 4. The angle φ_w may be taken as 90 degrees provided the smallest angle is not less than 75 degrees.

I2.5.8 When the cross-sectional area of the attached plate flange exceeds the cross-sectional area of the local frame, the actual net effective plastic section modulus, Z_p, is given by:

$$Z_p = A_{pn} t_{pn} / 20 + \frac{h_w^2 \, t_{wn} \sin\varphi_w}{2000} + A_{fn} \left(h_{fc} \sin\varphi_w - b_w \cos \varphi_w\right)/10 \text{ [cm}^3\text{]} \qquad \text{[Equation 19]}$$

h, t_{wn},, t_c, and φ_w are as given in I2.5.7 and s as given in I2.4.2.
A_{pn} = net cross-sectional area of attached plate [cm^2] (equal to t_{pn}*s*10, but not to be taken greater than the net cross-sectional area of the local frame)
t_{pn} = fitted net shell plate thickness [mm] (shall comply with t_{net} as required by I2.4.2)
h_w = height of local frame web [mm], see Figure 4
A_{fn} = net cross-sectional area of local frame flange [cm^2]
h_{fc} = height of local frame measured to centre of the flange area [mm], see Figure 4
b_w = distance from mid thickness plane of local frame web to the centre of the flange area [mm], see Figure 4

When the cross-sectional area of the local frame exceeds the cross-sectional area of the attached plate flange, the plastic neutral axis is located a distance z_{na} above the attached shell plate, given by:

$$z_{na} = \left(100 A_{fn} + h_w \, t_{wn} - 1000 \, t_{pn} \, s\right) / \left(2 t_{wn}\right) \text{ [mm]} \qquad \text{[Equation 20]}$$

and the net effective plastic section modulus, Z_p, is given by:

$$Z_p = t_{pn} \, s \, z_{na} \sin\varphi_w + \left(\begin{array}{c} \dfrac{\left(\left(h_w - z_{na}\right)^2 + z_{na}^2\right) t_{wn} \sin\varphi_w}{2000} \\ + A_{fn} \left(\left(h_{fc} - z_{na}\right) \sin\varphi_w - b_w \cos \varphi_w\right)/10 \end{array} \right) \text{ [cm}^3\text{]} \qquad \text{[Equation 21]}$$

I2.5.9 In the case of oblique framing arrangement (70 deg > Ω > 20 deg, where Ω is defined as given in I2.4.2), linear interpolation is to be used.

I2.6 Framing - Transversely-Framed Side Structures and Bottom Structures

I2.6.1 The local frames in transversely-framed side structures and in bottom structures (i.e. hull areas B_{lb}, M_b and S_b) are to be dimensioned such that the combined effects of shear and bending do not exceed the plastic strength of the member. The plastic strength is defined by the magnitude of midspan load that causes the development of a plastic collapse mechanism.

I2.6.2 The actual net effective shear area of the frame, A_w, as defined in I2.5.7, is to comply with the following condition: $A_w \geq A_t$, where:

$A_t = 100^2 * 0.5 * LL * s * (AF * PPF_t * P_{avg}) / (0.577 * \sigma_y)$ [cm^2] [Equation 22]

where LL = length of loaded portion of span
= lesser of a and b [m]

I2
(cont)

a = frame span as defined in I2.5.5 [m]
b = height of design ice load patch according to Equation 12 or 14 [m]
s = transverse frame spacing [m]
AF = Hull Area Factor from Table 3
PPF_t = Peak Pressure Factor from Table 2
P_{avg} = average pressure within load patch according to Equation 15 [MPa]
σ_y = minimum upper yield stress of the material [N/mm^2]

I2.6.3 The actual net effective plastic section modulus of the plate/stiffener combination, Z_p, as defined in I2.5.8, is to comply with the following condition: $Z_p \geq Z_{pt}$, where Z_{pt} is to be the greater calculated on the basis of two load conditions: a) ice load acting at the midspan of the transverse frame, and b) the ice load acting near a support. The A_1 parameter in Equation 23 reflects the two conditions:

$$Z_{pt} = 100^3 * LL * Y * s* (AF * PPF_t * P_{avg})* a * A_1 / (4*\sigma_y) \ [cm^3] \qquad \text{[Equation 23]}$$

where AF, PPF_t, P_{avg}, LL, b, s, a and σ_y are as given in I2.6.2
Y = 1 - 0.5 * (LL / a)
A_1 = maximum of
$A_{1A} = 1 / (1 + j / 2 + k_w * j / 2 * [(1 - a_1^2)^{0.5} - 1])$
$A_{1B} = (1 – 1 / (2 * a_1 * Y)) / (0.275 + 1.44 * k_z^{0.7})$
j = 1 for framing with one simple support outside the ice-strengthened areas
= 2 for framing without any simple supports
$a_1 = A_t / A_w$
A_t = minimum shear area of transverse frame as given in I2.6.2 [cm^2]
A_w = effective net shear area of transverse frame (calculated according to I2.5.7) [cm^2]
$k_w = 1 / (1 + 2 * A_{fn} / A_w)$ with A_{fn} as given in I2.5.8
$k_z = z_p / Z_p$ in general
= 0.0 when the frame is arranged with end bracket
z_p = sum of individual plastic section modulii of flange and shell plate as fitted [cm^3]
$= (b_f * t_{fn}^2 / 4 + b_{eff} * t_{pn}^2 / 4) / 1000$
b_f = flange breadth [mm], see Figure 4
t_{fn} = net flange thickness [mm]
$= t_f – t_c$ (t_c as given in I2.5.7)
t_f = as-built flange thickness [mm], see Figure 4
t_{pn} = the fitted net shell plate thickness [mm] (not to be less than t_{net} as given in I2.4)
b_{eff} = effective width of shell plate flange [mm]
= 500 s
Z_p = net effective plastic section modulus of transverse frame (calculated according to I2.5.8) [cm^3]

I2.6.4 The scantlings of the frame are to meet the structural stability requirements of I2.9.

I2.7 Framing - Side Longitudinals (Longitudinally-Framed Ships)

I2.7.1 Side longitudinals are to be dimensioned such that the combined effects of shear and bending do not exceed the plastic strength of the member. The plastic strength is defined by the magnitude of midspan load that causes the development of a plastic collapse mechanism.

I2.7.2 The actual net effective shear area of the frame, A_w, as defined in I2.5.7, is to comply with the following condition: $A_w \geq A_L$, where:

I2
(cont)

$A_L = 100^2 * (AF * PPF_s * P_{avg}) * 0.5 * b_1 * a / (0.577 * \sigma_y)$ [cm^2] [Equation 24]

where AF = Hull Area Factor from Table 3
PPF_s = Peak Pressure Factor from Table 2
P_{avg} = average pressure within load patch according to Equation 15 [MPa]
$b_1 = k_o * b_2$ [m]
$k_o = 1 - 0.3 / b'$
$b' = b / s$
b = height of design ice load patch from Equation 12 or 14 [m]
s = spacing of longitudinal frames [m]
$b_2 = b (1 - 0.25 * b')$ [m], if $b' < 2$
$= s$ [m], if $b' \geq 2$
a = longitudinal design span as given in I2.5.5 [m]
σ_y = minimum upper yield stress of the material [N/mm^2]

I2.7.3 The actual net effective plastic section modulus of the plate/stiffener combination, Z_p, as defined in I2.5.8, is to comply with the following condition: $Z_p \geq Z_{pL}$, where:

$Z_{pL} = 100^3 * (AF * PPF_s * P_{avg}) * b_1 * a^2 * A_4 / (8 * \sigma_y)$ [cm^3] [Equation 25]

where AF, PPF_s ,P_{avg}, b_1, a and σ_y are as given in I2.7.2
$A_4 = 1 / (2 + k_{wl} * [(1 - a_4^2)^{0.5} - 1])$
$a_4 = A_L / A_w$
A_L = minimum shear area for longitudinal as given in I2.7.2 [cm^2]
A_w = net effective shear area of longitudinal (calculated according to I2.5.7) [cm^2]
$k_{wl} = 1 / (1 + 2 * A_{fn} / A_w)$ with A_{fn} as given in I2.5.8

I2.7.4 The scantlings of the longitudinals are to meet the structural stability requirements of I2.9.

I2.8 Framing - Web Frame and Load-Carrying Stringers

I2.8.1 Web frames and load-carrying stringers are to be designed to withstand the ice load patch as defined in I2.3. The load patch is to be applied at locations where the capacity of these members under the combined effects of bending and shear is minimised.

I2.8.2 Web frames and load-carrying stringers are to be dimensioned such that the combined effects of shear and bending do not exceed the limit state(s) defined by each member society. Where these members form part of a structural grillage system, appropriate methods of analysis are to be used. Where the structural configuration is such that members do not form part of a grillage system, the appropriate peak pressure factor (PPF) from Table 2 is to be used. Special attention is to be paid to the shear capacity in way of lightening holes and cut-outs in way of intersecting members.

I2.8.3 The scantlings of web frames and load-carrying stringers are to meet the structural stability requirements of I2.9.

I2.9 Framing - Structural Stability

I2.9.1 To prevent local buckling in the web, the ratio of web height (h_w) to net web thickness (t_{wn}) of any framing member is not to exceed:

I2 (cont)

For flat bar sections: $h_w / t_{wn} \le 282 / (\sigma_y)^{0.5}$

For bulb, tee and angle sections: $h_w / t_{wn} \le 805 / (\sigma_y)^{0.5}$

where h_w = web height
t_{wn} = net web thickness
σ_y = minimum upper yield stress of the material [N/mm^2]

I2.9.2 Framing members for which it is not practicable to meet the requirements of I2.9.1 (e.g. load carrying stringers or deep web frames) are required to have their webs effectively stiffened. The scantlings of the web stiffeners are to ensure the structural stability of the framing member. The minimum net web thickness for these framing members is given by:

$$t_{wn} = 2.63 \times 10^{-3} * c_1 * \sigma_y / (5.34 + 4 * (c_1 / c_2)^2) \text{ [mm]} \quad \text{[Equation 26]}$$

where $c_1 = h_w - 0.8 * h$ [mm]
h_w = web height of stringer / web frame [mm] (see Figure 5)
h = height of framing member penetrating the member under consideration (0 if no such framing member) [mm] (see Figure 5)
c_2 = spacing between supporting structure oriented perpendicular to the member under consideration [mm] (see Figure 5)
σ_y = minimum upper yield stress of the material [N/mm^2]

I2.9.3 In addition, the following is to be satisfied:

$$t_{wn} \ge 0.35 * t_{pn} * (\sigma_y / 235)^{0.5}$$

where σ_y = minimum upper yield stress of the material [N/mm^2]
t_{wn} = net thickness of the web [mm]
t_{pn} = net thickness of the shell plate in way the framing member [mm]

I2.9.4 To prevent local flange buckling of welded profiles, the following are to be satisfied:

(i) The flange width, b_f [mm], shall not be less than five times the net thickness of the web, t_{wn}.

(ii) The flange outstand, b_{out} [mm], shall meet the following requirement:

$$b_{out} / t_{fn} \le 155 / (\sigma_y)^{0.5}$$

where t_{fn} = net thickness of flange [mm]
σ_y = minimum upper yield stress of the material [N/mm^2]

I2.10 Plated Structures

I2.10.1 Plated structures are those stiffened plate elements in contact with the hull and subject to ice loads. These requirements are applicable to an inboard extent which is the lesser of:

(i) web height of adjacent parallel web frame or stringer; or
(ii) 2.5 times the depth of framing that intersects the plated structure

I2
(cont)

I2.10.2 The thickness of the plating and the scantlings of attached stiffeners are to be such that the degree of end fixity necessary for the shell framing is ensured.

I2.10.3 The stability of the plated structure is to adequately withstand the ice loads defined in I2.3.

I2.11 Corrosion/Abrasion Additions and Steel Renewal

I2.11.1 Effective protection against corrosion and ice-induced abrasion is recommended for all external surfaces of the shell plating for all Polar ships.

I2.11.2 The values of corrosion/abrasion additions, t_s, to be used in determining the shell plate thickness for each Polar Class are listed in Table 4.

I2.11.3 Polar ships are to have a minimum corrosion/abrasion addition of t_s = 1.0 mm applied to all internal structures within the ice-strengthened hull areas, including plated members adjacent to the shell, as well as stiffener webs and flanges.

Table 4 - Corrosion/Abrasion Additions for Shell Plating

Hull Area	t_s [mm]					
	With Effective Protection			Without Effective Protection		
	PC1 - PC3	PC4 & PC5	PC6 & PC7	PC1 - PC3	PC4 & PC5	PC6 & PC7
Bow; Bow Intermediate Icebelt	3.5	2.5	2.0	7.0	5.0	4.0
Bow Intermediate Lower; Midbody & Stern Icebelt	2.5	2.0	2.0	5.0	4.0	3.0
Midbody & Stern Lower; Bottom	2.0	2.0	2.0	4.0	3.0	2.5
Other Areas	2.0	2.0	2.0	3.5	2.5	2.0

I2.11.4 Steel renewal for ice strengthened structures is required when the gauged thickness is less than t_{net} + 0.5 mm.

I2.12 Materials

I2.12.1 Plating materials for hull structures are to be not less than those given in Tables 6 and 7 based on the as-built thickness of the material, the Polar ice class notation assigned to the ship and the Material Class of structural members given in Table 5.

I2.12.2 Material classes specified in Table 1 of UR S6.1 are applicable to polar ships regardless of the ship's length. In addition, material classes for weather and sea exposed structural members and for members attached to the weather and sea exposed shell plating of polar ships are given in Table 5. Where the material classes in Table 5 and those in Table 1 of UR S6.1 differ, the higher material class is to be applied.

I2
(cont)

Table 5 - Material Classes for Structural Members of Polar Ships

Structural Members	Material Class
Shell plating within the bow and bow intermediate icebelt hull areas (B, B_{Ii})	II
All weather and sea exposed SECONDARY and PRIMARY, as defined in Table 1 of UR S6.1, structural members outside 0.4L amidships	I
Plating materials for stem and stern frames, rudder horn, rudder, propeller nozzle, shaft brackets, ice skeg, ice knife and other appendages subject to ice impact loads	II
All inboard framing members attached to the weather and sea-exposed plating including any contiguous inboard member within 600 mm of the shell plating	I
Weather-exposed plating and attached framing in cargo holds of ships which by nature of their trade have their cargo hold hatches open during cold weather operations	I
All weather and sea exposed SPECIAL, as defined in Table 1 of UR S6.1, structural members within 0.2L from FP	II

I2.12.3 Steel grades for all plating and attached framing of hull structures and appendages situated below the level of 0.3 m below the lower waterline, as shown in Figure 6, are to be obtained from Table 2 of UR S6 based on the Material Class for Structural Members in Table 5 above, regardless of Polar Class.

I2.12.4 Steel grades for all weather exposed plating of hull structures and appendages situated above the level of 0.3 m below the lower ice waterline, as shown in Figure 6, are to be not less than given in Table 6.

Table 6 - Steel Grades for Weather Exposed Plating

Thickness, t [mm]	Material Class I				Material Class II				Material Class III					
	PC1-5		PC6&7		PC1-5		PC6&7		PC1-3		PC4&5		PC6&7	
	MS	HT	MS	HT	MS	HT	MS	HT	MS	HT	MS	HT	MS	HT
t ≤ 10	B	AH	B	AH	B	AH	B	AH	E	EH	E	EH	B	AH
10 < t ≤ 15	B	AH	B	AH	D	DH	B	AH	E	EH	E	EH	D	DH
15 < t ≤ 20	D	DH	B	AH	D	DH	B	AH	E	EH	E	EH	D	DH
20 < t ≤ 25	D	DH	B	AH	D	DH	B	AH	E	EH	E	EH	D	DH
25 < t ≤ 30	D	DH	B	AH	E	EH2	D	DH	E	EH	E	EH	E	EH
30 < t ≤ 35	D	DH	B	AH	E	EH	D	DH	E	EH	E	EH	E	EH
35 < t ≤ 40	D	DH	D	DH	E	EH	D	DH	F	FH	E	EH	E	EH
40 < t ≤ 45	E	EH	D	DH	E	EH	D	DH	F	FH	E	EH	E	EH
45 < t ≤ 50	E	EH	D	DH	E	EH	D	DH	F	FH	F	FH	E	EH

Notes to Table 6:
1) Includes weather-exposed plating of hull structures and appendages, as well as their outboard framing members, situated above a level of 0.3 m below the lowest ice waterline.
2) Grades D, DH are allowed for a single strake of side shell plating not more than 1.8 m wide from 0.3 m below the lowest ice waterline.

I2.12.5 Steel grades for all inboard framing members attached to weather exposed plating are to be not less than given in Table 7. This applies to all inboard framing members as well as

I2 (cont)

to other contiguous inboard members (e.g. bulkheads, decks) within 600 mm of the exposed plating.

Table 7 - Steel Grades for Inboard Framing Members Attached to Weather Exposed Plating

Thickness t, mm	PC1 - PC5		PC6 & PC7	
	MS	HT	MS	HT
$t \leq 20$	B	AH	B	AH
$20 < t \leq 35$	D	DH	B	AH
$35 < t \leq 45$	D	DH	D	DH
$45 < t \leq 50$	E	EH	D	DH

I2.12.6 Castings are to have specified properties consistent with the expected service temperature for the cast component.

I2.13 Longitudinal Strength

I2.13.1 Application

I2.13.1.1 Ice loads need only be combined with still water loads. The combined stresses are to be compared against permissible bending and shear stresses at different locations along the ship's length. In addition, sufficient local buckling strength is also to be verified.

I2.13.2 Design Vertical Ice Force at the Bow

I2.13.2.1 The design vertical ice force at the bow, F_{IB}, is to be taken as

F_{IB} = minimum ($F_{IB,1}$; $F_{IB,2}$) [MN] [Equation 27]

where $F_{IB,1} = 0.534 * K_I^{0.15} * \sin^{0.2}(\gamma_{stem}) * (D * K_h)^{0.5} * CF_L$ [MN] [Equation 28]

$F_{IB,2} = 1.20 * CF_F$ [MN] [Equation 29]

K_I = indentation parameter = K_f / K_h

a) for the case of a blunt bow form

$K_f = (2 * C * B^{1-eb} / (1 + e_b))^{0.9} * \tan(\gamma_{stem})^{-0.9*(1 + eb)}$

b) for the case of wedge bow form (α_{stem} < 80 deg), e_b =1 and the above simplifies to

$K_f = (\tan(\alpha_{stem}) / \tan^2(\gamma_{stem}))^{0.9}$

K_h = $0.01 * A_{wp}$ [MN/m]

CF_L = Longitudinal Strength Class Factor from Table 1

e_b = bow shape exponent which best describes the waterplane (see Figures 7 and 8)

= 1.0 for a simple wedge bow form

= 0.4 to 0.6 for a spoon bow form

= 0 for a landing craft bow form

An approximate e_b determined by a simple fit is acceptable

γ_{stem} = stem angle to be measured between the horizontal axis and the stem tangent at the upper ice waterline [deg] (buttock angle as per Figure 2 measured on the centreline)

$C = 1 / (2 * (L_B / B)^{eb})$

B = ship moulded breadth [m]

I2
(cont)

L_B = bow length used in the equation $y = B / 2 * (x/L_B)^{eb}$ [m] (see Figures 7 and 8)
D = ship displacement [kt], not to be taken less than 10 kt
A_{wp} = ship waterplane area [m^2]
CF_F = Flexural Failure Class Factor from Table 1
Where applicable, draught dependent quantities are to be determined at the waterline corresponding to the loading condition under consideration.

I2.13.3 Design Vertical Shear Force

I2.13.3.1 The design vertical ice shear force, F_I, along the hull girder is to be taken as:

$F_I = C_f * F_{IB}$ [MN] [Equation 30]

where C_f = longitudinal distribution factor to be taken as follows:

(a) Positive shear force
C_f = 0.0 between the aft end of L and 0.6L from aft
C_f = 1.0 between 0.9 L from aft and the forward end of L

(b) Negative shear force
C_f = 0.0 at the aft end of L
C_f = -0.5 between 0.2 L and 0.6L from aft
C_f = 0.0 between 0.8 L from aft and the forward end of L

Intermediate values are to be determined by linear interpolation

I2.13.3.2 The applied vertical shear stress, τ_a, is to be determined along the hull girder in a similar manner as in UR S11.5.4.2 by substituting the design vertical ice shear force for the design vertical wave shear force.

I2.13.4 Design Vertical Ice Bending Moment

I2.13.4.1 The design vertical ice bending moment, M_I, along the hull girder is to be taken as:

$M_I = 0.1 * C_m * L * \sin^{-0.2}(\gamma_{stem}) * F_{IB}$ [MNm] [Equation 31]

where L = ship length (Rule Length as defined in UR S2.1) [m]
γ_{stem} is as given in I2.13.2.1
F_{IB} = design vertical ice force at the bow [MN]
C_m = longitudinal distribution factor for design vertical ice bending moment to be taken as follows:
C_m = 0.0 at the aft end of L
C_m = 1.0 between 0.5L and 0.7L from aft
C_m = 0.3 at 0.95L from aft
C_m = 0.0 at the forward end of L
Intermediate values are to be determined by linear interpolation
Where applicable, draught dependent quantities are to be determined at the waterline corresponding to the loading condition under consideration.

I2.13.4.2 The applied vertical bending stress, σ_a, is to be determined along the hull girder in a similar manner as in UR S11.5.4.1, by substituting the design vertical ice bending moment for the design vertical wave bending moment. The ship still water bending moment is to be taken as the maximum sagging moment.

I2
(cont)

I2.13.5 Longitudinal Strength Criteria

I2.13.5.1 The strength criteria provided in Table 8 are to be satisfied. The design stress is not to exceed the permissible stress.

Table 8 - Longitudinal Strength Criteria

Failure Mode	Applied Stress	Permissible Stress when $\sigma_y / \sigma_u \leq 0.7$	Permissible Stress when $\sigma_y / \sigma_u > 0.7$
Tension	σ_a	$\eta * \sigma_y$	$\eta * 0.41 (\sigma_u + \sigma_y)$
Shear	τ_a	$\eta * \sigma_y / (3)^{0.5}$	$\eta * 0.41 (\sigma_u + \sigma_y) / (3)^{0.5}$
Buckling	σ_a	σ_c for plating and for web plating of stiffeners $\sigma_c / 1.1$ for stiffeners	
	τ_a	τ_c	

where σ_a = applied vertical bending stress [N/mm^2]
τ_a = applied vertical shear stress [N/mm^2]
σ_y = minimum upper yield stress of the material [N/mm^2]
σ_u = ultimate tensile strength of material [N/mm^2]
σ_c = critical buckling stress in compression, according to UR S11.5 [N/mm^2]
τ_c = critical buckling stress in shear, according to UR S11.5 [N/mm^2]
η = 0.8

I2.14 Stem and Stern Frames

I2.14.1 The stem and stern frame are to be designed according to the requirements of each member society. For PC6/PC7 vessels requiring 1AS/1A equivalency, the stem and stern requirements of the Finnish-Swedish Ice Class Rules may need to be additionally considered.

I2.15 Appendages

I2.15.1 All appendages are to be designed to withstand forces appropriate for the location of their attachment to the hull structure or their position within a hull area.

I2.15.2 Load definition and response criteria are to be determined by each member society.

I2.16 Local Details

I2.16.1 For the purpose of transferring ice-induced loads to supporting structure (bending moments and shear forces), local design details are to comply with the requirements of each member society.

I2.16.2 The loads carried by a member in way of cut-outs are not to cause instability. Where necessary, the structure is to be stiffened.

I2 (cont)

I2.17 Direct Calculations

I2.17.1 Direct calculations are not to be utilised as an alternative to the analytical procedures prescribed in this unified requirement.

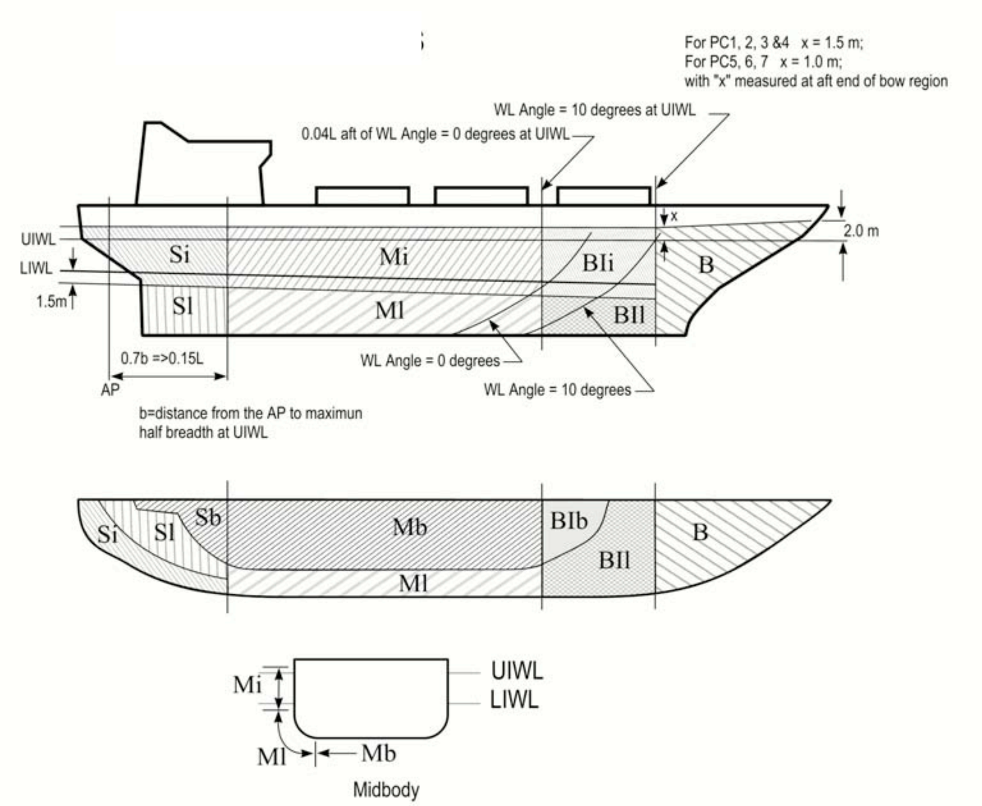
I2.17.2 Where direct calculation is used to check the strength of structural systems, the load patch specified in I2.3 is to be applied.

I2.18 Welding

I2.18.1 All welding within ice-strengthened areas is to be of the double continuous type.

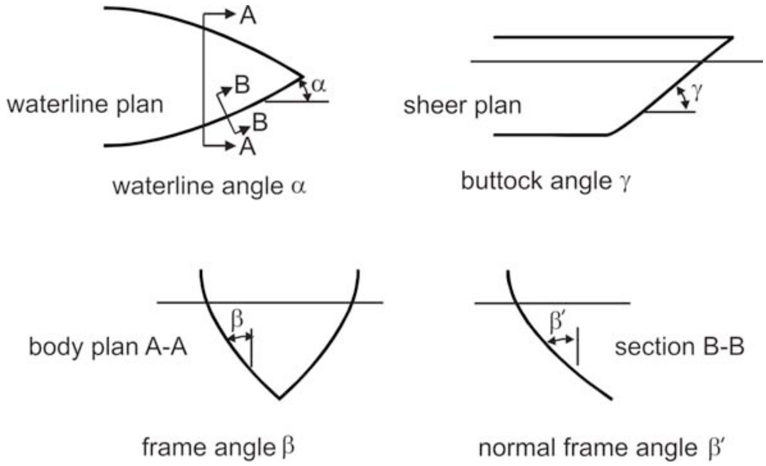
I2.18.2 Continuity of strength is to be ensured at all structural connections.

Figure 1 - Hull Area Extents



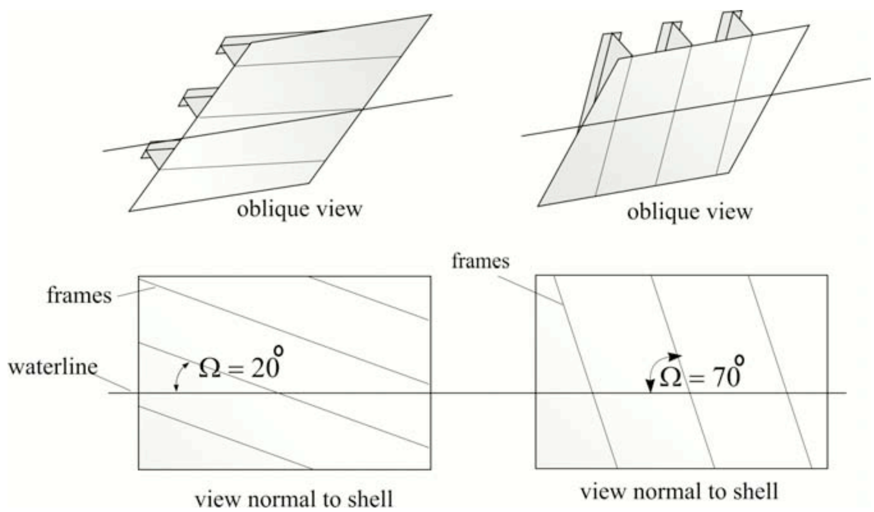
I2
(cont)

Figure 2 - Definition of Hull Angles



Note: β' = normal frame angle at upper ice waterline [deg]
α = upper ice waterline angle [deg]
γ = buttock angle at upper ice waterline (angle of buttock line measured from horizontal) [deg]
$\tan(\beta) = \tan(\alpha)/\tan(\gamma)$
$\tan(\beta') = \tan(\beta)\cos(\alpha)$

Figure 3 - Shell Framing Angle Ω



I2
(cont)

Figure 4 - Stiffener geometry

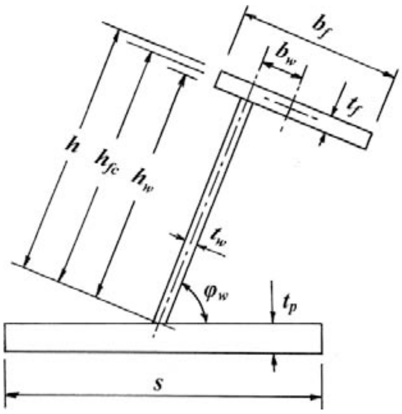


Figure 5 - Parameter Definition for Web Stiffening

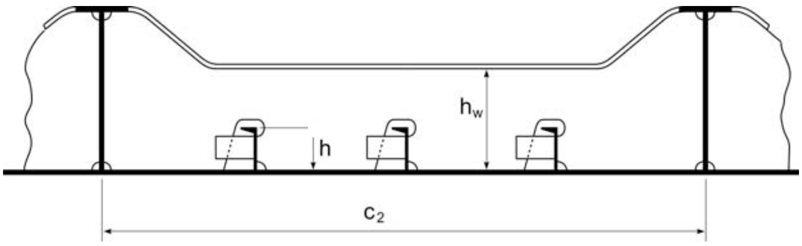
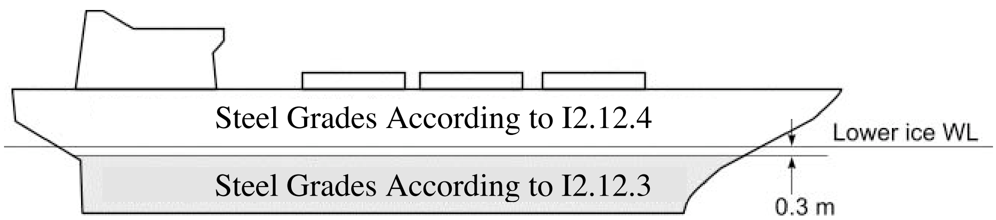


Figure 6 - Steel Grade Requirements for Submerged and Weather Exposed Shell Plating



I2
(cont)

Figure 7 - Bow Shape Definition

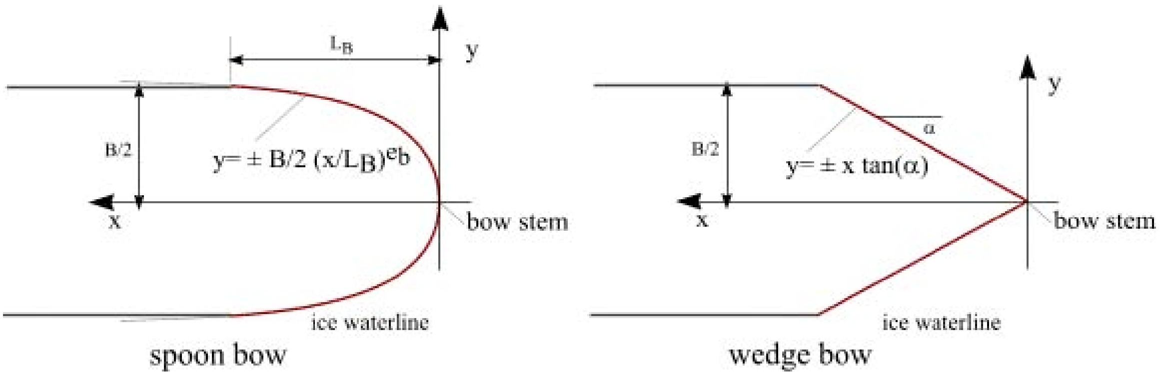
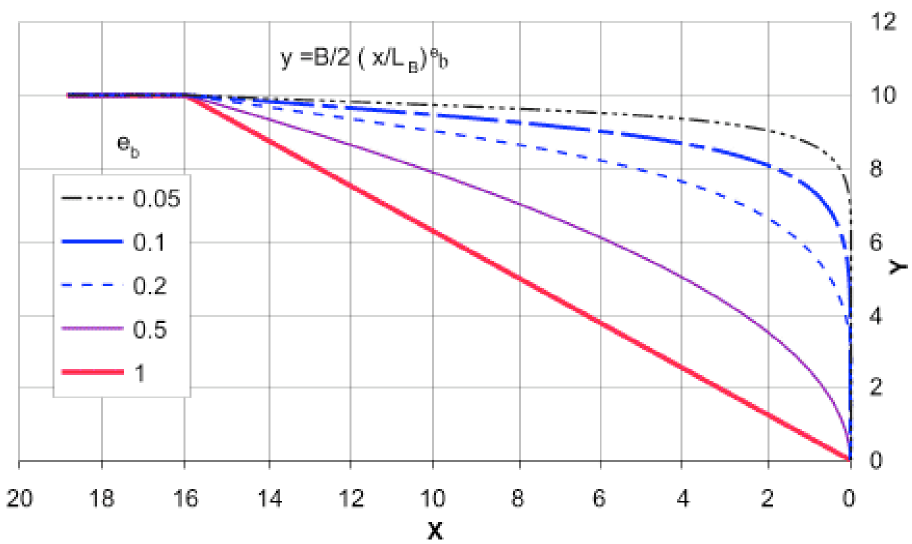


Figure 8 - Illustration of e_b Effect on the Bow Shape for B = 20 and L_B =16



End of Document

I3 Machinery Requirements for Polar Class Ships

(August 2006) (Rev.1 Jan 2007) (Corr.1 Oct 2007)

I3.1 Application *

The contents of this Chapter apply to main propulsion, steering gear, emergency and essential auxiliary systems essential for the safety of the ship and the survivability of the crew.

I3.2

I3.2.1 Drawings and particulars to be submitted

I3.2.1.1 Details of the environmental conditions and the required ice class for the machinery, if different from ship's ice class.

I3.2.1.2 Detailed drawings of the main propulsion machinery. Description of the main propulsion, steering, emergency and essential auxiliaries are to include operational limitations. Information on essential main propulsion load control functions.

I3.2.1.3 Description detailing how main, emergency and auxiliary systems are located and protected to prevent problems from freezing, ice and snow and evidence of their capability to operate in intended environmental conditions.

I3.2.1.4 Calculations and documentation indicating compliance with the requirements of this chapter.

I3.2.2 System Design

13.2.2.1 Machinery and supporting auxiliary systems shall be designed, constructed and maintained to comply with the requirements of "periodically unmanned machinery spaces" with respect to fire safety. Any automation plant (i.e. control, alarm, safety and indication systems) for essential systems installed is to be maintained to the same standard.

I3.2.2.2 Systems, subject to damage by freezing, shall be drainable.

I3.2.2.3 Single screw vessels classed PC1 to PC5 inclusive shall have means provided to ensure sufficient vessel operation in the case of propeller damage including CP-mechanism.

---

* Note:

1. This UR is to be uniformly applied by IACS Societies on ships contracted for construction on and after 1 March 2008.

2. The "contracted for construction" date means the date on which the contract to build the vessel is signed between the prospective owner and the shipbuilder. For further details regarding the date of "contract for construction", refer to IACS Procedural Requirement (PR) No. 29.

I3 (cont)

I3.3 Materials

I3.3.1 Materials exposed to sea water

Materials exposed to sea water, such as propeller blades, propeller hub and blade bolts shall have an elongation not less than 15% on a test piece the length of which is five times the diameter.

Charpy V impact test shall be carried out for other than bronze and austenitic steel materials. Test pieces taken from the propeller castings shall be representative of the thickest section of the blade. An average impact energy value of 20 J taken from three Charpy V tests is to be obtained at minus 10 ºC.

I3.3.2 Materials exposed to sea water temperature

Materials exposed to sea water temperature shall be of steel or other approved ductile material.

An average impact energy value of 20 J taken from three tests is to be obtained at minus 10 ºC.

I3.3.3 Material exposed to low air temperature

Materials of essential components exposed to low air temperature shall be of steel or other approved ductile material.

An average impact energy value of 20 J taken from three Charpy V tests is to be obtained at 10 ºC below the lowest design temperature.

I3.4 Ice Interaction Load

I3.4.1 Propeller Ice Interaction

These Rules cover open and ducted type propellers situated at the stern of a vessel having controllable pitch or fixed pitch blades. Ice loads on bow propellers and pulling type propellers shall receive special consideration. The given loads are expected, single occurrence, maximum values for the whole ships service life for normal operational conditions. These loads do not cover off-design operational conditions, for example when a stopped propeller is dragged through ice. These Rules apply also for azimuthing (geared and podded) thrusters considering loads due to propeller ice interaction. However, ice loads due to ice impacts on the body of azimuthing thrusters are not covered by I3.

The loads given in section I3.4 are total loads (unless otherwise stated) during ice interaction and are to be applied separately (unless otherwise stated) and are intended for component strength calculations only. The different loads given here are to be applied separately.

F_b is a force bending a propeller blade backwards when the propeller mills an ice block while rotating ahead. F_f is a force bending a propeller blade forwards when a propeller interacts with an ice block while rotating ahead.

I3
(cont)

I3.4.2 Ice Class Factors

The Table below lists the design ice thickness and ice strength index to be used for estimation of the propeller ice loads.

Ice Class	**H_{ice} [m]**	**S_{ice} [-]**	**S_{qice} [-]**
PC1	4.0	1.2	1.15
PC2	3.5	1.1	1.15
PC3	3.0	1.1	1.15
PC4	2.5	1.1	1.15
PC5	2.0	1.1	1.15
PC6	1.75	1	1
PC7	1.5	1	1

H_{ice} Ice thickness for machinery strength design

S_{ice} Ice strength index for blade ice force

S_{qice} Ice strength index for blade ice torque

I3.4.3 Design Ice Loads for Open Propeller

I3.4.3.1 Maximum Backward Blade Force, F_b

when $D < D_{limit}$,

$$F_b = -27\, S_{ice}\left[nD\right]^{0.7}\left[\frac{EAR}{Z}\right]^{0.3}\left[D\right]^2 \quad \text{kN} \qquad \text{[Equation 1]}$$

when $D \geq D_{limit}$,

$$F_b = -23\, S_{ice}\left[nD\right]^{0.7}\left[\frac{EAR}{Z}\right]^{0.3}\left[H_{ice}\right]^{1.4}\left[D\right] \quad \text{kN} \qquad \text{[Equation 2]}$$

where $D_{limit} = 0.85 *(H_{ice})^{1.4}$

n is the nominal rotational speed (at MCR free running condition) for CP-propeller and 85% of the nominal rotational speed (at MCR free running condition) for a FP-propeller (regardless driving engine type).

F_b is to be applied as a uniform pressure distribution to an area on the back (suction) side of the blade for the following load cases:

a) Load case 1: from 0.6R to the tip and from the blade leading edge to a value of 0.2 chord length.

b) Load case 2: a load equal to 50% of the F_b is to be applied on the propeller tip area outside of 0.9R.

I3
(cont)

c) Load case 5: for reversible propellers a load equal to 60% of the F_b is to be applied from 0.6R to the tip and from the blade trailing edge to a value of 0.2 chord length.

See load cases 1, 2 and 5 in Table 1 of Appendix.

I3.4.3.2 Maximum Forward Blade Force, F_f

when $D < D_{limit}$

$$F_f = 250 \left[\frac{EAR}{Z}\right] [D]^2 \quad \text{kN} \qquad \text{[Equation 3]}$$

when $D \geq D_{limit}$

$$F_f = 500 \left(\frac{1}{1-\frac{d}{D}}\right) H_{ice} \left[\frac{EAR}{Z}\right] [D] \quad \text{kN} \qquad \text{[Equation 4]}$$

where

$$D_{limit} = \left(\frac{2}{1-\frac{d}{D}}\right) H_{ice} \qquad \text{[Equation 5]}$$

d = propeller hub diameter [m]
D = propeller diameter [m]
EAR = expanded blade area ratio
Z = number of propeller blades

F_f is to be applied as a uniform pressure distribution to an area on the face (pressure) side of the blade for the following loads cases:

a) Load case 3: from 0.6R to the tip and from the blade leading edge to a value of 0.2 chord length.

b) Load case 4: a load equal to 50% of the F_f is to be applied on the propeller tip area outside of 0.9R.

c) Load case 5: for reversible propellers a load equal to 60% F_f is to be applied from 0.6R to the tip and from the blade trailing edge to a value of 0.2 chord length.

See load cases 3, 4 and 5 in Table 1 of Appendix.

I3.4.3.3 Maximum Blade Spindle Torque, Q_{smax}

Spindle torque Q_{smax} around the spindle axis of the blade fitting shall be calculated both for the load cases described in I3.4.3.1 & I3.4.3.2 for F_b F_f. If these spindle torque values are less than the default value given below, the default minimum value shall be used.

Default Value: $Q_{smax} = 0.25 \cdot F \cdot c_{0.7}$ [kNm] [Equation 6]

I3 (cont)

where

$c_{0.7}$ = length of the blade chord at 0.7R radius [m]

F is either F_b or F_f which ever has the greater absolute value.

I3.4.3.4 Maximum Propeller Ice Torque applied to the propeller

When $D < D_{limit}$

$Q_{max} = 105 \times (1 - d / D) \times S_{qice} \times (P_{0.7} / D)^{0.16} \times (t_{0.7} / D)^{0.6} \times (nD)^{0.17} \times D^3$ kNm [Equation 7]

When $D \geq D_{limit}$

$Q_{max} = 202 \times (1 - d / D) \times S_{qice} \times H_{ice}^{1.1} \times (P_{0.7} / D)^{0.16} \times (t_{0.7} / D)^{0.6} \times (nD)^{0.17} \times D^{1.9}$ kNm [Equation 8]

where

D_{limit} = 1.81 H_{ice}
S_{qice} = Ice strength index for blade ice torque
$P_{0.7}$ = propeller pitch at 0.7 R [m]
$t_{0.7}$ = max thickness at 0.7 radius

n is the rotational propeller speed, [rps], at bollard condition. If not known, n is to be taken as follows:

Propeller type	**n**
CP propellers	n_n
FP propellers driven by turbine or electric motor	n_n
FP propellers driven by diesel engine	0.85 n_n

Where n_n is the nominal rotational speed at MCR, free running condition.

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

I3.4.3.5 Maximum Propeller Ice Thrust applied to the shaft

$T_f = 1.1 \cdot F_f$ kN [Equation 9]

$T_b = 1.1 \cdot F_b$ kN [Equation 10]

I3.4.4 Design Ice Loads for Ducted Propeller

I3.4.4.1 Maximum Backward Blade Force, Fb

when $D < D_{limit}$

$$F_b = -9.5\, S_{ice} \left[\frac{EAR}{Z} \right]^{0.3} \left[nD \right]^{0.7} D^2$$ [Equation 11]

I3
(cont)

when $D \geq D_{limit}$

$$F_b = -66\, S_{ice} \left[\frac{EAR}{Z}\right]^{0.3} [nD]^{0.7}\, D^{0.6}\, [H_{ice}]^{0.4}$$ [Equation 12]

where $D_{limit} = 4\, H_{ice}$

n shall be taken as in I3.4.3.1

F_b is to be applied as a uniform pressure distribution to an area on the back side for the following load cases (see Table 2 of Appendix):

a) Load case 1: On the back of the blade from 0.6R to the tip and from the blade leading edge to a value of 0.2 chord length.

b) Load case 5: For reversible rotation propellers a load equal to 60% of F_b is applied on the blade face from 0.6R to the tip and from the blade trailing edge to a value of 0.2 chord length.

I3.4.4.2 Maximum Forward Blade Force, F_f

when $D \leq D_{limit}$

$$F_f = 250 \cdot \left[\frac{EAR}{Z}\right] \cdot D^2 \quad \text{[kN]}$$ [Equation 13]

When $D > D_{limit}$

$$F_f = 500 \cdot \left[\frac{EAR}{Z}\right] \cdot D \cdot \frac{1}{\left(1 - \frac{d}{D}\right)} \cdot H_{ice} \quad \text{[kN]}$$ [Equation 14]

where $$D_{limit} = \frac{2}{\left(1 - \frac{d}{D}\right)} \cdot H_{ice} \quad \text{[m]}$$ [Equation 15]

F_f is to be applied as a uniform pressure distribution to an area on the face (pressure) side for the following load case (see Table 2 Appendix):

a) Load case 3: On the blade face from 0.6R to the tip and from the blade leading edge to a value of 0.5 chord length.

b) Load case 5: A load equal to 60% F_f is to be applied from 0.6R to the tip and from the blade leading edge to a value of 0.2 chord length.

I3.4.4.3 Maximum Propeller Ice Torque applied to the propeller

Q_{max} is the maximum torque on a propeller due to ice-propeller interaction.

I3
(cont)

$$Q_{max} = 74 \cdot \left[1 - \frac{d}{D}\right] \cdot \left[\frac{P_{0.7}}{D}\right]^{0.16} \cdot \left[\frac{t_{0.7}}{D}\right]^{0.6} \cdot (nD)^{0.17} \cdot S_{q\,ice} . D^3 \text{ [kNm]} \quad \text{[Equation 16]}$$

when $D \le D_{limit}$

$$Q_{max} = 141 \cdot \left[1 - \frac{d}{D}\right] \cdot \left[\frac{P_{0.7}}{D}\right]^{0.16} \cdot \left[\frac{t_{0.7}}{D}\right]^{0.6} \cdot (nD)^{0.17} \cdot S_{q\,ice} . D^{1.9} \cdot H_{ice}^{\;1.1} \text{ [kNm]} \quad \text{[Equation 17]}$$

when $D > D_{limit}$

where $D_{limit} = 1.8 \cdot H_{ice}$ [m]

n is the rotational propeller speed [rps] at bollard condition. If not known, n is to be taken as follows:

	n
CP propellers	n_n
FP propellers driven by turbine or electric motor	n_n
FP propellers driven by diesel engine	0.85 n_n

Where n_n is the nominal rotational speed at MCR, free running condition.

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

I3.4.4.4 Maximum Blade Spindle Torque for CP-mechanism Design, Q_{smax}

Spindle torque Q_{smax} around the spindle axis of the blade fitting shall be calculated for the load case described in 3.4.1. If these spindle torque values are less than the default value given below, the default value shall be used.

Default Value: $Q_{smax} = 0.25 \cdot F \cdot c_{0.7}$ [kNm] [Equation 18]

Where $c_{0.7}$ the length of the blade section at 0.7R radius and F is either F_b or F_f which ever has the greater absolute value.

I3.4.4.5 Maximum Propeller Ice Thrust (applied to the shaft at the location of the propeller)

$T_f = 1.1 \cdot F_f$ [Equation 19]

$T_b = 1.1 \cdot F_b$ [Equation 20]

I3.4.5 *Reserved*

I3
(cont)

I3.4.6 Design Loads on Propulsion Line

I3.4.6.1 Torque

The propeller ice torque excitation for shaft line dynamic analysis shall be described by a sequence of blade impacts which are of half sine shape and occur at the blade. The torque due to a single blade ice impact as a function of the propeller rotation angle is then

$Q(\varphi) = C_q * Q_{\max} * \sin(\varphi(180/\alpha_i))$ when $\varphi = 0...\alpha_i$ [Equation 21]

$Q(\varphi) = 0$ when $\varphi = \alpha_i....360$

where C_q and α_i parameters are given in table below.

Torque excitation	Propeller-ice interaction	C_q	α_i
Case 1	Single ice block	0.5	45
Case 2	Single ice block	0.75	90
Case 3	Single ice block	1.0	135
Case 4	Two ice blocks with 45 degree phase in rotation angle	0.5	45

The total ice torque is obtained by summing the torque of single blades taking into account the phase shift 360deg./Z. The number of propeller revolutions during a milling sequence shall be obtained with the formula:

$N_Q = 2 \cdot H_{ice}$ [Equation 22]

The number of impacts is $Z \cdot N_Q$.
See Figure 1 in Appendix.

Milling torque sequence duration is not valid for pulling bow propellers, which are subject to special consideration.

The response torque at any shaft component shall be analysed considering excitation torque $Q_{(\_)}$ at the propeller, actual engine torque Q_e and mass elastic system.

Q_e = actual maximum engine torque at considered speed

Design torque along propeller shaft line
The design torque (Q_r) of the shaft component shall be determined by means of torsional vibration analysis of the propulsion line. Calculations have to be carried out for all excitation cases given above and the response has to be applied on top of the mean hydrodynamic torque in bollard condition at considered propeller rotational speed.

I3.4.6.2 Maximum Response Thrust

Maximum thrust along the propeller shaft line is to be calculated with the formulae below. The factors 2.2 and 1.5 take into account the dynamic magnification due to axial vibration. Alternatively the propeller thrust magnification factor may be calculated by dynamic analysis.

Maximum Shaft Thrust Forwards: $T_r = T_n + 2.2 \times T_f$ [kN] [Equation 24]

Maximum Shaft Thrust Backwards: $T_r = 1.5 \times T_b$ [kN] [Equation 25]

I3
(cont)

T_n = propeller bollard thrust [kN]
T_f = maximum forward propeller ice thrust [kN]

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

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

T = nominal propeller thrust at MCR at free running open water conditions

I3.4.6.3 Blade Failure Load for both Open and Nozzle Propeller

The force is acting at 0.8R in the weakest direction of the blade and at a spindle arm of 2/3 of the distance of axis of blade rotation of leading and trailing edge which ever is the greatest.

The blade failure load is:

$$F_{ex} = \frac{0.3 \cdot c \cdot t^2 \cdot \sigma_{ref}}{0.8 \cdot D - 2 \cdot r} 10^3 \quad \text{[kN]} \qquad \text{[Equation 26]}$$

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

Where σ_u and $\sigma_{0.2}$ are representative values for the blade material.

c, t and *r* are respectively the actual chord length, thickness and radius of the cylindrical root section of the blade at the weakest section outside root fillet, and typically will be at the termination of the fillet into the blade profile.

I3.5 Design

I3.5.1 Design Principle

The strength of the propulsion line shall be designed

a) for maximum loads in I3.4;

b) such that the plastic bending of a propeller blade shall not cause damages in other propulsion line components;

c) with sufficient fatigue strength.

I3.5.2 Azimuthing Main Propulsors

In addition to the above requirements special consideration shall be given to the loading cases which are extraordinary for propulsion units when compared with conventional

I3
(cont)

propellers. Estimation of the loading cases must reflect the operational realities of the ship and the thrusters. In this respect, for example, the loads caused by impacts of ice blocks on the propeller hub of a pulling propeller must be considered. Also loads due to thrusters operating in an oblique angle to the flow must 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 plastic bending of a blade shall be considered in the propeller blade position, which causes the maximum load on the studied component.

Azimuth thrusters shall also be designed for estimated loads due to thruster body / ice interaction as per I2.15

I3.5.3 Blade Design

I3.5.3.1 Maximum Blade Stresses

Blade stresses are to be calculated using the backward and forward loads given in section 4.3 & 4.4. The stresses shall be calculated with recognised and well documented FE-analysis or other acceptable alternative method. The stresses on the blade shall not exceed the allowable stresses $\_{all}$ for the blade material given below.

Calculated blade stress for maximum ice load shall comply with the following:

$\_{calc} < \_{all} = \_{ref} / S$

$S = 1.5$

$\_{ref}$ = reference stress, defined as:

$\_{ref} = 0.7 \cdot \sigma_u$ or [Equation 27]

$\_{ref} = 0.6 \cdot \sigma_{0.2} + 0.4 \cdot \sigma_u$ whichever is less [Equation 28]

Where σ_u and $\sigma_{0.2}$ are representative values for the blade material.

I3.5.3.2 Blade Edge Thickness

The blade edge thicknesses t_{ed} and tip thickness t_{tip} are to be greater than t_{edge} given by the following formula:

$$t_{edge} \geq x\, S\, S_{ice} \sqrt{\frac{3\, p_{ice}}{\sigma_{ref}}} \qquad \text{[Equation 29]}$$

x = distance from the blade edge measured along the cylindrical sections from the edge and shall be 2.5% of chord length, however not to be taken greater than 45 mm. In the tip area (above 0.975R radius) *x* shall be taken as 2.5% of 0.975R section length and is to be measured perpendicularly to the edge, however not to be taken greater than 45 mm.

S = safety factor
= 2.5 for trailing edges
= 3.5 for leading edges
= 5 for tip

S_{ice} = according to Section I3.4.2

I3 (cont)

p_{ice} = ice pressure
= 16 Mpa for leading edge and tip thickness

$\_{ref}$ = according 5.3.1

The requirement for edge thickness has to be applied for leading edge and in case of reversible rotation open propellers also for trailing edge. Tip thickness refers to the maximum measured thickness in the tip area above 0.975R radius. The edge thickness in the area between position of maximum tip thickness and edge thickness at 0.975 radius has to be interpolated between edge and tip thickness value and smoothly distributed.

I3.5.3.3 to I3.5.4.2 *Reserved*

I3.5.5 *Reserved*

I3.5.6 Prime Movers

I3.5.6.1 The Main engine is to be capable of being started and running the propeller with the CP in full pitch.

I3.5.6.2 Provisions shall be made for heating arrangements to ensure ready starting of the cold emergency power units at an ambient temperature applicable to the Polar class of the ship.

I3.5.6.3 Emergency power units shall be equipped with starting devices with a stored energy capability of at least three consecutive starts at the design temperature in I3.5.6.2 above. The source of stored energy shall be protected to preclude critical depletion by the automatic starting system, unless a second independent means of starting is provided. A second source of energy shall be provided for an additional three starts within 30 min., unless manual starting can be demonstrated to be effective.

I3.6 Machinery fastening loading accelerations

I3.6.1 Essential equipment and main propulsion machinery supports shall be suitable for the accelerations as indicated in as follows. Accelerations are to be considered acting independently.

I3.6.2 Longitudinal Impact Accelerations, a_l

Maximum longitudinal impact acceleration at any point along the hull girder

$$= (F_{IB}/\Delta) \{ [1.1 \tan(\gamma + \phi)] + [7 \frac{H}{L}] \} \quad [m/s^2] \qquad \text{[Equation 31]}$$

I3.6.3 Vertical acceleration, a_v

Combined vertical impact acceleration at any point along the hull girder

$$= 2.5 (F_{IB}/\Delta) F_X \quad [m/s^2] \qquad \text{[Equation 32]}$$

I3 (cont)

F_X = 1.3 at FP
= 0.2 at midships
= 0.4 at AP
= 1.3 at AP for vessels conducting ice breaking astern
Intermediate values to be interpolated linearly.

I3.6.4. Transverse impact acceleration, a_t

Combined transverse impact acceleration at any point along hull girder

$$= 3\ F_i \frac{F_X}{\Delta} \quad [m/s^2] \qquad \text{[Equation 33]}$$

F_X = 1.5 at FP
= 0.25 at midships
= 0.5 at AP
= 1.5 at AP for vessels conducting ice breaking astern
Intermediate values to be interpolated linearly.

where
ϕ = maximum friction angle between steel and ice, normally taken as 10° [deg.]
γ = bow stem angle at waterline [deg.]
Δ = displacement
L = length between perpendiculars [m]
H = distance in meters from the waterline to the point being considered [m]

F_{IB} = vertical impact force, defined in UR I2.13.2.1

F_i = total force normal to shell plating in the bow area due to oblique ice impact, defined in UR I2.3.2.1

I3.7 Auxiliary Systems

I3.7.1 Machinery shall be protected from the harmful effects of ingestion or accumulation of ice or snow. Where continuous operation is necessary, means should be provided to purge the system of accumulated ice or snow.

I3.7.2 Means should be provided to prevent damage due to freezing, to tanks containing liquids.

I3.7.3 Vent pipes, intake and discharge pipes and associated systems shall be designed to prevent blockage due to freezing or ice and snow accumulation.

I3.8 Sea Inlets and cooling water systems

I3.8.1 Cooling water systems for machinery that are essential for the propulsion and safety of the vessel, including sea chests inlets, shall be designed for the environmental conditions applicable to the ice class.

I3
(cont)

I3.8.2 At least two sea chests are to be arranged as ice boxes for class PC1 to PC5 inclusive where. The calculated volume for each of the ice boxes shall be at least 1m^3 for every 750 kW of the total installed power. For PC6 and PC7 there shall be at least one ice box located preferably near centre line.

I3.8.3 Ice boxes are to be designed for an effective separation of ice and venting of air.

I3.8.4 Sea inlet valves are to be secured directly to the ice boxes. The valve shall be a full bore type.

I3.8.5 Ice boxes and sea bays are to have vent pipes and are to have shut off valves connected direct to the shell.

I3.8.6 Means are to be provided to prevent freezing of sea bays, ice boxes, ship side valves and fittings above the load waterline.

I3.8.7 Efficient means are to be provided to re-circulate cooling seawater to the ice box. Total sectional area of the circulating pipes is not to be less than the area of the cooling water discharge pipe.

I3.8.8 Detachable gratings or manholes are to be provided for ice boxes. Manholes are to be located above the deepest load line. Access is to be provided to the ice box from above.

I3.8.9 Openings in ship sides for ice boxes are to be fitted with gratings, or holes or slots in shell plates. The net area through these openings is to be not less than 5 times the area of the inlet pipe. The diameter of holes and width of slot in shell plating is to be not less than 20 mm. Gratings of the ice boxes are to be provided with a means of clearing. Clearing pipes are to be provided with screw-down type non return valves.

I3.9 Ballast tanks

I3.9.1 Efficient means are to be provided to prevent freezing in fore and after peak tanks and wing tanks located above the water line and where otherwise found necessary.

I3.10 Ventilation System

I3.10.1 The air intakes for machinery and accommodation ventilation are to be located on both sides of the ship.

I3.10.2 Accommodation and ventilation air intakes shall be provided with means of heating.

I3.10.3 The temperature of inlet air provided to machinery from the air intakes shall be suitable for the safe operation of the machinery.

I3.11 *Reserved*

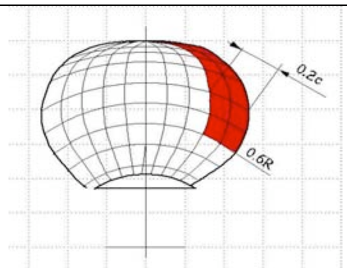
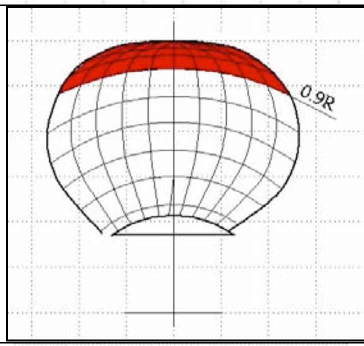
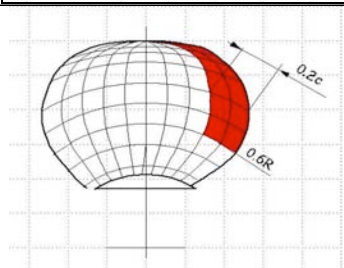
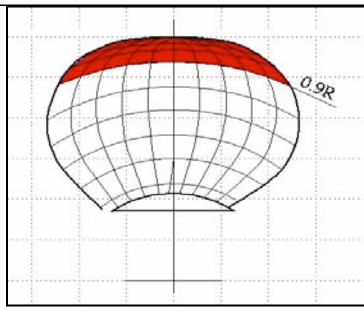
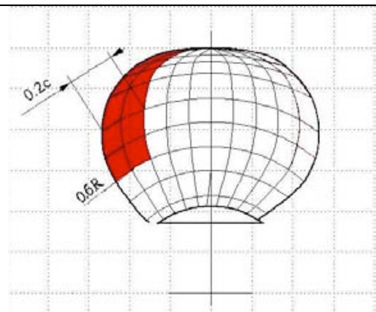
I3.12 Alternative Design

I3.12.1 As an alternative – a comprehensive design study may be submitted and may be requested to be validated by an agreed test programme.

I3
(cont)

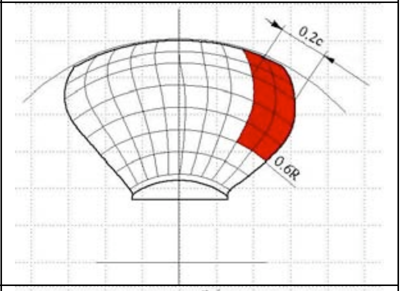
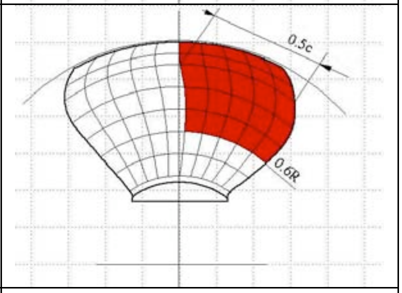
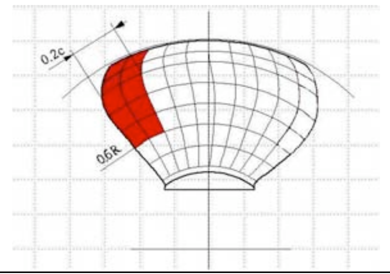
APPENDIX

Table 1 Load cases for open propeller

	Force	Loaded area	Right handed propeller blade seen from back
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 of 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 of 0.9R radius.	
Load case 5	60 % of F_f or F_b which one 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.	 e

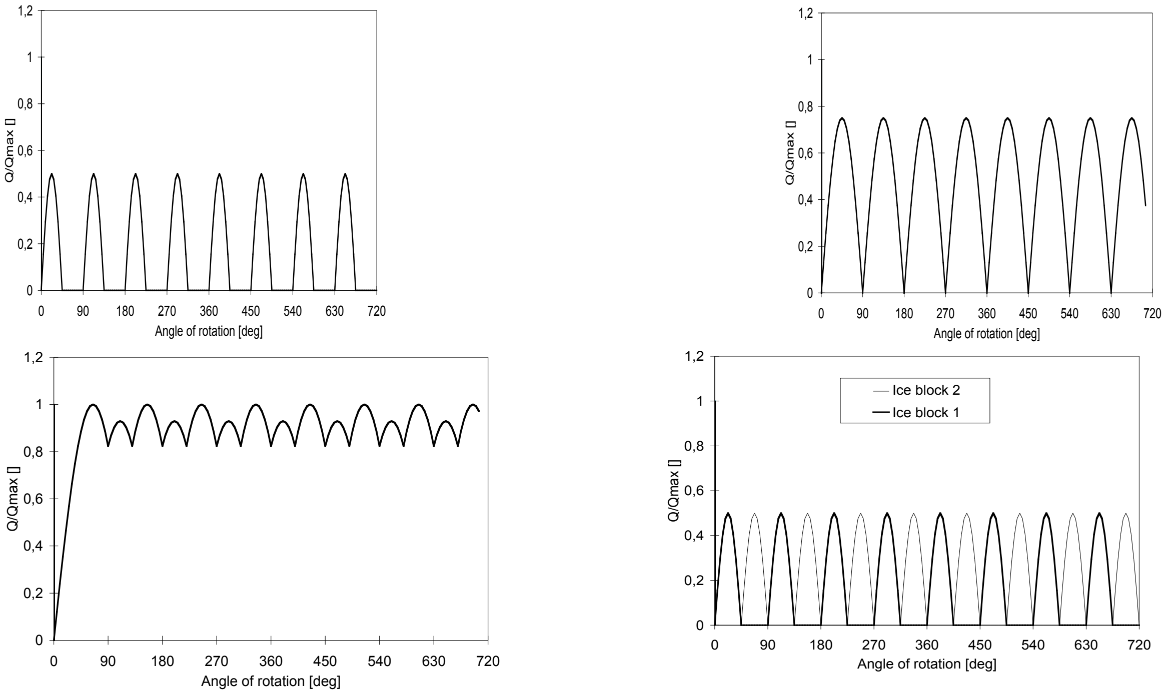
I3
(cont)

Table 2 Load cases for ducted propeller

	Force	Loaded area	Right handed propeller blade seen from back
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 which one 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.	

I3
(cont)

Figure 1 The shape of the propeller ice torque excitation for 45, 90, 135 degrees single blade impact sequences and 45 degrees double blade impact sequence(two ice pieces) on a four bladed propeller.



End of Document