RULES FOR CLASSIFICATION OF

Ships

PART 5 CHAPTER 1

NEWBUILDINGS
SPECIAL SERVICE AND TYPE – ADDITIONAL CLASS

Ships for Navigation in Ice

JULY 2011

DET NORSKE VERITAS AS

FOREWORD

DET NORSKE VERITAS (DNV) is an autonomous and independent foundation with the objectives of safeguarding life, property and the environment, at sea and onshore. DNV undertakes classification, certification, and other verification and consultancy services relating to quality of ships, offshore units and installations, and onshore industries worldwide, and carries out research in relation to these functions.

The Rules lay down technical and procedural requirements related to obtaining and retaining a Class Certificate. It is used as a contractual document and includes both requirements and acceptance criteria.

CHANGES

General

The present edition of the rules includes additions and amendments approved by the Executive Committee as of June 2011 and supersedes the January 2011 edition of the same chapter.

The rule changes come into force as indicated below.

Text affected by the main rule changes is highlighted in red colour in the electronic pdf version. However, where the changes involve a whole chapter, section or sub-section, only the title may be in red colour.

This chapter is valid until superseded by a revised chapter.

Main changes coming into force 1 January 2012

• **Sec.1 General Requirements**

— D102: Marking also by welding seam to be accepted.
— E101: Highlighting IACS rule requirement of Material Grade B for ice strengthened ships.
— E102: Other materials shall be considered by class.

• **Sec.2 Basic Ice Strengthening**

— B101: Ice belt extension for **ICE-C** changed from 0.5 to 0.4 m above UIWL.

• **Sec.3 Ice Strengthening for the Northern Baltic**

— A204: Procedure and acceptance criteria for Direct Analysis.
— A206: Definition of span and spacing.
— A207: Reference to definition of effective breadth.
— A208: Reference to definition of members not normal to the plating.
— B201: Change in pressure formulation, parameter c_a.
— C101: Change in vertical extension of the ice strengthening for plates below LIWL.
— D101: Change in vertical extension of the ice framing below LIWL.
— D101: New shear requirement for transverse frames.
— D301: Change in formula due to change in pressure formulation, ref. B201. Change in m-factor.
— D402: Item 2 aligned with FIN/SWE Ice Class Rules. Item 3 updated according to FIN/SWE Ice Class Rules.
— E101, E201 and F101: Formulas updated due to change in pressure formulation, ref. B201.
— G100: In the FIN/SWE Ice Class Rules, the text has been moved to the FIN/SWE Guidelines. DNV kept general req. to Bilge Keel, and spec. req. to **ICE-1A*F**.
— H200: In the FIN/SWE Ice Class Rules, the text has been moved to the FIN/SWE Guidelines. General towing requirement remains.
— I100: In the FIN/SWE Ice Class Rules, text related to "Transom" moved to the FIN/SWE Guidelines. General towing requirement remains.
— I205: Specification of pressure used on the rudder.

• **Sec.4 Vessels for Arctic and Ice Breaking Service**

— Added length limitation for stability requirements in Sub-section L.

• **Sec.6 Winterization**

— C300: Ice Class not to be a requirement for having **WINTERIZED COLD** Notation (previous item C301 deleted).
— C600: Requirements better specified.
— D200: For Winterized Arctic, Ice Class according to Sec.3 also accepted.

• **Sec.7 DAT(-X°C)**

— A301: Distance changed from 0.5 m to 0.6 m to align with PC.
— A302: Text description of extreme low temp. changed to "Guidance Note".
— B101: Updated to align w/ 1A1 requirement.
— B101 Table B1: Updated in line with Pt.3 Ch.1 (Table B2, C3) and UR S6.
— B201: Item related to Cranes deleted, not relevant for DAT.
— B202: Requirement for impact test deleted, and reference made to impact test requirement in Sec.6 C605.

• **Sec.8 Polar Class**

— Ice compression load added as a load to be checked according to Sec.4.
— Revision of IACS URI2, Rev.2 Nov.2010 (typographical errors corrected.)

Corrections and Clarifications

In addition to the above stated rule requirements, a number of corrections and clarifications have been made in the existing rule text.

CONTENTS

SECTION 1
GENERAL REQUIREMENTS

A. Classification

A 100 Application

101 The rules in this chapter apply to vessels occasionally or primarily intended for navigation in waters with ice conditions. The requirements shall be regarded as supplementary to those given for the assignment of main class.

A 200 Class notations

201 Vessels complying with relevant additional requirements of this chapter will be assigned one of the following class notations:

Table A1 Class notations	
Notation	*Reference*
ICE-C **ICE-E**	(See Sec.2)
ICE-1A*F **ICE-1A*** **ICE-1A** **ICE-1B** **ICE-1C**	(See Sec.3)
(for max draught x.x m)	(See Sec.1)
ICE-05(or **-10** or **-15**) **POLAR-10**(or **-20** or **-30**) **Icebreaker**	(See Sec.4)
WINTERIZED BASIC **WINTERIZED COLD (t₁, t₂)** **WINTERIZED ARCTIC (t₁, t₂)**	(See Sec.6)
Sealer	(See Sec.5)
DAT(-X°C)	(See Sec.7)
PC-1 **PC-2** **PC-3** **PC-4** **PC-5** **PC-6** **PC-7** **Icebreaker**	(See Sec.8)

B. Definitions

B 100 Symbols

101 *General*

L = rule length in m *)
B = rule breadth in m *)
D = rule depth in m *)
T = rule draught in m *)
Δ = rule displacement in t *)
C_B = block coefficient *)
Δ_f = displacement in t in fresh water (density 1.0 t/m^3) at ice class draught
P_s = maximum continuous output of propulsion machinery in kW
s = stiffener spacing in m measured along the plating between ordinary and/or intermediate stiffeners
l = stiffener span in m measured along the top flange of the member. For definition of span point, see Pt.3 Ch.1 Sec.3 C100
S = girder span in m. For definition of span point, see Pt.3 Ch.1 Sec.3 C100.
σ_F = minimum upper yield stress of material in N/mm^2

For NV-NS-steel and HS-steel, σ_F to be taken as given in Pt.3 Ch.1 Sec.2 B201 and Pt.3 Ch.2 Sec.2 B201.

g_0 = standard acceleration of gravity ($\approx$ 9.81 m/s^2).

*[)] For details see Pt.3 Ch.1.

B 200   Upper (UIWL) and Lower (LIWL) Ice Waterlines

201   *The upper ice waterline,* (UIWL)

shall be the envelope of the highest points of the waterline at which the ship is intended to operate in ice irrespective of water salinity. The line may be a broken line.

202   *The lower ice waterline,* (LIWL)

shall be the envelope of the lowest points of the waterline at which the ship is intended to operate in ice. The line may be a broken line.

203   All design loading conditions in ice, including trim, shall be within the draught envelope limited by the UIWL and LIWL. The lower ice waterline should further be determined with due regard to the vessel's ice-going capability in the ballast loading conditions (e.g. propeller submergence). See also Sec.3 B.

(IACS UR I 1.3)

C. Documentation

C 100   General

101   Details related to additional classes regarding design, arrangement and strength are in general to be included in the plans specified for the main class.

102   Additional documentation not covered by the main class are specified in appropriate sections of this chapter.

D. Marking and on Board Documentation

D 100   General

101   The maximum and minimum ice class draughts fore, amidships and aft shall be indicated in the "Appendix to the Classification Certificate".

102   If the "Summer Load Line" in fresh water is anywhere located at a higher level than the UIWL, the maximum amidships draft shall be indicated with the qualifier **(for max draught x.x m)**.

For such ships, the ship sides shall be provided with a warning triangle and with ice class draught marks at the maximum permissible amidships draught, see Fig. 1.
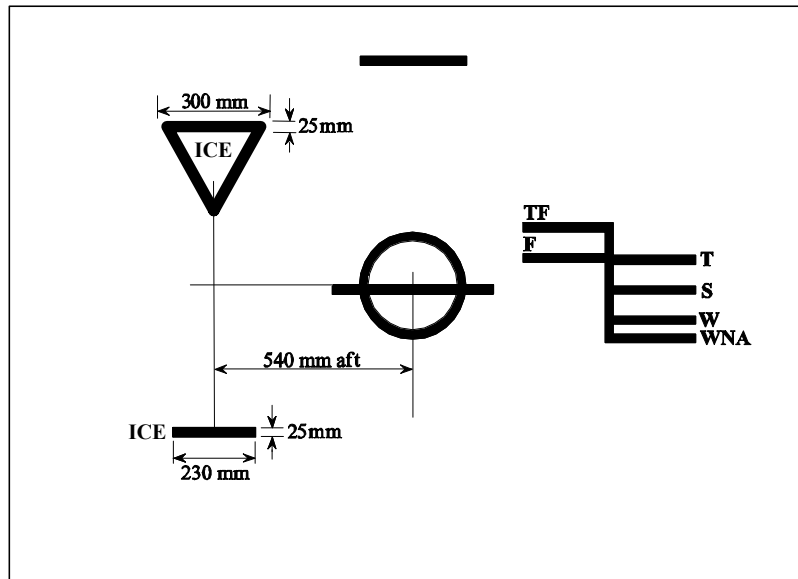
Fig. 1
Ice class draught marking

Marking requirements:

1) The ice class draught marking "ICE" shall indicate the maximum ice class draught.

2) The bottom of the warning triangle shall be located at the height 1 000 mm above Summer Fresh Water Load Line, but not higher than the deck line. The sides of the triangle shall be 300 mm in length.

3) The ice class draught mark shall be located 540 mm abaft the centre of the load line ring or 540 mm abaft the vertical line of the timber load line mark, if applicable.

4) The ice marks and letters shall be cut out of 5 to 8 mm plate and then welded to the ship's side or marking shall be indicated by weld seam directly on the ship side. The marks and letters shall be painted in a red or yellow reflecting colour in order to make the marks and figures plainly visible even in ice conditions.

5) The dimensions of all letters shall be the same as those used in the load line mark.

6) For vessels not having load line markings, the warning triangle and ice draught mark shall be vertically aligned with the draught mark. The warning triangle shall be placed 1 000 mm above the draught mark, but in no case above the deck line.

E. Materials

E 100   General

101   For minimum material grade for ice strengthening ships, reference is made to Pt.3 Ch.1 Sec.2 Table B6/ Pt.3 Ch.2 Sec.2 Table B3. Shell strakes in way of ice strengthening area for plates shall be minimum grade B/AH.

102   The use of materials other than those specified in Pt.3 Ch.1/ Pt.3 Ch2 shall be agreed with Class.

SECTION 2
BASIC ICE STRENGTHENING

A. General

A 100 Classification

101 The requirements in this section apply to vessels intended for service in waters with light ice conditions.

The requirements in D for class notation **ICE-E** are intended for light localised drift ice in mouths of rivers and coastal areas.

102 Vessels built in compliance with the following requirements may be given the class notation **ICE-C**.

103 Vessels built in compliance with the requirements in D may be given the class notation **ICE-E**.

B. Structural Requirements for the Class Notation ICE-C

B 100 General

101 The requirements for the bow ice belt region, as defined in Sec.3 Fig.1, for sub-section elements 200 to 700, shall be in accordance with Sec.3 as follows:

— In Table B1, the value of ho and h shall be as given for **ICE-1C**.
— The ice pressure shall be determined in accordance with Sec.3 B200, where the factor c_1, as given in Table B3, is taken as being equal to 0.55.
— Vertical extension of the ice belt plating and framing shall be:
  Plating: 0.4 m above UIWL and 0.5 m below LIWL
  Framing: 0.62 m above UIWL and 1.0 m below LIWL.

B 200 Plating

201 In the bow ice belt region as defined in 101, the shell plate thickness shall be as given in Sec.3 C.

B 300 Framing

301 In the bow ice belt region as defined in 101, the frames shall be as given in Sec.3 D100 to D300.

In addition, the following shall apply:

1) Frames shall be effectively attached to all supporting structures. Transverse and longitudinal frames crossing support structures shall be connected to these with lugs. Alternatively, top stiffener in combination with lug may be used. The upper end of intermediate frames may be sniped at a stringer or deck provided the ice belt covers not more than 1/3 of the span.

2) Frames where the angle between the web and the shell is less than 75 degrees shall be supported against tripping by brackets, intercostals, stringers or similar at a distance preferably not exceeding 2.5 m.
   Transverse frames perpendicular to shell which are of unsymmetrical profiles shall have tripping preventions if the span is exceeding 4.0 m.

3) The web thickness of the frames shall be at least one half of the thickness of the shell plating. Where there is a deck, tank top, bulkhead, web frame or stringer in lieu of a frame, at least one half of the thickness of shell plating shall be kept to a depth of not less than 0.0025 L, minimum 0.2 m.

B 400 Stringers and web frames

401 Stringers situated inside and outside the ice belt shall be as given in Sec.3 E100 - E200. Web frames shall be as given in Sec.3 E200 - F200. The product p·h shall not be taken less than 200.

B 500 Weld connections

501 Weld connections to shell in fore peak shall be double continuous.

B 600 Rudder and steering arrangement

601 The rudder and steering arrangement shall comply with Sec.3 I200, given that the maximum service speed of the vessel is not taken less than 14 knots.

B 700 Stem

701 The plate thickness of a shaped plate stem and any part of the bow which forms an angle of 60 degrees

or more to the centreline in a horizontal plane shall comply with Sec.3 H102 up to 600 mm above UIWL.

C. Machinery

C 100 Output of propulsion machinery

101 The maximum continuous output is generally not to be less than:

$$P_s = 0.73 \, L \, B \quad (kW)$$

For ships with a bow specially designed for navigation in ice, a reduced output may be accepted. In any case, the output shall not be less than:

$$P_s = 0.59 \, L \, B \quad (kW)$$

102 If the ship is fitted with a controllable pitch propeller, the output may be reduced by 25%.

C 200 Design of propeller and propeller shaft

201 The formulae for scantlings are based on the following loads:

T_o = mean torque of propulsion engine at maximum continuous rating in Nm.

(If multi-engine plant, T_o is the mean torque in an actual branch or after a common point. T_o is always referred to engine r.p.m).

Th_o = mean propeller thrust in N at maximum continuous speed
R = as given in 202
T_{ice} = ice torque in Nm (referred to propeller r.p.m.)
　　 = $35\,200 \, R^2$ for open propellers
　　 = $35\,200 \, R^2 (0.9 - 0.0622 \, R^{-0.5})$ for ducted propellers.

Skewed propellers will be especially considered with respect to the risk of blade bending at outer radii if f_{sk} exceeds 1.15 (see 204).

202 The particulars governing the requirements for propeller scantlings are:

R = propeller radius (m)
H_r = pitch in m at radius in question
θ = rake in degrees at blade tip (backward rake positive)
Z = number of blades
t = blade thickness in mm at cylindrical section considered
$t_{0.25}$ = t at 0.25 R
$t_{0.35}$ = t at 0.35 R
$t_{0.6}$ = t at 0.6 R
c_r = blade width in m at cylindrical section considered

　　 $c_{0.25}$ = c_r at 0.25 R
　　 $c_{0.35}$ = c_r at 0.35 R
　　 $c_{0.6}$ = c_r at 0.6 R

e = distance between skew line and generatrix in m at cylindrical section considered, positive when skew line is forward of generatrix.

　　 $e_{0.6}$ = e at 0.6 R
　　 $e_{1.0}$ = e at 1.0 R

u = gear ratio:

　　 u = 1, if the shafting system is directly coupled to engine.

n_o = propeller speed at maximum continuous output, for which the machinery shall be approved, in revolutions per minute.

203 Propellers and propeller parts (defined in Pt.4 Ch.5 Sec.1 A103) shall be of steel or bronze as specified in Pt.2 Ch.2. Nodular cast iron of Grade NV 1 and NV 2 may be used for relevant parts in CP-mechanism. Other type of nodular cast iron with elongation ≥ 12% may be accepted upon special consideration for same purposes.

204 The blade thickness of the cylindrical sections at 0.25 R (fixed pitch propellers only) and at 0.35 R shall not be less than:

$$t = C_1 \sqrt{\frac{2RK_1(U_2C_4 + 0.2) + K_4}{Zc_r(K_{Mat}U_1 - U_2S_r)}} \quad (mm)$$

The thickness at 0.6 R shall not be less than:

$$t = t_{0.35} \sqrt{\frac{0.45 \cdot f_{sk} \cdot c_{0.35}}{c_{0.6}}} \quad (mm)$$

$$f_{sk} = 1 + \left(\frac{e_{0.6} - e_{1.0}}{R}\right)^2$$

U_1 and U_2 = material constants to be taken as given in Pt.4 Ch.5 Sec.1 Table B1.

$$S_r = \left(\frac{2Rn_o}{100}\right)^2 (C_2\theta + C_3)$$

$$K_1 = A_1 d\, T\, h_o 0.85 + A_2\left(\frac{0.75uT_o}{R}\right)$$

For fixed blade propellers

$$K_1 = A_1 d\, T\, h_o 1.25 + A_2\frac{uT_o}{R}$$

For controllable pitch propellers

K_4	=	$k_i Z T_{ice} \sin\alpha$
C_1, C_2, C_3, C_4	=	as given in Table C1.
A	=	$q_0 + q_1 d + q_2 d^2 + q_3 d^3$
q_0, q_1, q_2, q_3	=	as given in Table C2.

d $\quad = \dfrac{2\pi R}{H_r}$ for fixed blade propellers

d $\quad = \dfrac{2\pi R}{0.7H_r}$ for controllable pitch propellers

k_i $\quad = 96$ at 0.25 R
$\quad\quad = 92$ at 0.35 R

K_{Mat} $\quad = 1.0$ for stainless steel propellers
$\quad\quad = 0.8$ for other materials

$\sin\alpha$ $\quad = \dfrac{4}{\sqrt{d^2 + 16}}$ at 0.25 R

$\quad\quad = \dfrac{2.86}{\sqrt{d^2 + 8.18}}$ at 0.35 R

K_1 as given above is only valid for propulsion by diesel engines (by about zero speed, it is assumed 85% thrust and 75% torque for fixed pitch propellers and 125% thrust and 100% torque for controllable pitch propellers).

For turbine, diesel-electric or similar propulsion machinery K_1 will be considered in each particular case.

Guidance note:

K_1 may be calculated for other than diesel driven propellers by replacing the constants 0.85 by 1.1 and 0.75 by 1.0 for FP provided that maximum torque of the driving engine is limited to 100% of the nominal torque. If driving torque exceeds 100%, the torque constant 1.0 shall be multiplied by the ratio T_{max}/T_o and corresponding thrust value (Th_o times constant) calculated based on the actual maximum torque.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

The thickness of other sections is governed by a smooth curve connecting the above section thicknesses.

Table C1 Values of C_1, C_2, C_3, C_4

r	0.25 R	0.35 R	0.6 R
C_1	0.278	0.258	0.150
C_2	0.026	0.025	0.020
C_3	0.055	0.049	0.034
C_4	1.38	1.48	1.69

Table C2 Values of q_0, q_1, q_2, q_3

R		q_0	q_1	q_2	q_3
0.25 R	A1	8.30	0.370	-0.340	0.030
	A2	63.80	-4.500	-0.640	0.0845
0.35 R	A1	9.55	-0.015	-0.339	0.0322
	A2	57.30	-7.470	-0.069	0.0472
0.6 R	A1	14.60	-1.720	-0.103	0.0203
	A2	52.90	-10.300	0.667	0.0

205 If found necessary by the torsional vibration calculations, minor deviations from the dimensions given in 204 may be approved upon special consideration.

206 The section modulus of the blade bolt connection referred to an axis tangentially to the bolt pitch diameter, shall not be less than:

$$W_b = 0.1 \ c_{0.35} \ t_{0.35}^2 \ \frac{\sigma_b}{\sigma_y} \quad (cm^3)$$

σ_b = tensile strength of propeller blade material (N/mm^2)

σ_y = yield stress of bolt material (N/mm^2).

The propeller blade foot shall have a strength (including stress concentration) not less than that of the bolts.

207 Fitting of the propeller to the shaft is given in Pt.4 Ch.4 Sec.1 as follows:

— flanged connection in B300
— keyless cone connection in B400
— keyed cone connection in B500.

(Considering 0°C seawater temperature)

If the propeller is bolted to the propeller shaft, the bolt connection shall have at least the same bending strength as the propeller shaft.

The strength of the propeller shaft flange (including stress concentration) shall be at least the same as the strength of the bolts.

208 The propeller shaft diameter need not exceed 1.05 times the rule diameter given for main class, irrespective of the dimension required below.

The diameter of the propeller shaft at the aft bearing shall not be less than:

$$d_p = 11.5 \left(\frac{\sigma_b C_{0.35} t_{0.35}^2}{\sigma_y} \right)^{\frac{1}{3}} \quad (mm)$$

σ_b = tensile strength of propeller blade material (N/mm^2)

σ_y = yield strength of propeller shaft material (N/mm^2)

$c_{0.35}$ = as defined in 202

$t_{0.35}$ = as defined in 202.

Between the aft and second aft bearing, the shaft may be evenly tapered to 1.22 times the diameter of the intermediate shaft, as required for the main class.

Forward of the after peak bulkhead, the shaft may be evenly tapered down to 1.05 times the rule diameter of intermediate shaft, but not less than the actual diameter of the intermediate shaft.

C 300 Sea suctions and discharges

301 The sea cooling water inlet and discharge for main and auxiliary engines shall be so arranged so that blockage of strums and strainers by ice is prevented. In addition to requirements in Pt.4 Ch.1 and Ch.6 the

requirements in 302 and 303 shall be complied with.

302 One of the sea cooling water inlet sea chests shall be situated near the centre line of the ship and well aft. At least one of the sea chests shall be sufficiently high to allow ice to accumulate above the pump suctions.

303 A full capacity discharge branched off from the cooling water overboard discharge line shall be connected to at least one of the sea inlet chests. At least one of the fire pumps shall be connected to this sea chest or to another sea chest with de-icing arrangements.

> **Guidance note:**
> Heating coils may be installed in the upper part of the sea chest(s). Arrangement using ballast water for cooling purposes is recommended but will not be accepted as a substitute for sea inlet chest arrangement as described above.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

D. Requirements for the Class Notation **ICE-E**

D 100   General

101 The requirements for the bow ice belt region, as defined in Sec.3 Fig.1, shall, for sub-section elements D200 to D400, be in accordance with Sec.3 as follows:

— In Table B1, the value of h_o and h shall be as given for **ICE-1C**.
— The ice pressure shall be determined in accordance with Sec.3 B200 where:
  - For determination of k, the machinery output, P_s need not be taken >750 kW.
  - The factor c_1, as given in Table B3, shall be taken as equal to 0.3.

D 200   Plating

201 In the bow ice belt region, as defined in 101, the shell plate thickness shall be as given in Sec.3 C.

202 The vertical extension of the ice strengthening, as given in Sec.3 C100, shall be as given for notation **ICE-C**.

D 300   Framing

301 In the bow ice belt region as defined in 101, the frames shall be as given in Sec.3 D100 to D300.

302 The framing shall extend vertically not less than 0.62 m above the UIWL and 1.0 m below the LIWL.

303 For the bow ice belt region tripping brackets shall be fitted as given in B301.

D 400   Stem

401 The plate thickness of a shaped plate stem and any part of the bow which forms an angle of 60 degrees or more to the centreline in a horizontal plane shall comply with Sec.3 H102 up to 600 mm above UIWL.

SECTION 3
ICE STRENGTHENING FOR THE NORTHERN BALTIC

A. General

A 100   Classification

101   The requirements in this section apply to vessels for service in the northern Baltic in winter or areas with similar ice conditions.

102   Vessels built in compliance with the following requirements may be given one of the class notations **ICE-1A*, ICE-1A, ICE-1B** or **ICE-1C** whichever is relevant.

> **Guidance note:**
> The DNV ice classes are accepted as equivalent to the Finnish-Swedish ice classes.

DNV Ice Class notation	Equivalent Finnish-Swedish Ice Class
ICE-1A*	1A Super
ICE-1A	1A
ICE-1B	1B
ICE-1C	1C

> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

103   Vessels built in compliance with the requirements relevant for class **ICE-1A*** and with the additional requirements given below may acquire the class notation **ICE-1A*F**.

> **Guidance note:**
> The additional ice class **ICE-1A*F** is recommended applied to vessels with relatively high engine power designed for regular traffic in the northern Baltic and other relevant areas, normally operating according to rather fixed timetables irrespective of ice conditions and to a certain degree independent of ice breaker assistance.

> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

A 200   Assumptions

201   The method for determining the hull scantlings, engine output and other properties are based on certain assumptions concerning the nature of the ice load on the structure and operation of the ship as described in the Finnish-Swedish Ice Class Rules. These assumptions rest on full scale observations made in the northern Baltic.

Table A1 Operation of the ship	
ICE-1A*	normally capable of navigating in difficult ice conditions without the assistance of icebreakers
ICE-IA	capable of navigating in difficult ice conditions, with the assistance of icebreakers when necessary
ICE-IB	capable of navigating in moderate ice conditions, with the assistance of icebreakers when necessary
ICE-IC	capable of navigating in light ice conditions, with the assistance of icebreakers when necessary

202   Assistance from icebreakers is normally assumed when navigating in ice bound waters.

203   The formulae given for plating, stiffeners and girders are based on special investigations as to the distribution of ice loads from plating to stiffeners and girders as well as redistribution of loads on stiffeners and girders. Special values have been given for distribution factors and certain assumptions have been made regarding boundary conditions.

204   For the formulae and values given in this section for the determination of the hull scantlings more sophisticated methods may be substituted subject to special approval. However, direct analysis is not to be utilized as an alternative to the analytical procedures prescribed by explicit requirements in Sec.3 C, D and E (Plates, Frames and Stringers), unless these are invalid or inapplicable for a given structural arrangement or detail.

Direct analyses are to be carried out using the load patch defined in Sec.3 B (p, h and l_a). The pressure to be used is $1.8 \cdot p$ where p is determined according to Sec.3 B201. The load patch is to be applied at locations where the capacity of the structure under the combined effects of bending and shear are minimized. In particular, the structure is to be checked with load centred at the UIWL, $0.5 \cdot h_o$ below the LIWL, and positioned several vertical locations in between. Several horizontal locations shall also be checked, especially the locations centred at the mid-span or -spacing. Further, if the load length l_a cannot be determined directly from the arrangement of the structure, several values of l_a shall be checked using corresponding values for c_a.

Acceptance criteria for designs are that the combined stresses from bending and shear, using the von Mises yield criterion, are lower than the yield point σ_y. If the structure is analyzed by the use of beam models, the allowable bending and shear stress is not to be larger than $0.9 \cdot \sigma_y$ and $0.9 \cdot \tau_y$ respectively, where $\tau_y = \sigma_y / \sqrt{3}$.

205 If scantlings derived from these regulations are less than those required for a non ice-strengthened ship, the latter shall be used.

206 The frame spacings and spans defined in the following text are in general to be as given in Pt.3 Ch.1. Sec.3 and Pt.3 Ch.2 Sec.3 and normally assumed to be measured along the plate and perpendicular to the axis of the stiffener for plates, along the flange for members with a flange, and along the free edge for flat bar stiffeners. For curved members the span (or spacing) is defined as the chord length between span (or spacing) points. The span points are defined by the intersection between the flange or upper edge of the member and the supporting structural element (Stringer, Web frame, Deck or Bulkhead). Figure 1 illustrates the determination of span and spacing for curved members.
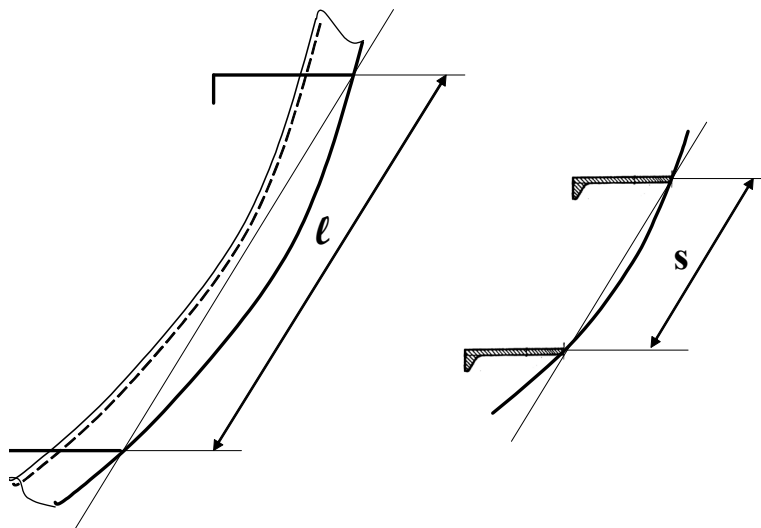
Fig. 1
Definition of the frame span (left) and frame spacing (right) for curved members.

207 The effective breadth of the attached plate to be used for calculating the combined section modulus of the stiffener, stringer and web frame and attached plate is to be taken as given in Pt.3 Ch.1 Sec.3 and Pt.3 Ch.2 Sec.3.

208 The requirements for the section modulus and shear area of the frames, stringers and web frames in D. E. and F. with respect to the effective member cross section, where the member is not normal to the plating, the section properties are to be calculated in accordance with Pt.3 Ch.1 Sec.3 and Pt.3 Ch.2 Sec.3.

A 300 Definitions

301 *Extent of ice strengthening*

The extent of the ice strengthening is determined from the Upper Ice Water Line (UIWL) to the Lower Ice Water Line (LIWL), which defines the extreme draughts. For operation in Baltic, the upper ice waterline (UIWL) is in general the same as the Fresh Water Summer Load Line. See also Sec.1 B201.

302 *Transit in ballast condition*

The minimum forward draught shall be at least:

$$(2 + 0.00025 \, \Delta_f) \, h_o \ \ (m)$$

but need not exceed $4 \, h_o$ where

Δ_f = displacement of the ship (t) on the maximum ice class draught according to 301
h_o = ice thickness according to Table B1.

303 *Ice belt regions*

The ice belt is divided into regions as follows (see also Fig.2):

Bow region: From the stem to a line parallel to and 0.04 L aft of the forward borderline of the part of the hull where the waterlines run parallel to the centre line. For ice classes **ICE-1A*F**, **ICE-1A*** and **ICE-1A** the overlap of the borderline need not exceed 6 m, for ice classes **ICE-1B** and **ICE-1C** this overlap need not exceed 5 m.

Midbody region: From the aft boundary of the Bow region to a line parallel to and 0.04 L aft of the aft borderline of the part of the hull where the waterlines run parallel to the centre line. For ice classes **ICE-1A*F**, **ICE-1A*** and **ICE-1A** the overlap of the borderline need not exceed 6 m, for ice classes **ICE-1B** and **ICE-1C** this overlap need not exceed 5 m.

Stern region: From the aft boundary of the Midbody region to the stern.

A 400   Documentation requirements

401   Document requirements are shown in Table A2. For a full definition of the documentation types, see Pt.0 Ch.3.

Table A2 Document requirements			
Object	*Documentation type*	*Additional description*	*For approval (AP) or For information (FI)*
Ship hull	H060 – Shell expansion drawing	UIWL and LIWL shall be indicated together with the lines separating the Bow, Midbody and Stern regions of the ice belt, see 402.	AP
Ship	Z100 – Specification	Displacement, machinery type, propulsion power.	FI
Propulsion line	C040 – Design analysis	Applicable if a first blade order torsional resonance is within operational speed range +/- 20%. Torsional vibration analysis of ice torque response.	AP
Propeller blades	C040 – Design analysis	Final element analysis of blade stresses introduced by ice loads.	AP
Propulsion system	C040 – Design analysis	Applicable for alternative designs, not applying loads defined in the rules. Comprehensive design analysis of entire system.	AP

402   UIWL and LIWL shall be indicated on the shell expansion plan together with the lines separating the Bow, Midbody and Stern regions of the ice belt. The machinery, displacement, Δ_f, and the output of propulsion machinery, P_s, shall be stated on the shell expansion and/or the framing plan.
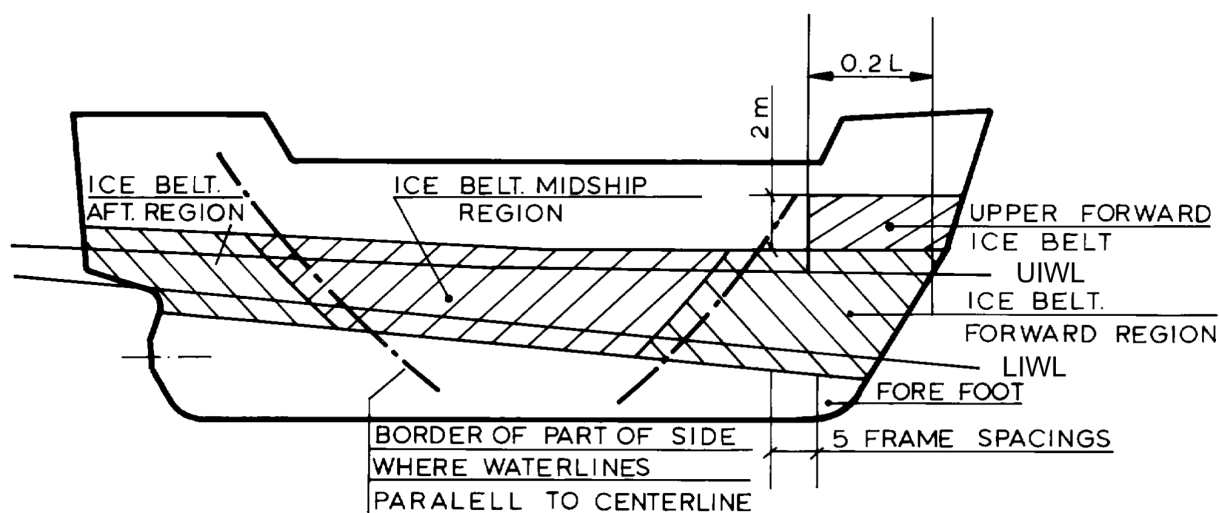
Fig. 2
Ice belt regions

403   For a full definition of the documentation types, see Pt.0 Ch.3.

B. Design Loads

B 100   Height of the ice load area

101   An ice strengthened ship is assumed to operate in open sea conditions corresponding to a level ice thickness not exceeding h_o. The design the ice height (h) of the area actually under ice pressure at any particular point of 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.

Table B1 Values of h_o and h		
Ice class	h_o *(m)*	*h (m)*
ICE-1A*	1.0	0.35
ICE-1A	0.8	0.30
ICE-1B	0.6	0.25
ICE-1C	0.4	0.22

B 200   Ice pressure

201   The design ice pressure (based on a nominal ice pressure of 5600 kN/m^2) is determined by the formula:

$$p = 5600\ c_d\ c_1\ c_a\ \ (kN/m^2)$$

c_d = a factor which takes account of the influence of the size and engine output of the ship. This factor is taken as maximum $c_d = 1$. It is calculated by the formula:

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

$$k = \frac{\sqrt{\Delta_f P_s}}{1000}$$

a and b are given in Table B2.

Table B2 Values of a and b				
	Region			
	Bow		*Midbody and Stern*	
	$k \leq 12$	$k > 12$	$k \leq 12$	$k > 12$
a	30	6	8	2
b	230	518	214	286

Δ_f = displacement (t) as defined in A302

P_s = machinery output (kW) as defined in J101

c_1 = a factor which takes account of the probability that the design ice pressure occurs in a certain region of the hull for the ice class in question.

The value of c_1 is given in Table B3:

Table B3 Values of c_1			
Ice class	*Region*		
	Bow	*Midbody*	*Stern*
ICE-1A*	1.0	1.0	0.75
ICE-1A	1.0	0.85	0.65
ICE-1B	1.0	0.70	0.45
ICE-1C	1.0	0.50	0.25

For ice class **ICE-1A*F** an additional Lower Bow ice belt (see C102) is defined with factor $c_1 = 0.20$.

c_a = a factor which takes account of the probability that the full length of the area under consideration will be under pressure at the same time. It is calculated by the formula:

$$c_a = \sqrt{\frac{l_0}{l_a}}\ ,\ \ \text{maximum 1.0, minimum 0.35, } l_0 = 0.6\ m$$

l_a shall be taken as given in Table B4.

Table B4 Values of l_a		
Structure	*Type of framing*	l_a
Shell	transverse	frame spacing
	longitudinal	1.7 × frame spacing
Frames	transverse	frame spacing
	longitudinal	span of frame
Ice stringer		span of stringer
Web frame		2 × web frame spacing

C. Shell Plating

C 100   Vertical extension of ice strengthening for plating

101   The vertical extension of the ice belt (see Fig.1) shall not be less than given in Table C1.

Table C1 Vertical extension of ice belt			
Ice class	*Region*	*Above UIWL (m)*	*Below LIWL (m)*
ICE 1A*	Bow	0.60	1.20
	Midbody		
	Stern		1.0
ICE 1A	Bow	0.50	0.90
	Midbody		0.75
	Stern		
ICE 1B and **ICE 1C**	Bow	0.40	0.70
	Midbody		0.60
	Stern		

102   In addition the following areas shall be strengthened:

Fore foot: For ice class **ICE-1A*** and **ICE-1A*F** 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 shall have at least the thickness required in the ice belt in the Midbody region, calculated for the actual frame spacing.

Upper Bow ice belt: For ice classes **ICE-1A*** and **ICE-1A** on ships with an open water service speed equal to or exceeding 18 knots, the shell plate from the upper limit of the ice belt to 2 m above it and from the stem to a position at least 0.2 L abaft the forward perpendicular, shall have at least the thickness required in the ice belt in the Midbody region, calculated for the actual frame spacing.

> **Guidance note:**
> A similar strengthening of the bow region is advisable also for a ship with a lower service speed, when it is, e.g. on the basis of the model tests, evident that the ship will have a high bow wave.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

For ice class **ICE-1A*F** the upper Bow ice belt shall be taken 3 m above the normal ice belt, extending within the Bow region.

Lower Bow ice belt: For ice class **ICE-1A*F** a Lower Bow ice belt below the normal ice belt is defined covering the Bow region aft of the forefoot and down to the lower turn of bilge.

103   Sidescuttles shall not be situated in the ice belt. If the weather deck in any part of the ship is situated below the upper limit of the ice belt (e.g. in way of the well of a raised quarter deck), the bulwark shall 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 shall meet the same requirements.

C 200   Plate thickness in the ice belt

201   For transverse framing the thickness of the shell plating shall be determined by the formula:

$$t = 21.1 \cdot s \cdot \sqrt{\frac{f_1 \cdot p_{PL}}{\sigma_F}} + t_c \, (mm)$$

For longitudinal framing the thickness of the shell plating shall be determined by the formula:

$$t = 21.1s\sqrt{\frac{p}{f_2 \sigma_F}} + t_c \ (mm)$$

p_{PL} = 0.75 p
p   = as given in B200.

f_1 = $1.3 - \dfrac{4.2}{(h/s + 1.8)^2}$, maximum 1.0

f_2 = $0.6 + \dfrac{0.4}{(h/s)}$, when h/s ≤ 1

    = 1.4 – 0.4 (h/s); when 1 ≤ h/s < 1.8
    = 0.35 + 0.183 (h/s) for 1.8 ≤ h/s < 3
    = 0.9 for h/s > 3

h   = as given in B100

σ_F = yield stress of the material   (N/mm^2)

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

202   For ice class **ICE-1A*F** the following additional requirements are given:

— bottom plating in the Bow region (below the Lower Bow ice belt defined in 102) shall have a thickness not less than:

$$t = 0.7 \cdot (s + 0.8) \cdot \sqrt{\frac{235 \cdot L}{\sigma_F}} (mm) \ , \text{minimum 12 mm}$$

— side and bottom plating in the Stern region below the ice belt shall have a thickness not less than:

$$t = 0.6 \cdot (s + 0.8) \cdot \sqrt{\frac{235 \cdot L}{\sigma_F}} (mm) \ , \text{minimum 10 mm}$$

D. Frames

D 100   Vertical extension of ice framing

101   The vertical extension of the ice strengthening of the framing shall be at least as given in Table D1:

Table D1 Vertical extension of ice strengthening of the framing			
Ice class	*Region*	*Above UIWL (m)*	*Below LIWL (m)*
ICE- 1A*F, ICE-1A*	Bow		to double bottom or below top of floors
	Midbody	1.2	2.0
	Stern		1.6
ICE-1A, 1B, 1C	Bow		1.6
	midship	1.0	1.3
	Stern		1.0

Where an upper Bow ice belt is required (see C102), the ice strengthened part of the framing shall be extended at least to the top of this ice belt.

102   Where the ice strengthening would go beyond a deck or a tank top (or tank bottom) by not more than 250 mm, it can be terminated at that deck or tank top (or tank bottom).

D 200 Transverse frames

201 The section modulus of a main or intermediate transverse frame shall be calculated by the formula:

$$Z = \frac{p \cdot s \cdot h \cdot l}{m_t \cdot \sigma_F} \cdot 10^3 \, (cm^3)$$

and the effective shear area is calculated from

$$A = \frac{8.7 \cdot f_3 \cdot p \cdot h \cdot s}{\sigma_F} \quad [cm2]$$
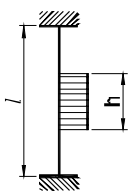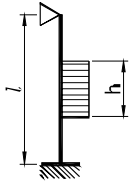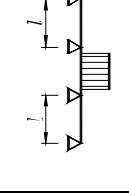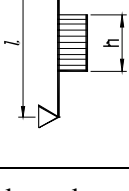
p   = ice pressure as given in B200
h   = height of load area as given in B100

$$m_t = \frac{7m_o}{7 - 5h/l}$$

f_3 = is a factor which takes into account the maximum shear force versus the load location and the shear stress distribution, f_3 =1.2.
m_o = values as given in Table D2.

Table D2 Values of m_o		
Boundary condition	*m_o*	*Example*
	7	Frames in a bulk carrier with top wing tanks
	6	Frames extending from the tank top to a single deck
	5.7	Continuous frames between several decks or stringers
	5	Frames extending between two decks only

The boundary conditions are those for the main and intermediate frames. Possible different conditions for main and intermediate frames are assumed to be taken care of by interaction between the frames and may be calculated as mean values. Load is applied at mid span.

If the ice belt covers less than half the span of a transverse frame, (b < 0.5 l) the following modified formula may be used for the section modulus:

$$Z = \frac{p \cdot s \cdot h \cdot b \cdot (l-b)^2}{\sigma_F \cdot l^2} \cdot 10^3 \, (cm^3)$$

b   = distance in m between upper or lower boundary of the ice belt and the nearest deck or stringer within the ice belt.

Where less than 15% of the span, *l*, of the frame is situated within the ice-strengthening zone for frames as defined in D101, ordinary frame scantlings may be used.

202   *Upper end of transverse framing*

1)   The upper end of the strengthened part of a main frame and of an intermediate ice frame shall be attached to a deck or an ice stringer (see E).

2)   Where an intermediate frame terminates above a deck or an ice stringer which is situated at or above the upper limit of the ice belt (see C100) the part above the deck or stringer may have the scantlings required for a non ice-strengthened ship and the upper end be connected to the adjacent main frames by a horizontal member of the same scantlings as the main frame.

203   *Lower end of transverse framing*

1)   The lower end of the strengthened part of a main frame and of an intermediate ice frame shall be attached to a deck, tank top (or tank bottom) or ice stringer (see E).

2)   Where an intermediate frame terminates below a deck, tank top (or tank bottom) or ice stringer which is situated at or below the lower limit of the ice belt (see C100), the lower end to be connected to the adjacent main frames by a horizontal member of the same scantlings as the main frames. Note that the main frames below the lower edge of ice belt must be ice strengthened, see A303.

D 300   Longitudinal frames

301   The section modulus of longitudinal frame with and without brackets shall be calculated by the formula:

$$Z = \frac{f_4 \cdot p \cdot h \cdot l^2}{m_1 \cdot \sigma_F} \cdot 10^3 \, (cm^3)$$

The shear effective area of a longitudinal frame shall be:

$$A = \frac{8.7 \cdot f_4 \cdot f_5 \cdot p \cdot h \cdot l}{\sigma_F} \, (cm^2)$$

In calculating the actual shear area of the frames, the shear area of the brackets is not to be taken into account.

f_4 = factor which takes account of the load distribution to adjacent frames:

$x_3 = (1 - 0.2 \, h/s)$

p   = ice pressure as given in B200

h   = height of load area as given in B100

m_1 = is a boundary condition factor; $m_1 = 13.3$ for a continuous beam; where the boundary conditions deviate significantly from those of a continuous beam, e.g. in an end field, a smaller boundary factor may be required. For frames without brackets a value $m_1 = 11.0$ is to be used.

D 400   Structural details

401   Within the ice strengthened area all frames shall be effectively attached to all supporting structures. Longitudinal or transverse frames crossing supporting structures, such as web frames or stringers, shall be connected to these structures on both sides (by collar plates or lugs in way of cut-outs).

Brackets or top stiffeners shall be fitted, in order to provide proper transfer of forces to supporting elements, as necessary. Connection of non-continuous frames to supporting structures shall be made by brackets or similar construction. When a bracket is installed, it has to have at least the same thickness as the web plate of the frame, and the edge shall be appropriately stiffened against buckling.

402   For ice class **ICE-1A*F** and **ICE-1A***, for ice class **ICE-1A** in the Bow and midbody regions and for ice classes **ICE-1B** and **ICE-1C** in the Bow region, the following shall apply in the ice strengthened area:

1)   Frames which are not at a straight angle to the shell shall be supported against tripping by brackets, intercostals, stringers or similar at a distance preferably not exceeding 1.3 m.

Transverse frames perpendicular to shell which are of unsymmetrical profiles shall have tripping preventions if the span is exceeding 4.0 m.

2)   Frames shall be attached to the shell by double continuous welds. No scalloping is allowed (except when crossing shell plate butts).

3) The web thickness of the frames shall be at least the maximum of the following:

— 9 mm
— one half of the net shell plating requirement as given by C201, where the yield stress, σ_F, shall not be taken larger than that given for the frame.
— $\dfrac{h_w \sqrt{\sigma_F}}{C}$, h_w is the web height and C = 805 for profiles and C = 282 for flat bars;

Where there is a deck, tank top (or tank bottom) or bulkhead in lieu of a frame, the plate thickness of this shall be as above, to a depth corresponding to the height of adjacent frames.

E. Ice Stringers

E 100   Stringers within the ice belt

101   The section modulus of a stringer situated within the ice belt (see C100) shall be calculated by the formula:

$$Z = \frac{f_6 \cdot f_7 \cdot p \cdot h \cdot l^2}{m_1 \cdot \sigma_F} \cdot 10^3 \, (cm^3)$$

The shear area shall not be less than:

$$A = \frac{8.7 \cdot f_6 \cdot f_7 \cdot f_8 \cdot p \cdot h \cdot l}{\sigma_F} \, (cm^2)$$

p = ice pressure as given in B200
h = height of load area as given in B100

The product p h shall not be taken as less than 150

l = span of stringer (m)
m_1 = boundary condition factor as given in D301.
f_6 = which takes account of the distribution of load to the transverse frames; to be taken as 0.9.
f_7 = factor of stringers; to be taken as 1.8.
f_8 = factor that takes into account the maximum shear force versus load location and the shear stress distribution; f_8 = 1.2.

E 200   Stringers outside the ice belt

201   The section modulus of a stringer situated outside the ice belt but supporting ice strengthened frames shall be calculated by the formula:

$$Z = \frac{f_9 \cdot f_{10} \cdot p \cdot h \cdot l^2}{m_1 \cdot \sigma_F} (1 - h_s / l_s) \cdot 10^3 \, (cm^3)$$

The shear area shall not be less than:

$$A = \frac{8.7 \cdot f_9 \cdot f_{10} \cdot f_{11} \cdot p \cdot h \cdot l}{\sigma_F} (1 - h_s / l_s)(cm^2)$$

p = ice pressure as given in B200
h = height of load area as given in B100

The product p h shall not be taken as less than 150.

l = span of stringer (m)
m_1 = boundary condition factor as given in D301
l_s = the distance to the adjacent ice stringer (m)
h_s = the distance to the ice belt (m).
f_9 = factor which takes account of the distribution of load to the transverse frames; to be taken as 0.80.
f_{10} = safety factor of stringers; to be taken as 1.8.
f_{11} = factor that takes into account the maximum shear force versus load location and the shear stress distribution; f_{11} = 1.2.

E 300   Deck strips

301   Narrow deck strips abreast of hatches and serving as ice stringers shall comply with the section modulus and shear area requirements in 100 and 200 respectively. In the case of very long hatches the lower limit of the product p h may be reduced to 100.

302   Regard shall be paid to the deflection of the ship's sides due to ice pressure in way of very long hatch openings (more than B/2), when designing weatherdeck hatch covers and their fittings.

F. Web Frames

F 100   Design ice load

101   The design ice load transferred to a web frame from an ice stringer or from longitudinal framing shall be calculated by the formula:

$$F = f_{12} \cdot p \cdot h \cdot s \quad (kN)$$

p   = ice pressure as given in B200, when calculating factor c_a, however, l_a shall be taken as 2 s
h   = height in m of load area as given in B100

The product ph shall not be taken less than 150.

s   = web frame spacing in m
f_{12} = factor of web frames; to be taken as 1.8

In case the supported stringer is outside the ice belt, the load F may be multiplied by:

$$\left(1 - \frac{h_s}{l_s}\right)$$

as given in E201.

F 200   Section modulus and shear area

201   The section modulus requirement is given by:

$$Z = \frac{M}{\sigma_F} \sqrt{\frac{1}{1 - \left(\gamma \frac{A}{A_a}\right)^2}} 10^3 \quad (cm^3)$$

M   = maximum calculated bending moment under the ice load F, as given in 101. This is to be taken as $M = 0.193 \cdot F \cdot l$.
γ = as given in Table F1
A   = required shear area from 202
A_a = actual cross sectional area of web frame, $A_a = A_f + A_w$.

202   With boundary conditions as given in 201, the shear area of a web frame is given by:

$$A = \frac{17.3 \cdot \alpha \cdot f_{13} \cdot Q}{\sigma_F} (cm^2)$$

Q   = maximum calculated shear force under the load F, as given in 101
f_{13} = factor that takes into account the shear force distribution, $f_{13} = 1.1$
α = factor given in Table F1
A_f = cross sectional area of free flange
A_w = actual effective cross sectional area of web plate.

Table F1 Values of α and γ											
$\frac{A_f}{A_w}$	0.0	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

G. Bilge Keels

G 100   Arrangement

101   The connection of bilge keels to the hull shall be so designed that the risk of damage to the hull, in case a bilge keel is ripped off, is minimised.

102   For class **ICE-1A*F** bilge keels are normally to be avoided and should be replaced by roll-damping equipment. Specially strengthened bilge keels may be considered.

H. Special Arrangement and Strengthening Forward

H 100   Stem, baltic ice strengthening

101   The stem may be made of rolled, cast or forged steel or of shaped steel plates. as shown in Fig. 3.
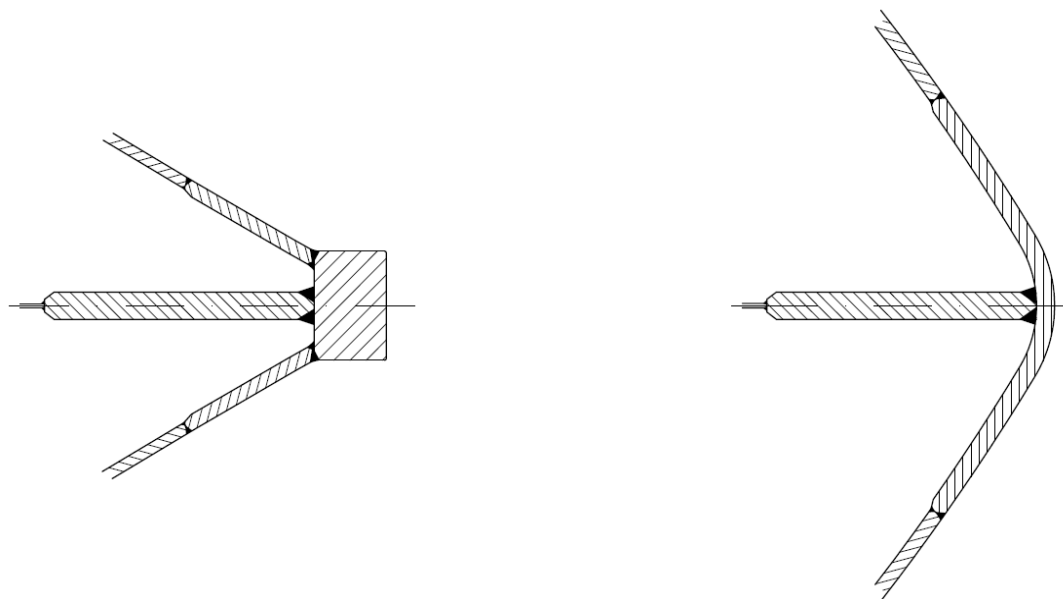
Fig. 3
Examples of suitable stems

102   The plate thickness of a shaped plate stem and in the case of a blunt bow, any part of the shell where $\alpha \geq 30°$ and $\psi \geq 75°$ (see J103 for angle definitions), shall be calculated according to the formulae in C200 assuming that:

s   = spacing of elements supporting the plate (m)
p_{PL} = p (see B200).
l_a = spacing of vertical supporting elements (m)
        (see Table B4).

For class **ICE-1A*F** the front plate and upper part of the bulb and the stem plate up to a point 3.6 m above UIWL (lower part of bow door included) shall have a minimum thickness of:

$$t = c \sqrt{\frac{235 \, L}{\sigma_f}} \quad (mm)$$

c   = 2.3 for the stem plate
      = 1.8 for the bulb plating.

The width of the increased bulb plate shall not be less than 0.2 b on each side of the centre line, b = breadth of the bulb at the forward perpendicular.

103   The stem and the part of a blunt bow defined above shall be supported by floors or brackets spaced not more than 0.6 m apart and having a thickness of at least half the plate thickness. The reinforcement of the stem shall be extend from the keel to a point 0.75 m above UIWL or, in case an upper bow ice belt is required (C102) to the upper limit of this.

H 200   Arrangements for towing

201   The vessel to be arranged for towing.

202   A bitt or other means for securing a towline, dimensioned to stand the breaking force of the towline of the ship shall be fitted.

I. Special Arrangement and Strengthening Aft

I 100   Stern

101   The introduction of new propulsion arrangements with azimuthing thrusters or "podded" propellers, which provide an improved manoeuvrability, will result in increased ice loading of the Stern region and stern area. This fact should be considered in the design of the aft/stern structure.

102   In order to avoid very high loads on propeller blade tips, the minimum distance between propeller(s) and hull (including stern frame) should not be less than h_0 (see B101).

103   On twin and triple screw ships the ice strengthening of the shell and framing shall be extended to the double bottom for 1.5 metre forward and aft of the side propellers.

104   Shafting and stern tubes of side propellers are normally to be enclosed within plated bossings. If detached struts are used, their design, strength and attachment to the hull shall be duly considered.

For class **ICE-1A*F** the skin plating of propeller shaft bossings shall not be less than:

$$t \;=\; 0.9(s+0.8)\sqrt{\frac{235\,L}{\sigma_f}} \quad \text{(mm)}.$$

I 200   Rudder and steering arrangements

201   The scantlings of rudder, rudder post, rudder stock, pintles, steering gear etc. as well as the capacity of the steering gear shall be determined according to the rules. The maximum service speed of the ship to be used in these calculations is, however, not to be taken less than that stated below:

Table I1 Maximum service speed	
Ice class	*Maximum service speed*
ICE-1A*	20 knots
ICE-1A	18 knots
ICE-1B	16 knots
ICE-1C	14 knots

If the actual maximum service speed of the ship is higher, that speed shall be used.

When calculating the rudder force according to the formula given in Pt.3 Ch.3 Sec.2 D and with the speed V in ahead condition as given above, the factors $k_1 = k_2 = 1.0$ irrespective of condition, rudder profile type or arrangement. In the astern condition half the speed values shall be used.

202   For the ice classes **ICE-1A*** and **ICE-1A** the rudder stock and the upper edge of the rudder shall be protected against ice pressure by an ice knife or equivalent means.

> **Guidance note:**
> Upper forward part of rudder and forward part of rudder horn should be protected against abrasion by a special coating or increase in thickness.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

203   For ice classes **ICE-1A*** and **ICE-1A** due regard shall be paid to the excessive loads caused by the rudder being forced out of the midship position when backing into an ice ridge.

204   Relief valves for hydraulic pressure shall be effective. The components of the steering gear shall be dimensioned to stand the yield torque of the rudder stock. Where possible rudder stoppers working on the blade or rudder head shall be fitted.

205   The local scantlings of rudders are to be determined assuming that the whole rudder belongs to the ice belt. Further, the rudder plating and frames are to be designed using the ice pressure p for the plating and frames in the Midbody Region.

J. Propulsion Machinery

J 100 Engine output

101 *Definition of engine output*

The engine output P_S is the maximum output the propulsion machinery can continuously deliver to the propeller(s). If the output of the machinery is restricted by technical means or by any regulations applicable to the ship, P_S shall be taken as the restricted output.

102 *Documentation on board*

Minimum engine output corresponding to the ice class shall be given in the Classification Certificate.

103 *Required engine output for ice classes*

Definitions

The dimensions of the ship and some other parameters are defined below:

L = length of the ship between the perpendiculars (m)
L_{BOW} = length of the bow (m), Fig.4
L_{PAR} = length of the parallel midship body (m), Fig.4
B = maximum breadth of the ship (m)
T = actual ice class draughts of the ship (m) according to A301
A_{wf} = area of the waterline of the bow (m²), Fig.4
α = the angle of the waterline at B/4 (°), Fig.4
φ_1 = the rake of the stem at the centreline (°), Fig.4
φ_2 = the rake of the bow at B/4 (°), Fig.4
ψ = flare angle (°) calculated as ψ = arc tan (tanφ/sinα) using angles α and φ at each location. For paragraph J, flare angle is calculated using $\varphi = \varphi_2$
D_P = diameter of the propeller or outer diameter of nozzle for the nozzle propeller, maximum 1.2 times propeller diameter (m)
H_M = thickness of the brash ice in mid channel (m)
H_F = thickness of the brash ice layer displaced by the bow (m).
R_{CH} = resistance (in Newton) of the ship in a channel with brash ice and a consolidated layer (see formula in 104)
K_e = factor depending on no. of propellers, CPP (or similar), fixed pitch type (see Table J2)
P_s = minimum engine output
C = empirical coefficients (misc. sub index)
f = empirical factors (misc. sub index)
g = empirical factors (misc. sub index).

Range of validity

The range of validity of the formulae for powering requirements in 104 is presented in Table J1. When calculating the parameter DP/T, T shall be measured at UIWL.

Table J1 Parameter validity range		
Parameter	*Minimum*	*Maximum*
α [degrees]	15	55
φ_1 [degrees]	25	90
φ_2 [degrees]	10	90
L [m]	65.0	250.0
B [m]	11.0	40.0
T [m]	4.0	15.0
L_{BOW}/L	0.15	0.40
L_{PAR}/L	0.25	0.75
D_P /T	0.45	0.75
A_{wf} /(L×B)	0.09	0.27

If the ship's parameter values are beyond the ranges defined in Table J1, other methods for determining R_{CH} shall be used as defined in 105.
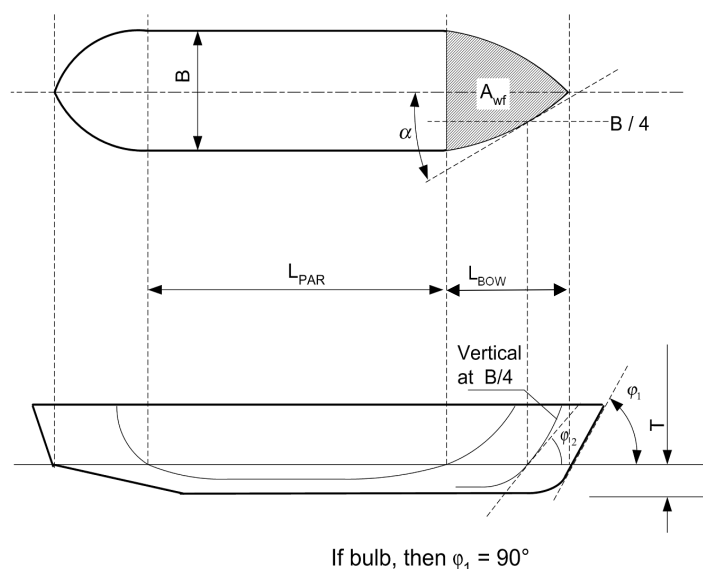
Fig. 4
Definitions

104 The engine output requirement shall be calculated for:

— Upper Ice Waterlines (UIWL) and
— Lower Ice Waterlines (LIWL),

as defined in Sec.1 B.

In the calculations the ship's parameters which depend on the draught shall be determined at the appropriate draught, but L and B shall be determined only at the UIWL. The engine output shall not be less than the greater of these two outputs.

The engine output P_S shall not be less than that determined by the formulae and in no case less than given in Table J3:

> **Guidance note:**
> "New ships" – see A102 Guidance note.
> For "existing **ICE-1A** and **ICE-1A*** ships" see Pt.7 Ch.2 Sec.2 A.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

$$P_S = K_e \frac{\left(\dfrac{R_{CH}}{1000}\right)^{\frac{3}{2}}}{D_P} \quad (kW)$$

Table J2 Value of factor K_e for conventional propulsion systems*)		
	Propeller type or machinery	
Numbers of propellers	*Controllable pitch propeller or electric or hydraulic propulsion machinery*	*Fixed pitch propeller*
1 propeller	2.03	2.26
2 propellers	1.44	1.6
3 propellers	1.18	1.31
*) For advanced systems see J105.		

Table J3 Minimum engine output P_S	
ICE-1A, **ICE-1B** and **ICE-1C**	1 000 kW
ICE-1A*	2 800 kW

R_{CH} is the resistance in Newton of the ship in a channel with brash ice and a consolidated layer:

$$R_{CH} = C_1 + C_2 + C_3 C_\mu (H_F + H_M)^2 (B + C_\psi H_F) +$$

$$C_4 L_{PAR} H_F^2 + C_5 \left(\frac{LT}{B^2}\right)^3 \frac{A_{wf}}{L} \quad (N)$$

C_μ = $0.15 \cos\varphi_2 + \sin\psi \sin\alpha$
$\qquad C_\mu \geq 0.45$ (minimum value)
C_ψ = $0.047\psi - 2.115$ and 0 if $\psi \leq 45°$
H_F = $0.26 + (H_M B)^{0.5}$
H_M = 1.0 for **ICE-1A** and **ICE-1A***
$\qquad$ = 0.8 for **ICE-1B**
$\qquad$ = 0.6 for **ICE-1C**.

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 **ICE-1A**, **ICE-1B** and **ICE-1C**.

For ice class **ICE-1A***:

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

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

For a ship with a bulbous bow, φ_1 shall be taken as 90°.

f_1 = 23 (N/m^2)
f_2 = 45.8 (N/m)
f_3 = 14.7 (N/m)
f_4 = 29 (N/m^2)
g_1 = 1 530 (N)
g_2 = 170 (N/m)
g_3 = 400 (N/m$^{1.5}$)
C_3 = 845 (kg/(m^{2}s^2))
C_4 = 42 (kg/(m^{2}s^2))
C_5 = 825 (kg/s^2)

$$\psi = \arctan\left(\frac{\tan\varphi_2}{\sin\alpha}\right)$$

$\left(\frac{LT}{B^2}\right)^3$ shall not be taken less than 5 and not more than 20.

105 *Other methods of determining K_e or R_{CH}*

For an individual ship, in lieu of the K_e or R_{CH} values defined in Table J2 and 104, the use of K_e or R_{CH} values based on more exact calculations or values based on model tests may be approved. Such approval will be given on the understanding that it can be revoked if experience of the ship's performance in practice motivates this.

Guidance note:
For ships intended for trading in Finnish waters and having the propulsion power determined by model tests or by means other than the rule formula, additional approval by Finnish or Swedish authorities is necessary.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

The design requirement for ice classes shall be a minimum speed of 5 knots in the following brash ice channels (see Table J4):

Table J4 Values of H_M	
Ice class	H_M
ICE-1A*	1.0 m and a 0.1 m thick consolidated layer of ice
ICE-1A	1.0 m
ICE-1B	0.8 m
ICE-1C	0.6 m

J 200 Materials

201 *Materials exposed to sea water*

Materials of components exposed to sea water, such as propeller blades, propeller hubs, and   thruster body, shall 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 shall be carried out for materials other than bronze and austenitic stainless steel. An average impact energy value of 20 J taken from three tests shall be obtained at minus 10ºC.

202 *Materials exposed to sea water temperature*

Materials exposed to sea water temperature shall be of ductile material. An average impact energy value of 20 J taken from three tests is to be obtained at minus 10ºC. 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.

J 300 Design loads for propeller and shafting

301 These regulations apply to propulsion machinery covering open- and ducted-type propellers with controllable pitch or fixed pitch design for the ice classes **ICE-IA***, **ICE-IA**, **ICE-IB** and **ICE-IC**. 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 regulations also apply to azimuting 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 azimuting thruster from the side (radially) or load case when ice block hits on the propeller hub of a pulling propeller.

302 *Design ice conditions*

In estimating the ice loads of the propeller for ice classes, different types of operation as given in Table J1 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 Table J2.

Table J1 Operation of the ship	
ICE-1A*	Operation in ice channels and in level ice. The ship may proceed by ramming
ICE-IA…1C	Operation in ice channels

Table J2 Thickness of the design maximum ice block H_{ice} entering the propeller				
Ice Class	**ICE-1A***	**ICE-IA**	**ICE-IB**	**ICE-IC**
(H_{ice})	1.75 m	1.5 m	1.2 m	1.0 m

Table J3 List of symbols		
Symbol	*Unit*	*Definition*
A.P.		the after perpendicular is the perpendicular at the after end of the length L
c	m	chord length of blade section
$c_{0.7}$	m	chord length of blade section at 0.7R propeller radius
CP		controllable pitch
D	m	propeller diameter
d	m	external diameter of propeller hub
D_{limit}	m	limit value for propeller diameter
EAR		expanded blade area ratio
F_b	kN	maximum backward blade force for the ship's service life
F_{ex}	kN	ultimate blade load resulting from blade loss through plastic bending
F_f	kN	maximum forward blade force for the ship's service life
F_{ice}	kN	ice load
$(F_{ice})_{max}$	kN	maximum ice load for the ship's service life
FP		fixed pitch
F.P.		the forward perpendicular is the perpendicular at the intersection of the summer load waterline with the fore side of the stem. For ships with unusual bow arrangements the position of the F.P. will be especially considered.
h_0	m	depth of the propeller centreline from the winter waterline
H_{ice}	m	thickness of maximum design ice block entering to propeller

Table J3 List of symbols (Continued)		
Symbol	*Unit*	*Definition*
I	kgm^2	equivalent mass moment of inertia of all parts on engine side of component under consideration
I$_t$	kgm^2	equivalent mass moment of inertia of the whole propulsion system
k		shape parameter for Weibull distribution
LIWL	m	lower ballast waterline in ice
m		slope for SN curve in log/log scale
M$_{BL}$	kNm	blade bending moment
MCR		maximum continuous rating
n	rev/s	propeller rotational speed
n$_n$	rev/s	nominal propeller rotational speed at MCR in free running condition
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$_{0.7}$	m	propeller pitch at 0.7R radius
P$_{0.7n}$	m	propeller pitch at 0.7R radius at MCR in free running condition
P$_{0.7b}$	m	propeller pitch at 0.7R radius at MCR in bollard condition
Q	kNm	torque
Q$_{emax}$	kNm	maximum engine torque
Q$_{max}$	kNm	maximum torque on the propeller resulting from propeller-ice interaction
Q$_{motor}$	kNm	electric motor peak torque
Q$_n$	kNm	nominal torque at MCR in free running condition
Q$_r$	kNm	maximum response torque along the propeller shaft line
Q$_{smax}$	kNm	maximum spindle torque of the blade for the ship's service life
R	m	propeller radius
r	m	blade section radius
T	kN	propeller thrust
T$_b$	kN	maximum backward propeller ice thrust for the ship's service life
T$_f$	kN	maximum forward propeller ice thrust for the ship's service life
T$_n$	kN	propeller thrust at MCR in free running condition
T$_r$	kN	maximum response thrust along the shaft line
t	m	maximum blade section thickness
Z		number of propeller blades
α_i	deg	duration of propeller blade/ice interaction expressed in rotation angle
γ_ε		the reduction factor for fatigue; scatter and test specimen size effect
γ_v		the reduction factor for fatigue; variable amplitude loading effect
γ_m		the reduction factor for fatigue; mean stress effect
ρ		a reduction factor for fatigue correlating the maximum stress amplitude to the equivalent fatigue stress for 108 stress cycles
$\sigma_{0.2}$	MPa	proof yield strength of blade material
σ_{exp}	MPa	mean fatigue strength of blade material at 10^8 cycles to failure in sea water
σ_{fat}	MPa	equivalent fatigue ice load stress amplitude for 10^8 stress cycles
σ_{fl}	MPa	characteristic fatigue strength for blade material
σ_{ref}	MPa	reference stress (ultimate strength) $\sigma_{ref} = 0.6\ \sigma_{0.2} + 0.4\ \sigma_u$
σ_{ref2}	MPa	reference stress (blade scantlings) $\sigma_{ref2} = 0.7\ \sigma_u$ or $\sigma_{ref2} = 0.6\ \sigma_{0.2} + 0.4\ \sigma_u$ whichever is less
σ_{st}	MPa	maximum stress resulting from F$_b$ or F$_f$
σ_u	MPa	ultimate tensile strength of blade material
$(\sigma_{ice})_{bmax}$	MPa	principal stress caused by the maximum backward propeller ice load
$(\sigma_{ice})_{fmax}$	MPa	principal stress caused by the maximum forward propeller ice load
$(\sigma_{ice})_{max}$	MPa	maximum ice load stress amplitude

Table J4 Definition of ice loads		
Load	*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 figure below	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_b 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 0.8R 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 behaviour 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 behaviour 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.

Back / suction side

Shaft Direction

Direction of
rotation

F_b
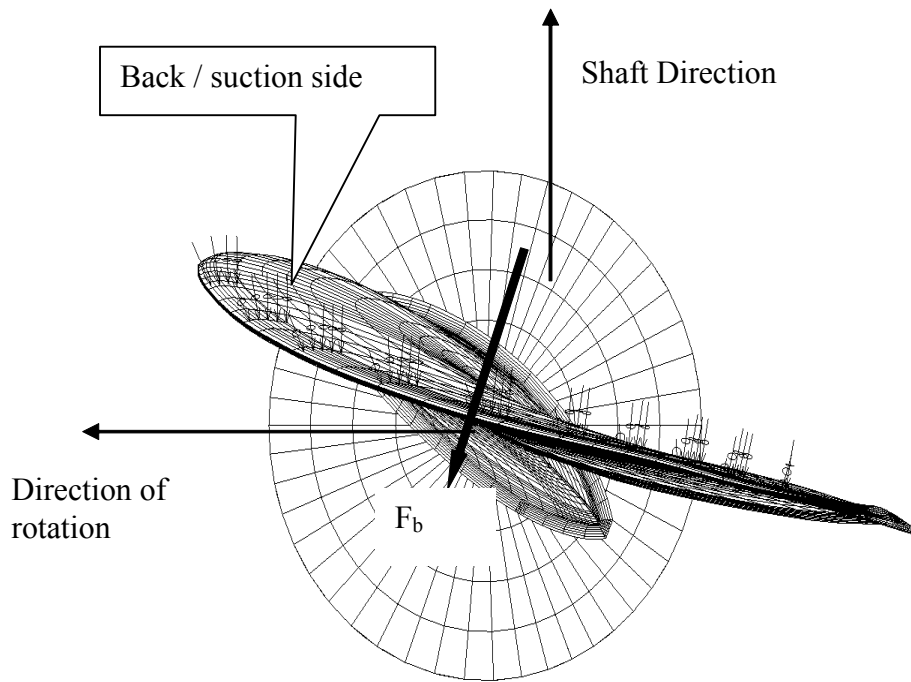
(Ice contact pressure at leading edge is shown with small arrows)
Fig. 5
Direction of the backward blade force resultant taken perpendicular to chord line at 0.7 r/R

J 400   Design loads

401   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.

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

403   If the propeller is not fully submerged when the ship is in ballast condition, the propulsion system shall be designed according to ice class **ICE-IA** for ice classes **ICE-IB** and **ICE-IC**.

J 500   Design loads on propeller blades

501 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. F_b and F_f originate from different propeller/ice interaction phenomena, not acting simultaneously. Hence they are to be applied to one blade separately.

502   *Maximum backward blade force F_b for open propellers*

$$F_b = 27 \cdot [n \cdot D]^{0.7} \cdot \left[\frac{EAR}{Z}\right]^{0.3} \cdot D^2 \quad [\text{kN}]$$

$$\text{when} \quad D \leq D_{limit} \quad (1)$$

$$F_b = 23 \cdot [n \cdot D]^{0.7} \cdot \left[\frac{EAR}{Z}\right]^{0.3} \cdot D \cdot H_{ice}^{1.4} \quad [\text{kN}]$$

$$\text{when} \quad D > D_{limit} \quad (2)$$

where

$$D_{limit} = 0.85 \cdot H_{ice}^{1.4} \quad [\text{m}]$$

n is the 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.

503   *Maximum forward blade force F_f for open propellers*

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

$$\text{when} \quad D \leq D_{limit} \qquad (3)$$

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

$$\text{when} \quad D > D_{limit} \qquad (4)$$
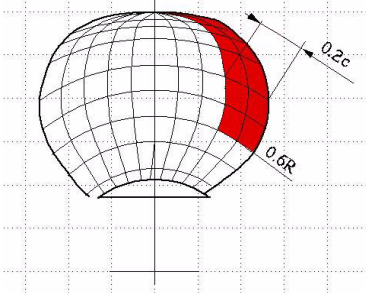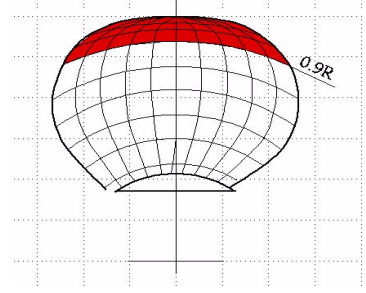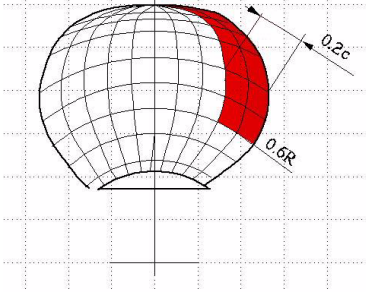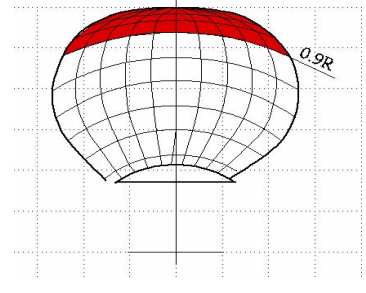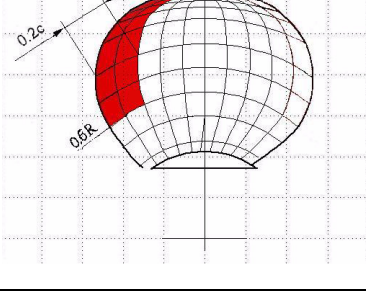
where

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

504   *Loaded area on the blade for open propellers*

Load cases 1-4 have to be covered, as given in Table J5 below, for CP and FP propellers. The load case 5 applies to reversible propellers in addition to the cases 1…4.

Table J5 Load cases for open propellers			
Load case	*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	

505 *Maximum backward blade ice force F_b for ducted propellers*

$$F_b = 9.5 \cdot [n \cdot D]^{0.7} \cdot \left[\frac{EAR}{Z} \right]^{0.3} \cdot D^2 \qquad [kN]$$

when $\qquad D \leq D_{limit} \qquad (5)$

$$F_b = 66 \cdot [n \cdot D]^{0.7} \cdot \left[\frac{EAR}{Z} \right]^{0.3} \cdot D^{0.6} \cdot H_{ice}^{1.4} \qquad [kN]$$

when $\quad D > D_{limit} \qquad (6)$

where

$$D_{limit} = 4 \cdot H_{ice} \qquad [m]$$

n is the 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.

506 *Maximum forward blade ice force F_f for ducted propellers*

$$F_f = 250 \cdot \left[\frac{EAR}{Z} \right] \cdot D^2 \qquad [kN]$$

when $\quad D \leq D_{limit} \qquad (7)$

$$F_f = 500 \cdot \left[\frac{EAR}{Z} \right] \cdot D \cdot \frac{1}{\left(1 - \dfrac{d}{D}\right)} \cdot H_{ice} \qquad [kN]$$
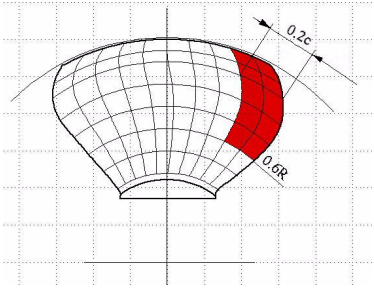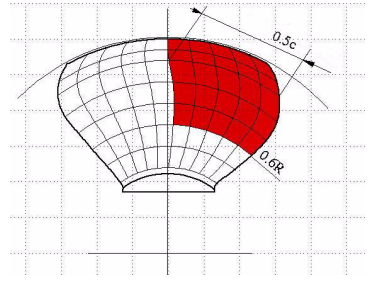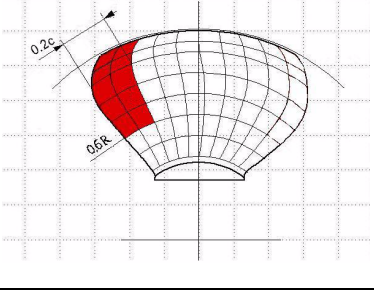
when $\quad D > D_{limit} \qquad (8)$

where

$$D_{limit} = \frac{2}{\left(1 - \dfrac{d}{D}\right)} \cdot H_{ice} \qquad [m]$$

507 *Loaded area on the blade for ducted propellers*
Load cases 1 and 3 have to be covered as given in Table J5 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 J6 Load cases for ducted propellers

Load case	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.	

508 *Maximum blade spindle torque Q_{smax} for open and ducted propellers*

The spindle torque Q_{smax} around the axis of the blade fitting shall be determined both for the maximum backward blade force F_b and forward blade force F_f, which are applied as in Table J5 and Table J6. If the above method gives a value which is less than the default value given by the formula below, the default value shall be used.

$$\text{Default value} \quad Q_{smax} = 0.25 \cdot F \cdot c_{0.7} \quad [\text{kNm}] \qquad (9)$$

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

509 *Load distributions for blade loads*

The Weibull-type distribution (probability of exceeding), as given in Fig.6, is used for the fatigue design of the blade.

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

Here, k is the shape parameter of the spectrum, N_{ice} is the number of load cycles in the spectrum, and F_{ice} is the random variable for ice loads on the blade, $0 \leq F_{ice} \leq (F_{ice})_{\max}$. The shape parameter k = 0.75 shall 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.
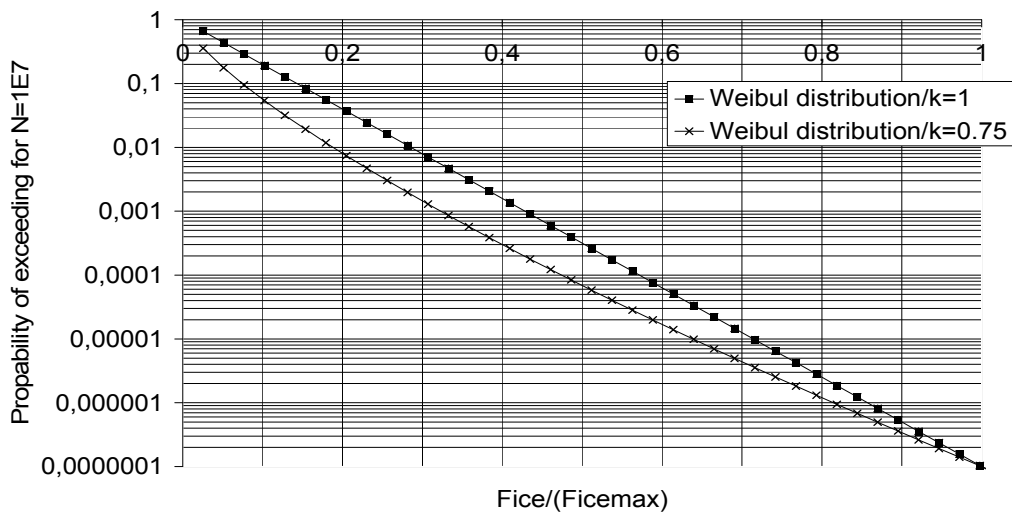
Fig. 6
The Weibull-type distribution (probability of exceeding) that is used for fatigue design

510 *Number of ice loads*

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

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

where:

n is propeller nominal rps as defined for loads.

Table J7 Reference number of loads for ice classes N_{class}				
	ICE-IA*	**ICE-IA**	**ICE-IB**	**ICE-IC**
Impacts in life/n	$9 \cdot 10^6$	$6 \cdot 10^6$	$3.4 \cdot 10^6$	$2.1 \cdot 10^6$

Table J8 Propeller location factor k_1		
Single propeller		*Twin propeller*
location	*centreline*	*twin wing*
k_1	1	1.35

Table J9 Propeller type factor k_2		
type	*open*	*ducted*
k_2	1	1.1

Table J10 Propulsion type factor k_3		
type	*fixed*	*azimuting*
k_3	1	1.2

The submersion factor k_4 is determined from the equation

$$
\begin{aligned}
k_4 &= 0.8 - f & \text{when} \quad f < 0 \\
&= 0.8 - 0.4 \cdot f & \text{when} \quad 0 \leq f \leq 1 \\
&= 0.6 - 0.2 \cdot f & \text{when} \quad 1 < f \leq 2.5 \\
&= 0.1 & \text{when} \quad f > 2.5
\end{aligned}
\tag{10}
$$

where the immersion function *f* is:

$$f = \frac{h_o - H_{ice}}{D/2} - 1 \qquad (11)$$

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

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).

J 600   Axial design loads for open and ducted propellers

601   *Design ice thrust on propeller T_f and T_b for open and ducted propellers*

The maximum forward and backward ice thrusts are:

$$T_f = 1.1 \cdot F_f \quad [kN] \qquad (12)$$

$$T_b = 1.1 \cdot F_b \quad [kN] \qquad (13)$$

602   *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 shall 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

$$T_r = T + 2.2 \cdot T_f \quad [kN] \qquad (14)$$

In a backward direction

$$T_r = 1.5 \cdot T_b \quad [kN] \qquad (15)$$

If the hydrodynamic bollard thrust, T, is not known, T is to be taken from Table J11, where T_n is the nominal propeller thrust at MCR in free running open water condition

Table J11 Selection of pollard thrust *)	
Propeller type	*T*
CP propellers (open)	1.25 T_n
CP propellers (ducted)	1.1 T_n
FP propellers driven by turbine or electric motor	T_n
FP propellers driven by diesel engine (open)	0.85 T_n
FP propellers driven by diesel engine (ducted)	0.75 T_n
*) When not known	

J 700   Torsional design loads

701   *Design ice torque on propeller Q_{max} for open propellers*

Q_{max} is the maximum torque on a propeller resulting from ice/propeller interaction.

$$Q_{max} = 10.9 \cdot \left[1 - \frac{d}{D}\right] \cdot \left[\frac{P_{0.7}}{D}\right]^{0.16} \cdot (nD)^{0.17} \cdot D^3 \qquad [kNm]$$

$$\text{when} \quad D \le D_{limit} \qquad (16)$$

$$Q_{max} = 20.7 \cdot \left[1 - \frac{d}{D}\right] \cdot \left[\frac{P_{0.7}}{D}\right]^{0.16} \cdot (nD)^{0.17} \cdot D^{1.9} \cdot H_{ice}^{1.1} \qquad [kNm]$$

$$\text{when} \quad D > D_{limit} \qquad (17)$$

where

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

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 $0.7 \cdot P_{0.7n}$, where $P_{0.7n}$ is the propeller pitch at MCR in free running condition.

Table J12 Rotational speed selection *)	
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	$0.85\ n_n$
*) n_n refers to MCR free running condition	

702 *Design ice torque on propeller Q_{max} for ducted propellers*

Q_{max} is the maximum torque on a propeller resulting from ice/propeller interaction.

$$Q_{max} = 7.7 \cdot \left[1 - \frac{d}{D}\right] \cdot \left[\frac{P_{0.7}}{D}\right]^{0.16} \cdot (nD)^{0.17} \cdot D^3 \quad [\text{kNm}]$$

$$\text{when} \qquad D \le D_{limit} \qquad (18)$$

$$Q_{max} = 14.6 \cdot \left[1 - \frac{d}{D}\right] \cdot \left[\frac{P_{0.7}}{D}\right]^{0.16} \cdot (nD)^{0.17} \cdot D^{1.9} \cdot H_{ice}^{1.1} \quad [\text{kNm}]$$

$$\text{when} \qquad D > D_{limit} \qquad (19)$$

where

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

and n and $P_{0.7}$ as defined for open propeller.

703 *Ice torque excitation for open and ducted propellers*

The propeller ice torque excitation for shaft line transient torsional vibration analysis shall be described by a sequence of blade impacts which are of a half sine shape, see Fig.7.

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

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

$$\text{when} \qquad \varphi = 0 ... \alpha_i \qquad (20)$$

$$Q(\varphi) = 0 \quad \text{when} \quad \varphi = \alpha_i .... 360$$

where C_q and α_i parameters are given in the table J13 and α_i is duration of propeller blade/ice interaction expressed in propeller rotation angle.

Table J13 Torque excitation parameters			
Torque excitation	*Propeller/ice interaction*	C_q	a_i
Case 1	Single ice block	0.75	90
Case 2	Single ice block	1.0	135
Case 3	Two ice blocks (phase shift 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 degrees/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 shall be obtained with the formula:

$$N_Q = 2 \cdot H_{ice} \qquad (21)$$

The number of impacts is $Z \cdot N_Q$ for blade order excitation.
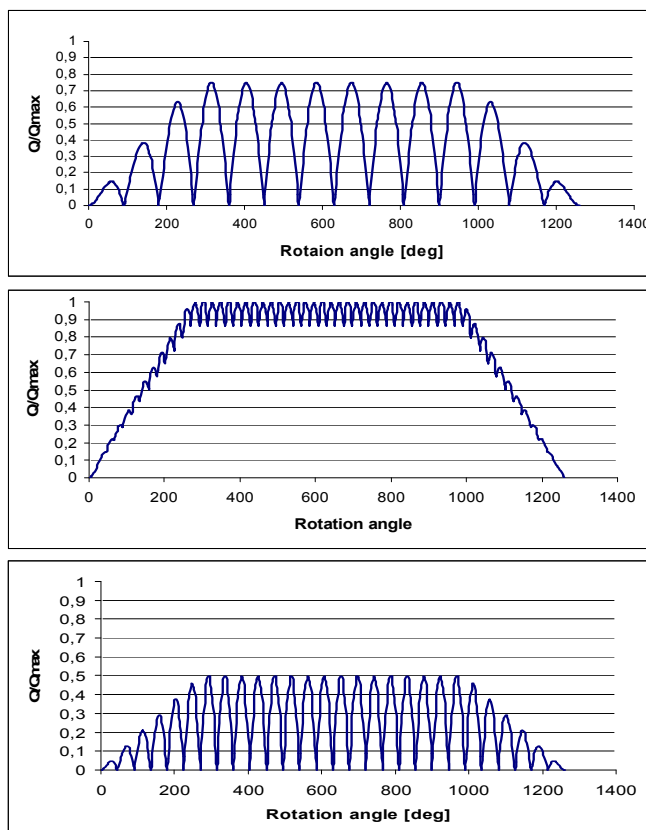
For 90- and 135-degree single-blade impact sequences and 45 degree double blade impact sequence (figures apply for propellers with 4 blades.)
Fig. 7
The shape of the propeller ice torque excitation

704 *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:

$$Q_r = Q_{e\max} + Q_{\max} \cdot \frac{I}{I_t} \quad [\text{kNm}] \qquad (22)$$

where I is equivalent mass moment of inertia of all parts on engine side of component under consideration and I_t is equivalent mass moment of inertia of the whole propulsion system. All the torques and the inertia moments shall be reduced to the rotation speed of the component being examined.

If the maximum torque, $Q_{e\max}$, is not known, it shall be taken as follows, where Q_{motor} is the electric motor peak torque:

Table J14 Selection of maximum motor torque Q_{emax}	
Propeller type	Q_{emax}
Propellers driven by electric motor	Q_{motor}
CP propellers not driven by electric motor	Q_n
FP propellers driven by turbine	Q_n
FP propellers driven by diesel engine	0.75 Q_n

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 shall be determined by means of torsional vibration analysis of the propulsion line.

J 800   Blade failure load

801   The ultimate load resulting from blade failure as a result of plastic bending around the blade root shall be calculated with the formula below. The ultimate load is acting on the blade at the 0.8R 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 0.8R radius.

$$F_{ex} = \frac{300 \cdot c \cdot t^2 \cdot \sigma_{ref}}{0.8 \cdot D - 2 \cdot r} \quad [\text{kN}] \qquad (24)$$

where

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

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.

J 900 Design principle

901 The strength of the propulsion line shall be designed according to the pyramid strength principle. This means that the loss of the propeller blade shall not cause any significant damage to other propeller shaft line components.

902 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 per cent 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.

J 1000 Propeller blade design

1001 *Calculation of blade stresses*

The blade stresses shall be calculated for the design loads given in J500. Finite element analysis shall 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.

$$\sigma_{st} = C_1 \frac{M_{BL}}{100 * ct^2} \quad [\text{MPa}] \qquad (25)$$

where the 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.

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

For relative radius r/R < 0.5

F is the maximum of F_b and F_f, whichever is greater.

1002 *Acceptability criterion – maximum load (static)*

The following criterion for calculated blade stresses has to be fulfilled.

$$\frac{\sigma_{ref2}}{\sigma_{st}} \geq 1.5 \qquad (26)$$

Where σ_{st} is the calculated stress for the design load. If FE analysis is used in estimating the stresses, von Mises stresses shall be used.

$\sigma_{ref\,2}$ is the reference stress, defined as:

$\sigma_{ref\,2} = 0.7 \cdot \sigma_u$

or

$\sigma_{ref\,2} = 0.6 \cdot \sigma_{0.2} + 0.4 \, \sigma_u$

whichever is less.

1003 *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 normalised for 100 million cycles.

If the following criterion is fulfilled fatigue calculations according to this Section are not required.

$$\sigma_{\exp} \geq B1 * \sigma_{ref\,2}{}^{B2} * \log(N_{ice})^{B3} \qquad (27)$$

where B1, B2 and B3 coefficients for open and nozzle propellers are given in the table J15 below.

Table J15 B coefficients		
Coefficient	*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 SN curves are available.

1) Two slope SN curve (slopes 4.5 and 10), see Fig.8.

2) One slope SN curve (the slope can be chosen), see Fig.9.

The type of the SN-curve shall be selected to correspond to the material properties of the blade. If SN-curve is not known the two slope SN curve shall be used.
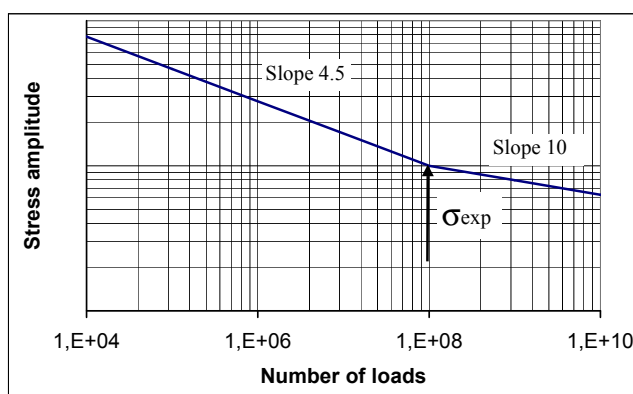
Fig. 8
Two-slope S-N curve
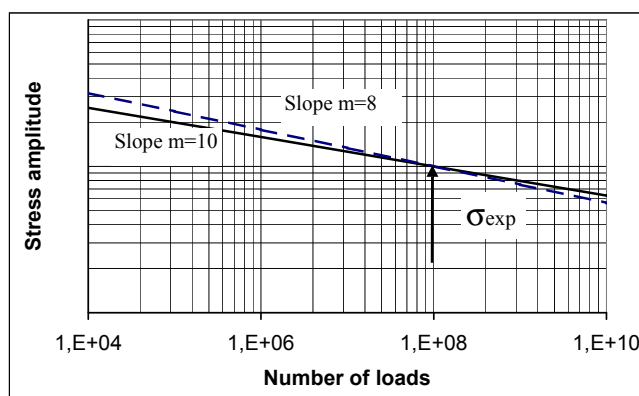
Fig. 9
Constant-slope S-N curve

1004 *Equivalent fatigue stress*

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

$$\sigma_{fat} = \rho \cdot (\sigma_{ice})_{max} \qquad (28)$$

where

$$(\sigma_{ice})_{max} = 0.5 \cdot \left((\sigma_{ice})_{f\,max} - (\sigma_{ice})_{b\,max} \right)$$

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

$(\sigma_{ice})_{f\,max} =$ the principal stress resulting from forward load

$(\sigma_{ice})_{b\,max} =$ the principal stress resulting from backward load.

In calculation of $(\sigma_{ice})_{max}$, load case 1 and load case 3 (or case 2 and case 4) are considered as a pair for $(\sigma_{ice})_{f\,max}$, and $(\sigma_{ice})_{b\,max}$ calculations. Load case 5 is excluded from the fatigue analysis.

1005 *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 formulae:

$$\rho = C_1 \cdot \left(\sigma_{ice}\right)_{max}{}^{C_2} \cdot \sigma_{fl}{}^{C_3} \cdot \log(N_{ice})^{C_4} \qquad (29)$$

where

$$\sigma_{fl} = \gamma_\varepsilon \cdot \gamma_v \cdot \gamma_m \cdot \sigma_{exp}$$

γ_ε = the reduction factor for scatter and test specimen size effect

γ_v = the reduction factor for variable amplitude loading

γ_m = the reduction factor for mean stress

$\sigma_{exp} =$ the mean fatigue strength of the blade material at 10^8 cycles to failure in seawater.

The following values should 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 Table J16

Table J16 C coefficients		
Coefficient	*Open propeller*	*Nozzle 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

1006 *Calculation of ρ parameter for constant-slope S-N curve*

For materials with a constant-slope S-N curve, see Fig.9 The ρ-factor shall be calculated with the following formula:

$$\rho = \left(G \frac{N_{ice}}{N_R} \right)^{1/m} (\ln(N_{ice}))^{-1/k} \qquad (30)$$

where k is the shape parameter of the Weibull distribution,
k = 1.0 for ducted propellers and k = 0.75 for open propellers.

N_R is the reference number of load cycles (=100 million).

Values for the G parameter are given in Table J17. Linear interpolation may be used to calculate the G value for other m/k ratios than given in the Table J17.

Table J17 Value for the G parameter for different m/k ratios					
m/k	*G*	*m/k*	*G*	*m/k*	*G*
3	6	*5.5*	287.9	*8*	40 320
3.5	11.6	*6*	720	*8.5*	119 292
4	24	*6.5*	1871	*9*	362 880
4.5	52.3	*7*	5040	*9.5*	$1.133 \cdot 10^6$
5	120	*7.5*	14034	*10*	$3.623 \cdot 10^6$

1007 *Acceptability criterion for fatigue*

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

$$\frac{\sigma_{fl}}{\sigma_{fat}} \geq 1.5 \qquad (31)$$

where

$$\sigma_{fl} = \gamma_\varepsilon \cdot \gamma_v \cdot \gamma_m \cdot \sigma_{exp}$$

γ_ε = the reduction factor for scatter and test specimen size effect

γ_v = the reduction factor for variable amplitude loading

γ_m = the reduction factor for mean stress

σ_{exp} = the mean fatigue strength of the blade material at 10^8 cycles to failure in seawater.

The following values should be used for the reduction factors if actual values are not available: γ_ε = 0.67, γ_v = 0.75, and γ_m = 0.75.

J 1100 Propeller bossing and CP mechanism

1101 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 J500. 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 J800 shall be greater than 1.0 against yielding.

J 1200 Propulsion shaft line

1201 The shafts and shafting components, such as the thrust and stern tube bearings, couplings, flanges and sealing, shall be designed to withstand the propeller/ice interaction loads as given in J500 - J700. The safety factor is to be at least 1.3.

1202 The design torque Q_r determined according to J700 shall be applied for low cycle and high cycle strength analysis respectively.

1203 *Shafts and shafting components*

The ultimate load resulting from total blade failure as defined in J800 should not 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.

Forward of the after peak bulkhead, the shaft may be evenly tapered down to 1.05 times the rule diameter of intermediate shaft, but not less than the actual diameter of the intermediate shaft.

J 1300 Design of shaft line components not specifically mentioned in FSICR

1301 Below criteria are given for application of Pt.4 Ch.4 for determination of scantlings for intermediate shafts, couplings, reduction gears and crank shafts.

Application factor K_{Aice} = Q_r/Q_n for low cycle criteria and/or static load criteria (ref. 1303). For components where fatigue is dimensioning, e.g. shaft and reduction gear, cumulative fatigue analysis are required. The actual Q_r/Q_n ratios shall be determined as given in 704.

1302 The diameter of intermediate shafts shall be determined based on methods given in Pt.4 Ch.4 Sec.1 B201.

a) When using the classification note 41.4 the necessary reinforcement is determined by using Q_r/Q_n in the given criteria.

b) With $Q_r/Q_n \leq 1.4$ the method in Pt.4 Ch.4 Sec.1 B206 may be used, i.e. no ice reinforcement beyond 1A1 rules.

When using the method in Pt.4 Ch.4 Sec.1 B208, the minimum diameter in item 3 of that paragraph shall be multiplied with:

$(Q_r/1.4 Q_n)^{1/3}$, where Q_r is relevant maximum value, but not less than 1.0.

In item 4 of same paragraph, the vibratory torsional stress τ_v is replaced by:

τ_v = 0.5 $(Q_r/Q_n - 1) T_o$

and shall not exceed τ_C.

1303 Regarding shaft connections, use Q_r/Q_n in Pt.4 Ch.4 Sec.1 as follows:

— flange connections, see B300
— shrink fit connections, see B400
— keyed connections, see B500.

Connections transmitting ice axial load determined in J800 from the propeller to the thrust bearing shall be capable of transmitting relevant loads without consequential damage.

1304 For reduction gears, use Q_r/Q_n in Pt.4 Ch.4 Sec.2.

1305 For clutches, use Q_r/Q_n in Pt.4 Ch.4 Sec.3 B100

1306 For torsional elastic coupling, use Q_r/Q_n in Pt.4 Ch.4 Sec.5 B200.

1307 For crank shafts in direct coupled diesel engines, see Pt.4 Ch.3 Sec.1 B506.

J 1400 Azimuting main propulsors and other thrusters

1401 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.

1402 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 the "Design ice conditions" section, 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 the "Design ice conditions" section.

1403 *Tunnel thrusters*

Ice strengthening of tunnel thrusters is not required.

1404 *Other thrusters*

Thrusters other than propulsion thrusters and tunnel thrusters need only comply with the relevant requirements in J if they shall be used in ice conditions or for any reason be exposed to ice loads.

For thrusters that are not intended for use in ice conditions, this will be stated in the class certificate and on signboards fitted at all relevant manoeuvring stands.

1405 The relevant structure parts of non-retractable thrusters shall be strengthened with respect to ice loads, independent of whether they are used in ice conditions or not.

J 1500 Alternative design

1501 *Scope*

As an alternative to J300 - J1400, 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 A200. It has to include both fatigue and maximum load design calculations and fulfil the pyramid strength principle, as given in J900.

1502 *Loading*

Loads on the propeller blade and propulsion system shall be based on an acceptable estimation of hydrodynamic and ice loads.

1503 *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.

K. Miscellaneous Machinery Requirements

K 100 Starting arrangements

101 The capacity of the air receivers shall be according to the requirements in Pt.4 Ch.6 Sec.5 I.

If the air receivers serve any other purposes than starting the propulsion engine, they shall have additional capacity sufficient for these purposes.

The capacity of the air compressors shall be sufficient for charging the air receivers from atmospheric to full pressure in one (1) hour, except for a ship with the ice class **ICE-1A*** if its propulsion engine has to be reversed for going astern, in which case the compressors shall be able to charge the receivers in half an hour.

K 200   Sea inlet and cooling water systems

201   The cooling water system shall be designed to ensure supply of cooling water when navigating in ice. The sea cooling water inlet and discharge for main and auxiliary engines shall be so arranged that blockage of strums and strainers is prevented.

For this purpose at least one cooling water inlet chest shall be arranged as follows:

1)   The sea inlet shall be situated near the centre line of the ship and well aft if possible. The inlet grids shall be specially strengthened.

2)   As a guidance for design the volume of the chest shall be about one cubic metre for every 750 kW engine output of the ship including the output of the auxiliary engines necessary for the ship's service.

3)   To allow for ice accumulation above the pump suction the height of the sea chest shall not be less than:

$$h_{min} \geq 1.5 \ \sqrt[3]{V_s}$$

V_s = volume of sea chest according to item 2.
The suction pipe inlet shall be located not higher than h_{min}/3 from top of sea chest.

4)   A pipe for discharge cooling water, allowing full capacity discharge, shall be connected to the chest. Where the sea chest volume and height specified in 2 and 3 are not complied with, the discharge shall be connected to both sea chests. At least one of the fire pumps shall be connected to this sea chest or to another sea chest with de-icing arrangements.

5)   The area of the strum holes shall be not less than four (4) times the inlet pipe sectional area.

If there are difficulties in meeting the requirements of 2) and 3) above, two smaller chests may be arranged for alternating intake and discharge of cooling water. The arrangement and situation otherwise shall be as above.

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

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

K 300   Ballast system

301   An arrangement to prevent freezing of the ballast water shall be provided for in ballast tanks located fully or partly above the LIWL, adjacent to the ship's shell, and needed to be filled for operation in ice conditions according to A302. For this purpose the following ambient temperatures shall be taken as design conditions:

— sea water temperature: 0°C
— air temperature: –10°C.

Necessary calculations shall be submitted.

302   When a tank is situated partly above the LIWL, an air-bubbling arrangement or a vertical heating coil, capable of maintaining an open hole in the ice layer, will normally be accepted.

The required heat-balance calculations may then be omitted.

> **Guidance note:**
> It is assumed that, before pumping of ballast water is commenced, proper functioning of level gauging arrangements is verified and air pipes are checked for possible blockage by ice.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

L. Guidelines for Strength Analysis of the Propeller Blade using Finite Element Method

See Appendix A for guidelines on strength analysis of the propeller blade using finite element method.

SECTION 4
VESSELS FOR ARCTIC AND ICE BREAKING SERVICE

A. General

A 100 Classification

101 The requirements in this section apply to icebreakers and to passenger and cargo vessels intended to operate unassisted in ice-infested waters of sub-Arctic, Arctic and/or Antarctic regions.

102 Vessels intended for ice breaking as their main purpose and built in compliance with the following requirements may be given one of the class notations **ICE-05** (or **-10** or **-15**) Icebreaker or **POLAR-10** (or **-20** or **-30**) Icebreaker, whichever is relevant.

Vessels built for another main purpose, while also intended for ice breaking, may be given the additional class notation **ICE-05** (or **-10** or **-15**) or the notation **POLAR-10** (or **-20** or **-30**).

103 Arctic class vessels intended for special services where intermediate ice condition values are relevant may, upon special consideration, be given intermediate notations (e.g. **POLAR-25**).

104 For **POLAR** class vessels the design ambient air temperature on which the classification has been based will be given the special feature notation **DAT(-X°C)**. For details, see Sec.7.

105 For vessels with the class notation **Icebreaker**, and for other **POLAR** class vessels the maximum operational speed on which the ramming design requirements have been based will be stated in the "Appendix to the classification certificate". The operational speed is in no case to be taken as smaller than stated in 300 for the various class notations.

A 200 Scope

201 The following matters are covered by the classification:

— materials in structures exposed to low ambient air temperatures
— subdivision, intact and damage stability
— hull girder longitudinal and transverse strength
— local hull structures exposed to ice loads
— rudders and steering gears
— propellers and propulsion machinery
— sea suctions for cooling water
— air starting systems.

MDHT	Mean Daily High (or maximum) Temperature
MDAT	Mean Daily Average Temperature
MDLT	Mean Daily Low (or minimum) Temperature
MAMDHT	Monthly Average of MDHT
MAMDAT	Monthly Average of MDAT
MAMDLT	Monthly Average of MDLT
MEHT	Monthly Extreme High Temperature (ever recorded)
MELT	Monthly Extreme Low Temperature (ever recorded).

Mean: Statistical mean over observation period (at least 20 years).

Average: Average during one day and night.

A 300 Design principles and assumptions

301 Each class notation is related to a particular ice condition that the vessel is expected to encounter. Relevant design ice conditions are as given in Table A1. In case intermediate ice conditions are relevant (see 103), nominal ice strength shall be related to the selected nominal ice thickness.

302 Vessels with the class notation **Icebreaker**, and other **POLAR** class vessels are expected to encounter pressure ridges and other ice features of significantly greater thickness than the average thicknesses specified in Table A1. Vessels with the class notation **POLAR** only are assumed not to make repeated ramming attempts if the ice fails to break during the first (occasional) ram unless the vessel's speed is kept well below the design ramming speed. Vessels with class notation **Icebreaker** may make several consecutive attempts to break the ice at maximum ramming speed. The design speed in ice infested waters when ramming may occur, V_{RAM}, shall be specified by the builder. In general this speed shall not be taken less than:

$$V_{RAM} = V_B + V_H \quad (m/s)$$

V_B = specified continuous speed, when breaking maximum average ice thickness
V_H = speed addition in thinner ice
    = h_{ice} (see Table A1).

In no case the design ramming speed shall be taken less than:

V_{RAM} (minimum)

    = 2.0 m/s (3.9 knots) for the notation **POLAR-10**
    = 3.0 m/s (5.8 knots) for the notation **POLAR-20**
    = 4.0 m/s (7.8 knots) for the notation **POLAR-30**.

For vessels with the class notation **Icebreaker** the minimum speed is 2 m/s (3.9 knots) but not less than 1.5 times the speed specified above when **POLAR** class notation is also specified.

A 400 Definitions

401 General symbols and terms are also given in Sec.1 B100.

402 *Symbols*

V_{RAM} = design speed in m/s when ramming may occur, see also 302
σ_{ice} = nominal strength of ice in N/mm^2, see Table A1
h_{ice} = average ice thickness in m, see Table A1
E_{KE} = vessel's kinetic energy before ramming
    = $1/2 \, \Delta \, (V_{RAM})^2$ (kNm)
α, γ = bow shape angles, see Fig.1
C_{WL} = vessel's water line area coefficient on UIWL
s = stiffener spacing in m, measured along the plating. Stiffener web thickness may be deducted
l = effective span of stiffener in m as defined in Pt.3 Ch.1 Sec.3 C100
S = girder span in m. The web height of in-plane girders may be deducted
t = rule thickness of plating in mm
t_k = corrosion addition in mm
t_w = rule web thickness in mm
Z = rule section modulus in cm^3
A_W = rule web area in cm^2, defined as the web thickness times the web height including thickness of flanges
A = rule cross-sectional area in cm^2

Table A1 Ice conditions				
Class notation	*Type of ice encountered*	*Nominal ice strength σ_{ice} (N/mm^2)*	*Nominal ice thickness h_{ice} (m)*	*Limiting impact conditions*
ICE-05 **ICE-10** **ICE-15**	Winter ice with pressure ridges	4.2 5.6 7.0	0.5 1.0 1.5	No ramming anticipated
POLAR-10 **POLAR-20** **POLAR-30**	Winter ice with pressure ridges and multi-year ice-floes and glacial ice inclusions	7.0 8.5 10.0	1.0 2.0 3.0	Occasional ramming
Icebreaker	As above	As above	As above	Repeated ramming
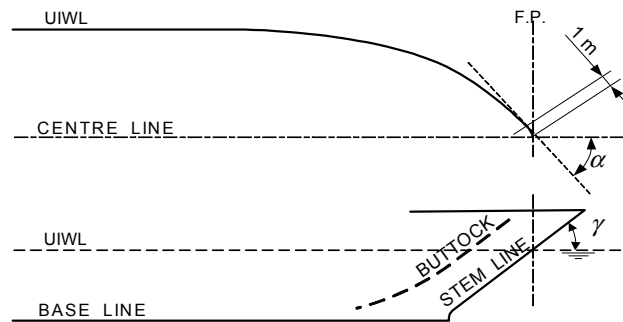
Fig. 1
Bow shape angles

403 The hull structure (shell plating with stiffening) to be reinforced against local ice loads is divided into 7 different areas. The areas are defined as follows (see also Fig.3):

Bow area

Longitudinally from stem to a line parallel to and 0.04 L aft of the border line of flat side of hull forward. If the hull breadth is increased over a limited length forward of the flat side the bow area need normally not extend aftwards beyond the widest section of each waterline.

The bow area need not extend aftwards beyond 0.3 L from the forward perpendicular.

Vertically from a line defined by the distance z_{lm} below LIWL (aft) and the intersection between the keel line and the stem line (forward) to a line defined by the distances z_{ua} (aft) and z_{uf} (forward) above UIWL. For ships with an ice knife fitted, the line of the lower vertical extension may be drawn to a point 0.04 L aft of the upper end of the knife and further down to the base line (see also Fig.3).

Stem area

The part of the bow area between the stem line and a line 0.06 L aft of the stem line or 0.125 B outboard from the centre line, whichever is first reached.

Vertically from a line defined by the distance z_{la} below LIWL, to a line defined by the distance z_{ua} above UIWL.

Stern area

Longitudinally from the stern to a line parallel to and 0.04 L forward of the border line of flat side of hull aft, or to a line 0.2 L aft of amidships, whichever is the aftermost.

Vertically from a line defined by the distance z_{la} below LIWL, to a line defined by a distance z_{ua} above UIWL.

Midship area

Longitudinally from the stern area to the bow area.

Vertically from a line defined by the distance z_{lm} below LIWL, to a line defined by a distance z_{ua} above UIWL.

Bottom area

Longitudinally aft of 0.3 L from forward perpendicular and transversely over the flat bottom including deadrise. For ships with bow ice knife, the bottom area may be extended forward to the ice knife.

Lower transition area

Transition area between the bottom area and the adjacent stern, and midship areas respectively.

Lower bow area

The area below the bow area.

UIWL and LIWL are defined in Sec.1 B200.

Values of z_{la}, z_{lm}, z_{ua}, and z_{uf} are given for various class notations in Table A2.

Table A2 Vertical extent of ice reinforced areas				
Class notation	*Parameters for vertical extent (m)*			
	z_{la}	z_{lm}[1]	z_{ua}	z_{uf}
ICE-05	1.7	1.1	0.8	1.5
ICE-10	2.2	1.6	1.0	2.0
ICE-15	4.6	3.7	1.9	2.5
POLAR-10	2.9	2.3	1.4	2.2
POLAR-20	6.0	4.6	2.8	3.7
POLAR-30	11.9	9.2	4.2	5.2
[1] z_{lm} (maximum) =	the vertical distance from the LIWL to the point on the frame contour amidships where the tangent is at 45 degrees.			

A 500 Documentation

501 UIWL and LIWL as well as the border line of flat side shall be indicated on the shell expansion plan together with the ice reinforced areas as given in Fig.3.

502 Maximum design ramming speed (V_{RAM}) in ice infested waters as well as design speed for continuous ice breaking operations (V_B) shall be stated on the midship section plan for ships with class notations **POLAR** or **Icebreaker**.

503 For documentation in connection with stability and watertight integrity, see L300.

504 Applicable design specifications for the operation of the vessel in ice infested waters shall be stated in the ship's loading manual, see Pt.3 Ch.1 Sec.5 F and Pt.3 Ch.2 Sec.4 E.

Possible design specifications are:

— allowable draughts, maximum and minimum
— loading conditions with respect to strength and stability
— ambient temperature
— design speed
— ramming speed
— instruction for filling of ballast tanks
— astern operation in ice.

505 Where ice exposed plating is fitted with a special wear addition, the plate thickness including wear addition shall be given on the shell expansion plan in addition to the net thickness required by the rules.
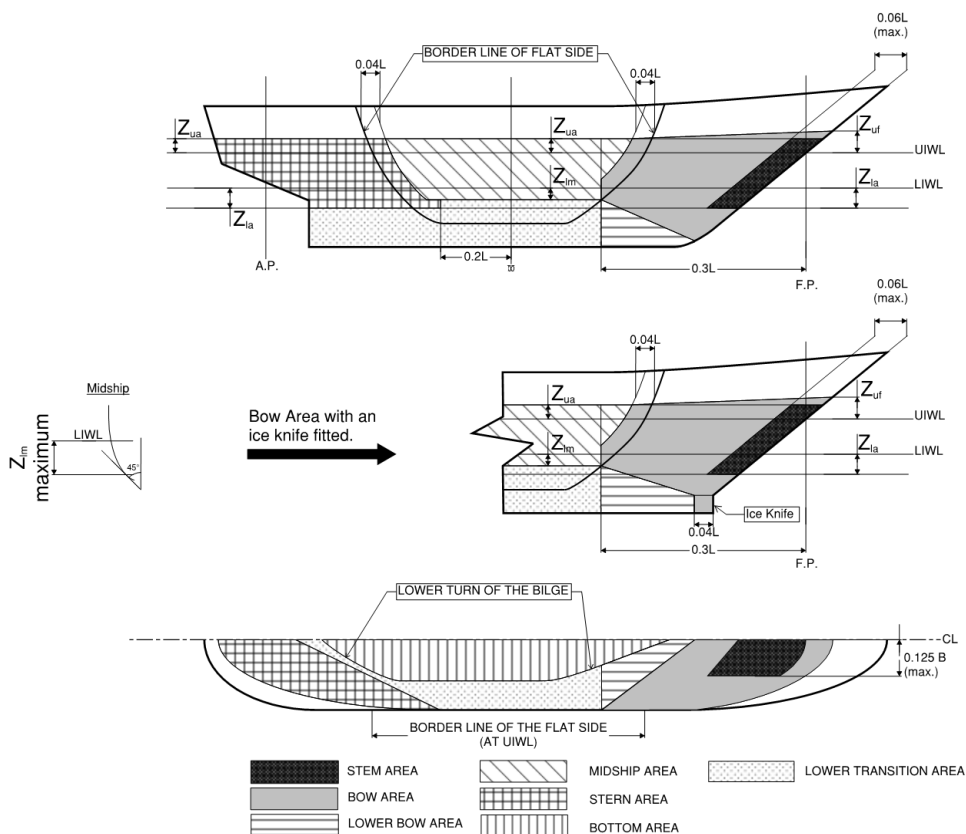
**Fig. 2
Ice reinforced areas**

506 Documentation requirements for stability and watertight integrity can be found in L200.

B. Materials and Corrosion Protection

B 100 Design temperatures

101 Steel grades to be used in hull structural members shall be determined based on the design temperature for the structure in question with requirements as given in Sec.7.

102 For **POLAR** class notations steel grades in exposed structures (external structure as defined in Sec.7) shall be based on air temperatures lower than those generally anticipated for world wide operation. Unless a service restriction notation is also given, limiting the navigation to specified areas and/or time of year, the design temperature shall not be taken higher than -30°C (corresponding extreme low temperature -50°C).

For operation in lower design temperatures, this must be clearly specified.

103 For **ICE** class notations no special consideration for low ambient air temperatures are given unless specified by the builder.

B 200 Selection of steel grades

201 Plating materials for various structural categories of exposed members above the ballast waterline of vessels with class notation **POLAR** shall not be of lower grades than obtained from Sec.7 using design temperatures as defined in 100.

Plating materials of non-exposed members and of vessels with class notation **ICE** shall not be of lower grade than obtained according to Pt.3 Ch.1 Sec.2 Table B1 and Pt.3 Ch.2 Sec.2 Table B1.

Cranes shall be in compliance with DNV Standard for Certification No. 2.22 "Lifting Appliances".

B 300 Coatings

301 Wear resistant coating is assumed used for the external surfaces of plating in ice reinforced areas.

B 400 Corrosion additions

401 Hull structures are in general to be given a corrosion addition t_k as required by the main class, see Pt.3 Ch.1 Sec.2 and or Pt.3 Ch.2 Sec.2.

C. Ship Design and Arrangement

C 100 Hull form

101 The bow shall be shaped so that it can break level ice effectively and at continuous speed, up to a thickness as indicated in Table A1 for the various class notations.

102 Vessels with class notation **Icebreaker**, and other **POLAR** class vessels shall have a bow shape so that the bow will ride up on the ice when encountering pressure ridges or similar ice features that will not break on the first ramming.

103 Masts, rigging, superstructures, deckhouses and other items on deck shall be designed and arranged so that excessive accumulation of ice is avoided. The rigging shall be kept at a minimum, and the surfaces of erections on deck shall be as even as possible.

104 Weathertight doors and hatches shall be suitably designed for use in low temperature environment with respect to:

— strength of cleats and the choice of steel with adequate ductility
— flexibility of packing material
— ease of maintenance, e.g. interior accessible grease fittings
— ease of operations, e.g. low weight and preference to central handwheel operated cleats.

105 Air pipe closures shall be designed so that icing or freezing will not make them inoperable.

106 Freeing ports shall be designed so that blocking by ice is avoided as far as possible and so that they are easily accessible for removal of ice should blocking occur.

C 200 Appendages

201 In vessels with class notation **Icebreaker** and in other **POLAR** class vessels an ice knife may be required forward to avoid excessive beaching and submersion of the deck aft. This requirement will be based

on consideration of design speed and freeboard, and may result in additional requirements regarding accelerations and strength.

202 Ice horns shall be fitted directly abaft each rudder in such a manner that:

— the upper edge of the rudder is protected within two degrees to each side of midposition when going astern, and
— ice is prevented from wedging between the top of the rudder and the vessel's hull.

C 300 Mooring equipment

301 The housing arrangement for anchors shall be designed so that possible icing will not prevent the anchor from falling when released.

D. Design Loads

D 100 Ice impact forces on the bow

101 The vertical design force component due to head on ramming (not applicable to vessels with class notation **ICE** only) is given by:

$$P_{ZR} = P_R\, F_{EL} \quad (kN)$$

$$P_R = 28\left(\frac{C_R E_{IMP}}{\tan\gamma}\right)^{0.6} (\sigma_{ice}\tan\alpha)^{0.4} \quad \text{in general}$$

For spoon bows: $\tan\alpha = 1.2\dfrac{B^{0.1}}{\sqrt{\cos\gamma}}$

$$E_{IMP} = E_{KE}\frac{\tan^2\gamma}{\tan^2\gamma + 2.5}$$

$$F_{EL} = \sqrt{\frac{E_{IMP}}{E_{IMP} + C_L P_R^{\,2}}}$$

$$C_L = \frac{L^3}{3\times 10^{10} I_V}$$

C_R = 1 for the class notation **POLAR** only
= 2 for the class notation **Icebreaker**

$E_{KE,}$ $\sigma_{ice,}$ α and γ as defined in A400.
L as defined in Sec.1 B100.

I_V = moment of inertia in m^4 about the horizontal neutral axis of the midship section.

102 The total design force normal to the shell plating in the bow area due to an oblique impact with an ice feature is given by:

$$P_{OI} = \frac{P_{ZR} F_{SIDE}}{\cos\gamma} \quad (kN)$$

$$F_{SIDE} = \frac{1.9}{(\tan\alpha)^{0.4}}\left(\frac{\sigma_{ice}}{E_{KE}}\right)^{0.05} \quad \text{in general}$$

$\tan\alpha = 1.2\dfrac{B^{0.1}}{\sqrt{\cos\gamma}}$ for spoon shaped bows

P_{ZR} = vertical ramming load as given in 101

L and B as defined in Sec.1 B100.

$E_{KE,}$ $\sigma_{ice,}$ α and γ as defined in A400.

D 200 Beaching forces

201 The vertical design force resulting from beaching on a large ice feature (not applicable to vessels with class notation **ICE** only) is in general given by:

$$P_{ZB} = G_B \sqrt{k_b E_{KE} LB} \quad (kN)$$

$$G_B = \sqrt{\frac{C_{WL}(C_{WL} - 0.5)}{(C_{WL} + 1)}}$$

$k_b = 2 g_o (1 - r_{fw})$
r_{fw} = reduction factor due to energy lost in friction and waves
$\quad$ = 0.3.

E_{KE}, σ_{ice}, C_{WL}, γ and α as defined in A400.

L, B and g_o as defined in Sec.1 B100.

202 For vessels with ice knife as shown in Fig. 3 the vertical design force in beaching need not be taken larger than:

$$P_{ZB} = \frac{10.6 C_{WL} BLX \tan \gamma}{1 + 15[0.55 - (X/L)]^2} \quad (kN)$$

X $\quad$ = horizontal distance from FP_{ICE} to centre of vertical ram bow in m
FP_{ICE} = intersection point of stem line and deepest icebreaking waterline
C_{WL} $\quad$ = waterline area coefficient.
L and B as defined in Sec.1 B100.

D 300 Ice compression loads amidships

301 All vessels shall withstand line loads acting simultaneously in the horizontal plane at the water level on both sides of the hull. These loads are assumed to arise when a vessel is trapped between moving ice floes.

302 The design line loads shall be taken as:

$$q = \frac{165}{\sin \beta_f} (h_{ice})^{1.5} \quad [kN/m]$$

$$= 950 \cdot (h_{ice})^{1.5} \quad [kN/m] \text{ for vertical side shells} (\beta_f < 10°)$$

h_{ice} = average ice thickness as defined in A400

β_f = angle of outboard flare at the waterlevel. The outboard flare angle shall not be taken as less than 10 degrees.

D 400 Local ice pressure

401 All vessels shall withstand local ice pressure as defined for the different ice class notations and as applied to the different ice reinforced areas. The design pressure shall be applied over a corresponding contact area reflecting the type of load in question.

402 The basic ice pressure is in general to be taken as:

$$p_o = 1\ 000\ F_A\ \sigma_{ice} \quad (kN/m^2)$$

F_A = correction factor for ice reinforced area in question
$\quad$ = 1.0 for bow and stem area in general.
$\quad$ = 0.6 for midship area in general
$\quad$ = 0.5 for midship area if ship breadth in bow area larger than ship breadth in midship area
$\quad$ = 0.20 for bottom area of vessels with notation **Icebreaker** or **POLAR**
$\quad$ = 0.10 for bottom area of vessels with notation **ICE** only
$\quad$ = 0.6 for stern area in general
$\quad$ = 0.8 for stern area in ships with class notation **Icebreaker**
$\quad$ = 1.0 for the stern area in ships with class notation **Icebreaker** or **POLAR**, and 0.8 for ships with **ICE** notations, fitted with pod or thruster propulsion units, and designed for continuous operation astern. The stern area structure shall in general be dimensioned as outlined for bow structure. See also G700.

For the transition areas and Lower Bow area, 2/3 of the F_A-value for the adjacent area above may be used in general.

σ_{ice} as defined in A400.

403 The design pressure is in general to be taken as:

$$p = F_B \, p_o \quad (kN/m^2)$$

F_B = correction factor for size of design contact area A_C

= $\dfrac{0.58}{(A_C)^{0.5}}$ for $A_C \leq 1.0 \text{ m}^2$

= $\dfrac{0.58}{(A_C)^{0.15}}$ for $A_C > 1.0 \text{ m}^2$

A_C = $h_o \, w \quad (m^2)$
h_o = h in general
= s, maximum for longitudinals
= l, maximum for non-longitudinal frames
= 1.4 l, maximum for connection area of non-longitudinal frames
= S, maximum for girders supporting longitudinals
= l, maximum for stringers supporting non-longitudinal frames
h = effective height of contact area in m
= 0.4 h_{ice} (m) in general
= 0.64 h_{ice} (m) in the stern area; for vessels fitted with pod or thruster propulsion units, and designed for continuous operation astern
= 0.8 h_{ice} (m) in stem area in general

= $\left(\dfrac{P}{645\,\sigma_{ice}}\right)^{0.6}\left(\dfrac{\tan^2\gamma + \tan^2\alpha}{\tan\alpha}\right)^{0.5}$

    in stem area for vessels with class notation **POLAR** or **Icebreaker**
= 0.8 h_{stem} (m) in bow area outside stem area
h_{stem} = h as given for stem area.

For spoon bows: $\tan\alpha = 1.2\dfrac{B^{0.1}}{\sqrt{\cos\gamma}}$

P = the largest of P_{ZR} and P_{ZB} as given in D100 and D200.
w = critical width of contact area in m
= l for longitudinals
= s for non-longitudinal frames
= 1.4 l for connection area for longitudinals
= l for vertical girders supporting longitudinal main frames
= S for stringers supporting vertical main frames.

l, S, α and γ as defined in A400.

The relations are illustrated in Fig.4.
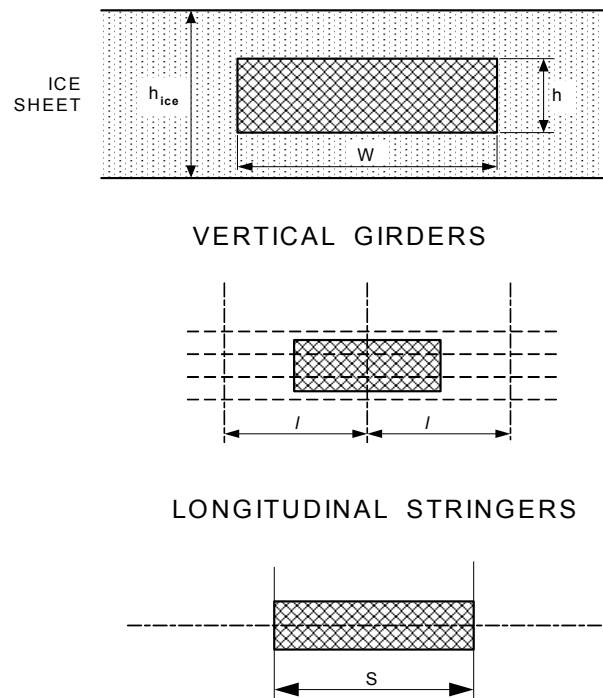
Fig. 3
Design contact areas

D 500 Accelerations

501 Substructures, equipment and supporting structures shall withstand accelerations arising as a result of impacts with ice features.

502 The combined vertical acceleration at any point along the hull girder (not applicable to vessels with class notation **ICE** only) may be taken as:

$$a_v = \frac{2.5 P_{ZR}}{\Delta} F_X \quad (m/s^2)$$

F_X = 1.3 at F.P.
= 0.1 at midships
= 0.4 at A.P.

Linear interpolation shall be applied between specified positions.

P_{ZR} as derived in 100.

Δ as defined in Sec.1 B100.

a_v does not include the acceleration of gravity.

503 The combined transverse acceleration at any point along the hull girder may be taken as:

$$a_t = \frac{3 P_{OI}}{\Delta} F_X \quad (m/s^2)$$

F_X = 1.5 at F.P.
= 0.25 at midships
= 0.5 at A.P.

Linear interpolation shall be applied between specified positions.

P_{OI} as derived in 100.

Δ as defined in Sec.1 B100.

504 The maximum longitudinal acceleration is taken to be the same at any point along the hull girder.

$$a_l = \frac{1.1 P_{ZR} \tan(\gamma + \phi)}{\Delta} + \frac{7 P_{ZR} H}{\Delta L} \quad (m/s^2)$$

φ = maximum friction angle (between steel and ice), normally taken as 10°

H = distance in m from lowest waterline to position considered.

P_{ZR} as derived in 100.

Δ as defined in Sec.1 B100.

γ as defined in A400.

E. Global Strength

E 100 General

101 Hull girder shear forces and bending moments as stipulated in this subsection shall be combined with relevant stillwater conditions as stipulated for the main class. Wave load conditions as stipulated for the main class need not be regarded as occurring simultaneously with the shear forces and bending moments resulting from ramming and beaching.

102 The shear forces and bending moments shall be regarded as the design values at probability level equivalent to the maximum load in a service life of 20 years.

103 In addition to the maximum stress requirements given in this subsection, individual elements shall be checked with respect to buckling under the ramming and beaching load conditions, according to accept criteria as stipulated for the main class.

E 200 Longitudinal strength

201 The following requirements are applicable to vessels with class notation **Icebreaker** and other **POLAR** class vessels (i.e. not to vessels with class notation **ICE** only).

202 The design vertical shear force at any position of the hull girder due to ramming and/or beaching is given by:

$$Q_{ICE} = k_{iq} P \quad (kN)$$

k_{iq} = 0.4 at F.P.
= 1.0 between 0.05 L and 0.1 L from F.P.
= 0.4 between 0.7 L and 0.2 L from A.P.
= 0.0 at A.P.

Between specified positions k_{iq} shall be varied linearly. Values of k_{iq} may also be obtained from Fig.5.

P = P_{ZR} as given in D100 or
= P_{ZB} as given in D200, whichever is the greater.

The thickness requirements for side shell and possible longitudinal bulkhead platings shall be calculated for different cargo and ballast conditions as stipulated in Pt.3 Ch.1 Sec.5 D replacing Q_W with Q_{ICE} as calculated above.
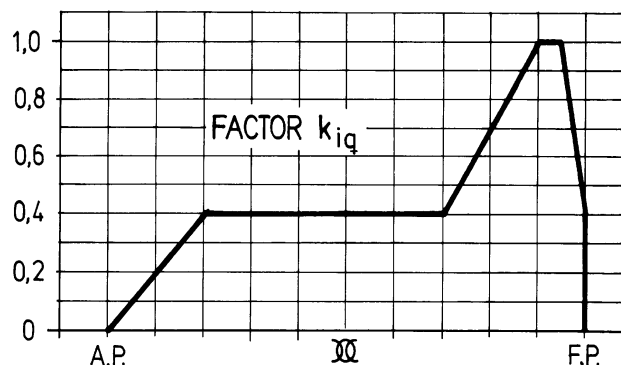
Fig. 4
Distribution of vertical shear force due to ramming and beaching
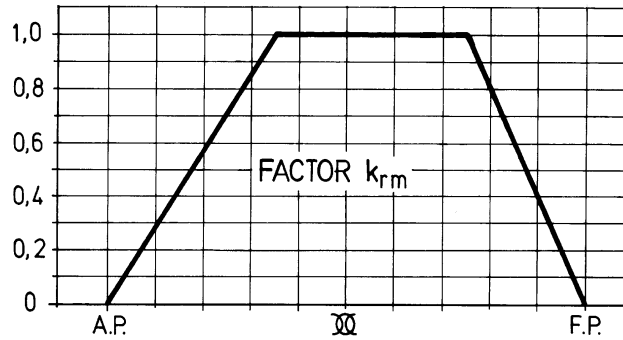
Fig. 5
Distribution of vertical bending moment due to ramming
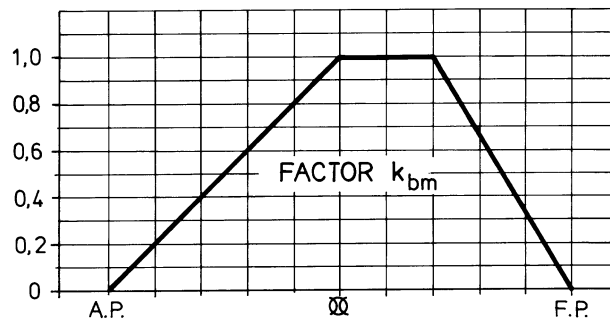
Fig. 6
Distribution of vertical bending moment due to beaching

203 The design vertical sagging bending moment at any position of the hull girder due to ramming and/or beaching is given by:

$$M_{ICE\ S} = 0.25\ k_{im}\ P\ L\quad(kNm)$$

k_{im} = 0.0 at F.P. and A.P.
  = 1.0 between 0.25 L from F.P. to 0.35 L from A.P. for ramming load condition
  = 1.0 between 0.3 L and 0.5 L from F.P. for beaching load condition.

Between specified positions k_{im} shall be varied linearly. Values of k_{im} may also be obtained from Fig.6 and Fig.7 for ramming and beaching load conditions respectively.

P = P_{ZR} or P_{ZB} as given in D100 or D200 for ramming and beaching load conditions respectively.
L as defined in Sec.1 B100.

204 The design vertical hogging bending moment at any position of the hull girder due to vibration following the initial ramming is given by:

$$M_{ICE\ H} = 0.6\ M_{ICE\ SR}\quad(kNm)$$

$M_{ICE\ SR}$ =as given in 203 for ramming load condition.

205 The section modulus requirement about the transverse neutral axis is given by:

$$Z = \frac{M_S + M_{ICE}}{0.7\sigma_f}10^3\quad(cm^3)$$

M_S = design stillwater bending moments according to Pt.3 Ch.1 Sec.5 B
M_{ICE} = design bending moment due to ramming and/or beaching, see 203 and 204.
The most unfavourable combinations of stillwater and ramming/beaching bending moments shall be applied.

206 The buckling strength of longitudinal strength members in bottom, side and deck as well as longitudinal bulkheads subject to compressive and/or shearing loads shall be checked according to Pt.3 Ch.1 Sec.13.

E 300   Transverse strength amidships

301   The line loads specified in D300 shall be applied at different water levels including UIWL and LIWL as found necessary depending on the structural arrangement of the vessel.

302   The line loads shall be applied over one full hold/tank length or as found necessary to assess the structural strength of transverse bulkheads and decks supporting the ice reinforced regions.

303   The calculations of transverse strength amidships shall be based on the most severe realistic combination of ice compression loads and static load conditions.

304   Recognised structural idealisation and calculation methods shall be applied. Effects to be considered are indicated in Pt.3 Ch.1 Sec.12 D200.

305   The calculated stresses shall not exceed allowable stresses as stipulated in Pt.3 Ch.1 Sec.12 B400.

E 400   Overall strength of substructure in the foreship

401   The total impact forces as stipulated in D100 may have a decisive effect on primary structural systems in the foreship. The loads are assumed to be evenly distributed in such a manner that local pressures will not exceed those stipulated for local members directly exposed to the load as given in D402.

402   The design ramming load (not applicable to vessels with class notation **ICE** only) taken as

$$P_{ZR}/\cos\gamma$$

shall be applied with its center on the stem line at the water line forward. The most unfavourable design draught forward shall be assumed with regard to positioning of the load.

403   The design bow side impact load taken as P_{OI} should be positioned at various positions within bow side area considered critical for the overall strength of the substructure.

Such parts of the bow side area which are aft of the border line of the flat side need normally not be considered with respect to P_{OI}.

404   Recognised structural idealisation and calculation methods shall be applied. Effects to be considered are indicated in Pt.3 Ch.1 Sec.12 D200.

405   The equivalent stress as defined in Pt.3 Ch.1 Sec.12 B400 shall not exceed σ_f. This is normally achieved for girder type members when the bending stress is not exceeding $0.9\sigma_f$ and the mean shear stress over a web cross-section is not exceeding $0.45\sigma_f$.

F. Local Strength

F 100   General

101   The requirements in this subsection apply to members that may be directly exposed to local ice pressure.

102   The buckling strength of web plates and face plates in girders and stringers subject to ice loads shall be checked according to methods given in Pt.3 Ch.1 Sec.13 or equivalent.

103   In curved regions of ice exposed plating, the stiffening is normally to be in the direction of the maximum curvature.

104   Framing in ice reinforced areas are in general to have symmetrical cross-section with the web to the extent possible positioned at right angle to the plane of the plate. The bending efficiency and tripping capacity of frames shall be documented by calculations according to recognised methods as considered necessary.

105   Ice exposed knuckles are in general to be supported by carlings or equivalent structures.

106   Plate fields adjacent to stem and possible knuckles in the forward shoulder shall be supported so as to be of square shape or otherwise locally strengthened to equivalent standard.

F 200   Plating

201   The thickness of plating exposed to patch load is generally not to be less than:

$$t = 23k_a \frac{s^{0.75}}{h_o^{0.25}} \sqrt{\frac{k_w p_o}{m_p \sigma_f}} + t_k \quad (\text{mm})$$

k_a = aspect ratio factor for plate field
    = $1.1 - 0.25\, s/l$, maximum 1.0, minimum 0.85

k_w = influence factor for narrow strip of load (perpendicular to s)

$$= 1.3 - \frac{4.2}{(a/s + 1.8)^2} \text{ , maximum } 1.0$$

m_p = bending moment factor
= f(b/s), see Table F1 (taking r as b/s)

a = s in general
= h_o for transversely stiffened panels

h_o = h, see D400
= s, whichever is the smaller

b = s in general
= h_o for longitudinally stiffened plating

p_o = basic ice pressure in kN/m^2 as calculated in D400

t_k = corrosion addition as given in B500.

s and *l* as defined in A400.

F 300 Longitudinal stiffeners

301 Stiffeners in the bow-, midship- and stern ice reinforced areas which are largely parallel to the waterline are defined as longitudinals.

302 The web sectional area of stiffeners in ice reinforced areas shall not be less than:

$$A_W = \frac{3.7(l - 0.5s)\, h_o^{1-\alpha} p_o}{\tau \sin\beta\, l^{\alpha}} + A_K \quad (cm^2)$$

and the web thickness shall not be less than:

$$t_w = 1.5 \left(\frac{p_o}{\sigma_f \sin\beta}\right)^{0.67} \left(\frac{h_w h_o}{t_s}\right)^{0.33} + t_k \quad (mm)$$

for flanged profiles.

Table F1 Parameters for local strength formulae (general application)		
r	m_p	m_e
0.05	27.4	132.3
0.10	14.25	67.9
0.15	9.87	46.5
0.20	7.69	35.8
0.25	6.40	29.5
0.30	5.57	25.3
0.35	4.95	22.3
0.40	4.50	20.2
0.45	4.09	18.5
0.50	3.77	17.2
0.60	3.31	15.4
0.70	3.02	14.1
0.80	2.83	13.4
0.90	2.72	13.0
1.00	2.68	12.9
For intermediate values of r the parameters may be obtained by linear interpolation.		

The section modulus shall not be less than:

$$Z = \frac{41 h_o^{1-\alpha}\, l^{2-\alpha} p_o w_k}{\sigma \sin\beta} \quad (cm^3)$$

The stiffener connection area a_o as defined in Pt.3 Ch.1 Sec.11 C400 shall not be less than:

h_o = h, see D400
= s, whichever is smaller

h_w = height of web in mm

$$a_0 = \frac{10cP}{\tau \sin\beta} = \frac{6.5\,c\,h_0^{1-\alpha}(l-0.5s)p_0}{\tau \sin\beta\,(1.4l)^{\alpha}} \quad (cm^2)$$

p_o = basic ice pressure in kN/m² as calculated in D400

τ = 0.45 σ_f

σ = 0.9 σ_f

t_s = shell plate thickness in mm.

s, l and σ_y as defined in A400.

A_K = $t_k\,h_w\,10^{-2}$ (cm²)

w_k = section modulus corrosion factor, see Pt.3 Ch.1 Sec.3 C1004

c = factor as given in Table C4 of Pt.3 Ch.1 Sec.11 C400.

α = 0.5 for $A_C \leq 1.0$

= 0.15 for $A_C > 1.0$

A_C = as defined in D403

β = angle of web with shell plating.

β = $\tan^{-1}\left(\dfrac{\tan\gamma}{\sin\theta}\right)$, γ and θ as shown on Fig.8
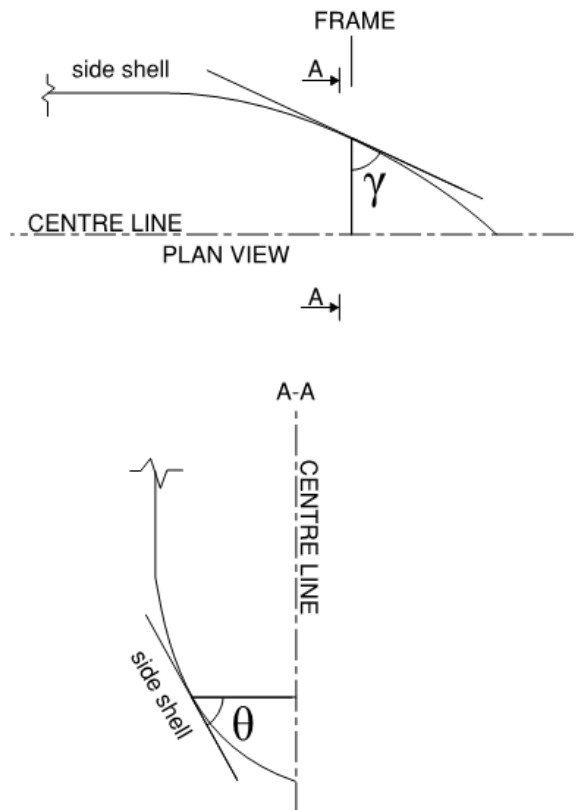
Fig. 7
Determination of β-angle

F 400 Other stiffeners

401 The web sectional area shall not be less than:

$$A_W = \frac{5.8k_s(h_o s)^{1-\alpha}(l-0.5s)p_o}{\tau\,l\sin\beta} + A_K \quad (cm^2)$$

and the web thickness shall not be less than:

$$t_w = 1.5\left(\frac{p_o}{\sigma_f \sin\beta}\right)^{0.67}\left(\frac{h_w s}{t_s}\right)^{0.33} + t_k \quad (mm)$$

for flanged profiles.

The section modulus shall not be less than:

$$Z = \frac{520 l^2 s^{1-\alpha} p_o w_k}{m_e \sigma h_o{}^\alpha \sin\beta} \quad (cm^3)$$

For end connections with brackets, section modulus including bracket shall be at least 1.2 Z. the bracket thickness shall not be less than t_w.

The connection area a_o as defined in Pt.3 Ch.1 Sec.11 C400 shall not be less than:

$$a_0 = \frac{5.8 c s^{1-\alpha}\left(1 - 0.1\frac{h_1{}^2}{l^2}\right)(l - 0.5s)h_o{}^{1-\alpha} p_o}{\tau l \sin\beta} \quad (cm^2)$$

$$k_s = 1 + 0.5\frac{(C_1 + 0.5h_o)^3}{l^3} - 1.5\frac{(C_1 + 0.5h_o)^2}{l^2}$$

 = 0.69 minimum

C_1 = arm length of bracket in m

h_o = h, see D400
 = l, whichever is the smaller

h_1 = h
 = 1.4 l, whichever is the smaller

h_w = web height in mm

m_e = bending moment factor
 = f (h_o/l), see Table F1 (taking r = h_o/l) in general

 = $\dfrac{8}{\left(2 - \dfrac{h_o}{l}\right)\dfrac{h_o}{l}}$

 for stiffener with simply supported ends

p_o = basic ice pressure in kN/m² , see D400

τ = 0.45 σ_f

σ = 0.9 σ_f in general
 = 0.8 σ_f when both ends are simply supported

t_s = shell plate thickness in mm.

s, l and σ_y as defined in A400.

A_K = $t_k h_w 10^{-2}$ (cm²)

w_k = section modulus corrosion factor, see Pt.3 Ch.1 Sec.3 C1004

c = factor as given in Table C4 of Pt.3 Ch.1 Sec.11 C400

α = 0.5 for $A_C \leq 1.0$
 = 0.15 for $A_C > 1.0$

A_C = as given in D403

β = angle of web with shell plating.

F 500 Girders

501 Within ice reinforced areas, girder structures supporting shell stiffeners shall be considered for ice loading. The ice load area to be applied for the girder system will depend on the structure considered, its position and orientation etc. The ice pressure load and load area are generally to be taken as given in D403.

> **Guidance note:**
> For other girders reference is made to E304 and E305.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

502 For girders being part of a complex system of primary structures, analysis by direct calculation may be

required. For such girder structures in the foreship, the requirements given in E400 apply.

503 The following requirements apply to evenly spaced girders for which the ends may be considered as fixed, simply supported or constrained due to repetitive continuation of the member beyond the support. The stiffness of supported members (frames or longitudinals) is assumed to be much smaller than the stiffness of the girder considered.

The web sectional area at any point along a girder shall not be less than:

$$A_W = \frac{5.8 \, k_s \, a \, b \, p_o}{\tau \sin\beta \, A_C{}^\alpha} + A_K \quad (cm^2)$$

and the section modulus shall not be less than:

$$Z = \frac{550 S^2 b p_o w_k}{m_e \sigma \, \sin\beta \, A_C{}^\alpha}$$

k_s = shear factor, see Table F2 (taking r as $(a + s)/S$)

s = spacing of secondary members in m

m_e = bending moment factor

 = $f(a/S)$ in case of a continuous member, see Table F1 (taking r as a/S)

 = $\dfrac{24}{\left(3 - \left(\dfrac{a}{S}\right)^2\right)\dfrac{a}{S}}$ in case of fixed ends

 = $\dfrac{8}{\left(2 - \left(\dfrac{a}{S}\right)\right)\dfrac{a}{S}}$ in case of simply supported ends

a = S in general

 = h_o, maximum for girders supporting longitudinals

b = l in general

 = h_o, maximum for girders supporting non-longitudinal frames

h_o = h, see D400

p_o = basic ice pressure in kN/m^2 as given in D400

τ = 0.45 σ_f

σ = 0.9 σ_f in general

 = 0.8 σ_f when both ends are simply supported

α = 0.5 for $A_C \le 1.0$
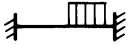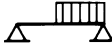
 = 0.15 for $A_C > 1.0$

A_C = as given in D403

β = angle of web with shell plating.

l and S as defined in A400.

A_K and w_k, see 302.

Table F2 Shear factor k_s			
r			
0.0	1.00	1.00	1.00
0.1	0.99	0.99	0.95
0.2	0.96	0.98	0.90
0.3	0.92	0.96	0.85
0.4	0.87	0.93	0.80
0.5	0.81	0.89	0.75
0.6	0.75	0.85	0.70
0.7	0.69	0.80	0.65
0.8	0.62	0.74	0.60
0.9	0.56	0.69	0.55
1.0	0.50	0.63	0.50
1.1	0.5-0.05 i	0.63-0.06 i	0.5-0.05 i
1.2	0.5-0.10 i	0.63-0.12 i	0.5-0.10 i
1.3	0.5-0.15 i	0.63-0.18 i	0.5-0.15 i
1.4	0.5-0.20 i	0.63-0.24 i	0.5-0.20 i
1.5	0.5-0.25 i	0.63-0.30 i	0.5-0.25 i
i = b/2s. maximum = 1.0			

G. Hull Appendages and Steering Gears

G 100 General

101 Sternframes, rudders, propeller nozzles and steering gears are in general to be designed according to the rules given in Pt.3 Ch.3 Sec.2 and Pt.4 Ch.14 Sec.1.

102 Additional requirements for ice reinforced vessels are given in the following. For vessels with rudders which are not located behind the propeller, special consideration will be made with respect to the longitudinal ice load.

103 Plating materials in rudders, propeller nozzles and rudder horns shall be in accordance with Sec.7. Forged or cast materials in structural members subject to lower design temperatures than –10°C according to B100 shall be impact tested at 5°C below (colder than) design temperature.

104 The rudder stock and upper edge of the rudder shall be effectively protected against ice pressure.

105 Aft of the rudder an ice horn with depth minimum = 0.8 h_{ice} or an equivalent arrangement shall be arranged.

106 Exposed seals for rudder stock are assumed to be designed for the given environmental conditions such as:

— ice formation
— specified design temperature.

G 200 Ice loads on rudders

201 An ice load area is defined on the rudder with a length equal to the length of the rudder profile l_r and height equal to the effective ice load height (h). The general design rudder force (F_R) is given by the following formula:

$$F_R = 0.2 \, (h \, l_r)^{0.85} \, K \, p_o \quad (kN)$$

$$K = 1 + \frac{z}{z_{bl} - 0.01 \, L}$$

z = distance from rudder bottom to centre of the assumed ice load area in m
z_{bl} = distance from rudder bottom to the ballast waterline in m
L = as defined in Sec.1 B100
p_o = as given in D400.

The rudder force F_R gives rise to a rudder torque (M_{TR}) and a bending moment in the rudder stock (M_B), which both will vary depending on the position of the assumed ice load area, and on the rudder type and arrangement used.

In general the load giving the most severe combination of F_R, M_{TR} and M_B with respect to the structure under consideration shall be applied in a direct calculation of the rudder structure.

The design value of M_{TR} is given by:

$$M_{TR} = F_R (0.6 \, l_r - X_F) \quad \text{(kNm)}$$
$$= 0.15 \, FR \, l_r \text{ minimum}$$

X_F = longitudinal distance in m from the leading edge of the rudder to the centre line of the rudder stock.

In lieu of direct calculation design values of M_B and F_R, applicable for the rudder stock diameter at the lower end, may normally be taken as:

Spade rudders:

$$F_R = 0.2 \, (h \, l_r)^{0.85} \, p_o \quad \text{(kN)}$$
$$M_B = F_R \, H_B \quad \text{(kNm)}$$

Semi spade rudders:

$$F_R = 0.2 \, (h \, l_r)^{0.85} \, p_o \quad \text{(kN)}$$
$$M_B = 0.5 \, F_R \, H_P \quad \text{(kNm)}$$

Balanced rudders:

$$F_R = 0.2(h l_r)^{0.85}\left(1 + \frac{H_B}{2z_{bl} - 0.02L}\right)p_o \quad \text{(kN)}$$

$$M_B = 0.25 \, F_R \, H_H \quad \text{(kNm)}$$

H_B = distance (m) from lower end of rudder to middle of neck bearing
H_P = distance (m) from lower end of rudder to middle of pintle bearing
H_H = distance (m) from centre of heel bearing to centre of neck bearing
h = as given in D403.

202 An additional ice load area is defined on the uppermost part of the rudder including ice knife with a length equal to the rudder (including ice knife) (l_r) and height below the hull equal to the nominal ice height (h_{ice}). This gives rise to a force (F) given by:

$$F = k \, p \, h_{ice} \, l_r \quad \text{(kN)}$$

p = design ice pressure in kN/m² in stern area as given in D400
k = 0.7 in general
= 1.0 for vessels with class notations **POLAR** or **Icebreaker**.

The force F shall be divided between rudder and ice knife according to their support position. The force acting on the ice knife may generally be taken as:

$$F_K = \frac{F(X - X_F)}{(X_K - X_F)}$$

X = distance from leading edge of rudder to point of attack of the force F
= 0.5 l_r (m) minimum
= 0.67 l_r (m) maximum
X_K = distance in m from leading edge of rudder to centre of ice knife.

G 300 Rudder scantlings

301 The scantlings of rudders, rudder stocks and shafts, pintles, rudder horns and rudder actuators shall be calculated from the formulae given in Pt.3 Ch.3 Sec.2, inserting the rudder torque M_{TR}, bending moments M_B and rudder force F_R as given in 201, all multiplied by factor 0.7.

302 Provided an effective torque relief arrangement is installed for the steering gear, and provided effective ice stoppers are fitted, the design rudder torque need not be taken greater than:

$$M_{TR} = M_{TRO}$$

M_{TRO} = steering gear relief torque in kNm.

303 For rudder plating the ice load thickness shall be calculated as given in F200 using the basic ice pressure as given for the stern area reduced linearly to half value at the lower end of the rudder.

304 Scantlings of rudder, rudder stock, rudder horn, rudder stoppers and ice knife as applicable are also to be calculated for the rudder force given in 202 acting on the rudder and ice knife, with respect to bending and shear. Allowable stresses as given in F400.

G 400 Ice loads on propeller nozzles

401 A transverse ice load area positioned at the level of the nozzle center is defined on the nozzle with a length equal to the nozzle length and a height equal to the ice load height h given by:

h = 0.8 h_{ice} in general
   = 0.6 h_{ice} for nozzle directly inside of protecting structures, e.g. other nozzle or propeller.

402 The following two alternative longitudinal ice load areas shall be considered:

— an area positioned at the lower edge of the nozzle with a width equal to 0.65 D and a height equal to the height of the nozzle profile
— an area on both sides of the nozzle at the propeller shaft level, with a transverse width equal to the height of the nozzle profile and with a height equal to 0.35 D. Both symmetric and asymmetric loading shall be checked.

D = nozzle diameter.

403 The design ice pressure p (in kN/m^2) for the stern area as given in D400 shall be assumed for the ice load areas specified under 401 and 402 giving rise to a force (F) given by:

$$F = k \, p \, A \quad (kN)$$

A = ice load area as defined in 401 and 402
k = 0.7 in general
   = 1.0 for vessels with class notations **POLAR** or **Icebreaker**.

G 500 Propeller nozzle scantlings

501 The scantlings of the propeller nozzle and its supports in the hull shall be calculated for the ice loads given in 400, with stresses not exceeding allowable values given in F400. For nozzle plating the ice load thickness shall be taken as given in F200 using the design ice pressure as given for the stern area.

G 600 Steering gear

601 The main steering gear shall be capable of putting the rudder over from 35° on one side to 30° on the other side in 20 seconds, when the vessel is running ahead at maximum service speed (corresponding to MCR) and at deepest ice draught.

602 For the additional class notation **Icebreaker** the above time shall not exceed 15 seconds.

603 The effective holding torque of the rudder actuator, at safety valve set pressure, shall be capable of holding the rudder in the preset position, when backing in ice, unless arranged in accordance with 302 and 604.

The holding torque means the rudder torque the actuator is capable to withstand before the safety valve discharges.

The holding torque need normally not exceed the values given in Table G1.

Table G1 Values of holding torque		
ICE-05 to **-15**	**POLAR-10** to **-30**	**Icebreaker**
0.5 M_{TR}	0.75 M_{TR}	M_{TR}

M_{TR} = as given in 201.

604 The torque relief arrangement, when installed, shall provide protection against excessive rudder ice peak torque, e.g. when backing towards ice ridges.

The arrangement shall be such that steering capability is either maintained or speedily regained after activation of such arrangement.

605 All hydraulic rudder actuators shall be protected by means of relief valves. Discharge capacity at set pressure shall not be less than given in Table G2.

Table G2 Relief valve discharge capacity			
	ICE-05 to **-15**	**POLAR-10** to **-30**	**Icebreaker**
Rudder speed (degrees/s)	4.5	5	6.5

606 Where practicable rudder stoppers working on the rudder blade or head shall be fitted.

G 700 Podded propulsors and azimuth thrusters

701 Vessels operating in ice and equipped with podded propulsors or azimuth thrusters shall be designed according to operational mode and purpose stated in the design specification. If not given, it shall be assumed that the vessel will be intended for continuous operation astern. This information shall also be stated in the ship's papers.

702 Ramming astern is not anticipated.

703 The structure (housings, struts, bearings etc) of the pod/thruster shall be dimensioned for basic ice pressures as given in D400 for stern area in accordance with requested class notation and the operational mode.

704 Documentation of both local and global strength capacity of the pod and or thruster shall be submitted for class assessment. Recognised structural idealisation and calculation methods shall be applied.

705 The equivalent stress as defined in Pt.3 Ch.1 Sec.12 B400 shall not exceed σ_y. This is normally achieved for girder type members when the bending stress is not exceeding $0.9\sigma_y$ and the mean shear stress over a web cross-section is not exceeding $0.45\sigma_y$

H. Welding

H 100 General

101 The requirements in this subsection apply to members that may be directly exposed to local ice pressure and support structures for these. Otherwise weld dimensions shall be in accordance with the rules for main class.

H 200 External welding

201 The welding of ice strengthened external plating to stiffeners and to webs and bulkheads fitted in lieu of stiffeners is in any case to have a double continuous weld with throat thickness which is not less than:

$$t = \frac{0.55\sqrt{s}\ p_o}{\sigma_{fw}} + 0.5t_k \quad (mm)$$

Where σ_{fw} = yield strength in N/mm^2 of weld deposit. See Pt.3 Ch.1 Sec.11 and Pt.3 Ch.2 Sec.11.

Need not be greater than:
    = $0.45 \times$ plate thickness for mild steel, and
    = $0.50 \times$ plate thickness for high strength steel.

If the welding method leads to deeper penetration than normal, the additional penetration can be included in the throat thickness.

Weld throat shall in no case be less than for main class requirements.

H 300 Fillet welds and penetration welds subject to high stresses

301 In structural parts where high tensile stresses due to local ice load act through an intermediate plate, the throat thickness of double continuous welds shall not be less than given by Pt.3 Ch.1 Sec.11 C202, with $\sigma = 0.77\ \sigma_i$.

σ_i = calculated maximum tensile stress in abutting plate due to ice load in N/mm^2.

302 Where high shear stresses in web plates due to local ice load, double continuous boundary fillet welds shall have throat thickness not less than given by Pt.3 Ch.1 Sec.11 C302 with $\tau = 0.77\ \tau_i$.

τ_i = calculated maximum shear stress due to ice load in N/mm^2.

I. Machinery Systems

I 100 Pneumatic starting arrangement

101 In addition to the requirements given in Pt.4 Ch.6 Sec.5 for a vessel having a propulsion engine(s), which has to be reversed for going astern, the compressors shall have the capacity to charge the receivers in half an hour.

I 200 Sea inlets and discharges

201 The sea cooling water inlet and discharge for main and auxiliary engines shall be so arranged that

blockage of strums and strainers by ice is prevented.

In addition, the requirements in Pt.4 Ch.6 Sec.5 B302 and B303 shall be complied with.

202 At least one of the sea chests shall be sufficiently high to allow ice to accumulate above the pump suctions and cooling water tank inlet, arranged as follows:

1) The sea inlet shall be situated near the centre line of the ship and well aft if possible. The inlet grids shall be specially strengthened.

2) As a guidance for design the volume of the chest shall be about one cubic metre for every 750 kW engine output of the ship including the output of the auxiliary engines necessary for the ship's service.

3) To allow for ice accumulation above the pump suction the height of the sea chest shall not be less than:

$$h_{min} \geq 1.5 \sqrt[3]{V_s}$$

V_s = volume of sea chest according to item 2.
The suction pipe inlet shall be located not higher than $h_{min}/3$ from top of sea chest.

4) The area of the strum holes shall be not less than four (4) times the inlet pipe sectional area.

Heating coils may be installed in the upper part of the chests.

203 A full capacity discharge branched off from the cooling water overboard discharge line shall be connected to the sea chests. At least one of the fire pumps shall be connected to this sea chest or to another sea chest with de-icing arrangement.

I 300 Sea cooling water arrangements

301 The sea cooling water inlets and discharges for main and auxiliary engines shall be connected to a cooling water double bottom tank having direct supply from the sea chests. The cross-sectional area of the supply line between each sea chest and the cooling water tank shall be twice that of all pump suctions connected to the tank.

302 Vessels with the class notation **Icebreaker** or **POLAR** shall comply with 303 to 307.

303 The cooling water tank volume in m^3 shall be at least 0.01 times the output in kW of the main and auxiliary engines.

304 The sea water suction line strainers required in Pt.4 Ch.6 Sec.5 shall be arranged outstream from the cooling water tank.

305 The sea water cooling pumps shall be of the self-priming type or connected to a central priming system.

306 The sea water cooling and ballast piping shall be arranged so that water in the cooling water tank can be circulated through the ballast tanks for the purpose of spare cooling capacity in the case of blocked sea chests.

307 Arrangements providing additional cooling capacity equivalent to that specified in 301 through 306 may be considered.

I 400 Ballast system

401 Arrangement to prevent freezing shall be provided for ballast tanks where found necessary.

Guidance note:
Double bottom tanks are normally not required to be provided with arrangement to prevent freezing.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

J. Propulsion Machinery and Propellers

J 100 General

101 Special cold climate environmental conditions shall be taken into consideration in machinery design.

102 *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 10ºC.

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 10ºC. Nodular cast iron of Grade NV 1 and NV 2 may be used for relevant parts in CP-mechanism. Other type of nodular cast iron with elongation ≥ 12% may be accepted upon special consideration for same purposes.

103 Grey cast iron is normally not accepted for components subject to ice shocks, as e.g. thrust bearing housings.

104 Shafting systems equipped with specially designed mechanical torque limiting devices are subject to special consideration. Such devices, when accepted, shall comply with redundancy type R2 in Pt.4 Ch.1.

The torque limit is normally not less than $1.5 \, K_A \, T_O$.

For K_A and T_O, see 500.

105 Ice induced vibrations (repetitive ice chocks) in the shafting system shall be considered.

Forced torsional vibration calculations shall include an evaluation of transient vibrations excited by ice on the propeller.

106 For non-reversible machinery plants, special means shall be provided for reversing the propellers stuck in ice.

107 The propulsion line shall be designed such that the blade failure load F_{ice} given in 404 shall not cause damage in the blade bolt connection, propeller hub, pitch mechanism, shaft connection, propeller shaft and thrust bearing.

> **Guidance note:**
> Damage, in this context, means when the stresses in the highest loaded part of the considered cross section reaches yield stress. The local effect of stress raisers may be ignored.
>
> Blade failure load (Fice) is the load causing plastic bending of the propeller blade in a section just outside the root fillet.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

J 200 Engine output

201 The maximum continuous output of propulsion machinery shall not be less than:

$$P = 1.5 \, c_s \, c_p \, I \, N \, B \left[1 + 1.6 \, T + 27 \, (0.1 \, I \, N \, / \, T^{0.25})^{0.5}\right] \text{ (kW)}$$

c_s = 1.0 for vessels with conventional «icebreaker stem»
= $0.9 + \gamma / 200$; minimum 1.0, but need not exceed 1.2
c_p = 1.0 for controllable pitch propeller
= 1.1 for fixed pitch propeller
IN = ice class number (figure added to class notation)
B = moulded breadth at waterline (m), local increase in way of stem area is normally not to be taken into account
T = rule draught (m)
γ = stem angle (see Fig.1).

202 When the vessel is provided with special means which will improve her performance in ice (e.g. air bubbling system), the input rating of machinery used for such purpose may be added to the actual rating of propulsion machinery.

The propeller rating is, however, not to be less than 85% of that required in 201.

203 When the vessel is provided with a nozzle of efficient design, a reduction of required engine output corresponding to increase of thrust in ice conditions will be considered. The reduction is, however, not to exceed 20% of required output in 201 and 202.

204 Additional reduction of the required output may be considered for a vessel having design features improving her performance in ice conditions. Such features shall be documented, either by means of model tests or full scale measurements.

It is understood that such approval can be revoked, if experience motivates it.

J 300 Determination of ice torque and loads

301 Ice torque (T_{ICE}), used for determination of scantlings in propellers and shafting systems, shall be taken as follows:

$$T_{ICE} = m \, D^2 \text{ (kNm)}$$

The factor m is given in Table J1 as function of ice class:

Table J1 Values of m			
Ice class	*m*	*Icebreaker*	*m*
ICE-05	*16*	**ICE-05**	*21*
ICE-10	*21*	**ICE-10**	*30*
ICE-15	*27*	**ICE-15**	*30*
POLAR	*33*	**POLAR**	*40*

D = propeller diameter in m.

302 For propellers running in nozzles of satisfactory design, the ice torque will be considered based on submitted documentation, e.g. measurements carried out on similar vessels.

However, if nothing else is documented, the following may be used:

$$T_{ICE} = (0.9 - 0.01 \, m \, D^{-0.5}) \, m \, D^2 \quad (kNm)$$

Large fragments of ice shall not have free access into or towards the front of the nozzle.

303 Axial loads in shaftline:

$F = T_H + 1.5 \, F_{LE}$ (axial load, ahead)

$F = 0.8 \, T_H + F_{LE}$ (axial load, astern)

The axial load F shall be applied on the propeller side of the thrust bearing.

T_H and F_{LE} according to 400 and 500.

J 400 Propeller

401 The blade scantling requirements given in Sec.2 apply, except as given below. In calculations involving the ice torque, T_{ICE} according to 300 shall be applied.

Propeller blade scantlings of martensitic — austenitic and ferritic — martensitic stainless steel may be specially considered.

402 Arrangement of propellers in ice classes **ICE-15** and **POLAR-10** to **-30** shall be such that large fragments of ice do not have free access into the front of the propeller disc within 0.7 radius.

403 When the outer sections of the propeller blade is not subject to special consideration according to Sec.2 C201, the blade tip thickness at the radius 0.95 R shall not be less than:

$$t = (m + 2D) \sqrt{\frac{490}{\sigma_b}} \quad (mm)$$

D and σ_b as given in 404.

σ_b shall not be taken higher than 2.5 σ_y.

For propellers running in nozzles blade tip thickness smaller than above may be accepted. The tip thickness, however, shall not be less than 3/4 of the above value.

The thickness of the blade edge and the propeller tip shall not be less than 50% of minimum t as given above, measured at 1.25 t from the edge or tip, respectively. For propellers where the direction of rotation is not reversible, this requirement only applies to the leading edge and propeller tip.

404 The fitting of the propeller blades and the pitch control mechanism shall withstand a design static load not less than:

$$F_{ICE} = 0.3 \frac{\sigma_n c_r t_r^2}{D[0.9 - R_R/R]} 10^{-6} \quad (kN)$$

This load shall be applied on the blade at a radius 0.9 R and at an offset from blade centre axis of 2/3C_{TE} or 2/3C_{LE}, whichever is the greater.
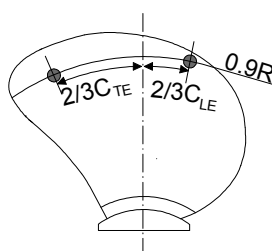
σ_n = 0.37 σ_b + 0.6 σ_y
σ_b = ultimate tensile strength of the blade (N/mm^2)
σ_y = the blade yield stress or 0.2% offset point (N/mm^2)
c_r = the length of the blade section at R_R radius (mm)
t_r = the corresponding thickness (mm)
D = propeller diameter (m)
R = D/2 (m)
R_R = radius to a blade section taken at the termination of the blade root fillet (rounded upwards to the nearest R/20), ref. c_r and t_r (m)
C_{TE} = distance from axis of rotation of the blade to the trailing edge, measured along the cylindrical section at 0.9 R
C_{LE} = distance from axis of rotation of the blade to the leading edge, measured along the cylindrical section at 0.9 R.

405 Propeller blade bolts shall have a section modulus, referred to an axis tangential to the bolt pitch diameter, not less than:

$$W_{BS} = 0.15 \ S \ c_r \ t_r^{\ 2} \ \frac{\sigma_n}{\sigma_y} \ \frac{0.9 - R_B / R}{0.9 - R_R / R} \quad (mm^3)$$

S = 1.0 for CP-propellers
= 1.25 for FP-propellers
σ_y = yield stress of bolt material (N/mm^2)
R_B = radius to bolt plan (m).

c_r, t_r and σ_n as given in 404.

The bolts shall have a design which minimises stress concentrations in transition zones to threads and bolt head as well as in way of the threads, and reduces risk for plastic deformations in the threads.

406 For all parts in the pitch control mechanism, which are subject to variable ice loads, stress concentration shall be taken into consideration.

407 The blade fitting and other parts in the pitch control mechanism shall be designed to withstand all forces produced by the pitch control system at its maximum power. The forces shall be assumed to act towards one blade at a time.

Guidance note:
The pitch control mechanism shall be designed for the following dynamic ice loads:

F_{LE} = T_{ICE} / 0.9 R (kN) at leading edge,
F_{TE} = − 0.5 F_{LE} at trailing edge,

applied at the 0.9 radius perpendicular to the blade plane at the respective blade edges.

Number of load cycles to be considered shall not be taken less than one million for ice classes **ICE-05** to **-15** and infinitive for **POLAR-10** to **-30** and class notation **Icebreaker**. The design pressure of the hydraulic system shall not be taken less than twice the pressure needed to produce the blade spindle torque based on the above forces. The forces are assumed to act on one blade at a time only.

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408 Fitting of the propeller to the shaft is given in Pt.4 Ch.4 Sec.1 as follows:

— flanged connection in B300
— keyless cone connection in B400
— keyed cone connection in B500.

(Considering 0°C sea water temperature)

If the propeller is bolted to the propeller shaft, the bolt connection shall have at least the same bending strength as the propeller shaft.

J 500 Propulsion shaft line reinforcement

501 Determination of factors for ice reinforcement of shaft line.

T_O = torque (kNm) in the actual component
T_{ICE} = ice torque (kNm) according to 300
u = gear ratio (if no reduction gear, or for components on the propeller side of a reduction gear use u = 1)

I   = equivalent mass moment of inertia in kgm^2 based on torque of all parts on engine side of component under consideration.

Masses rotating with engine speed to be transformed according to:

$$I_{equiv} = I_{actual}\, u^2$$

In propulsion systems with hydraulic coupling, torque converter or electromagnetic slip coupling, the masses in front of the coupling shall not be taken into consideration

I_t = equivalent mass moment of inertia of propulsion system in kgm^2. (Masses in front of hydraulic or electromagnetic slip coupling shall not be taken into consideration.)

502   Application factor for diesel and or turbine machinery in general:

$$K_{Aice} = 1 + \frac{T_{ice}I}{uT_0I_T}$$

503   Application factor for electric motor machinery or diesel machinery with hydrodynamic torque converter:

1) Diesel engine with torque converter or hydrodynamic coupling:

$$K_{Aice} = \frac{T_{TC\,max}}{T_0} + \frac{T_{ice}I}{uT_0I_t}$$

   $T_{TC\,max}$ = maximum possible transmittable torque through converter/coupling.

2) Electric motor drive:

$$K_{Aice} = \frac{T_{max}}{T_0} + \frac{T_{ice}I}{uT_0I_T}$$

   T_{max} = motor peak torque (steady state condition).

Alternatively to the above criteria, the ice impact load may be documented by simulation of the transient dynamic response in the time domain. For branched systems, such simulation is in general recommended.

504   Regarding shaft connections, use K_{Aice} in Pt.4 Ch.4 Sec.1 as follows:

— flange connections, see B300
— shrink fit connections, see B400
— keyed connections, see B500.

505   The diameter of the propeller shaft in way of aft bearing and at least a length 2.5 times the required diameter forward of propeller flange or hub, shall not be less than:

$$d_p = 1.16 \left(\frac{0.9\sigma_n c_r t^2}{[0.9 - (R_R/R)]\sigma_y} \right)^{\frac{1}{3}} \ (mm)$$

$c_r t^2$ = actual value of blade section considered at the termination of the blade root fillet (rounded upwards to nearest 1/20 of R).

σ_y refers to the shaft material.

σ_n refers to the blade material, see 404.

c_r and t as given in 404.

The propeller shaft diameter may be evenly tapered to 1.15 times the required intermediate shaft diameter between the aft bearing and the second aft bearing. Forward of this bearing the propeller shaft diameter may be reduced to 1.05 times the required diameter of the intermediate shaft (using material factor valid for propeller shaft).

The propeller shaft flange thickness (propeller fitting) shall be at least 0.3 times the actual shaft diameter. The fillet radius shall be at least 0.125 times the actual shaft diameter.

506   The diameter of intermediate shafts shall be determined based on methods given in Pt.4 Ch.4 Sec.1 B201.

a) When using the classification note 41.4 the necessary reinforcement is determined by using K_{Aice} in the given criteria.

b) With $K_{Aice} \leq 1.4$ the method in Pt.4 Ch.4 Sec.1 B206 may be used, i.e. no ice reinforcement beyond 1A1 rules.

c) When using the method in Pt.4 Ch.4 Sec.1 B208, the minimum diameter in item 3 of that paragraph shall

be multiplied with:

$$\left(\frac{K_{Aice}}{1.4} \right)^{\frac{1}{3}}$$

but not less than 1.0

In item 4 of same paragraph, the vibratory torsional stress τ_v is replaced by:

$$\tau_v = 0.5 \cdot (K_{Aice} - 1) \cdot T_0$$

and shall not exceed τ_C.

507 Support and construction of the thrust bearing shall be designed to avoid excessive axial shaft movements caused by heavy axial forces when the propeller hits ice.

The thrust bearing shall have static strength designed for not less than the nominal thrust plus the static ice force as defined in 404. The ice force is assumed to act in the axial direction. Both forward and astern directions shall be considered.

The basic static load ratings of roller bearings shall not be less than 2 times the load.

For calculation of the bearing pressures in the ice conditions, the following thrust force applies:

$$T_{HI} = 1.1\ T_H + 0.25\ F_{LE} \pm 0.75\ F_{LE}\ \text{(kN)}$$

F_{LE} = according to 407

T_H = mean «bollard thrust» of the propeller or 1.25 times the mean thrust at maximum continuous ahead speed, in kN.

Calculated lifetime (B_{10}) of roller bearings shall be minimum 40 000 h, by applying the load T_{HI}.

508 For reduction gears, use K_{Aice} in Pt.4 Ch.4 Sec.2.

Axial ice load according to 507, when applicable, shall be considered with respect to bearing arrangement and stiffness of the gear housing.

509 For clutches, use K_{Aice} in Pt.4 Ch.4 Sec.3 B100.

510 For torsional elastic coupling, use K_{Aice} in Pt.4 Ch.4 Sec.5 B200.

K. Thrusters

K 100 General

101 Special cold climate environmental conditions shall be taken into consideration in the thruster design.

102 Means for heating and circulation of lubrication and hydraulic oil shall be provided.

K 200 Propulsion thrusters

201 Thrusters, which are used for propulsion purpose, shall comply with the relevant requirements in J.

Guidance note:
Any thruster intended to be used for propulsion in ice, not only the main propulsion thrusters, is defined as propulsion thrusters in this context.

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202 Steering gear for azimuth thrusters shall be designed to withstand all relevant ice loads. Both ice loads on propeller nozzle (G400) and on propeller blade (J400) shall be considered.

K 300 Other thrusters

301 For shafting the following applies:

— Maximum peak torque, which may occur due to ice in the propeller, shall be taken into consideration.
— The load F in 303 shall be considered for the propeller shaft.

Maximum permissible equivalent stress is 80% of the yield stress or 0.2% proof stress of materials.

302 For reduction gears the application factor (K_A) shall be taken as minimum 1.2.

303 The propeller blade shall be designed to withstand a peak load, without exceeding 80% of blade material yield or 0.2% proof stress of:

$$F = \frac{T}{0.85\,R\sin\alpha_{0.85}} \quad \text{(kN)}$$

T = maximum peak torque of prime mover (kNm)

$\alpha_{0.85}$ = pitch angle at radius 0.85 R

R = propeller radius (m).

The load F is assumed to apply at 0.85 R, perpendicular to the blade plane.

L. Stability and Watertight Integrity

L 100 Application

101 Vessels with a length L_F of 24 m and above and class notation **Icebreaker** or **POLAR** shall comply with the requirements of Pt.3 Ch.3 Sec.9 as well as the requirements of this subsection.

Guidance note:
The requirements contained in this section are based on the IMO MSC/Circ.1056 "Guidelines for Ships Operating in Arctic Ice-covered waters" as applicable for polar classes 1 to 3.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

L 200 Documentation

201 *Documentation for approval*

— preliminary damage stability calculations
— final damage stability calculations

(not required in case of approved limit curves, or if approved lightweight data are not less favourable than estimated lightweight data).

202 *Documentation for information*

— internal watertight integrity plan.

203 Details of above documentation are given in Classification Note No. 20.1.

L 300 Requirements for intact stability

301 The initial metacentric height GM shall not be less than 0.5 m.

302 Account shall be taken of the effect of icing in the stability calculations.

Guidance note:
The realistic figures for thickness and density of the accumulated ice load may vary with different areas. In lack of detailed information the following ice loads should be accounted for:

- 30 kg per square metre on exposed weather decks and gangways
- 7.5 kg per square metre for projected lateral area of each side of the vessel above the water plane
- the weight distribution of ice on discontinuous structures such as railings, rigging, posts and equipment shall be included by increasing the total area for the projected lateral plane of the vessel's sides by 5%. The static moment of this area shall be increased by 10%.

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303 Suitable calculations should be carried out and or tests conducted to demonstrate the following:

1) the ship, when operated in ice within approved limitations, during a disturbance causing roll, pitch, heave or heel due to turning or any other cause, should maintain sufficient positive stability, and

2) when riding up in ice and remaining momentarily poised at the lowest stem extremity, should maintain sufficient positive stability.

304 Sufficient positive stability in paragraphs 303 1) and 2) means that the ship is in a positive state of equilibrium with a positive metacentric height of at least 150 mm, and a line 150 mm below the edge of the freeboard deck as defined in the applicable LL-Convention, is not submerged.

305 For performing stability calculations on ships that ride up onto the ice, the ship should be assumed to remain momentarily poised at the lowest stem or extremity as follows:

— for a regular stem profile, at the point at which the stem contour is tangent to the keel line
— for a stem fitted with a structurally defined skeg, at the point at which the stem contour meets the top of the skeg
— for a stem profile where the skeg is defined by shape alone, at the point at which the stem contour tangent

intersects the tangent of the skeg, or
— for a stem profile of novel design, the position should be specially considered
— the same considerations shall be made for ships designed for breaking ice at the stern.

L 400 Requirements for damage stability

401 The damage assumptions in 402 to 403 and the criteria in 407 and 408 shall be the basis of damage stability calculations.

402 The dimensions of an ice damage penetration should be taken as:

— longitudinal extent 0.045 of deepest ice waterline length if centred forward of the point of maximum beam on the waterline, and 0.015 of waterline length otherwise,
— depth 760 mm measured normal to the shell over the full extent of the damage, and
— vertical extent the lesser of 0.2 of deepest ice draught, or of longitudinal extent.

403 The centre of the ice damage may be located at any point between the keel and 1.2 times the deepest ice draught. The vertical extent of damage may be assumed to be confined between the keel and 1.2 times the deepest ice draught.

404 If damage of lesser extent than that specified above results in a more severe condition, such lesser extent shall be assumed.

405 For pipes, ducts or tunnels situated within the assumed extent of damage, see 500.

406 The following permeability factors shall be assumed:

– store rooms: 0.60
– machinery spaces: 0.85
– tanks and other spaces: 0.95
– partially filled ballast tanks: consistent with minimum tank content.

407 Damage criteria at the final stage of flooding:

— the final equilibrium waterline after damage shall be below the edge of any non-watertight opening
— the final equilibrium heel angle after damage shall not exceed 15°. This may be increased to 17° if the deck edge is not submerged
— GZ after damage has at least 20° positive range beyond equilibrium
— maximum GZ of at least 0.10 m within 20° beyond the maximum equilibrium position.

408 Damage criteria at the intermediate stages of flooding:

— the waterline after damage shall be below the edge of any non-weathertight opening
— the heel angle after damage shall not exceed 25°. This may be increased to 30° if the deck edge is not submerged
— GZ after damage has at least 10° positive range beyond equilibrium
— maximum GZ of at least 0.05 m within 10° beyond the maximum equilibrium position.

409 A maximum allowable VCG curve with respect to damage stability shall be included in the stability manual. Otherwise the damage stability approval shall be limited to the presented loading conditions.

L 500 Requirements to watertight integrity

501 As far as practicable, tunnels, ducts or pipes which may cause progressive flooding in case of damage, shall be avoided in the damage penetration zone. If this is not possible, arrangements shall be made to prevent progressive flooding to volumes assumed intact. Alternatively, these volumes shall be assumed flooded in the damage stability calculations.

502 The scantlings of tunnels, ducts, pipes, doors, staircases, bulkheads and decks, forming watertight boundaries, shall be adequate to withstand pressure heights corresponding to the deepest equilibrium waterline in damaged condition.

SECTION 5
SEALERS

A. General

A 100 Classification

101 The requirements in this Section apply to vessels specially built for catching.

102 Vessels built in compliance with the following requirements may be given the class notation **Sealer**.

A 200 Hull form

201 The hull form of the vessel shall be suitable for navigation in pack ice and shall be such that the ship cannot be pressed down by ice. The sides of the hull shall be convex, with the greatest breadth at the first continuous deck above the design waterline. The angle between the tangent to the ship's side at the deck and the vertical shall not be less than 5 degrees.

B. Strength of Hull and Superstructures

B 100 Ship's sides and stem

101 The scantlings of shell plating, frames, girders and stem shall at least be as required for ice class **ICE-05**, see Sec.4.

B 200 Superstructures

201 Side plating in superstructures shall have increased thickness in an area extending not less than 1 m above the upper ice waterline (UIWL), as defined in Sec.1 B, of the vessel or above deck if the vessel has no freeboard mark. In the mentioned area the plate thickness forward of 0.25 L from F.P. shall not be less than:

$$t = 10 + 0.08 \, L \quad (mm)$$

Aft of 0.25 L from forward perpendicular the plate thickness shall not be less than:

$$t = 7.5 + 0.06 \, L \quad (mm)$$

202 Frames in superstructures in way of crew accommodation shall have a section modulus at least 50% in excess of the requirement for main class. The frames shall have brackets at both ends.

203 Intermediate frames with section modulus as for frames according to 202, shall be fitted in way of the strengthened side plating stated in 201. The top of intermediate frames shall be connected to a horizontal girder of same depth as the frames and with a flange area not less than 10 cm^2. The horizontal girder shall be attached to all side frames.

C. Sternframe, Rudder and Steering Gear

C 100 Design rudder force

101 The scantlings shall be based on a rudder force 3 times the design rudder force for main class.

C 200 Protection of rudder and propeller

201 Ice fins shall be fitted for protecting rudder and propeller.

D. Anchoring and Mooring Equipment

D 100 General

101 The equipment may be as required for fishing vessels.

E. Machinery

E 100 Output of propulsion machinery

101 The output shall not be less than 735 kW. If the vessel has a controllable pitch propeller, the output

requirement may be reduced by 10%.

E 200   Thrust bearing, reduction gear, shafting and propeller

201   The scantlings are at least to be as required for class notation **ICE-05**, see Sec.4.

E 300   Machinery systems

301   For requirements to sea inlets and cooling water system, see Sec.3 J602.

SECTION 6
WINTERIZATION

A. General

A 100   Classification

101   The requirements in this section apply to ships intended for service in cold climate environments.

The **WINTERIZED BASIC** notation is relevant for vessels operating in cold climate environments for shorter periods, not necessarily including ice covered waters.

The **WINTERIZED COLD (t_1, t_2)** and **WINTERIZED ARCTIC (t_1, t_2)** are relevant for vessels operating in cold climate environments for longer periods, where:

t_1 = material design temp. in °C
t_2 = extreme design temp. in °C.

> **Guidance note:**
> The design temperatures are defined by the user when signing the class contract. The material design temperature should reflect the lowest mean daily average air temperature in the area of operation. The extreme design temperature may be set to about 20°C below the lowest mean daily average air temperature, or the material design temperature, if information for the relevant trade area is not available.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

The **WINTERIZED ARCTIC (t_1, t_2)** notation also takes the environmental vulnerability of the Arctic regions into consideration.

102   The class notation **WINTERIZED BASIC** may be assigned to ships complying with the requirements in B.

> **Guidance note:**
> For the purpose of calculating heat balances for space heating an extreme temperature of - 30°C may be assumed
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

103   The class notation **WINTERIZED COLD (t_1, t_2)** may be assigned to ships complying with the requirements in subsections B and C.

104   The class notation **WINTERIZED ARCTIC (t_1, t_2)** may be assigned to ships complying with the requirements in subsections B through D.

A 200   Documentation

201   For the class notation **WINTERIZED BASIC**, the following plans and particulars shall be submitted for approval:

— arrangement of anti-icing and de-icing equipment for the various areas. Heating capacities shall be specified
— diagram of compressed air supply to important consumers outside machinery space
— electrical single line distribution diagrams for anti-icing and de-icing equipment with information about:
  - full load
  - cable type and cross section
  - make, type and rating of fuse and switch gear
  - make, type and rating of heating cable
— electrical schematic diagram, for all control and instrumentation circuits, with information on make, type and rating of all equipment
— fastening arrangement and spacing of electrical cables and fluid pipes for heating purposes
— mechanical de-icing arrangements, methods and location
— storage facilities and specification of hand tools for manual ice removing, protective clothing, lines, etc., to be carried onboard
— test program for anti-icing and de-icing systems.

The following manuals shall be submitted for approval and shall be kept onboard:

— manual for anti-icing precautions and de-icing procedures.

202   For the class notation **WINTERIZED COLD (t_1, t_2)**, the following documentation shall be submitted for approval in addition to the documentation required by 201:

— heat balance calculations

— arrangements for anti-freezing of ballast tanks and fresh water tanks.

The following manual shall be submitted for approval and shall be kept onboard:

— stability manual including load conditions with ice accretion.

203 For the class notation **WINTERIZED ARCTIC(.. , ..)**, the following documentation shall be submitted for approval in addition to the documentation required by 201 and 202:

— documentation as specified for the class notation **OPP-F**
— calculations for Oil Outflow Index
— documentation of stern tube/CP propeller oils
— calculations of bunker capacity.
— documentation as specified for the selected ice class notation.

A 300 Definitions

301 Required measures against ice accretion are divided in two categories:

— category I
— category II.

302 For category I installations anti-icing arrangements are required with sufficient capacity to keep the equipment or areas free from ice (generally by means of heating or cover) at all times.

303 Typical category I installations are related to:

— navigation
— steering
— propulsion
— anchoring
— lifesaving/escape routes.

304 For category II installations de-icing arrangements are required with sufficient capacity for removal of accreted ice within a reasonable period of time (normally 4 to 6 hours) under the icing conditions specified.

305 Typical category II installations are related to:

— decks and superstructures
— helicopter decks
— railings
— cargo deck area.

B. Requirements for WINTERIZED BASIC

B 100 Arrangements, anti-icing and de-icing

101 Arrangements and methods for anti-icing and de-icing will be considered for approval in each case. Manual de-icing may be accepted to a limited extent.

Guidance note:
More detailed requirements for different parts of the ship and equipment may be found later in B100.

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102 Heating power capacity for anti-icing and de-icing shall not be less than:

— 300 W/m^2 for open deck areas, helicopter decks, gangways, stairways, etc.
— 200 W/m^2 for superstructures
— 50 W/m for railings with inside heating.

Heating capacities for other areas will be considered in each individual case.

103 In arrangements with electric heating cables or heating pipes with fluids as heating medium, special attention shall be paid to the heat transfer from the cables or pipes to the equipment or structure to be heated. The spacing of cables or pipes shall be appropriate for efficient heating. The fastening of cables or pipes shall be such that the heat will be readily dissipated to the equipment or structure to be heated.

104 Switchboard for anti-icing and de-icing shall be arranged as required for distribution switchboards. A wattmeter or ampere meter, indicating the total load shall be installed on the switchboard. Marking on the switchboard shall state the load on each circuit, as well as the total load.

105 All circuits shall have earth failure monitoring with automatic disconnection and alarm. Energized circuits shall be indicated by means of a signal lamp for each circuit.

106 Heating cables shall be short circuit and overload protected as required by Pt.4 Ch.8. However, self regulated cables do not require overload protection.

107 Motors on open deck, being part of category I or category II installations, shall be naturally cooled, i.e. without external fan. The electrical installation shall also comply with the rule requirements in Pt.4 Ch.8.

108 For anti-icing and de-icing arrangements applying heating by fluids in pipes, the valves shall be marked with equipment or area heated. Open and closed position of the valves shall also be indicated. Pumps applied for anti-icing purposes (category I installations) shall be arranged with redundancy.

Due regard shall be paid to the piping arrangements avoiding that the heating fluid freezes.

The piping systems for anti-icing and de-icing purposes shall also to comply with the rules in Pt.4 Ch.6.

> **Guidance note:**
> Insulation of piping simultaneously with circulation of the heating medium is one way to ensure that the heating medium is not freezing.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

109 Supply of compressed air to category I consumers outside machinery space, shall be provided with air drying sufficient to lower the dew point to not warmer than −30°C at the actual pressure.

110 The specified installations (A300) of category I, shall have anti-icing arrangements, normally by heating or cover. Other means of anti-icing may be accepted upon special consideration. Alternative means of providing anti-icing shall not interfere with the proper functioning of the vessel.

Further detailed category I installations requiring anti-icing are:

— communication equipment(i.e. antenna)

> **Guidance note 1:**
> Whip type antennae may not need heating arrangements.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

— scanning equipment (radar)
— navigation lights.

> **Guidance note 2:**
> Normally, the navigation lights develop sufficient heat to avoid ice deposit, except for forward lower light.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

— window wipers, where arranged

> **Guidance note 3:**
> Reference is made to ISO 17899 for marine electric window wipers.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

— equipment necessary for maintaining propulsion (i.e. cooling water sea chests)
— special equipment essential for safety, depending on type of vessel
— fire fighting lines and monitors (if arranged for fighting fires in other vessels and offshore structures, e.g., class notation **Fire Fighter**)
— anchors including windlass, chain and hawse pipe.

> **Guidance note 4:**
> For large vessels not occupied in coastal operations the anchor windlass can be accepted so arranged that a reasonable time for ice removal is necessary (see A300), and a combination of de-icing and anti-icing may give an acceptable availability.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

— air pipe vent heads for tanks.

> **Guidance note 5:**
> As a minimum this should be applied to ballast and fresh water tanks, as well as pressure relief valves for cargo tanks if relevant.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

— air horns
— lifeboats with davits
— pick-up boats including launching area
— rafts
— escape exits including doors
— storage facilities for lifesaving outfit, e.g., rescue suits, lines, picks and similar equipment for de-icing purposes
— ventilation inlets to spaces where ventilation is essential for the safe operation of the ship
— scuppers and drains for heated decks and spaces.

111 Specified installations (A300) of category II, shall have de-icing arrangements.

Further detailed category II installations requiring de-icing are:

— open deck areas
— gangways and stairways
— helicopter deck if any
— superstructure
— railings
— outdoor piping
— winches
— shark jaw and guide pins
— stern roller
— deck lighting equipment.

In addition to the above, other operational equipment may be required to have de-icing arrangements as found necessary.

112 Spaces containing piping or components with water shall have arrangements to prevent freezing of the water.

> **Guidance note:**
> Assessment of heating need shall be based on an outdoor temperature of $-30°C$.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

113 Installations made in connection with optional class notations are not required fitted with de-icing or anti-icing measures unless safety related.

> **Guidance note:**
> Rescue arrangements in a vessel with class notation **Standby Vessel** should be regarded as category I.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

114 For tankers the following ship-type specific installations shall be considered as category I:

— cargo tank ventilation arrangement (e.g. P/V valves, safety valves, flame arresters, P/V breakers).
— ESD valves (gas tankers).
— emergency towing arrangement.

115 Safe access to bow should as far as possible and practicable be located in an under-deck or on-deck tunnel. If this is not fulfilled, personal safety equipment suitable for safe walking on iced surfaces must be readily available for use close to the entrance to cargo deck.

116 For large vessels not occupied in coastal operations a longer ice removal period than defined in A305 may be considered for some of the category II installations, depending on an evaluation of the effect on the vessel's safety.

B 200 Special equipment

201 Protective clothing, safety lines, hand tools, crampons for shoes and similar equipment for de-icing purposes shall be kept onboard. The quantity of the equipment shall be sufficient for the assumed extent of manual de-icing.

202 The equipment for manual de-icing shall be kept in storage facilities and at locations protected from accretion of ice by covers or other anti-icing arrangements.

B 300 Power generator capacity

301 For calculation of required electric generator capacity (see Pt.4 Ch.8), the power requirements for the heating arrangements shall be included as specified below:

— 100% of electric power needed for anti-icing purposes
— 50% of electric power needed for de-icing purposes.

302   For anti-icing and de-icing arrangements applying heating by fluids in pipes, additional capacity of steam plants or thermal oil heaters must be calculated, taking 100% of the power consumption for category I installations, and 50% of the power consumption for category II installations.

C. Additional Requirements for Class Notation WINTERIZED COLD (t_1, t_2)

C 100   General

In addition to the requirements given in B, ships with class notation **WINTERIZED COLD (t_1, t_2)** shall fulfil the requirements given in this sub-section.

C 200   De-icing requirements

201   Ships with class notation **WINTERIZED COLD (t_1, t_2)** shall additionally fulfil the following:

— anti-icing and/or de-icing of mooring equipment
— de-icing and/or anti icing of cranes covered by **CRANE** notation
— de-icing arrangements for anchor chain
— fire main and foam main, if applicable, shall be heat traced or located inside a heated passageway
— water pipes on open decks and in non-heated spaces shall be arranged self-draining or provided with heat tracing
— hydraulic oil systems on open decks and in non-heated spaces shall be arranged with heating, alternatively special hydraulic oil for low temperatures shall be used
— horizontal surfaces of superstructure used as walkways shall be provided with heating to ease ice removal
— thermal protection suits including face masks, gloves and boots shall be provided for all crew members.
— ballast tanks and fresh water tanks located partly or fully above ballast water line shall be provided with means for heating unless it can be shown by calculations that the tanks will not freeze at the material design temperature.
— fuel oil storage tanks shall be provided with sufficient heating enabling transfer of fuel
— fuel oil transfer lines exposed to the low temperature environment shall have heat tracing
— where heating of horizontal deck areas and/or outdoor passageways is required in accordance with 101, the heating capacity shall not be less than 450 W/m^2.

> **Guidance note:**
> For calculation of heating need and choice of hydraulic oil for piping systems located outdoors, or in non heated spaces, the extreme design temperature **t_2** should be used.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

C 300   Ship arrangement

301   Life boats shall be located in deck-house recesses in superstructures or in separate semi-enclosures provided with protection from water spray. Free fall lifeboats are not accepted unless they have alternative means for lowering.

302   Anchor windlass shall be located inside a deckhouse, a semi-enclosure providing protection from water spray or inside a forecastle space.

303   The "Emergency towing arrangements" aft on tankers shall be located inside a deckhouse, in a semi-enclosed space or in an under-deck space.

304   The cargo manifold, and manifold valves on tankers shall be located in a semi-enclosed space. If protection by a semi-enclosure is impracticable alternative arrangements may be considered, e.g. hot water for de-icing in combination with heat tracing of valves and portable covers with heating.

305   Access to the bow shall be arranged via an on-deck trunk or under-deck passageway.

306   Navigation bridge wings shall be fully enclosed.

307   A heated watchman's shelter shall be arranged at the gangway or at a location covering both the gangway and the loading manifold.

308   Immersion suits shall be of the insulated type.

309   Engine room and other spaces containing important equipment shall be fitted with heating unless the equipment and piping installations are so designed and/or heated that they can operate at the lowest indoor temperature that can be generated by the lowest outdoor temperature, t_2, defined in the notation, with realistic space ventilation.

> **Guidance note 1:**
> Spaces that may need heating are: Emergency generator room, steering gear room, emergency fire pump room, CO_2 rooms, foam rooms, battery rooms, cargo compressor rooms, cargo pump rooms and bow thruster rooms. Insulation

of the rooms should also be considered in order to improve heating efficiency.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

Guidance note 2:
Heating of accommodation spaces is outside scope of class notations. However, it is assumed that the building specifications states the conditions for calculating heat balance at extreme temperature conditions, i.e. indoor temperature, humidity and re-circulation rate.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

310 Emergency generators shall be so arranged and located that they are able to operate at the extreme design temperature (t_2).

311 The machinery shall be so located and arranged that the machinery is able to start from a black out after 30 minutes, taking realistic temperature drop in the machinery spaces at the extreme design temperature into consideration. A procedure for start up after black out shall be approved and kept on board.

312 An ice search light shall be provided on the wheelhouse top capable of being remotely operated from the wheelhouse.

313 Water based full flooding fire extinguishing system for engine room is not accepted.

Guidance note:
This requirement is given with respect to the situation in the engine room after a fire extinguishing situation when the outdoor temperature is low, so that the water in the engine room may freeze and make the start-up impossible. A water based system may be considered if the engine room is fitted with sufficient heating from a heat source outside engine room to avoid temperature below 0°C at the extreme outdoor temperature, t_2, given in the notation. Such heating arrangements must not be destroyed by heat, or by the water extinguishing being released.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

C 400 Stability and Watertight Integrity

401 The vessels are in any intended service condition in cold climate, including additional weights due to accretion of ice as specified in A305, to be able to satisfy intact and damage stability criteria.

402 The ice load as calculated according to 403 shall be included in the loading conditions and satisfying applicable stability requirements.

The damage extent definition in combination with ice load may be taken from MSC/Circ. 1056. The damage extent reference shall be included in the loading manual.

403 The ice weight distribution shall as a minimum be as calculated from the following:

$$W = \frac{300}{K}(1 - C) \quad kg/m^2$$

where

W = the weight distribution over the horizontally projected area of the ship
K = constant, taken from Table C1
C = constant, taken from Table C2.

Table C1 K constant	
Summer freeboard	*K*
FB ≤ 2 m	1
2 m < FB ≤ 6 m	1.25
6 m < FB ≤ 9 m	1.5
FB > 9 m	1.75

Table C2 C constant	
Ship length	*C*
Lpp < 50 m	0
50 m ≤ Lpp < 100 m	0.075
100 m ≤ Lpp < 200 m	0.2
Lpp ≥ 200 m	0.25

For ships with length above 100 m, the weight distribution W aft of L/2 can be set to 100 kg/m^2 based on horizontally projected area.

404   The weight of ice on vertical surfaces has been taken into account and included in 403 and need not be calculated separately.

C 500   Hull material

501   Material used in external structures above the lower ice waterline (LIWL), as defined in Sec.1 B, shall be appropriate for the material design temperature given in the class notation. External structure is defined as the plating with stiffening to a distance of 0.6 meter inwards from the shell plating, exposed decks and sides of superstructure and deckhouses. The requirement also applies to masts.

502   Steel grades shall be selected in accordance with Pt.2 Ch.2 Sec.1 and as given in the requirements of the **DAT(t$_1$)** in Sec.7 B or as given in the requirements of the **PC** in Sec.8 H for ships built to the Rules in Sec.8.

C 600   Materials for equipment

601   All equipment exposed to the low temperature and being important for ship operations shall be made from materials suitable for the material design temperature specified in the class notation.

> **Guidance note:**
> Cranes are outside of class scope and the material requirements are therefore not considered relevant for cranes.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

602   Equipment for which 601 applies include, but is not limited to:

— anchor chain and chain stopper (e.g. shackle, end link, swivel, common link and kenter shackle of chain; lever, casing, shaft, shaft bearing, bush, roller of chain stopper; rod, casing, stopper bolt, bearing, bush, seat of anchor stopper)
— mooring equipment such as bollards, chocks, fairleads and roller pedestal (e.g. body and seat of fairleads and bollards; roller, pin, boss, bush, seat of deck stand rollers; body of sunken bits; chain wheel, gear wheel, shaft, casing, foundation bolt, drum, warping head of windlass/ mooring winches; mooring wires)
— lifeboats and/or rescue boat davits and winches
— rudderstock with flanges and bolts if flanged connection
— cargo oil piping, vents
— air pipes
— hatches for cargo holds and cargo tanks
— strongpoint for emergency towing
— hydraulic oil pipes for deck machinery or valve remote control unless heated and insulated
— hydraulic valve actuators
— control air pipes unless heated and insulated.
— helicopter deck, if applicable.

Windlass and mooring winches shall have foundation bolts and shaft bearing holding bolts made from low temperature steel. Grey cast iron shall not be used in any load bearing parts.

> **Guidance note:**
> Electric cables exposed to the low temperature should comply with the latest revision of Canadian CSA standard C22.2 No. 0.3 for impact test at -35°C and bending test at -40°C.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

603   The anchor chain is to be chosen in accordance with the following table:

	Chain type
$t_1 \geq -20°C$	K2
$t_1 < -20°C$	K3

604   For equipment or parts of equipment fabricated from plate material, steel grades shall be selected as follows, according to sec.7 B.

Class III:

— life/rescue boat davits
— mooring equipment

Class II:

— other equipment not belong to class I or class III

Class I

— natural vents
— doors
— access hatches

605 For equipment or parts of equipment fabricated from forged or cast material, the impact test temperature and energy shall fulfil the requirements in Table C3.

Table C3 Material testing		
t_1	t_{test}	*Charpy Value (minimum)*
$t_1 \geq -20°C$	0°C	27 J
$-20°C > t_1 > -35°C$	-20°C or (0°C)	27 J (48 J)
$t_1 \leq -35°C$	-20°C	27 J

606 For pipes, steel grades according to Pt.2 Ch.2 Sec.4 D shall be used. As an alternative, the pipe material can be selected in the same manner as for plate material as described in 603.

607 The wire ropes for lifeboat, rescue boat, and emergency towing shall fulfil the requirements in Table C3.

C 700 Testing of equipment

701 The following equipment shall be tested, as found necessary, for operation at the extreme design temperature, t_2:

— lifeboats and liferafts
— navigation equipment located outdoor
— communication equipment located outdoor.

D. Additional Requirements for Class Notation WINTERIZED ARCTIC (.. , ..)

D 100 General

101 In addition to the requirements given in B and C, ships with class notation **WINTERIZED ARCTIC (.. , ..)** shall fulfil the requirements given in this sub-section.

D 200 Ice strengthening and propulsion

201 The ship shall be built to an ice class notation according to Sec.3, Sec.4 or Sec.8.

202 Propellers intended for propulsion shall be of the controllable pitch (CP) type, when driven by diesel engines, or either of controllable pitch (CP) or fixed (FP) type when electrically driven, provided that the electrical systems are designed to provide 100% of the nominal torque from 100% to 20% of the rpm.

203 The propeller material shall be austenitic stainless steel or a material providing equivalent low temperature properties.

204 The location of the power generation machinery and its auxiliary equipment shall be split between at least two separate machinery spaces to limit the consequences of engine room fire or flooding.

The sources for space heating and heating of accommodation spaces shall also be divided between the machinery spaces.

The optional class notation **RPS** (see Pt.6 Ch.2) will satisfy 204.

D 300 Enhanced oil pollution prevention

301 The requirements for class notation **OPP-F** (see Pt.6 Ch.1) shall be complied with.

302 For oil tankers the accidental oil outflow index: O_M shall not exceed 0.01 calculated in accordance with revised MARPOL Annex I, Reg. 23.

303 Cargo oil lines shall be located under deck or inside a deck trunk, except for the loading and unloading manifold

304 Non-toxic and biodegradable oil shall be used for stern tube and CP propeller systems.

305 The bunker capacity shall be sufficient for at least 30 days operation of the ship's accommodation power, in addition to what is needed for the transit distance.

D 400 Miscellaneous

401 Helicopter landing facility shall be provided.

402 Ice surveillance radar shall be fitted.

SECTION 7
DAT(-X°C)

A. General

A 100 Classification

101 The requirements in this section apply to materials in ships of any type intended to operate for longer periods in areas with low air temperatures (i.e. regular service during winter to Arctic or Antarctic waters).

Vessels built in compliance with the requirements of Sec.7, will be assigned the notation **DAT(-X°C)**, indicating the design temperature applied as basis for approval.

A 200 Documentation

201 Specification of design temperature.

A 300 Definitions

301 *External structure* is defined, with respect to design temperature, as the plating with stiffening to a inwards distance of 0.6 metre from the shell plating, exposed decks and exposed sides and ends of superstructure and deckhouses.

302 Temperature terms definitions (see also Fig.1):

Design temperature is a reference temperature used as a criterion for the selection of steel grades. The design temperature for external structures is defined as the lowest mean daily average air temperature in the area of operation. This temperature is considered to be comparable with the lowest monthly mean temperature in the area of operation −2°C. If operation is restricted to «summer» navigation the lowest monthly mean temperature comparison may only be applied to the warmer half of the month in question.

> **Guidance note:**
> The design temperatures are defined by the user when signing the class contract. The extreme design temperature may be set to about 20°C below the lowest mean daily average air temperature, or the material design temperature, if information for the relevant trade area is not available.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

Mean daily average temperature is the statistical mean average temperature for a specific calendar day, based on a number of years of observations (= MDAT).

Monthly mean temperature is the average of the mean daily temperature for the month in question (= MAMDAT).

Lowest mean daily average temperature is the lowest value on the annual mean daily temperature curve for the area in question. For seasonally restricted service the lowest value within the time of operation applies.

Lowest monthly mean temperature is the monthly mean temperature for the coldest month of the year.
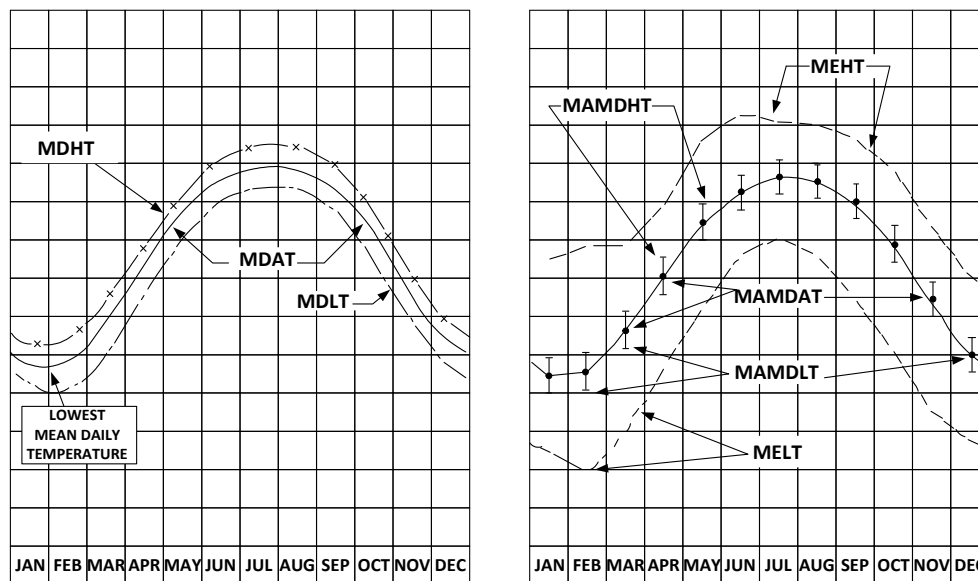
Fig. 1
Commonly used definitions of temperatures

MDHT	Mean* Daily High (or maximum) Temperature
MDAT	Mean* Daily Average Temperature
MDLT	Mean* Daily Low (or minimum) Temperature
MAMDHT	Monthly Average** of MDHT
MAMDAT	Monthly Average** of MDAT
MAMDLT	Monthly Average** of MDLT
MEHT	Monthly Extreme High Temperature (ever recorded)
MELT	Monthly Extreme Low Temperature (ever recorded).

*   Mean: Statistical mean over observation period (at least 20 years).
**   Average: Average during one day and night.

B. Material Selection

B 100   Structural categories

101   Structural strength members or areas are classified in 4 different classes for the purpose of selecting required material grades. The relevant members are classified as specified in Table B1. The classes are generally described as follows:

Class IV:

— Strakes in the strength deck and shell plating amidships intended as crack arrestors.
— Highly stressed elements in way of longitudinal strength member discontinuities.

Class III:

— Plating chiefly contributing to the longitudinal strength.
— Fore ship substructure in vessels with notations **Icebreaker** or **POLAR**.
— Appendages of importance for the main functions of the vessel, e.g. stern frames, rudder horns, rudder, propeller nozzles and shaft bracket.
— Aft ship substructures in vessels equipped with podded propulsors and azimuth thrusters, and intended for continuous operation astern.
— Foundations and main supporting structures for heavy machinery and equipment.
— Crane pedestal and main supporting structure

— Main supporting structure for helideck sub-structure
— Frames for windlasses, emergency towing and chain stopper, when equipment is welded to foundation or deck (i.e. not applicable when equipment is bolted to foundation or deck).

Guidance note:
Main supporting structures are primary load bearing members such as plates, girders, web frames/bulkheads and pillars.

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Class II:

— Structures contributing to longitudinal and/or transverse hull girder strength in general.
— Gutter bars of oil spill coamings attached to hull.
— Structures for subdivisions.
— Structures for cargo, bunkers and ballast containment.
— Internal longitudinal members (stiffeners, girders) on plating exposed to external low temperatures where class III and IV is required.
— Deck house or superstructure exposed to longitudinal stresses within 0.6L amidship.

Class I:

— Local members in general unless upgraded due to special considerations of loading rate, level and type of stress, stress concentrations and load transfer points and/or consequences of failure.
— Deckhouse or superstructure in general.
— Cargo hatch covers.

Table B1 Material Classes of strength members in general.

Structural member	Within 0.4 L amidships (Within 0.2 L aft of amidships and 0.3 L forward of amidships in vessels with notation Icebreaker or POLAR)	Elsewhere
SECONDARY: A1. Longitudinal bulkhead strakes, other than that belonging to the Primary category A2. Deck plating exposed to weather, other than that belonging to the Primary or Special category A3. Side plating A4. Transverse bulkhead plating	II	II
PRIMARY: B1. Bottom plating, including keel plate B2. Strength deck plating, excluding that belonging to the Special category B3. B3. Continuous longitudinal members above strength deck, excluding hatch coamings B4. B4. Uppermost strake in longitudinal bulkhead B5. Vertical strake (hatch side girder) and uppermost sloped strake in top wing tank	III [7]	II
SPECIAL: C1. Sheer strake at strength deck [1], [2] C2. Stringer plate in strength deck [1], [2] C3. Deck strake at longitudinal bulkhead, excluding deck plating in way of inner-skin bulkhead of double-hull ships [1] C4. Strength deck plating at outboard corners of cargo hatch openings in container carriers and other ships with similar hatch opening configurations [3] C5. Strength deck plating at corners of cargo hatch openings in bulk carriers, ore carriers combination carriers and other ships with similar hatch opening configurations [4] C7. Bilge strakes [1],[8],[9] C8. Longitudinal hatch coamings of length greater than 0.15L [5] C9. End brackets and deck house transition of longitudinal cargo hatch coamings [5]	IV	III [6]

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

2) Not to be less than grade NV E/EH within 0.4 L amidships in ships with length exceeding 250 m.

3) Min. class IV within cargo region.

4) Class IV within 0.6L amidships and class III within rest of cargo region.

5) Not to be less than grade NV D/DH.

6) May be class II outside 0.6 L amidships.

7) May be class II if relevant midship section modulus as built is not less than 1.5 times the rule midship section modulus, and the excess is not credited in local strength calculations.

8) Not to be less than grade NV D/DH within 0.4 L amidships in ships with length exceeding 250 m.

9) May be of class III in ships with double bottom over the full breadth and length less than 150 m.

102 The material class requirement may be reduced by one class for:

— Laterally loaded plating having a thickness exceeding 1.25 times the requirement according to design formulae.
— Laterally loaded stiffeners and girders having section modulus exceeding 1.5 times the requirement according to design formulae.

B 200 Selection of steel grades

201 Plating materials for various structural categories as defined in 100 of exposed members above the ballast waterline of vessels with class notation **DAT (-XºC)** shall not be of lower grades than obtained from Fig.2 using the specified design temperature.

Plating materials of non-exposed members shall not be of lower grade than obtained according to Pt.3 Ch.1 Sec.2 Table B1 and or Pt.3 Ch.2 Sec.2 Table B1.
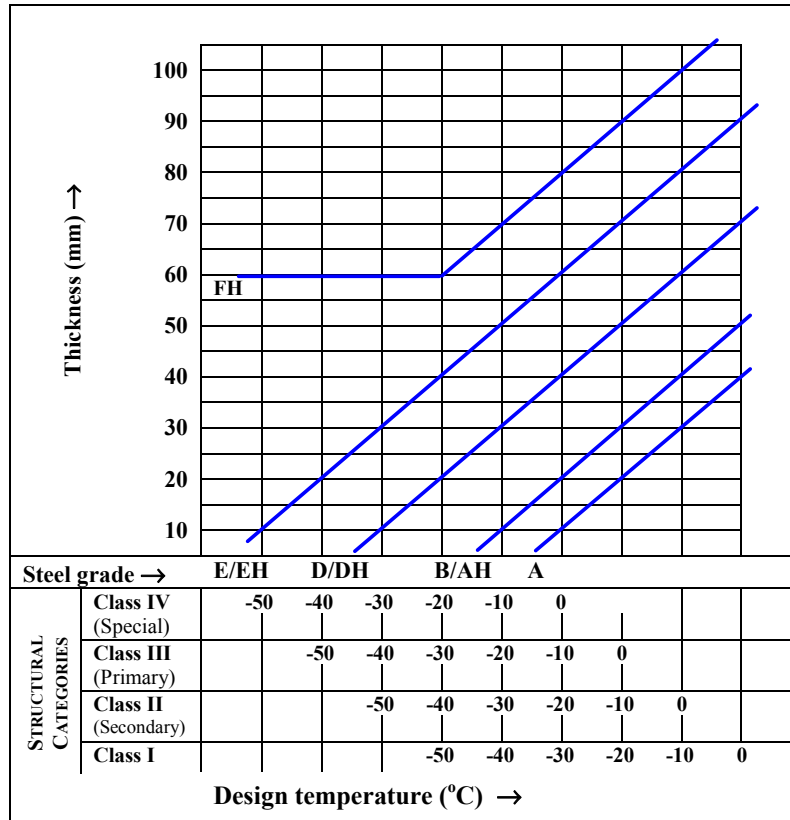
Fig. 2
Required steel grades

Guidance note:
When the structural category is known the material grade can be selected based on the design temperature and plate thickness. E.g. if a 30 mm plate should be applied for structural category III with a design temperature of –30ºC, grade E or EH need to be applied. Boundary lines form part of the lower grade.

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202 Forged or cast materials in structural members subject to lower design temperatures than –10°C according to B100 shall fulfil requirements given in Sec.6 C605.

SECTION 8
POLAR CLASS

A. General

A 100   Application

101   The requirements in this section are in general equivalent to the IACS Unified Requirements for Polar Ships (URI1 to URI3), which apply to ships constructed of steel and intended for navigation in ice-infested polar waters.

102   The rules consider hull structure, main propulsion, steering gear, emergency and essential auxiliary systems essential for the safety of the ship and the survivability of the crew.

> **Guidance note:**
> These rules do not consider aspects related to the operation of onboard equipment in cold climate. It is recommended that vessels intended to operate in cold climate environments for longer periods comply with the requirements as given in Sec.6, Winterization
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

103   Ships that comply with the requirements of Section 8 can be considered for a Polar Class notation as listed in Table A1. If the hull and machinery are constructed such as to comply with the requirements of different polar classes, then the ship shall 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.

104   Ships designed for ice breaking for the purpose of escort and ice management, and which are assigned a polar class notation **PC-1** – **PC-6**, may be given the additional notation **Icebreaker**.

A 200   Polar classes

201   The Polar Class (**PC**) notations and descriptions are given in Table A1. It is the responsibility of the owner to select an appropriate Polar Class. The descriptions in Table A1 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.

202   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.

Table A1 - 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

A 300   Documentation

301   UIWL and LIWL, as defined in Sec.1, shall be indicated on the shell expansion plan together with the lines separating the various hull areas (ref. A500). The ship displacement at UIWL shall also be stated.

302   Applicable design specifications for the operation of the vessel in ice infested waters shall be stated in the ship's loading manual, see Pt.3 Ch.1 Sec.5 F and Pt.3 Ch.2 Sec.4 E. Possible design specifications are:

— UIWL and LIWL
— loading conditions with respect to strength and stability
— design speed
— ramming speed
— instruction for filling of ballast tanks
— astern operation in ice
— design temperature.

Guidance note:

The design temperature reflects the lowest mean daily average air temperature in the intended area of operation. An extreme air temperature about 20°C below this may be tolerable to the structures and equipment from a material point of view. For calculations where the most extreme temperature over the day is relevant, the air temperature can be set 20°C lower than the design temperature in the notation.

If no specification of the design temperature has been given, the values -35ºC for notations **PC-1** to **PC-5** and -25ºC for notations **PC-6** and **PC-7** will be considered.

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

304 Detailed drawings of the main propulsion machinery. Description of the main propulsion, steering, emergency and essential auxiliaries shall include operational limitations. Information on essential main propulsion load control functions.

305 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.

306 Calculations and documentation indicating compliance with the requirements in subsections I and J.

307 For ships with class notation **PC-6** or **PC-7**, information whether equivalency with notation **1A Super** or **1A** (DNV: **ICE-1A*** or **ICE-1A**) is requested, if applicable.

Guidance note:

DNV Ice Class notation	Equivalent Finnish-Swedish ice class
PC-6 [1]	**1A Super**
PC-7 [1]	**1A**
[1] The equivalence may be granted provided that the engine output of the ship complies with the requirements of chapter 3 in the FMA Ice Class Rules, 2002 (20.9.2002 No. 5/30/2002, FMA Bulletin 13/1.10.1002).	

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

A 400   Ship design and arrangement

401 When the notation **Icebreaker** has been specified, the powering and the bow form shall be such that the ship can break the typical level ice condition, as defined in Table A1 for the specified Polar Class, effectively and at continuous speed.

EXTENT OF HULL AREAS

For PC1, 2, 3 &4   x = 1.5 m;
For PC5, 6, 7   x = 1.0 m;
with "x" measured at aft end of bow region

WL Angle = 10 degrees at UIWL

0.04L aft of WL Angle = 0 degrees at UIWL

UIWL
LIWL

1.5m

Si   Mi   BIi   B

Sl   Ml   BIl

2.0 m

0.7b =>0.15L

AP

WL Angle = 0 degrees

WL Angle = 10 degrees

b=distance from the AP to maximun
half breadth at UIWL

Si   Sl   Sb   Mb   BIb   B

Ml   BIl

Mi   UIWL
LIWL

Ml   Mb

Midbody
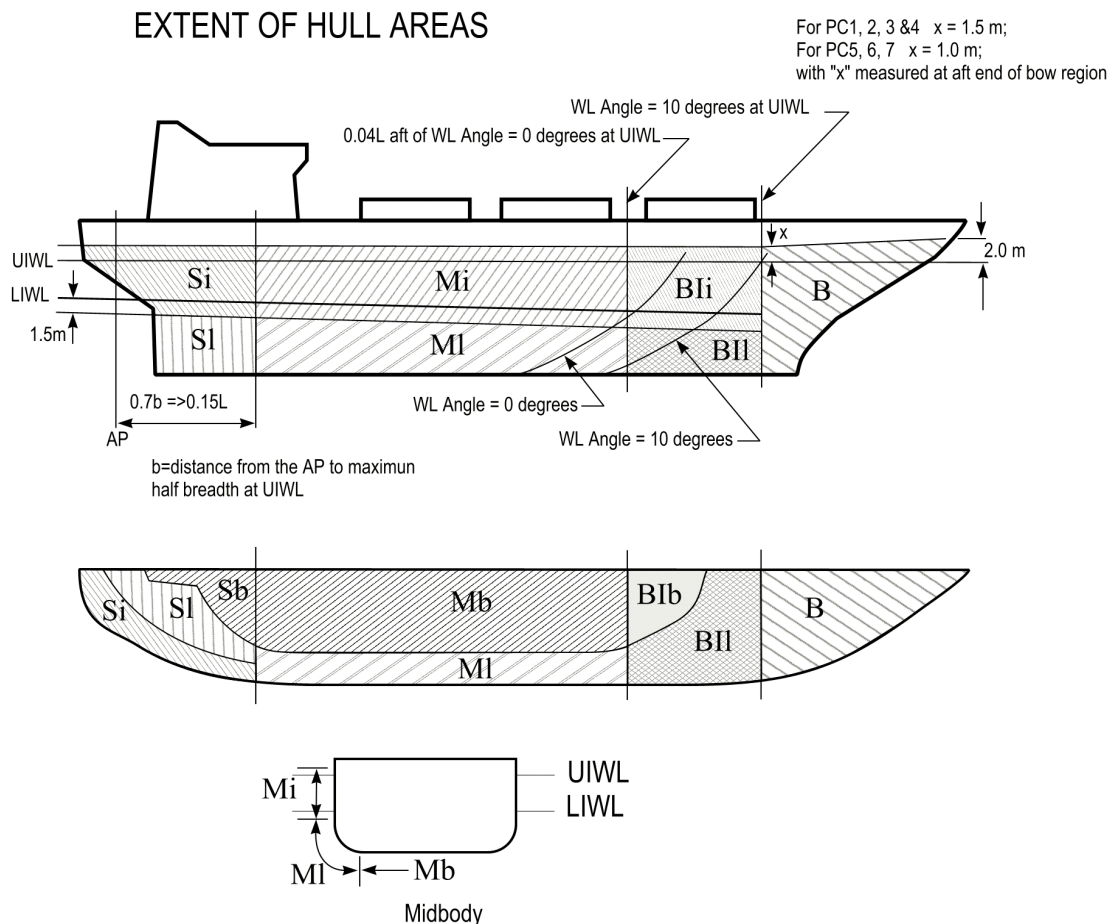
Fig. 1
Hull Area Extents

A 500   Design principles – hull areas

501   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 Ice belt regions. The extent of each Hull Area is illustrated in Fig.1.

502   The upper ice waterline (UIWL) and lower ice waterline (LIWL) are as defined in Sec.1.

503   Fig.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.

504   Fig.1 notwithstanding, the aft boundary of the Bow region need not be more than 0.45 L aft of the forward perpendicular (F.P.).

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

506   If a ship is intended to operate astern in ice regions, the aft section of the ship shall be designed using the Bow and Bow Intermediate hull area requirements as given in B700.

A 600   System design

601   Systems, subject to damage by freezing, shall be drainable.

602   Vessels classed **PC-1**, to **PC-5** inclusive shall have means provided to ensure sufficient vessel operation in the case of propeller damage including CP-mechanism (i.e. pitch control mechanism).

Sufficient vessel operation means that the vessel should be able to reach safe harbour (safe location) where repair can be undertaken in case of propeller damage. This may be achieved either by a temporary repair at sea, or by towing assuming assistance is available (condition for approval).

603   Means shall be provided to free a stuck propeller by turning backwards. This means that a plant intended for unidirectional rotation must be equipped at least with a sufficient turning gear that is capable of turning the propeller in reverse direction.

604 *Propulsion power*

Guidance note:

For **PC** no explicit power requirement exists. However, according to "IMO guidelines for Ships operating in Polar waters" ships shall have sufficient propulsion power and sufficient manoeuvrability for operation in intended area.

Engine power may be selected according to current DNV rule practice. We advise to use model test alternative.

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B. Design Ice Loads – Hull

B 100   General

101   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.

102   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).

103   Within the Bow area of all polar classes, and within the Bow Intermediate Ice belt area of polar classes **PC-6** and **PC-7**, 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).

104   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.

105   Design ice forces, calculated according to B, are in general considered valid for bow forms where the buttock angle, γ, is less than 80 degrees and the frame angle, β, is positive and more than 10 degrees, see Fig.2. Design ice forces for other bow forms and for bow forms that are otherwise considered to be non icebreaking will be specially considered.

106   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, as given in 107 – 109, which shall be considered as alternative to the design accelerations given in Pt.3 Ch.1 Sec.4.

107   Maximum longitudinal impact acceleration at any point along the hull girder,

$$a_l = \left(\frac{F_{IB}}{\Delta_{tk}}\right)\left(1.1\tan(\gamma+\phi)+7\frac{H}{L}\right) \; [\text{m/s}^2]$$

108   Combined vertical impact acceleration at any point along the hull girder,

$$a_v = \left(\frac{F_{IB}}{\Delta_{tk}}\right)F_x \; [\text{m/s}^2]$$

F_x = 1.3 at F.P.
  = 0.2 at midships
  = 0.4 at A.P.
  = 1.3 at A.P. for vessels conducting ice breaking astern.

Intermediate values to be interpolated linearly.

109   Combined transverse impact acceleration at any point along hull girder,

$$a_t = 3F_{Bow}\frac{F_x}{\Delta_{tk}}$$

F_x = 1.5 at F.P.
  = 0.25 at midships
  = 0.5 at A.P.
  = 1.5 at A.P. 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_{tk} = displacement at UIWL [kt]

H = vertical distance from UIWL to the point being considered [m]

F_{IB} = vertical impact force, defined in D200

F_{Bow} = as defined in B501.

B 200 Glancing impact load characteristics

201 The parameters defining the glancing impact load characteristics are reflected in the Class Factors listed in Table B1.

Table B1 - 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)*
PC-1	17.69	68.60	2.01	250	7.46
PC-2	9.89	46.80	1.75	210	5.46
PC-3	6.06	21.17	1.53	180	4.17
PC-4	4.50	13.48	1.42	130	3.15
PC-5	3.10	9.00	1.31	70	2.50
PC-6	2.40	5.49	1.17	40	2.37
PC-7	1.80	4.06	1.11	22	1.81

B 300 Bow area

301 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 Fig.2.
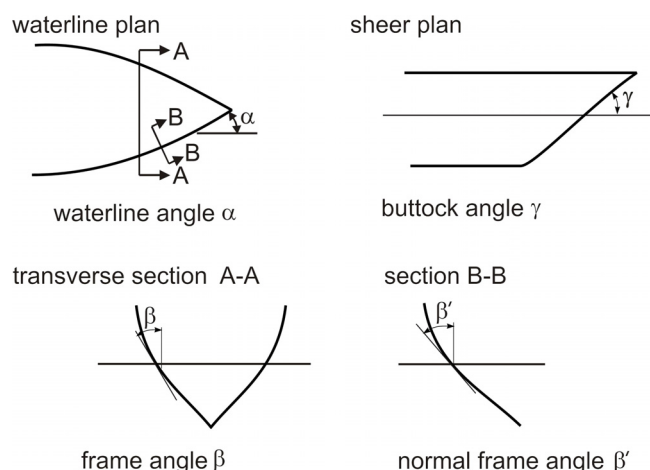
Fig. 2
Definition of hull angles

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]

$\tan(\beta)$ = $\tan(\alpha)/\tan(\gamma)$

$\tan(\beta')$ = $\tan(\beta)\cos(\alpha)$.

302 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) shall be calculated with respect to the mid-length position of each sub-region (each maximum of F, Q and P shall be used in the calculation of the ice load parameters P_{avg}, b and w).

303 The bow area load characteristics are determined as follows:

a) Shape coefficient, fa_i, shall be taken as

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

where

$\text{fa}_{i,1}$ = $(0.097 - 0.68 (x/L_{wl} - 0.15)^2)\cdot \alpha_i / (\beta'_i)^{0.5}$
$\text{fa}_{i,2}$ = $1.2\cdot CF_F / (\sin (\beta'_i)\cdot CF_C\cdot \Delta_{tk}^{0.64})$
$\text{fa}_{i,3}$ = 0.60
i = sub-region considered
L_{wl} = ship length as defined in Pt.3 Ch1/Pt.3 Ch2, measured on the upper ice waterline (UIWL) [m]
x = distance from the forward perpendicular (FP) to station under consideration [m]
α = waterline angle [deg], see Fig.2
β' = normal frame angle [deg], see Fig.2
Δ_{tk} = ship displacement [kt] at UIWL, not to be taken less than 5 kt
CF_C = Crushing Failure Class Factor from Table B1
CF_F = Flexural Failure Class Factor from Table B1

b) Force, F:

$F_i = \text{fa}_i \cdot CF_C \cdot \Delta_{tk}^{0.64}$ [MN]
where

i = sub-region considered
fa_i = shape coefficient of sub-region i
CF_C = Crushing Failure Class Factor from Table B1
Δ_{tk} = ship displacement [kt] at UIWL, not to be taken less than 5 kt

c) Load patch aspect ratio, AR:

$AR_i = 7.46\cdot \sin (\beta'_i) \geq 1.3$
where

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

d) Line load, Q:

$Q_i = F_i^{0.61}\cdot CF_D / AR_i^{0.35}$ [MN/m]
where

i = sub-region considered
F_i = force of sub-region i [MN]
CF_D = Load Patch Dimensions Class Factor from Table B1
AR_i = load patch aspect ratio of sub-region i

e) Pressure, P:

$P_i = F_i^{0.22}\cdot CF_D^2\cdot AR_i^{0.3}$ [MPa]
where

i = sub-region considered
F_i = force of sub-region i [MN]
CF_D = Load Patch Dimensions Class Factor from Table B1
AR_i = load patch aspect ratio of sub-region i

B 400 Hull areas other than the bow

401 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}:

$F_{NonBow} = 0.36\cdot CF_C\cdot DF$ [MN]

where

CF_C = Crushing Force Class Factor from Table B1

CF_D = Load Patch Dimensions Class Factor from Table B1

DF = ship displacement factor

= $\Delta_{tk}^{0.64}$ if $\Delta_{tk} \leq CF_{DIS}$

= $CF_{DIS}^{0.64} + 0.10 (\Delta_{tk} - CF_{DIS})$ if $\Delta_{tk} > CF_{DIS}$

Δ_{tk} = ship displacement [kt] at UIWL, not to be taken less than 10 kt

CF_{DIS} = Displacement Class Factor from Table B1

b) Line Load, Q_{NonBow}:

Q_{NonBow} = $0.639 \cdot F_{NonBow}^{0.61} \cdot CF_D$ [MN/m]

where

F_{NonBow} = force from (a) [MN]

CF_D = Load Patch Dimensions Class Factor from Table B1.

B 500   Design load patch

501   In the Bow area for all PC-classes, and the Bow Intermediate Ice belt area for ships with class notation **PC-6** and **PC-7**, the design load patch has dimensions of width, w_{Bow}, and height, b_{Bow}, defined as follows:

w_{Bow} = F_{Bow} / Q_{Bow} [m]

b_{Bow} = Q_{Bow} / P_{Bow} [m]

where

F_{Bow} = maximum force F_i in the Bow area, ref. 303 b) [MN]

Q_{Bow} = maximum line load Q_i in the Bow area, ref. 303 d) [MN/m]

P_{Bow} = maximum pressure P_i in the Bow area, ref. 303 e) [MPa]

502   In hull areas other than those covered by B501, the design load patch has dimensions of width, w_{NonBow}, and height, b_{NonBow}, defined as follows:

w_{NonBow} = F_{NonBow} / Q_{NonBow} [m]

b_{NonBow} = $w_{NonBow} / 3.6$ [m]

where

F_{NonBow} = ice force as given by 401 [MN]

Q_{NonBow} = ice line load as given by 401 [MN/m].

B 600   Pressure within the design load patch

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

$P_{avg} = F / (b \cdot w)$ [MPa]

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]

602   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 B2 are used to account for the pressure concentration on localized structural members.

B 700   Hull area factors

701   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 B3.

702   In the event that a structural member spans across the boundary of a hull area, the largest hull area factor

shall be used in the scantling determination of the member.

703 Due to their increased manoeuvrability, ships having propulsion arrangements with azimuting thruster(s) or "podded" propellers shall have specially considered Stern Ice belt (S_i) and Stern Lower (S_l) hull area factors.

704 For ships intended to operate astern in ice regions, the area factor as for the bow shall be used for all structure within the stern ice belt area, and the bow intermediate lower and bottom area factors increased by 10% shall be used for the stern lower and bottom areas, appendages included. In addition Stern Intermediate areas shall be defined for the aft ship as for the fore ship. The Area Factor (AF) for ships intended to operate astern is listed in Table B4.

705 For ships for which the class notation **Icebreaker** has been requested, the area factor for any hull area shall not be taken less than as given for **PC-3**. In addition the hull area factors for the stern ice belt and the stern lower area shall be increased by the factor 1.25. The hull area factor for the stern area need, however, in no case to be taken larger than specified for the bow region. The Area Factor (AF) for ships with class notation Icebreaker is listed in Table B5.

Table B2 - Peak Pressure Factors		
Structural Member		*Peak Pressure Factor (PPF$_i$)*
Plating	Transversely-Framed	$PPF_p = (1.8 - s) \geq 1.2$
	Longitudinally-Framed	$PPF_p = (2.2 - 1.2 \cdot s) \geq 1.5$
Frames in Transverse Framing Systems	With Load Distributing Stringers[1]	$PPF_t = (1.6 - s) \geq 1.0$
	With No Load Distributing Stringers[1]	$PPF_t = (1.8 - s) \geq 1.2$
Load Carrying Stringers Side and Bottom Longitudinals Web Frames		$PPF_s = 1$, if $S_w \geq 0.5 \cdot w$ $PPF_s = 2.0 - 2.0 \cdot S_w / w$, if $S_w < (0.5 \cdot w)$
where	s = frame or longitudinal spacing [m] S_w = web frame spacing [m] w = ice load patch width [m]	

[1] In order that the reduced PPF_t value may be used, the Load Distributing Stringer shall be located at or close to the middle of span of the transverse frames, to have web height not less than the 80% of the transverse frames, and to have net web thickness not less than the net web thickness of the transverse frames.

Table B3 Hull Area Factors (AF)									
Hull Area		*Area*	*Polar Class*						
			PC-1	**PC-2**	**PC-3**	**PC-4**	**PC-5**	**PC-6**	**PC-7**
Bow (B)	All	B	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Bow Intermediate (BI)	Ice belt	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)	Ice belt	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)	Ice belt	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	**	**

Notes:

*   See B103.
**   Indicates that strengthening for ice loads is not necessary.

Table B4 Hull Area Factors (AF) for ships intended to operate astern

Hull Area		Area	Polar Class						
			PC-1	PC-2	PC-3	PC-4	PC-5	PC-6	PC-7
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 Intermediate (SI)***	Icebelt	SI_i	0.90	0.85	0.85	0.80	0.80	1.00*	1.00*
	Lower	SI_l	0.70	0.65	0.65	0.60	0.55	0.55	0.50
	Bottom	SI_b	0.55	0.50	0.45	0.40	0.35	0.30	0.25
Stern (S)	Icebelt	S_i	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Lower	S_l	0.77	0.72	0.72	0.66	0.61	0.61	0.55
	Bottom	S_b	0.61	0.55	0.50	0.44	0.39	0.33	0.28

Notes:

* See B103.

** Indicates that strengthening for ice loads is not necessary.

*** The Stern intermediate region, if any, for vessels intended to operate astern is to be defied as the region forward of Stern region to section 0.04 L forward of WL angle = 0 degrees at UIWL (ref. definition of Bow Intermediate in Fig.1).

Table B5 Hull Area Factors (AF) for ships with class notation Icebreaker

Hull Area		Area	Polar Class						
			PC-1	PC-2	PC-3	PC-4	PC-5	PC-6	PC-7
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	0.85	0.85	1.00*	1.00*
	Lower	BI_l	0.70	0.65	0.65	0.65	0.65	0.65	0.65
	Bottom	BI_b	0.55	0.50	0.45	0.45	0.45	0.45	0.45
Midbody (M)	Icebelt	M_i	0.70	0.65	0.55	0.55	0.55	0.55	0.55
	Lower	M_l	0.50	0.45	0.40	0.40	0.40	0.40	0.40
	Bottom	M_b	0.30	0.30	0.25	0.25	0.25	0.25	0.25
Stern (S)	Icebelt	S_i	0.94	0.88	0.81	0.81	0.81	0.81	0.81
	Lower	S_l	0.56	0.50	0.44	0.44	0.44	0.44	0.44
	Bottom	S_b	0.35	0.30	0.30	0.30	0.30	0.30	0.30

Notes:

* See B103.

B 800 Ice compression load amidships

801 The ship shall de designed for the load given in Sec.4 D300. The parameter for ice thickness to be as given in Sec.4 for an assumed similar ice class, and in agreement with Class. The load application and strength calculations to be in line with Sec.4 E300.

C. Local Strength Requirements

C 100 Shell plate requirements

101 The required minimum shell plate thickness, t, is given by:

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

where

t_{net} = plate thickness required to resist ice loads according to C102 [mm]

t_s = corrosion and abrasion allowance according to H100 [mm]

102 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:

$$t_{net} = 500s\sqrt{\frac{AF \cdot PPF_p \cdot P_{avg}}{\sigma_F}}\frac{1}{1+s/(2b)} \quad [\text{mm}]$$

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

$$t_{net} = 500s\sqrt{\frac{AF \cdot PPF_p \cdot P_{avg}}{\sigma_F}}\frac{1}{1+s/(2l)} \quad [\text{mm}]$$

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

$$t_{net} = 500s\sqrt{\frac{AF \cdot PPF_p \cdot P_{avg}}{\sigma_F}}\sqrt{2\frac{b}{s}-\left(\frac{b}{s}\right)^2}\frac{1}{1+s/(2l)} \quad [\text{mm}]$$

In the case of obliquely-framed plating ($70° > \Omega > 20°$), linear interpolation shall be used.

where:

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

s = transverse frame spacing in transversely-framed ships or longitudinal frame spacing in longitudinally-framed ships [m]

AF = Hull Area Factor from Table B3

PPF_p = Peak Pressure Factor from Table B2

P_{avg} = average patch pressure as given in B600 [MPa]

σ_F = minimum upper yield stress of the material [N/mm²]

b = height of design load patch [m], where b ≤ (l – s/4) in the case of transversely framed plating

l = distance between frame supports, i.e. equal to the frame span as given in C205, 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.

oblique view   oblique view

frames
frames

waterline $\Omega = 20°$ $\Omega = 70°$

view normal to shell   view normal to shell
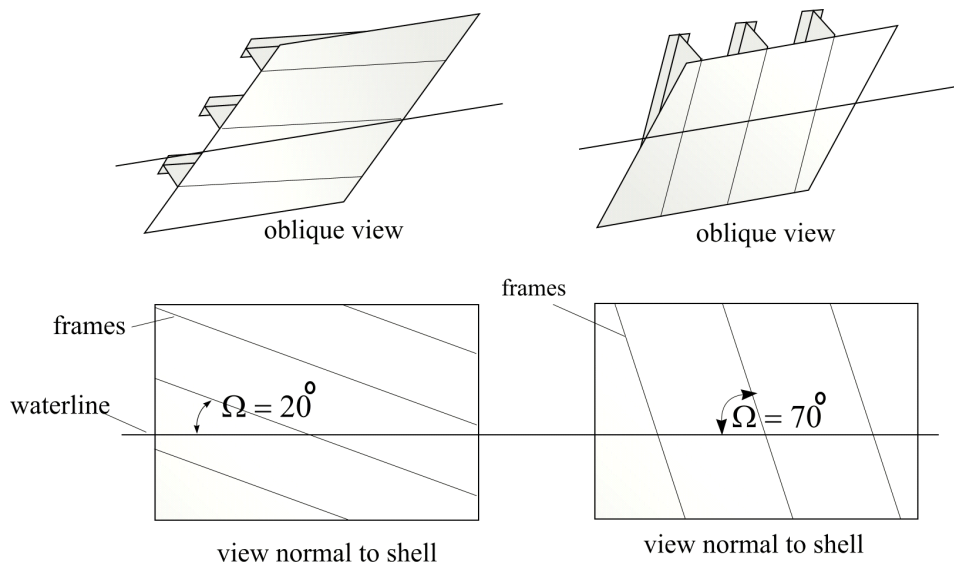
Fig. 3
Shell Framing Angle Ω

C 200   Framing general

201   Framing members of Polar class ships shall be designed to withstand the ice loads defined in B.

202   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 Fig.1.

203 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 should be assumed unless the connection can be demonstrated to provide significant rotational restraint. Fixity shall be ensured at the support of any framing which terminates within an ice-strengthened area.

204 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, shall be in accordance with 900 and Pt.3 Ch.1 Sec.3 C as applicable

205 The design span of framing members shall generally be determined according to Pt.3 Ch.1 Sec.3 C100. However, the span length is only to be reduced in accordance with Pt.3 Ch.1 Sec.3 C100 provided the end brackets fitted are flanged or the edge length in mm is equal to or less than $600\, t_{bn}/\sigma_F^{0.5}$.

t_{bn} = net thickness of bracket [mm]

σ_F = minimum upper yield stress of the material [N/mm^2]

206 Load-carrying stringers and web frames are generally to be of symmetrical cross-section. When the flange is arranged to be unsymmetrical, an effective tripping support shall be provided at the middle of each span length.

207 When calculating the section modulus and shear area of a framing member, net thicknesses of the web, flange (if fitted) and of the attached shell plating shall 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.

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

$$A_w = h\ t_{wn}\ \sin \varphi_w\, /100\ \ [\text{cm}^2]$$

where

h = height of stiffener [mm], see Fig.4

t_{wn} = net web thickness [mm]

$\quad = t_w - t_s$

t_w = as built web thickness [mm], see Fig.4

t_s = corrosion addition [mm], as given in H103, to be subtracted from the web and flange thickness

φ_w = smallest angle between shell plate and stiffener web, measured at the midspan of the stiffener, see Fig.4. The angle φ_w may be taken as 90 degrees provided the smallest angle is not less than 75 degrees.
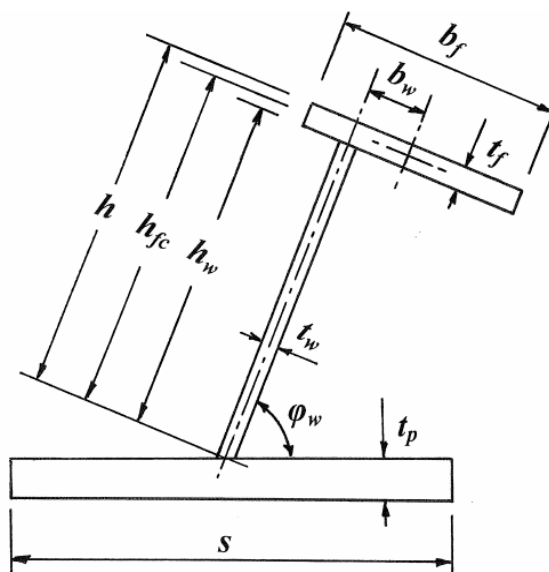

Fig. 4
Stiffener geometry

209 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:

$$Z_p = A_{pn} \cdot \frac{t_{pn}}{20} + \frac{h_w^2 \cdot t_{wn} \cdot sin\,\varphi_w}{2000} + A_{fn} \cdot \frac{h_{fc} \cdot sin\,\varphi_w - b_w \cdot cos\,\varphi_w}{10} \quad [cm^3]$$

h, t_{wn}, and φ_w are as given in C207 and s as given in C102.

A_{pn} = net cross-sectional area of the local frame [cm^2]
t_{pn} = fitted net shell plate thickness [mm] (shall comply with t_{net} as required by C102)
h_w = height of local frame web [mm], see Fig.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 Fig.4
b_w = distance from mid thickness plane of local frame web to the centre of the flange area [mm], see Fig.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:

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

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

$$Z_p = t_{pn} \cdot s \cdot \left(z_{na} + \frac{t_{pn}}{2} \right) \cdot sin\,\varphi_w + \frac{\left(\left(h_w - z_{na}\right)^2 + z_{na}^2\right) \cdot t_{wn} \cdot sin\,\varphi_w}{2000} + \frac{A_{fn} \cdot \left(\left(h_{fc} - z_{na}\right) \cdot sin\,\varphi_w - b_w \cdot cos\,\varphi_w\right)}{10} [cm^3]$$

210   In the case of oblique framing arrangement 70° > Ω > 20°, where Ω is defined as given in C102, linear interpolation shall be used.

C 300   Framing – Transversely framed side structures and bottom structures

301   The local frames in transversely-framed side structures and in bottom structures (i.e. hull areas BI_b, M_b and S_b) shall 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 patch load that causes the development of a plastic hinge mechanism.

302   The actual net effective shear area of the frame, A_w, as defined in C208, shall comply with the following condition:
$A_w \geq A_t$, where:

A_t = $100^2 \cdot 0.5 \cdot LL \cdot s \cdot (AF \cdot PPF_t \cdot P_{avg}) / (0.577 \cdot \sigma_F)$ [cm^2]
where

LL   = length of loaded portion of span
    = lesser of a and b [m]
a   = frame span as defined in C205 [m]
b   = height of design ice load patch as given in B500 [m]
s   = transverse frame spacing [m]
AF   = Hull Area Factor from Table B3
PPF_t = Peak Pressure Factor from Table B2
P_{avg} = average pressure within load patch as given in B600 [MPa]
σ_F = minimum upper yield stress of the material [N/mm^2]

303   The actual net effective plastic section modulus of the plate/stiffener combination, Z_p, as defined in C209, shall comply with the following condition: $Z_p \geq Z_{pt}$, where Z_{pt} shall 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 reflects the two conditions:

Z_{pt} = $100^3 \cdot LL \cdot Y \cdot s \cdot (AF \cdot PPF_t \cdot P_{avg}) \cdot a \cdot A_1 / (4 \cdot \sigma_F)$ [cm^3]

where:

AF, PPF_t, P_{avg}, LL, b, s, a and σ_F are as given in C302.

Y   = 1 - 0.5·(LL / a)

A_1 = maximum of:

A_{1A} = $1 / (1 + j / 2 + k_w \cdot j / 2 \cdot [(1 - a_1^2)^{0.5} - 1])$
A_{1B} = $(1 - 1 / (2 \cdot a_1 \cdot Y)) / (0.275 + 1.44 \cdot k_z^{0.7})$

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 C302 [cm²]
A_w = effective net shear area of transverse frame (calculated according to C208 [cm²]
k_w = $1 / (1 + 2 \cdot A_{fn} / A_w)$ with A_{fn} as given in C209
k_z = z_p / Z_p in general
0.0 when the frame is arranged with end bracket
z_p = sum of the individual plastic section modulus of flange and shell plate as fitted [cm³]
= $(b_f \cdot t_{fn}^2 / 4 + b_{eff} \cdot t_{pn}^2 / 4) / 1000$
b_f = flange breadth [mm], see Fig.4
t_{fn} = net flange thickness [mm]
= $t_f - t_s$ (t_s as given in C208)
t_f = as-built flange thickness [mm], see Fig.4
t_{pn} = the fitted net shell plate thickness [mm] (not to be less than t_{net} as given in C102)
b_{eff} = effective width of shell plate flange [mm]
= 500 s
Z_p = net effective plastic section modulus of transverse frame (calculated according to C209) [cm³].

304 The scantlings of the frame shall meet the structural stability requirements of C600.

C 400 Framing – Side longitudinals
(longitudinally framed ships)

401 Side longitudinals shall 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.

402 The actual net effective shear area of the frame, A_w, as defined in C208, shall comply with the following condition:

$$A_w \geq A_L$$

where

A_L = $100^2 \cdot (AF \cdot PPF_s \cdot P_{avg}) \cdot 0.5 \cdot b_1 \cdot a / (0.577 \cdot \sigma_F)$ [cm²]

where

AF = Hull Area Factor from Table B3
PPF_s = Peak Pressure Factor from Table B2
P_{avg} = average pressure within load patch as given in B600 [MPa]
b_1 = $k_o \cdot b_2$ [m]
k_o = $1 - 0.3 / b'$
b' = b / s
b = height of design ice load patch as given by B501/B502 [m]
s = spacing of longitudinal frames [m]
b_2 = $b (1 - 0.25 \cdot b')$ [m], if b' < 2
= s [m], if b' ≥ 2
a = longitudinal design span as given in C205 [m]
σ_F = minimum upper yield stress of the material [N/mm²].

403 The actual net effective plastic section modulus of the plate/stiffener combination, Z_p, as defined in C209, shall comply with the following condition:

$$Z_p \geq Z_{pL}, \text{ where:}$$

Z_{pL} = $100^3 \cdot (AF \cdot PPF_s \cdot P_{avg}) \cdot b_1 \cdot a^2 \cdot A_4 / (8 \cdot \sigma_F)$ [cm³]

where

AF, PPF$_s$, P$_{avg}$, b$_1$, a and σ_F are as given in C402

$A_4 = 1 / (2 + k_{wl} \cdot [(1 - a_4{}^2)^{0.5} - 1])$
$a_4 = A_L / A_w$
A_L = minimum shear area for longitudinal as given in C402 [cm^2]
A_w = net effective shear area of longitudinal (calculated according to C208 [cm^2]
$k_{wl} = 1 / (1 + 2 \cdot A_{fn} / A_w)$ with A_{fn} as given in C209.

404 The scantlings of the longitudinals shall meet the structural stability requirements of C600.

C 500 Framing – web frame and load carrying stringers

501 Web frames and load-carrying stringers shall be designed to withstand the ice load patch as defined in B500. The load patch shall be applied at locations where the capacity of these members under the combined effects of bending and shear is minimised.

502 Where load carrying stringers or web frames supporting local frames constitute regular structures with sufficient and well defined support capacity and boundary condition at end supports, and with the stringer or web frame located within the hull area considered, see A500, the required effective net web area and net section modulus is as given in 503 or 505. The required shear area and section modulus of web frames supporting load carrying stringers is as given in 504. Alternatively, and where web frames and load-carrying stringers form part of a structural grillage system, appropriate methods of analysis as outlined in F103 shall be used.

503 The effective net web area in cm^2, as defined in Pt.3 Ch.1 Sec.3 C500, of web frames supporting longitudinal local frames, A$_{wf}$, shall not be less than:

$$A_{wf} = \frac{100^2 \left(AF\,PPF_s\,P_{avg}\right)LH_s\,LL_s\,K_s}{0.577\,\sigma_F\,\eta\,\sin\varphi_w} \quad [\text{cm}^2]$$

where

AF = Hull Area Factor from Table B3
PPF$_s$ = Peak Pressure Factor from Table B2
P$_{avg}$ = average pressure within load patch as given in B601 [MPa]
K$_s$ = [S – (LH$_s$ + s)/2]/S, minimum 0.55
LH$_s$ = load height with respect to shear response of web frame, given as the smaller of b and (S-s) [m]
LL$_s$ = load length with respect to shear response of web frame = w $(l – w/4)/l$ [m]
l = spacing of web frames, measured along the shell plate [m]
b = height of design ice load patch as given by B501/B502 [m]
s = longitudinal frame spacing [m]
S = span length of web frame as given in C205 [m]
w = length of load patch as given in B601[m], but is not to be taken larger than 2 l
η = usage factor
  = 0.9
σ_F = minimum upper yield stress of the material [N/mm^2]
φ_w = smallest angle between shell plate and the web of the web frame, measured at middle of span.
  The angle φ_w may be taken as 90 degrees provided the smallest angle is not less than 75 degrees.

The net elastic section modulus in cm^3 of web frames supporting longitudinal local frames, Z$_{wf}$, shall not be less than:

$$Z_{wf} = \frac{100^3 \left(AF\,PPF_s\,P_{avg}\right)LH_b\,LL_s\,\left(S - LH_b/2\right)}{4\,\sigma_F\,\sin\varphi_w\,k_f} - \frac{Z_p\,k_{fl}\,S^2}{16\,k_f\,s\,a}$$

where

a = design span of local frames as given in 205 [m]
LH$_b$ = load height w.r.t bending response of web frame, given as the smaller of b and S [m]

k$_f$ = end fixity parameter for the web frame
  = 2.0 when both end supports are fixed
  = 1.5 when one end support is fixed
  = 1.0 when both end supports are simply supported

k_{fl} = end fixity parameter for the local frames
   = 2.0 when both end supports are fixed
   = 1.5 when one end support is fixed
   = 1.0 when both end supports are simply supported

Z_p = net plastic section modulus of fitted local ice frames as given in 209.

504 The effective net web area in cm^2, as defined in Pt.3 Ch.1 Sec.3 C500, of web frames supporting load carrying stringers, A_{wf}, shall not be less than:

$$A_{wf} = \frac{100^2 \left(AF\,PPF_s\,P_{avg}\right)w\,b\ (S-C)(l_{LCS} - w/4)(l - b/4)}{0.577\ \sigma_F\ \eta\ \sin\varphi_w\ S\ l_{LCS}\ l}\ \left[cm^2\right]$$

where

AF = Hull Area Factor from Table B3
PPF_s = Peak Pressure Factor from Table B2
P_{avg} = average pressure within load patch as given in B601 [MPa]
b = height of design ice load patch as given by B501/B502 [m]
C = smallest distance from considered load carrying stringer to web frame support [m]
l_{LCS} = distance between web frames, measured along the shell plate [m]
l = distance from considered load carrying stringer to adjacent load carrying stringer or longitudinal support member, as applicable, measured along the shell plate [m]
S = span length of web frame as given in C205 [m]
w = length of load patch as given in B601 [m]
η = usage factor
   = 0.9
σ_F = minimum upper yield stress of the material [N/mm^2]
φ_w = smallest angle between shell plate and the web of the web frame, measured at the load carrying stringer.

The net elastic section modulus in cm^3 of web frames supporting load carrying stringer, Z_{wf}, shall not be less than:

$$Z_{wf} = \frac{100^3\left(AF\,PPF_s\,P_{avg}\right)w\,b\,C(S-C)(l_{LCS} - w/4)(1 - b/4)}{2\sigma_F\,\sin\varphi_w\,k_f\,S\,l_{LCS}\,l}\ \left[cm^3\right]$$

where

k_f = end fixity parameter for the web frame
   = 2.0 when both end supports are fixed
   = 1.5 when one end support is fixed
   = 1.0 when both end supports are simply supported.

505 The effective net web area in cm^2, as defined in Pt.3 Ch.1 Sec.3 C500, of load-carrying stringers, A_{lcs}, shall not be less than:

$$A_{lcs} = \frac{100^2\ \left(AF\,PPF_s\ P_{avg}\right)LH_s\ LL_s\ \left(S - (LL_s + s)/2\right)}{0.577\ \sigma_F\ \eta\ S\ \sin\varphi_w}\ \left[cm^3\right]$$

where

AF = Hull Area Factor from Table B3
PPF_s = Peak Pressure Factor from Table B2
P_{avg} = average pressure within load patch, as given in B601 [MPa]
LH_s = load height with respect to shear response of stringer = b (l – b/4)/l [m]
LL_s = load length with respect to shear response of stringer, given as the smaller of w and (S-s) [m]
l = distance between transverse frame supports, measured along the shell plate [m]
b = height of design ice load patch as given in B601[m]
w = length of load patch as given in B601[m]
s = spacing of transverse frames [m]
S = span of stringer as given in C205 [m]

η = usage factor
= 0.9

σ_F = minimum upper yield stress of the material [N/mm^2]

φ_w = smallest angle between shell plate and the web of the stringer, measured at middle of span. The angle φ_w may be taken as 90 degrees provided the smallest angle is not less than 75 degrees.

The net elastic section modulus in cm^3 of the stringer, Z_{lcs}, shall not be less than:

$$Z_{lcs} = \frac{100^3 \left(AF\,PPF_s\,P_{avg} \right) b\,LL_B \left(S - w/2 \right)}{4\sigma_F \sin\varphi_w\,k_f} - \frac{Z_p\,k_{fl}\,S^2}{16\,k_f\,s\,a}$$

where

a = design span of local frames as given in C205 [m]

k_f = end fixity parameter for the load-carrying stringer
= 2.0 when both end supports are fixed
= 1.5 when one end support is fixed
= 1.0 when both end supports are simply supported

k_{fl} = end fixity parameter for the local frames
= 2.0 when both end supports are fixed
= 1.5 when one end support is fixed
= 1.0 when both end supports are simply supported

LL_b = load length w.r.t bending response of stringer, given as the smaller of w and S [m]

Z_p = net plastic section modulus of fitted local ice frames as given in 209

506 The scantlings of web frames and load-carrying stringers shall meet the structural stability requirements of C600.

C 600 Framing – Structural stability

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

For flat bar sections:

$$h_w / t_{wn} \le 282 / (\sigma_F)^{0.5}$$

For bulb, tee and angle sections:

$$h_w / t_{wn} \le 805 / (\sigma_F)^{0.5}$$

where

h_w = web height

t_{wn} = net web thickness

σ_F = minimum upper yield stress of the material [N/mm^2].

602 Framing members for which it is not practicable to meet the requirements of C601 (e.g. load carrying stringers or deep web frames) are required to have their webs effectively stiffened. The scantlings of the web stiffeners shall ensure the structural stability of the framing member. The minimum net web thickness for these framing members is given by:

$$t_{wn} = 2.63 \cdot 10^{-3} \cdot c_1 \cdot \sqrt{(\sigma_F / (5.34 + 4 \cdot (c_1/c_2)^2))}\ \text{[mm]}$$

where

c_1 = $h_w - 0.8 \cdot h$ [mm]

h_w = web height of stringer/web frame [mm] (see Fig.5)

h = height of framing member penetrating the member under consideration (0 if no such framing member) [mm] (see Fig.5)

c_2 = spacing between supporting structure oriented perpendicular to the member under consideration [mm] (see Fig.5)

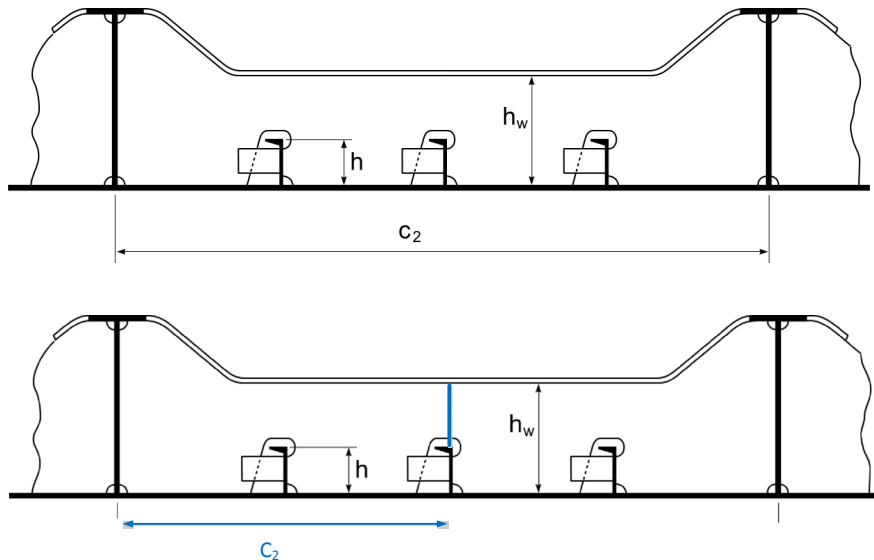σ_F = minimum upper yield stress of the material [N/mm^2].

Fig. 5
Parameter Definition for Web Stiffening

603   In addition, the following shall be satisfied:

$$t_{wn} \geq 0.35 \cdot t_{pn} \cdot (\sigma_F / 235)^{0.5}$$

where

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

604   To prevent local flange buckling of welded profiles, the following shall 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:

$$b_{out} / t_{fn} \leq 155 / (\sigma_F)^{0.5}$$

where

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

C 700   Plated structures

701   Plated structures are those stiffened plate elements in contact with the shell 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.

702   The thickness of the plating and the scantlings of attached stiffeners shall be consistent with the end connection requirements for supported framing as given in C900.

703   Plated structures subjected to direct ice loads, as defined in B, shall be considered with respect to the buckling requirements in Pt.3 Ch.1 Sec.13.

C 800   Stem and stern frames

801   For **PC-6**/**PC-7** vessels requiring **1A***/**1A** equivalency, the stem and stern requirements of the Finnish-Swedish Ice Class Rules may need to be additionally considered.

802   When the vessel has a sharp edged stem, the thickness of the stem side plate within a breadth not less than 0.7 s, where s denotes the spacing of stiffening members, shall not be less than 1.2 t, where t denotes the required net shell plate thickness for the bow area, as given in C100.

803   In vessels intended to operate under harsh ice condition, and of type and size that may cause excessive beaching to occur, a forward ice knife may be required fitted. This requirement will be based on consideration of design speed, stability and freeboard.

C 900   End Connections for framing members

901   The end connection for framing members exposed to ice loads, to supports, e.g. stringers, web frames, decks or bulkheads, shall be related to the response of the member when subjected to ice loads. The connection area is generally obtained through support members such as collar plate, lugs, end brackets or web stiffener.

The total net connection area of support members is given as:

$$a = \sum_n 0.01 \, k_\tau (t_i - t_s) \, h_i \qquad [cm^2]$$

where

h_i = effective dimension of connection area of member #i
t_i = thickness of connection area #i
k_t = 1.0 for members where critical stress response is shear
      = 1.5 for members where critical stress response is normal stress
n   = number of support members
t_s = minimum corrosion addition as given in H103.

902   The net end connection area fitted, a, is generally not to be less than a_o, given as:

for longitudinal local frames

$$a_o = \frac{100^2 \, (AF \, PPF_s \, P_{avg}) b_1 \, (w - s)(a - w/2)}{0.577 \, \sigma_F \, \eta \, a \sin \varphi_w} \qquad [cm^2]$$

for transverse local frames

$$a_o = \frac{100^2 \, (AF \, PPF_t \, P_{avg}) s \, b \, (a - (b + s)/2)}{0.577 \, \sigma_F \, \eta \, a \sin \varphi_w} \qquad [cm^2]$$

for load carrying stringers

$$a_o = \frac{100^2 \, (AF \, PPF_s \, P_{avg}) b \, (w - s)(S - w/2)}{0.577 \, \sigma_F \, \eta \, S \sin \varphi_w} \qquad [cm^2]$$

for transverse web frames supporting longitudinal local frames

$$a_o = \frac{100^2 \, (AF \, PPF_s \, P_{avg}) w \, b \, (S - (b + s)/2)}{0.577 \, \sigma_F \, \eta \, S \sin \varphi_w} \qquad [cm^2]$$

where

AF = Hull Area Factor from Table B3
PPF = Peak Pressure Factor from Table B2
P_{avg} = average pressure within load patch as given in B601 [MPa]
LH = load height, given as the smaller of b and (a-s) [m]
LL = load length, given as the smaller of w and (a-s) [m]
a, S = span of member as given in C205 [m]
s   = spacing of frames (m)
b, w = as given in B601
b_1 = as given in 402
η = usage factor
    = 0.9
σ_F = minimum upper yield stress of the material [N/mm²]
φ_w = smallest angle between shell plate and the web of the stringer or web frame as applicable, measured at the intersection with the stiffener. The angle φ_w may be taken as 90 degrees provided the smallest angle is not less than 75 degrees.

903   For support members constituting the end connection, the throat thickness in mm of double fillet welds for the attachment of the support member i, to the framing member and the support is given as the smaller of:

$$t_w = \frac{(t_i - t_c) a_o \sigma_F}{450 a \, f_w} + 0.5 t_s$$

$$= 0.5 \, t_i$$

where

a = as given in 901
a_o = as given in 902
t_i = thickness of connection member i [mm]
f_w = as given in Pt.3 Ch.1 Sec.11 C103
t_s = corrosion addition/abrasion addition as given in H103.

The throat thickness not be less than as given in Pt.3 Ch.1 Sec.11/Pt.3 Ch.2 Sec.11.

D. Longitudinal Strength

D 100 Application

101 Ice loads need only be combined with still water loads. The combined stresses shall 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.

D 200 Design Vertical Ice Force at the Bow

201 The design vertical ice force at the bow, F_{IB}, shall be taken as:

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

where

$F_{IB,1}$ = $0.534 \cdot K_I^{0.15} \cdot \sin^{0.2}(\gamma_{stem}) \cdot (\Delta_{kt} \cdot K_h)^{0.5} \cdot CF_L$ [MN]
$F_{IB,2}$ = $1.20 \cdot CF_F$ [MN]
K_I = indentation parameter = K_f / K_h

a) for the case of a blunt bow form
$K_f = (2 \cdot C \cdot B^{1-eb} / (1 + e_b))^{0.9} \cdot \tan(\gamma_{stem})^{-0.9 \cdot (1 + eb)}$

b) for the case of wedge bow form ($\alpha_{stem} < 80$ deg), $e_b = 1$ and the above simplifies to
$K_f = (\tan(\alpha_{stem}) / \tan^2(\gamma_{stem}))^{0.9}$
$K_h = 0.01 \cdot A_{wp}$ [MN/m]

CF_L = Longitudinal Strength Class Factor from Table B1
e_b = bow shape exponent which best describes the water plane (see Fig.6 and Fig.7)
= 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 Fig.2 measured on the centreline)
α_{stem} = Hull waterline angle to be measured at stem (centre line) at the UIWL, see Fig.2 [deg]
C = $1 / (2 \cdot (L_B / B)^{eb})$
B = ship moulded breadth [m]
L_B = bow length used in the equation
$y = B / 2 \cdot (x/L_B)^{eb}$ [m] (see Fig.6 and 7)
Δ_{kt} = ship displacement [kt] at UIWL, not to be taken less than 10 kt
A_{wp} = ship water plane area [m²]
CF_F = Flexural Failure Class Factor from Table B1.

Draught dependent quantities are, where applicable, to be determined at the waterline corresponding to the loading condition under consideration.

D 300 Design Vertical Shear Force

301 The design vertical ice shear force, F_I, along the hull girder shall be taken as:

$$F_I = C_f \cdot F_{IB} \text{ [MN]}$$

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 0.6 L 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 0.6 L from aft

C_f = 0.0 between 0.8 L from aft and the forward end of L.

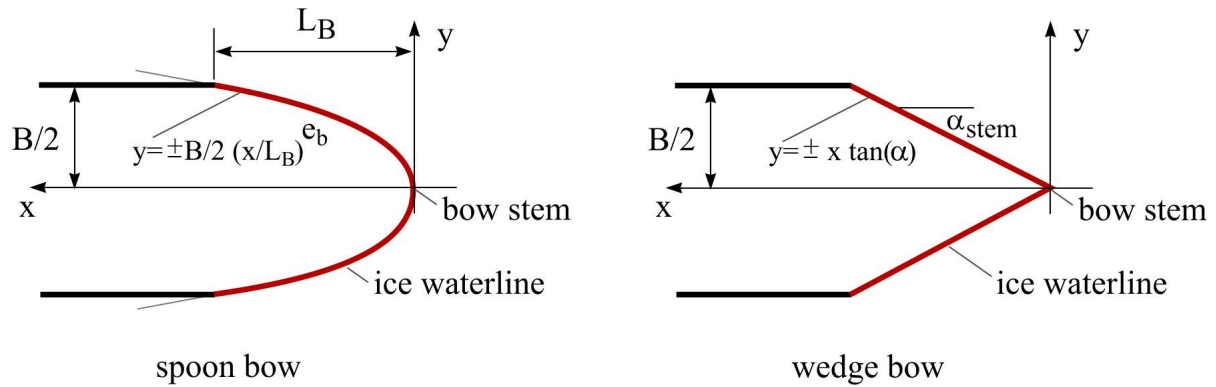Intermediate values shall be determined by linear interpolation.

Fig. 6
Bow Shape Definition
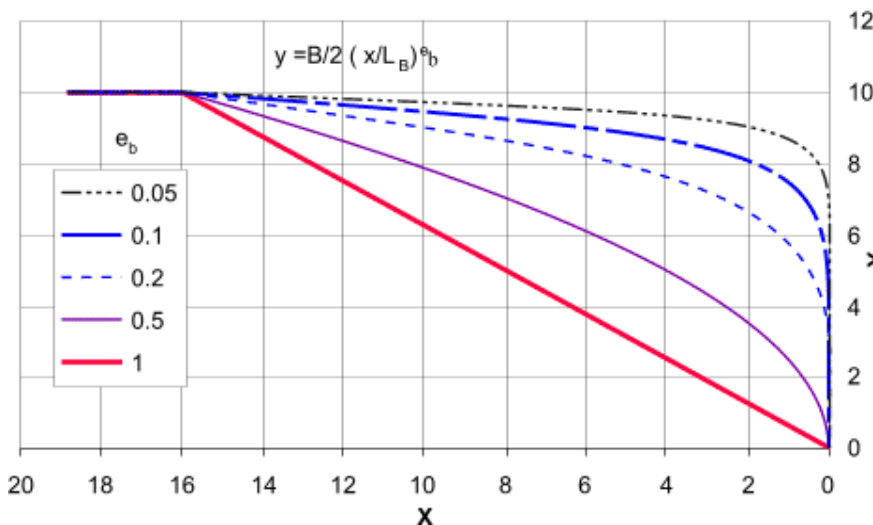
Fig. 7
Illustration of e_b Effect on the Bow Shape for B = 20 and L_B =16

Table D1 - Longitudinal strength criteria			
Failure Mode	*Applied Stress*	*Permissible Stress when $\sigma_F / \sigma_u \leq 0.7$*	*Permissible Stress when $\sigma_F / \sigma_u > 0.7$*
Tension	σ_a	$\eta \cdot \sigma_F$	$\eta \cdot 0.41 (\sigma_u + \sigma_F)$
Shear	τ_a	$\eta \cdot \sigma_F / (3)^{0.5}$	$\eta \cdot 0.41 (\sigma_u + \sigma_F) / (3)^{0.5}$
Buckling	σ_a	σ_c for plating and for web plating of stiffeners σ_c / 1.1 for stiffeners	
	τ_a	τ_c	

302 The applied vertical shear stress, τ_a, shall be determined along the hull girder in a similar manner as in Pt.3 Ch.1 Sec.5 by substituting the design vertical ice shear force for the design vertical wave shear force.

D 400   Design Vertical Ice Bending Moment

401   The design vertical ice bending moment, M_I, along the hull girder shall be taken as:

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

where

γ_{stem} is as given in D201

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 0.5 L and 0.7 L from aft

   C_m = 0.3 at 0.95 L from aft

   C_m = 0.0 at the forward end of L.

   L = ship length as defined in Pt.3 Ch.1/Pt.3 Ch.2, but measured on the upper ice waterline [UIWL] [m]

   Intermediate values shall be determined by linear interpolation.

Draught dependent quantities are, where applicable, to be determined at the waterline corresponding to the loading condition under consideration.

402   The applied vertical bending stress, σ_a, shall be determined along the hull girder in a similar manner as in Pt.3 Ch.1 Sec.5/Pt.3 Ch.2 Sec.4 by substituting the design vertical ice bending moment for the design vertical wave bending moment. The ship still water bending moment shall be taken as the maximum sagging moment.

D 500   Longitudinal Strength Criteria

501   The strength criteria provided in Table D1 shall be satisfied. The design stress shall not exceed the permissible stress.

where

σ_a = applied vertical bending stress [N/mm^2]
τ_a = applied vertical shear stress [N/mm^2
σ_F = 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 Pt.3 Ch.1 Sec.13/Pt.3 Ch.2 Sec.12 [N/mm^2]
τ_c = critical buckling stress in shear, according to Pt.3 Ch.1 Sec.13 [N/mm^2]
η = 0.8.

E. Appendages

E 100   General

101   All appendages shall be designed to withstand forces appropriate for the location of their attachment to the hull structure or their position within a hull area, as given below. For appendages of type or arrangement other than as considered in the following, the load definition and response criteria are subject to special consideration.

102   Stern frames, rudders, propeller nozzles are in general to be designed according to the rules given in Pt.3 Ch.3 Sec.2.

103   Bilge keels are normally to be avoided and should preferably be substituted by roll-damping equipment. If bilge keels are fitted, it is required that the connection to the hull is so designed that the risk of damage to the hull, in case the bilge keel is ripped off, is minimized.

104   Additional requirements for ice reinforced vessels are given in the following. For vessels with rudders which are not located behind the propeller, special consideration will be made with respect to the longitudinal ice load.

E 200   Rudders

201   The rudder stock and upper edge of the rudder shall be effectively protected against ice pressure.

202   Ice horns shall be fitted directly abaft each rudder in such a manner that:

— the upper edge of the rudder is protected within two degrees to each side of the mid position when   going astern, and
— ice is prevented from wedging between the top of the rudder and the vessel's hull.

The ice horn shall extend vertically to, minimum = 1.5 CF_D [m] below LIWL, where CF_D shall be taken as given in Table B1. Alternatively an equivalent arrangement shall be arranged.

203 Exposed seals for rudder stock are assumed to be designed for the given environmental conditions such as:

— ice formation
— specified design temperature.

E 300 Ice forces on rudder

301 The ice force, F_U, acting on the uppermost part of the rudder, the ice horn included shall be assessed on a case to case basis based on the Society's current practice.

The force F_U shall be divided between rudder and ice horn according to their support position. The force acting on the ice horn may generally be taken as:

$$F_H = \frac{F_U(X - X_F)}{X_K - X_F}$$

X = distance from leading edge of rudder to point of attack of the force F
  = $0.5\, l_r$ (m) minimum
  = $0.67\, l_r$ (m) maximum
l_r = length of rudder profile (including ice knife) in m
X_F = longitudinal distance in m from the leading edge of the rudder to the axis of the rudder stock
X_K = distance in m from leading edge of rudder to centre of ice knife.

For this loading the stress response of the rudder, the ice horn and support structures for these shall not exceed σ_y, where σ_y denotes the minimum upper yield stress of the material.

302 The ice force, F_R, acting on the rudder the distance
z_{LIWL} below LIWL shall be assessed on a case to case basis based on the Society's current practice.

The rudder force, F_R, gives rise to bending moments in the rudder, the rudder stock and the rudder horn, as applicable. Alternative positions for the ice load area shall be considered in order that the maximum bending moment shall be determined.

The bending moment, M_B, in way of the rudder section in question is given as:

$$M_B = F_R \cdot h_s \text{ (kNm)}$$

h_s = vertical distance from the ice load area position to the rudder section in question.

The rudder force, F_R, gives rise to a rudder torque (M_{TR}) and a bending moment in the rudder stock (M_B), which both will vary depending on the position of the assumed ice load area, and on the rudder type and arrangement used.

In general the load giving the most severe combination of F_R, M_{TR} and M_B with respect to the structure under consideration shall be applied in a direct calculation of the rudder structure.

The design value of M_{TR} is given by:

M_{TR} = $F_R (0.6\, l_r - X_F)$ (kNm)
   = $0.15\, F_R\, l_r$ minimum
X_F = longitudinal distance in m from the leading edge of the rudder to the axis of the rudder stock
l_r = length of rudder profile in m.

E 400 Rudder scantlings

401 Scantlings of rudder, rudder stock, rudder horn and rudder stoppers, as applicable, shall be calculated for the force, F, given in 301 acting on the rudder and ice horn, with respect to bending and shear. The nominal equivalent stress shall not exceed σ_f, where σ_f denotes the minimum upper yield stress of the material in N/mm^2.

402 The scantlings of rudders, rudder stocks and shafts, pintles, rudder horns and rudder actuators shall be calculated from the formulae given in Pt.3 Ch.3 Sec.2, inserting the rudder torque M_{TR}, bending moments M_B and rudder force F_R as given in 302.

403 Provided an effective torque relief arrangement is installed for the steering gear, and provided effective ice stoppers are fitted, the design rudder torque need not be taken greater than:

M_{TR} = M_{TRO}
M_{TRO} = steering gear relief torque in kNm.

404 For rudder plating the ice load thickness shall be calculated as given in C100 for the stern area or lower stern area as applicable.

E 500 Ice loads on propeller nozzles

501 The transverse ice force, F_N, shall be calculated as outlined in 700.

502 The longitudinal ice force, F_L, acting on the nozzle shall be assessed on a case to case basis based on the Society's current practice.

For the determination of F_L, the following two alternative ice load areas, A, shall be considered:

— an area positioned at the lower edge of the nozzle with width equal to 0.65 D and height equal to the height of the nozzle profile in m
— an area on both sides of the nozzle at the propeller shaft level, with transverse width equal to the height of the nozzle profile in m and with height equal to 0.35 D. Both symmetric and asymmetric loading shall be checked.

D = nozzle diameter in m.

E 600 Propeller nozzle scantlings

601 The scantlings of the propeller nozzle and its supports in the hull shall be calculated for the ice loads given in 500. The nominal equivalent stress shall not exceed σ_y, where σ_y denotes the minimum upper yield stress of the material in N/mm².

For nozzle plating the ice load thickness shall be taken as given in C100 using the design ice pressure as given for the stern area, lower stern area as applicable.

E 700 Podded propulsors and azimuth thrusters

701 Vessels operating in ice and equipped with podded propulsors or azimuth thrusters shall be designed according to operational mode and purpose stated in the design specification. If not given, it shall be assumed that the vessel may operate longer periods in ice using astern running mode as part of its operational profile. When limitations are given, this information shall also be stated in the ship's papers

702 Ramming astern is not anticipated.

703 Documentation of both local and global strength capacity of the pod/thruster shall be submitted for class assessment. Recognised structural idealisation and calculation methods shall be applied.

704 Ice loads on pod/thruster body shall be assessed on a case by case basis based on the Society's current practice.

705 The nominal equivalent stress shall not exceed σ_F, where σ_F denotes the minimum upper yield stress of the material in N/mm².

F. Direct Calculations

F 100 General

101 Direct calculations shall not be utilised as an alternative to the analytical procedures prescribed for shell plating and local frames.

102 Where direct calculation is used to check the strength of structural systems, the load patch specified in B500 with design pressure given as the product (AF P_{avg}) shall be applied at locations that maximize the shear and bending response of the structure members in focus for the calculation.

AF = as given in Table B3
P_{avg} = as given in B600.

103 Direct calculations may be used for the scantling control of the support structures for local frames, including load-carrying stringers, web frames and plated structures in general. The extent of the structure model must be such that possible inaccuracies in the support definition will not affect the calculation results significantly. The calculation shall ensure that stress response of webs and flanges of girder structures, when a usage factor = 0.9 is included, does not exceed yield or the buckling capacity. The documentation of direct strength analyses shall be in accordance with Pt.3 Ch.1 Sec.12 A300.

G. Welding

G 100 General

101 All welding within ice-strengthened areas shall be of the double continuous type.

102 Continuity of strength shall be ensured at all structural connections.

G 200 Minimum weld requirements

201 The weld connection of local frames and load carrying stringers and web frames supporting local frames to shell shall be as given in Pt.3 Ch.1 Sec.11 C103 with the weld factor C given as:

C $= 0.31 r_w$, minimum 0.26, for middle 60% of span
$= 0.52 r_w$, minimum 0.43, at ends.

r_w = ratio of required net web area over fitted net web area for member considered. For transverse local frames, r_w is, however, not to be taken less than:

$$r_w = \frac{100^2 \, LL \, s \left(AF \; PPF_s \; P_{avg} \right) \left(a - 0.25\,s - 0.5\,LL_s \right)}{0.577 \, \sigma_F \, a \, A_w}$$

where

LL_s = length of loaded portion of span
     = lesser of a and (b - 0.5 s) [m]
a = frame span as defined in C205 [m]
b = height of design ice load patch as given in B500 [m]
s = transverse frame spacing [m]
AF = Hull Area Factor from Table B3
PPF_t = Peak Pressure Factor from Table B2
P_{avg} = average pressure within load patch as given in B600 [MPa]
σ_F = minimum upper yield stress of the material [N/mm^2].

H. Materials and Corrosion Protection

H 100 Corrosion/abrasion additions and steel renewal

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

102 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 H1.

103 Polar ships shall 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. Additionally, the corrosion/abrasion addition, t_s, shall not be less than t_k as given in Pt.3 Ch.1 Sec.2 D200.

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

H 200 Hull materials

201 Plating materials for hull structures shall be not less than those given in Tables H3 and H4 based on the as-built thickness of the material, the Polar Class notation assigned to the ship and the material class of structural members given in 202.

202 Material classes specified in Pt.3 Ch.1 Sec.2/Pt.3 Ch.2 Sec.2 are applicable to Polar Class 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 Class ships are given in Table H2. Where the material classes in Table H2 and those in Pt.3 Ch.1 Sec.2/Pt.3 Ch.2 Sec.2 differ, the higher material class shall be applied.

Table H1 - Corrosion/abrasion additions for shell plating	t_s [mm]					
Hull Area	*With Effective Protection*			*Without Effective Protection*		
	PC-1 PC-2 PC-3	**PC-4 PC-5**	**PC-6 PC-7**	**PC-1 PC-2 PC-3**	**PC-4 PC-5**	**PC-6 PC-7**
Bow; Bow Intermediate Ice belt	3.5	2.5	2.0	7.0	5.0	4.0
Bow Intermediate Lower; Midbody and Stern Ice belt	2.5	2.0	2.0	5.0	4.0	3.0
Midbody and Stern Lower; Bottom	2.0	2.0	2.0	4.0	3.0	2.5

Table H2 - Material classes for structural members of Polar ships	
Structural Members	*Material Class*
Shell plating within the bow and bow intermediate ice belt hull areas (B, BI$_i$)	III
All weather and sea exposed SECONDARY and PRIMARY, as defined in Table B2 of Pt.3 Ch.1 Sec.2/ Table B2 of Pt.3 Ch.2 Sec.2, structural members outside 0.4 L amidships	II
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	III
All inboard framing members attached to the weather and sea-exposed plating including any contiguous inboard member within 600 mm of the plating	II
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	II
All weather and sea exposed SPECIAL, as defined in Table B2 of Pt.3 Ch.1 Sec.2/Table B2 of Pt.3 Ch.2 Sec.2, structural members within 0.2 L from FP	III

203 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 Fig.8, shall be obtained from Pt.3 Ch.1 Sec.2/Pt.3 Ch.2 Sec.2 based on the Material Class for Structural Members in Table H2 above, regardless of Polar Class.
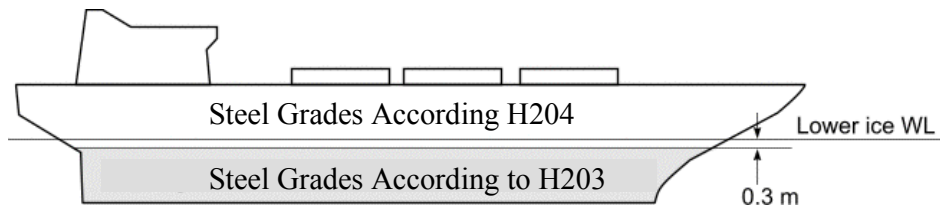
Fig. 8
Steel Grade Requirements for Submerged and Weather Exposed Shell Plating

Table H3 - Steel Grades for Weather Exposed Plating														
Thickness t [mm]	*Material Class II*				*Material Class III*				*Material Class IV*					
	PC-1 through **5**		**PC-6** and **7**		**PC-1** through **5**		**PC-6** and **7**		**PC-1** through **3**		**PC-4** and **5**		**PC-6** and **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	EH 2)	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:

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.

Table H4 - Steel grades for inboard framing members attached to weather exposed plating

Thickness t, mm	PC-1 through PC-5		PC-6 and PC-7	
	MS	HT	MS	HT
t ≤ 20	B	AH	B	AH
20 <t ≤ 35	D	DH	B	AH
35 <t ≤ 45	D	DH	D	DH
45 <t ≤ 50	E	EH	D	DH

204 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 Fig.8, shall be not less than given in Table H3.

205 Steel grades for all inboard framing members attached to weather exposed plating shall be not less than given in Table H4. This applies to all inboard framing members as well as to other contiguous inboard members (e.g. bulkheads, decks) within 600 mm of the exposed plating.

206 Castings and forgings shall have specified properties consistent with the expected service temperature for the cast component. Forged or cast materials in structural members exposed to design temperatures lower than 10°C, shall fulfil requirements given in Sec.6 C605. The test temperature of components fully exposed to the ambient air shall, if the design temperature has not been specified, for notations **PC-1** to **PC-5** be taken as -20ºC and for notations **PC-6** and **PC-7** as -10ºC.

H 300   Materials for machinery components exposed to sea water

301 Materials exposed to sea water, such as propeller blades, propeller hub, cast thrusters body shall have an elongation not less than 15% on a test specimen with a length which is five times the diameter of test specimen.

Charpy V impact tests shall be carried out for materials other than bronze and austenitic steel. Average impact energy of 20 J taken from three Charpy V tests is to be obtained at minus 10ºC.

H 400   Materials for machinery components exposed to sea water temperatures

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

Charpy V impact tests shall be carried out for materials other than bronze and austenitic steel.

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

H 500   Materials for machinery components exposed to low air temperature

501 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 shall be obtained at 10ºC below the lowest design temperature. This does not apply to surface hardened components, such as bearings and gear teeth.

For definition of structural boundaries exposed to air temperature see B100.

I. Ice Interaction Loads – Machinery

I 100   Propeller ice interaction

101 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 cover loads due to propeller ice interaction also for azimuth and fixed thrusters with geared transmission or integrated electric motor ("geared and podded propulsors"). However, the load models of these Rules do not cover propeller/ice interaction loads when ice enters the propeller of a turned azimuthing thruster from the side (radially) or when ice block hits on the propeller hub of a pulling propeller/thruster.

102 The loads given in this section are total loads (unless otherwise stated) during ice interaction and shall be applied separately (unless otherwise stated) and are intended for component strength calculations only.

103 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.

I 200 Ice class factors

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

Table I1 Ice class factors		
Ice Class	*H_{ice}[m]*	*S_{ice}[-]*
PC-1	4.0	1.2
PC-2	3.5	1.1
PC-3	3.0	1.1
PC-4	2.5	1.1
PC-5	2.0	1.1
PC-6	1.75	1
PC-7	1.5	1

where

H_{ice} = ice thickness for machinery strength design

S_{ice} = ice strength index for blade ice force.

I 300 Design ice loads for open propeller

301 Maximum Backward Blade Force, F_b

when $D < D_{limit}$:

$$F_b = 27 \cdot S_{ice} \cdot [n \cdot D]^{0.7} \cdot \left[\frac{EAR}{Z} \right]^{0.3} \cdot D^2 \quad [\text{kN}]$$

when $D \geq D_{limit}$:

$$F_b = 23 \cdot S_{ice} \cdot [n \cdot D]^{0.7} \cdot \left[\frac{EAR}{Z} \right]^{0.3} \cdot [H_{ice}]^{1.4} \cdot D \quad [\text{kN}]$$

$D_{limit} = 0.85 \cdot [H_{ice}]^{1.4}$

where:

n = 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) [rps]
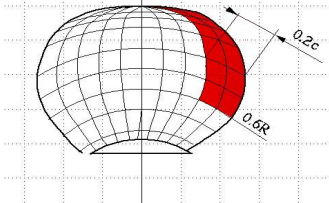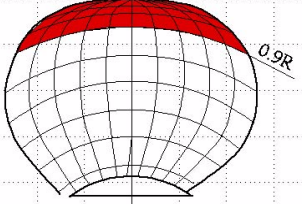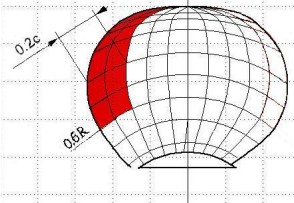
D = propeller diameter [m]

EAR = expanded blade area ratio

Z = number of propeller blades

F_b shall 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 0.6 R 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 shall be applied on the propeller tip area outside of 0.9 R

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

Table I2	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 0.6 R 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 0.9 R 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 0.6 R to the tip and from the trailing edge to 0.2 times the chord length	

302 Maximum Forward Blade Force, F_f

when $D < D_{limit}$:

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

when $D \geq D_{limit}$:

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

where

$$D_{limit} = \left(\frac{2}{1 - \dfrac{d}{D}} \right) H_{ice}$$

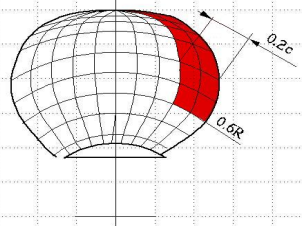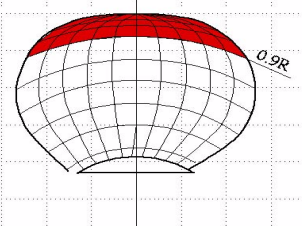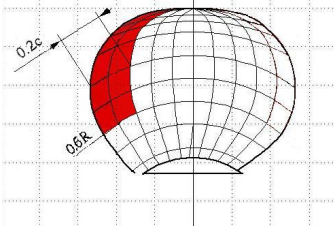d = propeller hub diameter [m]
D = propeller diameter [m]
EAR = expanded blade area ratio
Z = number of propeller blades.

F_f shall 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 0.6 R 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 shall be applied on the propeller tip area outside of 0.9 R

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

Table I3	*Force*	*Loaded area*	*Right handed propeller blade seen from back*
Load case 3	F_f	Uniform pressure applied on the blade face (pressure side) to an area from 0.6 R 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 0.9 R 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 0.6 R to the tip and from the trailing edge to 0.2 times the chord length	

303   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 I301 and I302 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 $Q_{smax} = 0.25\ F\ c_{0.7}$ [kNm]

where

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

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

304   Maximum Propeller Ice Torque applied to the propeller

when $D < D_{limit}$:

$$T_{max} = k_{open} \cdot \left[1 - \frac{d}{D}\right] \cdot \left[\frac{P_{0.7}}{D}\right]^{0.16} \cdot [n \cdot D]^{0.17} \cdot D^3 \ [\text{kNm}]$$

where:

k_{open} = 14.7 for PC1 - PC5; and
k_{open} = 10.9 for PC6 - PC7

when $D \geq D_{limit}$:

$$T_{max} = 1.9 \cdot k_{open} \cdot \left[1 - \frac{d}{D}\right] \cdot [H_{ice}]^{1.1} \cdot \left[\frac{P_{0.7}}{D}\right]^{0.16} \cdot [n \cdot D]^{0.17} \cdot D^{1.9} \ [\text{kNm}]$$

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

$P_{0.7}$ = propeller pitch at 0.7 R [m]
n   = rotational propeller speed [rps] at bollard condition. If not known, n is to be taken as follows:

Table I4	
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, $P_{0.7}$ shall be taken as $0.7\, P_{0.7n}$, where $P_{0.7n}$ is propeller pitch at MCR free running condition.

305 Maximum Propeller Ice Thrust applied to the shaft

$Th_f = 1.1\, F_f$ [kN]

$Th_b = 1.1\, F_b$ [kN]

However, the load models of this UR do not include propeller/ice interaction loads when ice block hits on the propeller hub of a pulling propeller.

I 400   Design Ice Loads for Ducted Propeller

401   Maximum Backward Blade Force, F_b

when $D < D_{limit}$:

$$F_b = 9.5 \cdot S_{ice} \cdot [n \cdot D]^{0.7} \cdot \left[\frac{EAR}{Z} \right]^{0.3} \cdot D^2 \quad [kN]$$
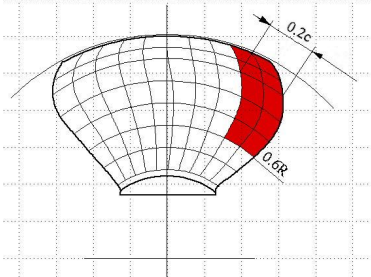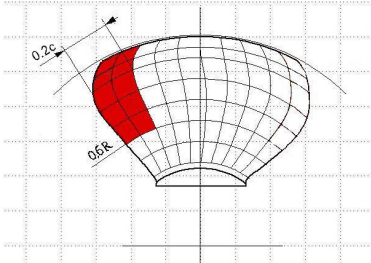
when $D \geq$ or equal D_{limit}:

$$F_b = 66 \cdot S_{ice} \cdot [n \cdot D]^{0.7} \cdot \left[\frac{EAR}{Z} \right]^{0.3} \cdot [H_{ice}]^{1.4} \cdot D^{0.6} \quad [kN]$$

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

n shall be taken as in I301.

F_b shall be applied as a uniform pressure distribution to an area on the back side for the following load cases:

a) *Load case 1:*
   On the back of the blade from 0.6 R 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 the greater of F_b or F_f is applied on the blade face from 0.6 R to the tip and from the blade trailing edge to a value of 0.2 chord length.

Table I5	*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 0.6 R to the tip and from the leading edge to 0.2 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 0.6 R to the tip and from the trailing edge to 0.2 times the chord length	

402 Maximum Forward Blade Force, F_f

when $D \leq D_{limit}$:

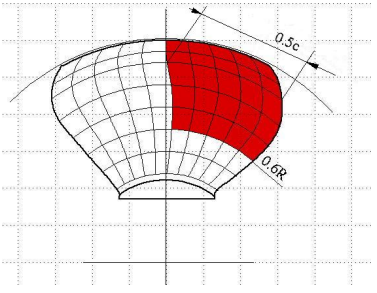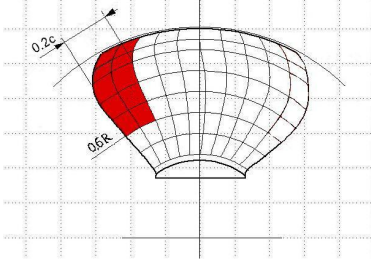$$F_f = 250 \cdot \left(\frac{EAR}{Z} \right) \cdot D^2 \quad [kN]$$

when $D > D_{limit}$:

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

where

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

F_f shall be applied as a uniform pressure distribution to an area on the face (pressure) side for the following load case:

a) *Load case 3:*
   On the blade face from 0.6 R 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% of the greater of F_f or F_b shall be applied from 0.6 R to the tip and from the blade leading edge to a value of 0.2 chord length.

Table I6	Force	Loaded area	Right handed propeller blade seen from back
Load case 3	F_f	Uniform pressure applied on the blade face (pressure side) to an area from 0.6 R 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 0.6 R to the tip and from the trailing edge to 0.2 times the chord length	

403 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 I100. If these spindle torque values are less than the default value given below, the default value shall be used

Default Value $Q_{smax} = 0.25\, F\, c_{0.7}$ [kNm]

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

404 Maximum Propeller Ice Torque applied to the propeller

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

when $D \leq D_{limit}$:

$$T_{max} = k_{ducted} \cdot \left[1 - \frac{d}{D} \right] \cdot \left[\frac{P_{0.7}}{D} \right]^{0.16} \cdot \left[n \cdot D \right]^{0.17} \cdot D^3 \text{ [kNm]}$$

where:

k_{ducted} = 10.4 for PC1 - PC5; and
k_{ducted} = 7.7 for PC6 - PC7

when $D > D_{limit}$:

$$T_{max} = 1.9 \cdot k_{ducted} \cdot \left[1 - \frac{d}{D}\right] \cdot [H_{ice}]^{1.1} \cdot \left[\frac{P_{0.7}}{D}\right]^{0.16} \cdot [nD]^{0.17} \cdot D^{1.9} \quad [kNm]$$

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

"n" is the rotational propeller speed [r.p.s.] at bollard condition. If not known, n shall be taken as follows:

Table I7	
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, $P_{0.7}$ shall be taken as $0.7 \, P_{0.7n}$, where $P_{0.7n}$ is propeller pitch at MCR free running condition".

405 Maximum Propeller Ice Thrust (applied to the shaft at the location of the propeller)

$Th_f = 1.1 \, F_f$ [kN]

$Th_b = 1.1 \, F_b$ [kN].

I 500 Propeller blade loads and stresses for fatigue analysis

501 *Blade stresses:*

The blade stresses at various selected load levels for fatigue analysis are to be taken proportional to the stresses calculated for maximum loads given in sections I301, I302, I401 and I402.

The peak stresses are those determined due to F_f and F_b. The peak stress range $\Delta\sigma_{max}$ and the maximum stress amplitude F_{Amax} are determined on the basis of:

$$\Delta F_{max} = 2 \cdot F_{Amax} = \left|F_f\right| + \left|F_b\right|$$

I 600 Design ice loads for propulsion line

601 *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

$T(\varphi) = C_q \, T_{max} \sin(\varphi(180/\alpha_i))$

when φ rotates from 0 to α_i plus integer revolutions

$T(\varphi) = 0$

when φ rotates from α_i to 360 plus integer revolutions

where C_q and α_i parameters are given in table below.

| Table I8			
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 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 360 deg/Z. The number of propeller revolutions during a milling sequence shall be obtained with the formula:
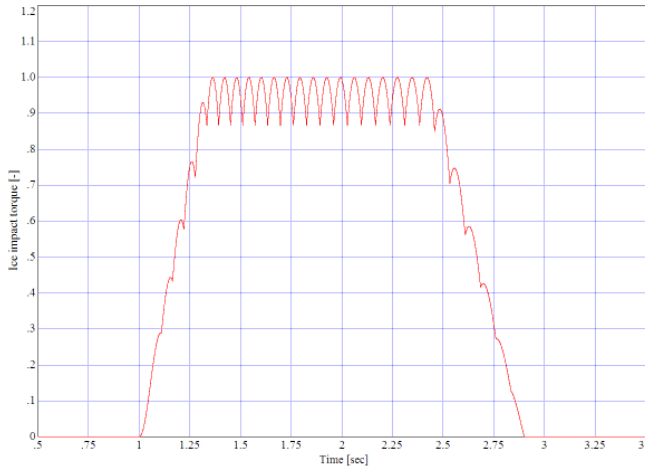
$$N_Q = 2 \, H_{ice}$$

and total number of impacts during one ice milling sequence is $Z \cdot N_T$.

In addition, the impacts are to ramp up over 270 degrees and subsequently ramp down over 270 degrees.

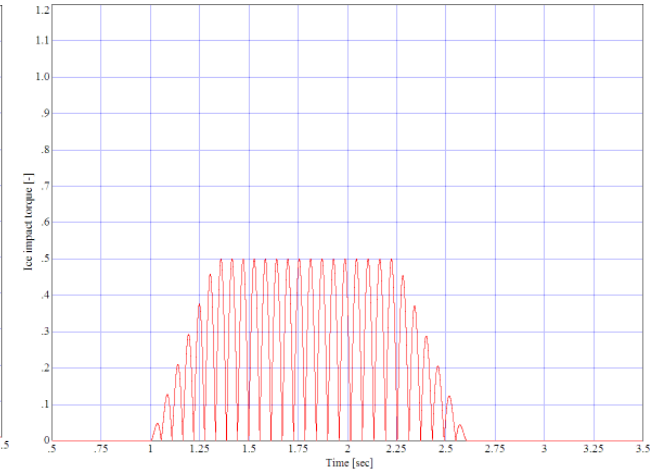The total excitation torque from the 3 cases will then look like the figures below. See Fig.9.
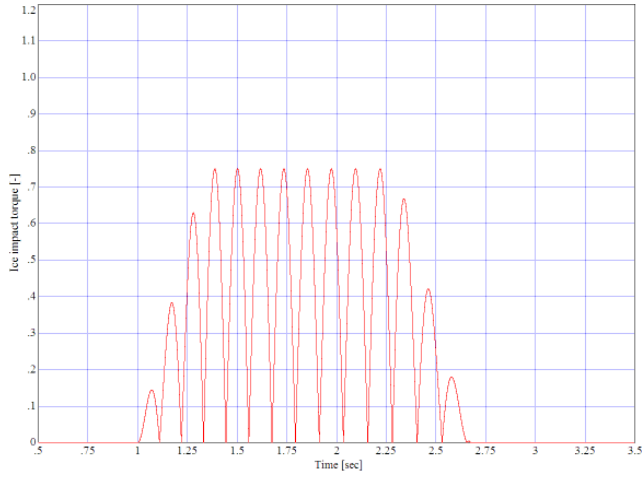
Case 1   Case 2   Case 3

Fig. 9
The shape of the propeller ice torque excitation for 90, 135 degrees single blade impact sequences and 45 degrees double blade impact sequence
(Case 1 to 3 respectively apply for propeller with 4 blades).

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

602   *Response torque in the propulsion system*

The response torque, $T_r(t)$ at any component in the propulsion system shall be analysed by means of transient torsional vibration analysis considering the excitation torque at the propeller $T(\varphi)$ as given in 601, the actual available engine torque T_e, and the mass elastic system. Calculations have to be carried out for all excitation cases given in 601 and the excitation torque has to be applied on top of the mean hydrodynamic torque in bollard condition at considered propeller rotational speed. The worst phase angle between the ice interactions and any high torsional vibrations caused by engine excitations (e.g. 4th order engine excitation in direct coupled 2-stroke plants with 7-cyl. engine) should be considered in the analysis.

> **Guidance note:**
>
> A recommended way of performing transient torsional vibration calculations is given in Classification Note 51.1.
>
> Alternative methods to the ones given in Classification Note 51.1 may also be considered on the basis of equivalence.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

The results of the 3 cases are to be used in the following way:

1) The highest peak torque (between the various lumped masses in the system) is in the following referred to as peak torque T_{peak}.

2) The highest torque amplitude during a sequence of impacts is to be determined as half of the range from max to min torque and is referred to as T_{Amax}.
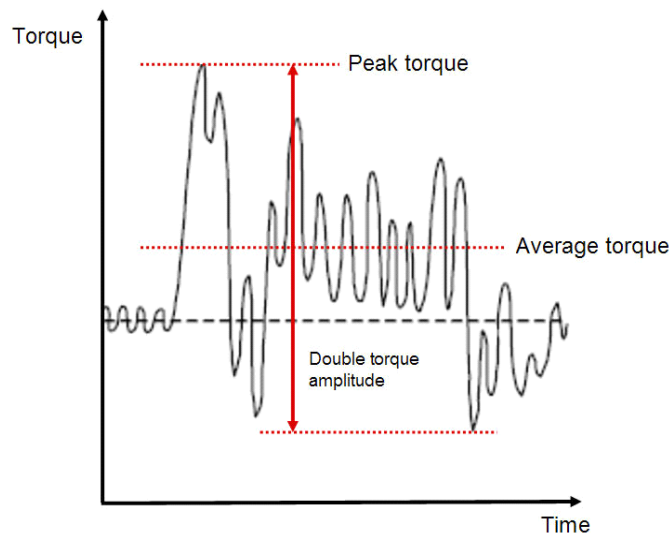

Fig. 10
Response Torque over time

603   *Maximum Response Thrust Th_r.*

Maximum thrust along the propeller shaft line shall 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: $Th_r = Th_n + 2.2\ Th_f$ [kN]

Maximum Shaft Thrust Backwards: $Th_r = 1.5\ Th_b$ [kN]

Th_n = propeller bollard thrust [kN]

Th_f = maximum forward propeller ice thrust [kN].

If hydrodynamic bollard thrust, Th_n is not known, Th_n shall be taken as follows:

Table I9	
Propeller type	Th_n
CP propellers (open)	1.25 *Th*
CP propellers (ducted)	1.1 *Th*
FP propellers driven by turbine or electric motor	Th_r
FP propellers driven by diesel engine (open)	0.85 *Th*
FP propellers driven by diesel engine (ducted)	0.75 *Th*

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

604 *Blade Failure Load for both Open and Nozzle Propeller F_{ex}*

The force is acting at 0.8R in the weakest direction of the blade at the centre of the blade. For calculation of spindle torque the force is assumed to act at a spindle arm of 1/3 of the distance from the axis of blade rotation to the leading or the trailing edge, whichever is greater.

The blade failure load is:

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

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

where σ_u (specified maximum ultimate tensile strength) and $\sigma_{0.2}$ (specified maximum yield or 0.2% proof strength) are representative values for the blade material. Representative in this respect means values for the considered section. These values may either be obtained by means of tests, or commonly accepted "thickness correction factors" approved by the classification society. If not available, maximum specified values shall be used.

c, t, D and r are respectively the actual chord length (m), thickness (m), propeller diameter (m) and radius (m) 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.

Alternatively the F_{ex} can be determined by means of FEA of the actual blade. Blade bending failure shall take place reasonably close to the root fillet end and normally not more 20% of R outside fillet. The blade bending failure is considered to occur when equivalent stress reach σ_{refl} times 1.5 in elastic model.

> **Guidance note:**
> A recommended FE analysis method is given in Classification Note 51.1.
>
> Alternative methods to the ones given in Classification Note 51.1 may also be considered on the basis of equivalence.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

I 700   Machinery fastening loading conditions

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

702 *Longitudinal Impact Accelerations, a_l*

Maximum longitudinal impact acceleration at any point along the hull girder,

$$a_l = \left(\frac{F_{IB}}{\Delta_{tk}}\right)\left(1.1\tan(\gamma + \phi) + 7\frac{H}{L}\right) \quad [\text{m/s}^2]$$

703 *Vertical acceleration a_v*

Combined vertical impact acceleration at any point along the hull girder,

$$a_v = \left(\frac{F_{IB}}{\Delta_{tk}}\right)F_x \quad [\text{m/s}^2]$$

F_X = 1.3 at F.P.
    = 0.2 at midships
    = 0.4 at A.P.
    = 1.3 at A.P. for vessels conducting ice breaking astern.

Intermediate values to be interpolated linearly.

704 *Transverse impact acceleration a_t*

Combined transverse impact acceleration at any point along hull girder,

$$a_t = 3F_{Bow}\frac{F_x}{\Delta_{tk}}$$

F_X = 1.5 at F.P.
    = 0.25 at midships
    = 0.5 at A.P.
    = 1.5 at A.P. 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_{tk} = displacement at UIWL [kt]
L = length between perpendiculars [m]
H = distance in meters from the water line to the point being considered [m]
F_{IB} = vertical impact force, defined in D200
F_{Bow} = as defined in B501.

J. Design – Machinery

J 100   Design principles

101   *Fatigue design in general*

The propeller and shaft line components are to be designed so as to prevent accumulated fatigue failure when considering the loads according to I300 through I600 using the linear elastic Palmgren-Miner's rule.

$$MDR = \frac{n_1}{N_1} + \frac{n_2}{N_2} + \cdots + \frac{n_k}{N_k} \le 1 \ \text{ or } \ MDR = \sum_{J=1}^{j=k} \frac{n_j}{N_j} \le 1$$

The long term ice load spectrum is approximated with two-parameter Weibull distribution.

102   *Propeller blades*

The load spectrum for backward loads is normally expected to have a lower number of cycles than the load spectrum for forward loads. Taking this into account in a fatigue analysis introduces complications that are not justified considering all uncertainties involved.

The blade stress amplitude distribution is therefore simplified and assumed to be as:

$$\sigma_A(N) = \sigma_{A\max} \cdot \left\{ 1 - \frac{\log(N)}{\log(N_{ice})} \right\}^{\frac{1}{k}} \qquad \text{[Equation 27]}$$

where the Weibull shape parameter is, k = 0.75 for open propeller and k = 1.0 for nozzle propeller

This is illustrated in the cumulative stress spectrum (stress exceedence diagram) in Fig. 11.

Number of load cycles N_{ice} in the load spectrum per blade is to be determined according to the formula:

$$N_{ice} = k_1 \cdot k_2 \cdot N_{class} \cdot n$$

where

N_{class} = reference number of impacts per propeller rotation speed for each ice class (table)

Ice Class	PC1	PC2	PC3	PC4	PC5	PC6	PC7
N_{class}	21×10^6	17×10^6	15×10^6	13×10^6	11×10^6	9×10^6	6×10^6

k_1 = 1 for centre propeller
= 2 for wing propeller
= 3 for pulling propeller (wing and centre)
= for pulling bow propellers number of load cycles is expected to increase in range of 10 times
k_2 = 0.8 - f when f < 0
= 0.8 - 0.4·f when 0 ≤ f ≤ 1
= 0.6 - 0.2·f when 1 < f ≤ 2.5
= 0.1 when f > 2.5
where the immersion function *f* is:

$$f = \frac{h_o - H_{ice}}{D/2} - 1 \quad \text{[Equation 28]}$$

where

h_o = depth of the propeller centreline at the minimum ballast waterline in ice (LIWL) of the ship.

103   Applicable loads in propulsion line components

The strength of the propulsion line components shall be designed

a)   for maximum loads in I300 and I400 (for open and ducted propellers respectively)

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

c) with fatigue strength as determined by the criteria in J500 with the following ice load spectrum

The Weibull shape parameter is k = 1.0 for both open and ducted propeller torque and bending forces. The load distribution is an accumulated load spectrum (load exceedence diagram).

$$T_A(N) = T_{A\max} \cdot \left\{ 1 - \frac{\log(N)}{\log(Z \cdot N_{ice})} \right\}$$

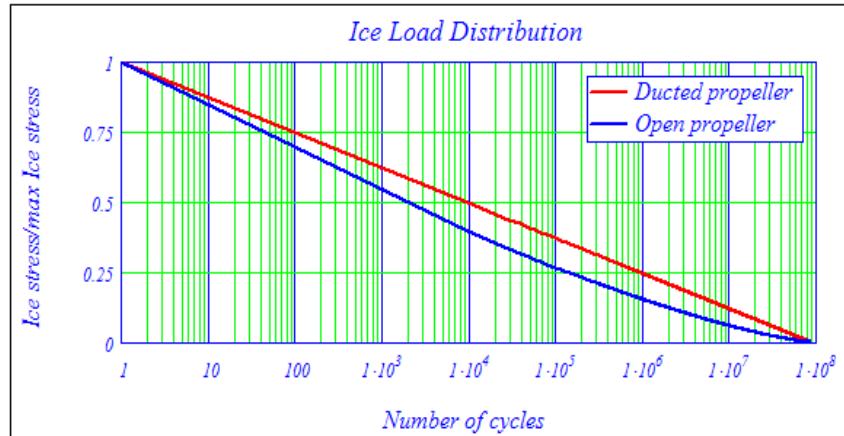This is illustrated by the example in the Fig. 12.

Fig. 11
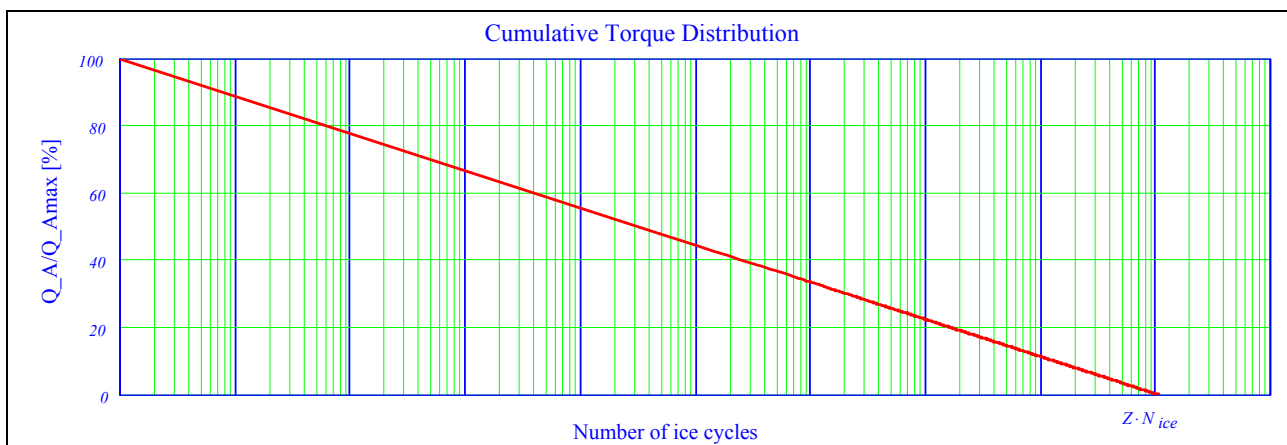**Ice load distribution for ducted and open propeller**

Fig. 12
The total number of load cycles in the load spectrum is determined as:Z·N$_{ice.}$

J 200 Propeller Blade design

201 *Maximum blade stresses*

Blade stresses (equivalent and principal stresses) shall be calculated using the backward and forward loads given in section I300 and I400. The stresses shall be calculated with recognised and well documented FE-analysis.

> **Guidance note:**
> A recommended FE analysis method is given in Classification Note 51.1.
> Alternative methods to the ones given in Classification Note 51.1 may also be considered on the basis of equivalence.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

The stresses on the blade shall not exceed the allowable stresses σ_{all} for the blade material given below.

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

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

S   = 1.5

σ_{ref} = reference stress, defined as:

σ_{ref} = $0.7\sigma_u$ or

σ_{ref} = $0.6\sigma_{0.2} + 0.4\sigma_u$ whichever is less

where σ_u and $\sigma_{0.2}$ are minimum specified values for the blade material according to approved maker's specification.

J 300   Fatigue design of propeller blades

301   Propeller blades are to be designed so as to prevent accumulated fatigue when considering the loads according to J102 and using the Miner's rule.

> **Guidance note:**
> A recommended fatigue analysis method is given in Classification Note 51.1.
> Alternative methods to the ones given in Classification Note 51.1 may also be considered on the basis of equivalence.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

302   The S-N curve characteristics are based on two slopes, the first slope 4.5 is from 10^0 to 10^8 load cycles; the second slope 10 is above 10^8 load cycles.

— The maximum allowable stress is limited by σ_{ref}/S
— The fatigue strength σ_{Fat-E7} is the fatigue limit at 10 million load cycles.

The geometrical size factor (K_{size}) is:

$$K_{size} = 1 - a \cdot ln\left(\frac{t}{25}\right)$$

Where t = actual blade thickness at considered section and a is given in table J2

The mean stress effect (K_{mean}) is

$$K_{mean} = 1.0 - \left(\frac{1.4 \cdot \sigma_{mean}}{\sigma_u}\right)^{0.75}$$

The fatigue limit for 10 million load cycles is then:

$$\sigma_{E7} = \frac{\sigma_{Fat-E7}}{S} \cdot K_{size} \cdot K_{mean}$$

where S is the safety factor S = 1.5

The S-N curve is extended by using the first slope *(4.5)* to 100 million load cycles due to the variable loading effect (stress interaction effect).

Table J2 Mean fatigue strength σ_{Fat-E7} for different material types			
Bronze and brass (a = 0.10)		Stainless steel (a = 0.05)	
Mn-Bronze, CU1 (high tensile brass)	80 MPa	Ferritic (12Cr 1Ni)	120 MPa
Mn-Ni-Bronze, CU2 (high tensile brass)	80 MPa	Martensitic (13Cr 4Ni/13Cr 6Ni)	150 MPa
Ni-Al-Bronze, CU3	120 MPa	Martensitic (16Cr 5Ni)	165 MPa
Mn-Al-Bronze, CU4	105 MPa	Austenitic (19Cr 10Ni)	130 MPa

Alternatively, σ_{Fat-E7} can be defined from fatigue test results from approved fatigue tests at 50% survival probability and stress ratio R = -1, ref. Rules Pt.4 Ch.5 Sec.1 B101.

J 400   Blade flange, bolts and propeller hub and CP Mechanism

401   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 I. 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 I604 shall be greater than 1 against yielding.

> **Guidance note:**
> A recommended fatigue analysis method is given in Classification Note 51.1.
> Alternative methods to the ones given in Classification Note 51.1 may also be considered on the basis of equivalence.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

402 Blade bolts shall withstand following bending moment considered around bolt pitch circle, or an other relevant axis for not circular joints, parallel to considered root section with a safety factor of 1.0:

$$M_{bolt} = F_{ex}(0.8\frac{D}{2} - r_{bolt}) \ \text{[kNm]}$$

where

r_{bolt} = radius to the bolt plan [m]

403 Blade bolt pre-tension shall be sufficient to avoid separation between mating surfaces with maximum forward and backward ice loads in I301 - I302 and I401 - I402 (open and ducted respectively).

404 Separate means, e.g. dowel pins, have to be provided in order to withstand a spindle torque resulting from blade failure (I604) Q_{sex} or ice interaction Q_{smax} (I303), whichever is greater. A safety factor S of 1.0 is required. The minimum diameter of the pins is:

$$d = 10^3 \sqrt{\frac{Q_s \cdot 8 \cdot \sqrt{3}}{PCD \cdot i \cdot \pi \cdot \sigma_{0.2}}} \ \ \text{[mm]}$$

PCD   =   Pitch circle diameter [mm]
i   =   number of pins
Q_s =   max(Q_{smax}; Q_{sex}) - Q_{fr1} - Q_{fr2} [kNm]
$\sigma_{0.2}$ =   yield strength of dovel pin material

$$Q_{sex} = F_{ex} \frac{1}{3} L_{ex} \ \ \text{[kNm]}$$

Q_{fr1} =   friction torque in blade bearings caused by the reaction forces due to F_{ex}
Q_{fr2} =   friction between connected surfaces resulting from blade bolt pretension forces.
L_{ex} =   maximum of distance from spindle axis to the leading, or trailing edge at radius 0,8R
Coefficient
of friction   =   0.15 may normally be applied in calculation of $Q_{fr1,2}$.

405 Components of CP mechanisms are to be designed to withstand the blade failure spindle torque Q_{sex} and maximum ice spindle torque.

The blade failure spindle torque Q_{sex} shall not lead to any consequential damages.

Fatigue strength is to be considered for parts transmitting the spindle torque from blades to a servo system considering ice spindle torque acting on one blade. The maximum amplitude is defined as:

$$Q_{sa\,max} = \frac{Q_{sb} + Q_{sf}}{2} \ \ \text{[kNm]}$$

Provided that calculated stresses duly considering local stress concentrations are less than yield strength, or maximum 70% of σ_u of respective materials, detailed fatigue analysis is not required. In opposite case components shall be analysed for cumulative fatigue.

406 Design pressure for servo system shall be taken as a pressure caused by Q_{smax} or Q_{sex} when not protected by relief valves, reduced by relevant friction losses in bearings caused by the respective ice loads. Design pressure shall in any case be less than relief valve set pressure

J 500 Propulsion Line Components

501 Propeller fitting to the shaft

A. Keyless cone mounting

The friction capacity (at 0°C) shall be at least 2.0 times the highest peak torque T_{peak} [kNm] as determined in I600 without exceeding the permissible hub stresses.

The necessary surface pressure can be determined as:

$$p_{0°C} = \frac{2 \cdot 2.0 \cdot T_{peak}}{\pi \cdot \mu \cdot D_S^2 \cdot L \cdot 10^3} \ \ \text{[MPa]}$$

where

μ =   0.14 for steel-steel,
      =   0.13 for steel-bronze
D_S =   is the shrinkage diameter at mid-length of taper [m]
L   =   is the effective length of taper [m]

Above friction coefficients may be increased by 0.04 if glycerine is used in wet mounting

B. Key mounting

Key mounting is not permitted.

C. Flange mounting

I   The flange thickness is to be at least 25% of the shaft diameter.
II   Any additional stress raisers such as recesses for bolt heads shall not interfere with the flange fillet unless the flange thickness is increased correspondingly.
III   The flange fillet radius is to be at least 10% of the shaft diameter.
IV   The diameter of ream fitted (light press fit) bolts shall be chosen so that the peak torque does not cause shear stresses beyond 30% of the yield strength of the bolts.
V   The bolts are to be designed so that the blade failure load F_{ex} (I604) does not cause yielding.

502   Propeller shaft

The propeller shaft is to be designed to fulfil the following:

A. The blade failure load F_{ex} (I604) applied parallel to the shaft (forward or backwards) shall not cause yielding. Bending moment need not to be combined with any other loads.
The diameter d in way of the aft stern tube bearing shall not be less than:

$$d = 160 \cdot \sqrt[3]{\frac{F_{ex} \cdot D}{\sigma_y \cdot \left(1 - \frac{d_i^4}{d^4}\right)}} \quad \text{[mm]}$$

where

σ_y =   minimum specified yield or 0.2% proof strength of the propeller shaft material [MPa]
d   =   shaft diameter [mm]
d_i =   shaft inner diameter [mm].

Forward from the aft stern tube bearing the diameter may be reduced based on direct calculation of actual bending moments, or by the assumption that the bending moment caused by F_{ex} is linearly reduced to 50% at the next bearing and in front of this linearly to zero at third bearing.

Bending due to maximum blade forces F_b and F_f have been disregarded since the resulting stress levels are much below the stresses due to the blade failure load.

B. The stresses due to the peak torque T_{peak} [kNm] shall have a minimum safety factor of 1.5 against yielding in plain sections and 1.0 in way of stress concentrations in order to avoid bent shafts.
Minimum diameter of

plain shaft:

$$d = 237 \cdot \sqrt[3]{\frac{T_{peak}}{\sigma_y \cdot \left(1 - \frac{d_i^4}{d^4}\right)}} \quad \text{[mm]}$$

notched shaft:

$$d = 207 \cdot \sqrt[3]{\frac{T_{peak} \cdot \alpha_t}{\sigma_y \left(1 - \frac{d_i^4}{d^4}\right)}} \quad \text{[mm]}$$

where α_t is the local stress concentration factor in torsion. Notched shaft diameter shall in any case not be less than the required plain shaft diameter.

C. The torque amplitudes with the foreseen number of cycles shall be used in an accumulated fatigue evaluation with the safety factors as defined below.

>   **Guidance note:**
>   A recommended fatigue analysis method is given in Classification Note 51.1 with further references to the CN 41.4. Alternative methods to the ones given in Classification Note 51.1 may also be considered on the basis of equivalence.
>
>   ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

D. For plants with reversing direction of rotation the stress range $\Delta\tau\,\alpha_t$ resulting from forward T_{peakf} to astern T_{peakb} shall not exceed twice the yield strength (in order to avoid stress-strain hysteresis loop) with a safety

factor of 1.5, i.e.:

$$\Delta\tau \cdot \alpha_t \le \frac{2 \cdot \sigma_y}{\sqrt{3} \cdot 1.5} \quad [\text{MPa}]$$

The fatigue strengths σ_F and τ_F (3 million cycles) of shaft materials may be assessed on the basis of the material's yield or 0.2% proof strength as:

$$\sigma_F = 0.436 \cdot \sigma_y + 77 = \tau_F \cdot \sqrt{3} \quad [\text{MPa}]$$

This is valid for small polished specimens (no notch) and reversed stresses, see "VDEH 1983 Bericht Nr. ABF11 Berechnung von Wöhlerlinien für Bauteile aus Stahl".

The *high cycle fatigue* (HCF) is to be assessed based on the above fatigue strengths, notch factors (i.e. geometrical stress concentration factors and notch sensitivity), size factors, mean stress influence and the required safety factor of 1.5.

The *low cycle fatigue* (LCF) representing 10^3 cycles is to based on the lower value of either half of the stress range criterion (see D) or the smaller value of yield or 0.7 of tensile strength/√3. Both criteria utilise a safety factor of 1.5.

The LCF and HCF as given above represent the upper and lower knees in a stress-cycle diagram. Since the required safety factors are included in these values, a Miner sum of unity is acceptable.

503 Intermediate shafts

The intermediate shafts are to be designed to fulfil the following:

A. The stresses due to the peak torque T_{peak} [kNm] shall have a minimum safety factor of 1.5 against yielding in plain sections and 1.0 in way of stress concentrations in order to avoid bent shafts.
Minimum diameter of

plain shaft:

$$d = 237 \cdot \sqrt[3]{\frac{T_{peak}}{\sigma_y \cdot \left(1 - \dfrac{d_i^{\;4}}{d^4}\right)}} \quad [\text{mm}]$$

notched shaft:

$$d = 207 \cdot \sqrt[3]{\frac{T_{peak} \cdot \alpha_t}{\sigma_y \left(1 - \dfrac{d_i^{\;4}}{d^4}\right)}} \quad [\text{mm}]$$

where α_t is the local stress concentration factor in torsion. Notched shaft diameter shall in any case not be less than the required plain shaft diameter.

B. The torque amplitudes with the foreseen number of cycles shall be used in an accumulated fatigue evaluation with the safety factors as defined below.

> **Guidance note:**
> A recommended fatigue analysis method is given in Classification Note 51.1.
> Alternative methods to the ones given in Classification Note 51.1 may also be considered on the basis of equivalence.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

C. For plants with reversing direction of rotation the stress range $\Delta\tau\,\alpha_t$ [MPa] resulting from forward T_{peakf} to astern T_{peakb} shall not exceed twice the yield strength (in order to avoid hysteresis) with a safety factor of 1.5, i.e.:

$$\Delta\tau \cdot \alpha_t \le \frac{2 \cdot \sigma_y}{\sqrt{3} \cdot 1.5} \quad [\text{MPa}]$$

The fatigue strengths σ_F and τ_F (3 million cycles) of shaft materials may be assessed on the basis of the material's yield or 0.2% proof strength as:

$$\sigma_F = 0.436 \cdot \sigma_y + 77 = \tau_F \cdot \sqrt{3} \quad [\text{MPa}]$$

This is valid for small polished specimens (no notch) and reversed stresses, see "VDEH 1983 Bericht Nr. ABF11 Berechnung von Wöhlerlinien für Bauteile aus Stahl".

The *high cycle fatigue* (HCF) is to be assessed based on the above fatigue strengths, notch factors (i.e. geometrical stress concentration factors and notch sensitivity), size factors, mean stress influence and the required safety factor of 1.5.

The *low cycle fatigue* (LCF) representing 10^3 cycles is to based on the lower value of either half of the stress range criterion (see C) or the smaller value of yield or 0.7 of tensile strength/√3. Both criteria utilise a safety factor of 1.5.

The LCF and HCF as given above represent the upper and lower knees in a stress-cycle diagram. Since the required safety factors are included in these values, a Miner sum of unity is acceptable.

504 Shaft connections

A. Shrink fit couplings (keyless)

The friction capacity shall be at least 1.8 times the highest peak torque T_{peak} as determined in I602 without exceeding the permissible hub stresses.

The necessary surface pressure can be determined as:

$$p = \frac{2 \cdot 1.8 \cdot T_{peak}}{\pi \cdot \mu \cdot D_S^2 \cdot L \cdot 10^3} \quad [MPa]$$

where

μ = coefficient of friction = 0.14 for steel to steel with oil injection (= 0.18 if glycerine injection)
D_S = is the shrinkage diameter at mid-length of taper [m]
L = is the effective length of taper [m].

B. Key mounting

Key mounting is not permitted.

C. Flange mounting

I   The flange thickness is to be at least 20% of the shaft diameter.
II   Any additional stress raisers such as recesses for bolt heads shall not interfere with the flange fillet unless the flange thickness is increased correspondingly.
III The flange fillet radius is to be at least 8% of the shaft diameter.
IV   The diameter of ream fitted (light press fit) bolts or pins shall be chosen so that the peak torque does not cause shear stresses beyond 30% of the yield strength of the bolts or pins.
V   The bolts are to be designed so that the blade failure load (I604) in backwards direction does not cause yielding.

505 Gear transmissions

A. Shafts

Shafts in gear transmissions shall meet the same safety level as intermediate shafts, but where relevant, bending stresses and torsional stresses shall be combined (e.g. by von Mises).

> **Guidance note:**
> A recommended fatigue analysis method is given in Classification Note 51.1.
> Alternative methods to the ones given in Classification Note 51.1 may also be considered on the basis of equivalence.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

Maximum permissible deflection in order to maintain sufficient tooth contact pattern is to be considered for the relevant parts of the gear shafts.

B. Gearing

The gearing shall fulfil following 3 acceptance criteria:

1) tooth root fracture
2) pitting of flanks
3) scuffing.

In addition to above 3 criteria subsurface fatigue may need to be considered.

Common for all criteria is the influence of load distribution over the face width. All relevant parameters are to be considered, such as elastic deflections (of mesh, shafts and gear bodies), accuracy tolerances, helix modifications, and working positions in bearings (especially for twin input single output gears).

The load spectrum (see J103) may be applied in such a way that the numbers of load cycles for the output wheel are multiplied by a factor of (number of pinions on the wheel / number of propeller blades Z). For pinions and wheels with higher speed the numbers of load cycles are found by multiplication with the gear ratios. The peak torque (T_{peak}) is also to be considered.

> **Guidance note:**
> The acceptance criteria for calculation assessment are given below. They refer to calculation methods as given in Classification Note 41.2, comprising information on calculation of tooth root strength (root fractures), flank surface durability (pitting, spalling, case crushing and tooth fractures starting from the flank), scuffing and subsurface fatigue.
> Alternative methods to the ones given in Classification Note 41.2 may also be considered on the basis of equivalence.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

Tooth root safety shall be assessed against the peak torque, torque amplitudes (with the pertinent average torque) as well as the ordinary loads (free water running) by means of accumulated fatigue analyses. The resulting safety factor is to be at least 1.5.

The safety against pitting shall be assessed in the same way as tooth root stresses, but with a minimum resulting safety factor of 1.2.

The scuffing safety (flash temperature method – ref. Classification Note 41.2) based on the peak torque shall be at least 1.2 when the FZG class of the oil is assumed one stage below specification.

The safety against subsurface fatigue of flanks for surface hardened gears (oblique fracture from active flank to opposite root) shall be assessed at the discretion of each society.

Bearings

See section I509.

506 Clutches

Clutches shall have a static friction torque of at least 1.3 times the peak torque and dynamic friction torque 2/3 of the static.

Emergency operation of clutch after failure of e.g. operating pressure shall be made possible within reasonably short time. If this is arranged by bolts, it shall be on the engine side of the clutch in order to ensure access to all bolts by turning the engine.

507 *Elastic couplings*

There shall be a separation margin of at least 20% between the peak torque and the torque where any twist limitation is reached.

The torque amplitude (or range Δ) shall not lead to fatigue cracking, i.e. exceeding the permissible vibratory torque. The permissible torque may be determined by interpolation in a log-log torque-cycle diagram where T_{Kmax1} respectively ΔT_{Kmax} refer to 50,000 cycles and T_{KV} refer to 10^6 cycles. See illustration in Fig. 13, 14 and 15.
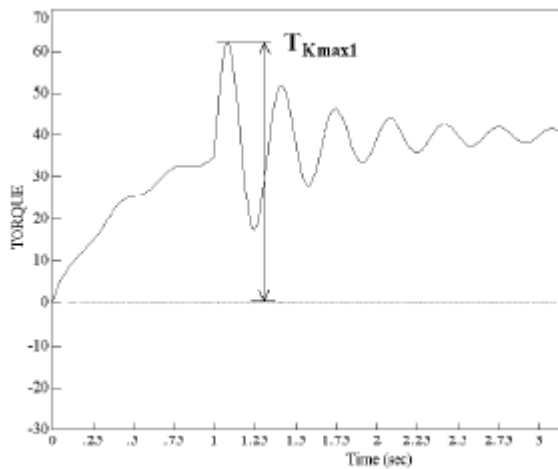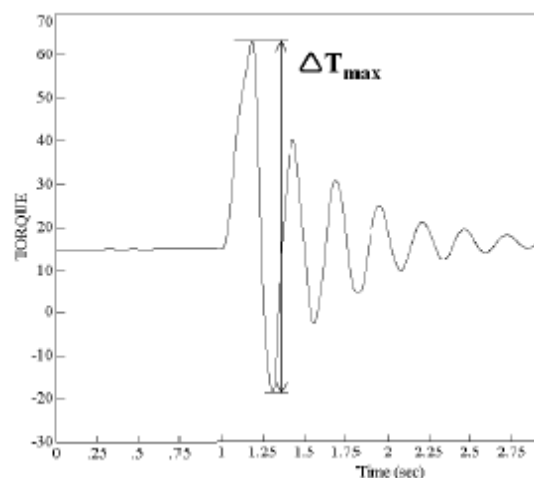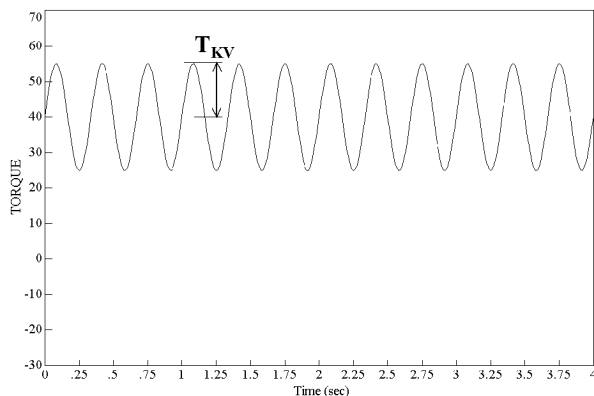

Fig. 13

Fig. 14

Fig. 15

508 *Crankshafts*

Special considerations apply for plants with large inertia (e.g. flywheel, tuning wheel or PTO) in the non-driving end of the engine.

509 *Bearings*

All shaft bearings are to be designed to withstand the propeller blade ice interaction loads according to I300 and I400. For the purpose of calculation the shafts are assumed to rotate at rated speed. Reaction forces due to the response torque (e.g. in gear transmissions) are to be considered.

Additionally the aft stern tube bearing as well as the next shaft-line bearing are to withstand F_{ex} as given in I600, in such a way that the ship can maintain operational capability.

Rolling bearings are to have a L_{10a} lifetime of at least 40 000 hours according to ISO-281.

Thrust bearings and their housings are to be designed to withstand maximum response thrust I600 and the force resulting from the blade failure force F_{ex}. For the purpose of calculation except for F_{ex} the shafts are assumed to rotate at rated speed. For pulling propellers special consideration is to be given to loads from ice interaction on propeller hub.

510 Seals

Basic requirements for seals:

A. Seals are to prevent egress of pollutants, and be suitable for the operating temperatures. Contingency plans for preventing the egress of pollutants under failure conditions are to be documented.

B. Seal are to be of type approved type or otherwise of proven design.

J 600   Azimuthing Main Propulsion

601   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.

602   Azimuth thrusters shall also be designed for estimated loads due to thruster body/ice interaction as per sub-section E. The thruster body has to stand the loads obtained when the maximum ice blocks, which are given in I201, 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 I200.

603   Design criteria for azimuth propulsors

Azimuth propulsors shall be designed for following loads:

1) Ice pressure on strut based on defined location area of the strut / ice interaction as per subsection E.

2) Ice pressure on pod based on defined location area of thruster body / ice interaction as per subsection E.

3) Plastic bending of one propeller blade in the worst position (typically top-down) without consequential damages to any other part

4) Steering gear design torque T_{SG} shall be minimum 60% of steering torque expected at propeller ice milling condition defined as T_{max}

$$T_{SG} = 0.6(T_{max} / 0.8R) \, l \, [kNm]$$

where l is distance from the propeller plane to steering (azimuth) axis [m].

5) Steering gear shall be protected by effective means limiting excessive torque caused by:

    a) Ice milling torque exceeding design torque and leading to rotation of unit

    b) Torque caused by plastic bending of one propeller blade in the worse position (related to steering gear) and leading to rotation of the unit.

6) Steering gear shall be ready for operation after above load, 5)a) or 5)b) has gone.

J 700   Steering system

701   Rudder stops are to be provided. The design ice force on rudder shall be transmitted to the rudder stops without damage to the steering system.

702 Ice knife shall in general be fitted to protect the rudder in centre position. The ice knife shall extend below BWL. Design forces shall be determined according to the subsection E.

703 The effective holding torque of the rudder actuator, at safety valve set pressure, is obtained by multiplying the open water requirement at design speed (maximum 18 knots) by following factors:

Ice Class	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Factor	5	5	3	3	3	2	1,5

The holding torque shall be limited to the actual twisting capacity of the rudder stock calculated at its yield strength (ref. Pt.4 Ch.14)

704 The rudder actuator *shall* be protected by torque relief arrangements, assuming the following turning speeds [deg/s] without undue pressure rise (ref. *Pt.4 Ch.14* for undue pressure rise):

Ice Class	PC1–2	PC3-5	PC6 - 7
Turning speeds [deg/s]	8	6	4

705 Additional fast acting torque relief arrangements (acting at 15% higher pressure than set pressure of safety valves in *704 shall* provide effective protection of the rudder actuator in case of the rudder is pushed rapidly hard over against the stops assuming following turning speeds [deg/s].

Ice Class	PC1–2	PC3-5	PC6 - 7
Turning speeds [deg/s]	40	20	10

The arrangement shall be so that steering capacity can be speedily regained.

J 800 Prime movers

801 Engines shall be capable of being started and running the propeller in bollard condition.

802 Propulsion plants with CP propeller shall be capable being operated even in case with the CP system in full pitch as limited by mechanical stoppers.

803 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.

804 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 I100 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.

J 900 Auxiliary systems

901 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.

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

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

J 1000 Sea inlets, cooling water systems and ballast tanks

1001 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.

1002 At least two sea chests shall be arranged as ice boxes for class **PC-1** to **PC-5** inclusive where. The calculated volume for each of the ice boxes shall be at least 1 m³ for every 750 kW of the total installed power. For **PC-6** and **PC-7** there shall be at least one ice box located preferably near centre line.

1003 Ice boxes shall be designed for an effective separation of ice and venting of air.

1004 Sea inlet valves shall be secured directly to the ice boxes. The valve shall be a full bore type.

1005 Ice boxes and sea bays shall have vent pipes and shall have shut off valves connected direct to the shell.

1006 Means shall be provided to prevent freezing of sea bays, ice boxes, ship side valves and fittings above the load water line.

1007 Efficient means shall be provided to re-circulate cooling seawater to the ice box. Total sectional area of the circulating pipes shall not be less than the area of the cooling water discharge pipe.

1008   Detachable gratings or manholes shall be provided for ice boxes. Manholes shall be located above the deepest load line. Access shall be provided to the ice box from above.

1009   Openings in ship sides for ice boxes shall be fitted with gratings, or holes or slots in shell plates. The net area through these openings shall be not less than 5 times the area of the inlet pipe. The diameter of holes and width of slot in shell plating shall be not less than 20 mm. Gratings of the ice boxes shall be provided with a means of clearing. Clearing pipes shall be provided with screw-down type non return valves.

J 1100   Ballast tanks

1101   Efficient means shall be provided to prevent freezing in fore and after peak tanks and wing tanks located above the water line and where otherwise found necessary.

J 1200   Ventilation systems

1201   The air intakes for machinery and accommodation ventilation shall be located on both sides of the ship.

1202   Accommodation and ventilation air intakes shall be provided with means of heating.

1203   The temperature of inlet air provided to machinery from the air intakes shall be suitable for the safe operation of the machinery

J 1300   Alternative design

1301   As an alternative, a comprehensive design study may be submitted and may be requested to be validated by an agreed test programme.

K. Stability and Watertight Integrity

K 100   General

101   The stability requirements according to Sec.4 L apply except as stated in 102.

102   For ships of Polar Classes 5, 6 and 7 not carrying any polluting or hazardous cargoes, damage may be assumed to be confined between watertight bulkheads, except where such bulkheads are spaced at less than the damage dimension.

APPENDIX A
GUIDELINES FOR STRENGTH ANALYSIS OF THE PROPELLER BLADE USING FINITE ELEMENT METHOD

A. Guidelines for Strength Analysis of the Propeller Blade using Finite Element Method

A 100 Requirements for FE model

101 The objective of the stress analysis of ice-strengthened propeller blades is to make sure that the designed propeller blade has an acceptable margin of safety against both ultimate and fatigue strength at the design loads.

The typical locations on the propeller blades at which the highest stresses caused by ice loads occur are the fillet at the root of the blade in the case of all propeller types and the section next to the tip load area in the case of skewed propellers.

The requirement for the finite element model is that it is able to represent the complex curvilinear geometry and the thickness variation of the blade and also the geometry of the fillet at the root of the blade, in order to represent the complex three-dimensional stress state of the structure and to represent the local peak stresses needed to assess the fatigue strength of the structure with acceptable accuracy. The load of the propeller blade is dominated by bending, leading to non-constant stress distribution over the thickness of the blade. The model should also be able to represent the stress distribution over the thickness of the blade.

A conventional stress analysis approach to propeller blades utilising beam theory, although capable of dealing with warping stresses, or an approach utilising coarse shell elements with a rough representation of the thickness variation of the blade do not lead to acceptable accuracy in the stress analyses of ice-strengthened propeller blades.

A 200 Good engineering practice for FE analysis

201 The use of solid elements is highly recommended for determining the stress distribution of the propeller blades. The use of a very dense parabolic tetrahedron mesh is recommended. Parabolic hexahedron solid elements may also be used, but hexahedra require considerably greater modelling effort. Linear elements and, especially, linear tetrahedrals should not be used in stress analysis.

As a rule of thumb, a minimum of two parabolic solid elements should be used over the thickness of the blade in the thinnest regions of the blade. Near the root region of the blade, where the geometry changes rapidly, the element size used should be chosen to be such that the local peak stress used in the fatigue assessment is obtained with good accuracy.

Additional geometric details which have a significant effect on the maximum peak stress at the root fillet should also be taken into account in the model, e.g. bolt holes located close to the root fillet. Well-shaped elements are a prerequisite for the stress analyses. The element formulation to be used should be chosen so as to be such that no locking, hour-glassing etc. phenomena occur.

A typical parabolic tetrahedron mesh of a propeller blade used in the verification studies is presented in Fig. 1 as an example.
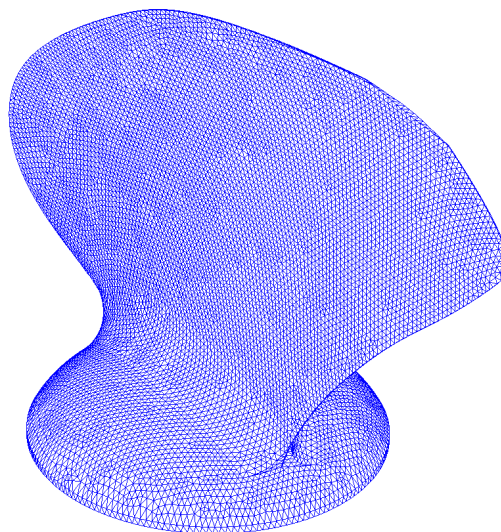

Fig. 1
A typical parabolic tetrahedron mesh of a propeller blade

Shell elements may be used in the stress analyses of propeller blades, but the accuracy of the modelling approach has to be proven by measurements or extensive verification calculations covering the thickness, dimensional, and geometrical variations of the propeller blade product range to be manufactured. For example, extreme sizes and an adequate number of intermediate sizes of the propeller blade product range should be used in verification calculations or measurements. The peak stress obtained using the shell element approach has to be within acceptable accuracy and the boundary conditions shall not cause significant disturbance in the peak stresses. The root fillet geometry has to be considered in the peak stress state used in the stress analysis. The modelling of the tip region is difficult. Thus, it is allowed, for example, to finish discretisation at the 0.975 chord and to make an artificial chord at the tip. The shell element formulation to be used should be chosen so as to be such that no locking, hour-glassing etc. phenomena occur.

A 300   Boundary conditions

301   The boundary conditions of the blade model should be given at an adequate distance from the peak stress location in order to ensure that the boundary condition has no significant effect on the stress field used in the stress analysis.

A 400   Applied pressure loads

401   The pressure loads applied on the finite element model can be given either in the normal direction of the curved blade surface or alternatively as a directional pressure load. The normal pressure approach - see Fig. 2 (a) - leads to a loss of the net applied transversal load as a result of the highly curved surface near the edge of the propeller blade.

Whichever approach is used, it should be ensured that the total force determined in the particular load case is applied on the model. In the normal pressure case, this can be done by scaling the load or, alternatively, by scaling the resulting stresses.

The directional pressure is better suited to propeller blade stress analyses. The pressure can be given on a surface in a direction defined using, for example, a local coordinate system; see Fig. 2 (b).
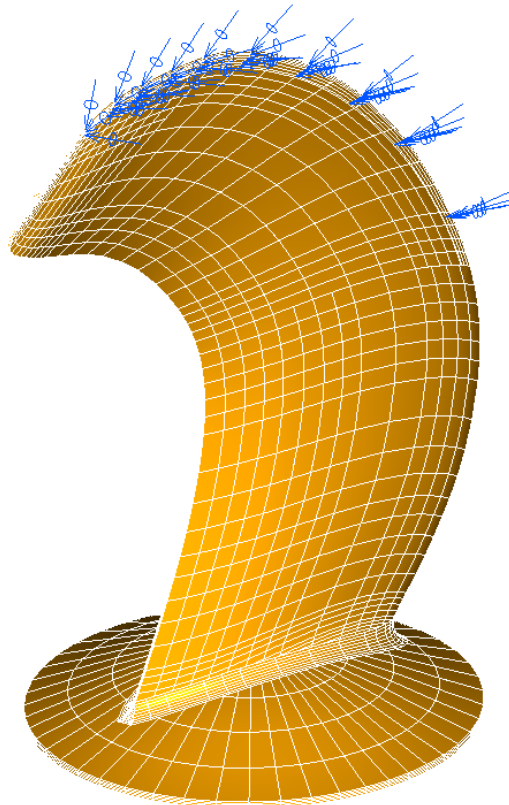

Fig. 2a
One possible way to apply the pressure load to the propeller blade. If the pressure load is given in the normal direction of the highly curved blade (Fig.a) surface, the resulting net applied load will be less than the intended load and should be scaled appropriately.
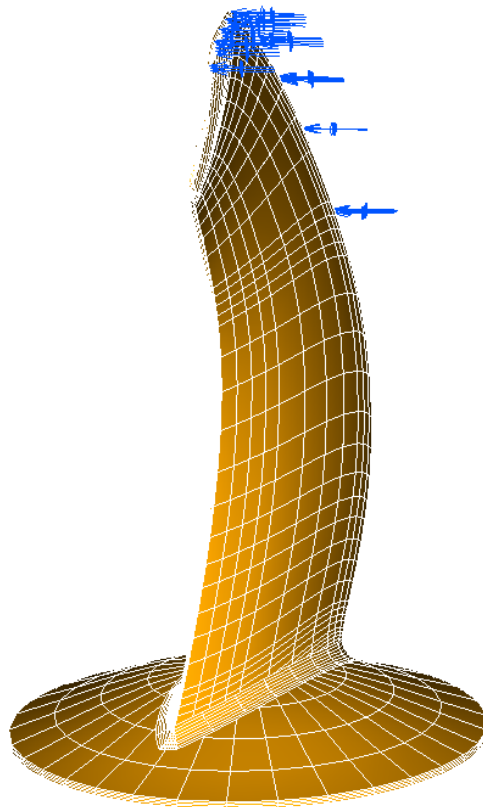
Fig. 2b
Second alternative: If the pressure load is given in a fixed direction (Fig.b), the net applied load is directly the intended load.