RULES FOR CLASSIFICATION OF

Ships

PART 3 CHAPTER 1

NEWBUILDINGS
HULL AND EQUIPMENT – MAIN CLASS

Hull structural design - Ships with length 100 metres and above

JANUARY 2016

The electronic pdf version of this document found through http://www.dnvgl.com is the officially binding version

DET NORSKE VERITAS AS

FOREWORD

DNV is a global provider of knowledge for managing risk. Today, safe and responsible business conduct is both a license to operate and a competitive advantage. Our core competence is to identify, assess, and advise on risk management. From our leading position in certification, classification, verification, and training, we develop and apply standards and best practices. This helps our customers safely and responsibly improve their business performance. DNV is an independent organisation with dedicated risk professionals in more than 100 countries, with the purpose of safeguarding life, property and the environment.

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.

Any comments may be sent by e-mail to *rules@dnvgl.com*

CHANGES – CURRENT

General

This document supersedes the January 2015 edition.

Text affected by the main changes in this edition is highlighted in red colour. However, if the changes involve a whole chapter, section or sub-section, normally only the title will be in red colour.

Det Norske Veritas AS, company registration number 945 748 931, has on 27th November 2013 changed its name to DNV GL AS. For further information, see www.dnvgl.com. Any reference in this document to "Det Norske Veritas AS" or "DNV" shall therefore also be a reference to "DNV GL AS".

Main changes January 2016, entering into force 1 July 2016

- **Sec.6 Bottom Structures**

— Previous item A311 has been deleted.

- **Sec.15 Bottom Structures**

— In A204, table A1 and A401 references to previous Pt.8 have been updated to CSR rules.
— In D702 the item 2.Grounding, the penetration height has been removed.

Editorial corrections

In addition to the above stated main changes, editorial corrections may have been made.

CONTENTS

SECTION 1 GENERAL REQUIREMENTS

A. Classification

A 100 Application

101 The rules in this chapter apply to steel hull structures for assignment of the main class for ships with length 100 metres and above, except for oil tankers and bulk carriers with mandatory class notation **CSR**. Application of the **CSR** notation is described in CSR Pt.1 and CSR Pt.2.

The requirements for material certificates in Sec.2 A200 also apply to vessels with **CSR** notation.

Sec.15 may be applied to vessels with **CSR** notation.

102 Applicable rules for assignment of main class for tankers with class notation **CSR** are given in Pt.5 Ch.3.

103 The rules also apply to aluminium structures and wooden decks to the extent that these materials are acceptable as alternative materials.

A 200 Class notations

201 The class notations applicable for the assignment of the main class are described in Pt.1 Ch.1 Sec.1.

202 The following special features notations are specified in this chapter:

ICM	increased corrosion margin (Sec.2 D300)
HL(ρ)	tanks for heavy liquid (Sec.4 C301)
DK(+)	decks for heavy cargo (Sec.4 C401)
HA(+)	hatches for heavy cargo (Sec.4 C401)
IB-X	inner bottom strengthened for grab loading and discharging (Sec.6 H300)
BIS	built for in-water survey (D100)

B. Definitions

B 100 Symbols

101 The following symbols are used:

L = length of the ship in m defined as the distance on the summer load waterline from the fore side of the stem to the axis of the rudder stock.

L shall not be taken less than 96%, and need not to be taken greater than 97%, of the extreme length on the summer load waterline. For ships with unusual stern and bow arrangement, the length L will be especially considered.

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.

A.P. = the after perpendicular is the perpendicular at the after end of the length L.

L_F = length of the ship as defined in the International Convention of Load Lines:

The length shall be taken as 96 per cent of the total length on a waterline at 85 per cent of the least moulded depth measured from the top of the keel, or as the length from the fore side of the stem to the axis of the rudder stock on that waterline, if that be greater. In ships designed with a rake of keel the waterline on which this length is measured shall be parallel to the designed waterline.

B = greatest moulded breadth in m, measured at the summer waterline.

D = moulded depth defined as the vertical distance in m from baseline to moulded deckline at the uppermost continuous deck measured amidships.

D_F = least moulded depth taken as the vertical distance in m from the top of the keel to the top of the freeboard deck beam at side.

In ships having rounded gunwales, the moulded depth shall be measured to the point of intersection of the moulded lines of the deck and side shell plating, the lines extending as though the gunwale was of angular design.

Where the freeboard deck is stepped and the raised part of the deck extends over the point at which the moulded depth shall be determined, the moulded depth shall be measured to a line of reference extending from the lower part of the deck along a line parallel with the raised part.

T = mean moulded summer draught in m.
Δ = moulded displacement in t in salt water (density 1.025 t/m^3) on draught T.
C_B = block coefficient,

$$= \frac{\Delta}{1.025\ L\ B\ T}$$

For barge rigidly connected to a push-tug C_B shall be calculated for the combination barge/ push-tug.
C_{BF} = block coefficient as defined in the International Convention of Load Lines:

$$= \frac{\nabla}{L_F\ B\ T_F}$$

∇ = volume of the moulded displacement, excluding bossings, taken at the moulded draught T_F.
T_F = 85% of the least moulded depth.
V = maximum service speed in knots, defined as the greatest speed which the ship is designed to maintain in service at her deepest seagoing draught.
g_0 = standard acceleration of gravity
= 9.81 m/s^2.
f_1 = material factor depending on material strength group. See Sec.2.
t_k = corrosion addition as given in Sec.2 D200 and D300, as relevant.
x = axis in the ship's longitudinal direction.
y = axis in the ship's athwartships direction.
z = axis in the ship's vertical direction.
E = modulus of elasticity of the material
= $2.06 \cdot 10^5$ N/mm^2 for steel
= $0.69 \cdot 10^5$ N/mm^2 for aluminium alloy.
C_W = wave load coefficient given in Sec.4 B200.

Amidships = the middle of the length L.

B 200 Terms

201 Linear and angular motions of the ship are defined as follows:
— *surge* is the linear motion along the x-axis
— *sway* is the linear motion along the y-axis
— *heave* is the linear motion along the z-axis
— *roll* is the angular motion about the x-axis
— *pitch* is the angular motion about the y-axis
— *yaw* is the angular motion about the z-axis.

202 *Moulded deck line, Rounded sheer strake, Sheer strake,* and *Stringer plate* are as defined in Fig.1.

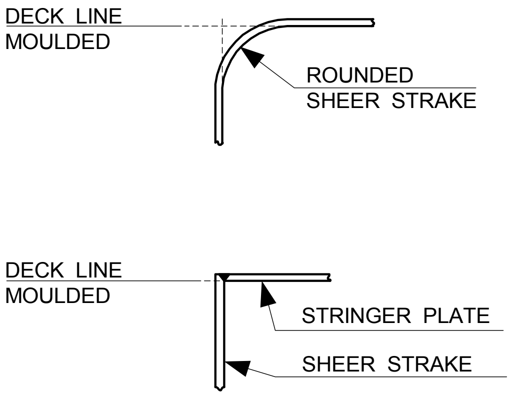


Fig. 1
Deck corners

203 The *freeboard* assigned is the distance measured vertically downwards amidships from the upper edge of the deck line to the upper edge of the related load line.

204 The *freeboard deck* is normally the uppermost complete deck exposed to weather and sea, which has permanent means of closing all openings in the weather part thereof, and below which all openings in the sides of the ship are fitted with permanent means of watertight closing. In a ship having a discontinuous freeboard deck, the lowest line of the exposed deck and the continuation of that line parallel to the upper part of the deck is taken as the freeboard deck. At the option of the owner and subject to the approval of the Administration, a lower deck may be designated as the freeboard deck provided it is a complete and permanent deck continuous in a fore and aft direction at least between the machinery space and peak bulkheads and continuous athwartships. When this lower deck is stepped the lowest line of the deck and the continuation of that line parallel to the upper part of the deck is taken as the freeboard deck. When a lower deck is designated as the freeboard deck, that part of the hull which extends above the freeboard deck is treated as a superstructure so far as concerns the application of the conditions of assignment and the calculation of freeboard. It is from this deck that the freeboard is calculated.

205 *Strength deck* is in general defined as the uppermost continuous deck. A superstructure deck which within 0.4 L amidships has a continuous length equal to or greater than

$$3\left(\frac{B}{2}+H\right) \quad (m)$$

shall be regarded as the strength deck instead of the covered part of the uppermost continuous deck.

H = height in m between the uppermost continuous deck and the superstructure deck in question.

Another deck may be defined as the strength deck after special consideration of its effectiveness.

206 *Double bottom structure* is defined as shell plating with stiffeners below the top of the inner bottom and other elements below and including the inner bottom plating. Note that sloping hopper tank top side shall be regarded as longitudinal bulkhead.

207 *Single bottom structure* is defined as shell plating with stiffeners and girders below the upper turn of bilge.

208 *Side structure* is defined as shell plating with stiffeners and girders between the bottom structure and the uppermost deck at side.

209 *Deck structure* is defined as deck plating with stiffeners, girders and supporting pillars.

210 *Bulkhead structure* is defined as transverse or longitudinal bulkhead plating with stiffeners and girders.

Watertight bulkhead is a collective term for transverse bulkheads required according to Sec.3 A.

Cargo hold bulkhead is a boundary bulkhead for cargo hold.

Tank bulkhead is a boundary bulkhead in tank for liquid cargo, ballast or bunker.

Wash bulkhead is a perforated or partial bulkhead in tank.

211 *Forepeak and afterpeak* are defined as the areas forward of collision bulkhead and aft of after peak bulkhead, respectively, up to the heights defined in Sec.3 A500.

212 *Superstructure*

a) A superstructure is a decked structure on the freeboard deck, extending from side to side of the ship or with the side plating not being inboard of the shell plating more than 4 per cent of the breadth (B). A raised quarter deck is regarded as a superstructure.
b) An enclosed superstructure is a superstructure with:
   i) enclosing bulkheads of efficient construction,
   ii) access openings, if any, in these bulkheads fitted with doors complying with the requirements of Ch.3 Sec.6 B101,
   iii) all other openings in sides or ends of the superstructure fitted with efficient weathertight means of closing.

   A bridge or poop shall not be regarded as enclosed unless access is provided for the crew to reach machinery and other working spaces inside these superstructures by alternative means which are available at all times when bulkhead openings are closed.
c) The height of a superstructure is the least vertical height measured at side from the top of the superstructure deck beams to the top of the freeboard deck beams.
d) The length of a superstructure (S) is the mean length of the part of the superstructure which lies within the length (L).
e) A *long forward superstructure* is defined as an enclosed forward superstructure with length S equal to or greater than 0.25 L.

213 A *flush deck ship* is one which has no superstructure on the freeboard deck.

214 *Girder* is a collective term for primary supporting members. Tank girders with special names are shown in Fig.2.

Other terms used are:

— floor (a bottom transverse girder)
— stringer (a horizontal girder).

215 *Stiffener* is a collective term for a secondary supporting member. Other terms used are:

— frame
— bottom longitudinal
— inner bottom longitudinal
— reversed frame (inner bottom transverse stiffener)
— side longitudinal
— beam
— deck longitudinal
— bulkhead longitudinal.

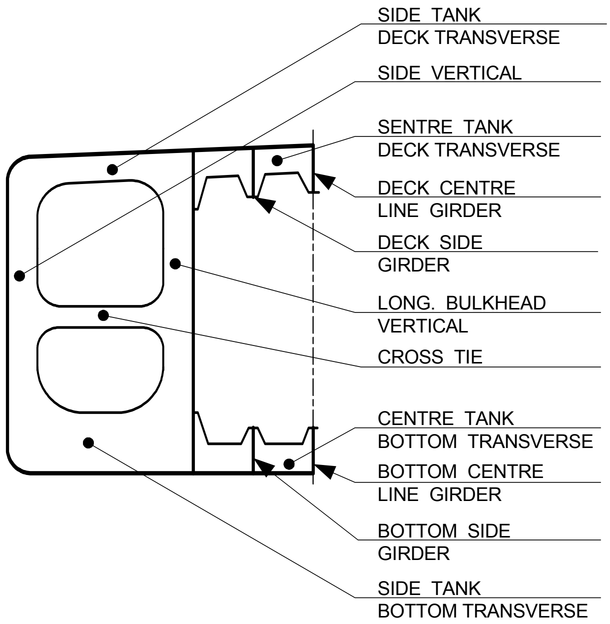


Fig. 2
Tank girders

216 *Supporting structure.* Strengthening of the vessel structure, e.g. a deck, in order to accommodate loads and moments from a heavy or loaded object.

217 *Foundation*. A device transferring loads from a heavy or loaded object to the vessel structure.

218 *Probability density function f(x)*. The probability that a realisation of a continuous random variable x falls in the interval (x, x+dx) is f(x)dx. f(x) is the derivative of the cumulative probability function F(x).

219 *Cumulative probability F(x)* is defined as:

$$F(x) = \int_{-\infty}^{x} f(x)dx$$

220 *Exceedance probability Q(x)* is defined as:

$$Q(x) = 1 - F(x)$$

221 *Probability of exceedance,* or *exceedance probability* may be illustrated by the following example: x shall be taken at a probability of exceedance of q, means that the variable, x, shall be taken as the value, x_q, defined as the upper *q* quantile in the long term distribution of x.

222 *Quantile*. The p quantile may be defined as the value, x_p, of a random variable x, which correspond to a fraction p of the outcomes of the variable.

$$F(x_p) = \int_{-\infty}^{x_p} f(x)dx = p$$

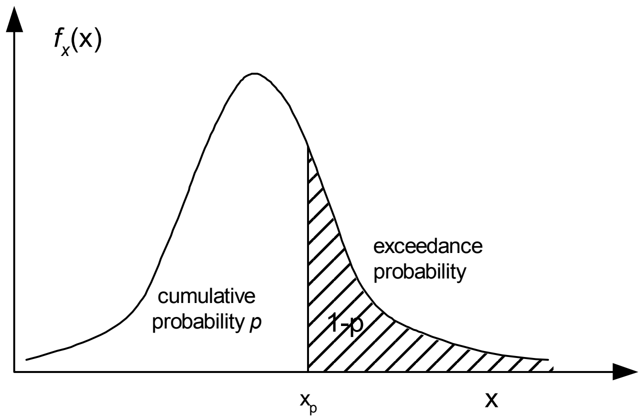
I.e. x_p is the *p* quantile of the variable x. One may denote x_p as the lower *p* quantile of x, or alternatively as the upper 1– *p* quantile of x.

B 300 Ship types

301 A *passenger ship* is a ship which carries more than 12 passengers.

302 A *cargo ship* is any ship which is not a passenger ship.

303 A *tanker* is a cargo ship constructed or adapted for the carriage in bulk of liquid cargoes.



(p quantile of X = Upper p quantile of X
= Lower (1– p) quantile of X)

Fig. 3
Probability density function

C. Documentation

C 100 Documentation requirements

101 Documentation shall be submitted as required by Table C1.

Table C1 – Documentation requirements			
Object	*Documentation type*	*Additional description*	*Info*
Ship	Z010 – General arrangement plan		FI
Hull structure	H030 - Tank and capacity plan		FI
	H050 – Structural drawing	Decks and inner bottom.	AP
	H050 – Structural drawing	Transverse bulkheads.	AP
	H050 – Structural drawing	Longitudinal bulkheads.	AP
	H050 – Structural drawing	Fore ship.	AP
	H050 – Structural drawing	Engine room area.	AP
	H050 – Structural drawing	Aft ship.	AP
	H052 - Midship section drawing		AP
	H060 - Shell expansion drawing		AP
	H061 – Framing plan.		AP
	H062 – Longitudinal section drawing		AP
	H082 – Longitudinal strength analysis		FI
	H110 - Loading manual		AP
Superstructure	H050 – Structural drawing		AP
Deck house structures	H050 – Structural drawing		AP
Supporting structures for heavy or loaded objects	H050 – Structural drawing	If static force > 50 kN or bending moment at deck > 100 kNm.	AP
Corrosion prevention system	Z030 – Arrangement plan	Sacrificial anodes.	AP

102 For class notation **BIS**, additional documentation shall be submitted as required by Table C2.

Table C2 – Documentation requirements: Class notation BIS			
Object	*Documentation type*	*Additional description*	*Info*
Hull structure	Z030 – Arrangement plan	Openings in sides and bottom below the deepest load waterline, bottom plugs, echo sounders and other underwater equipment.	FI
Bottom survey marks	Z030 – Arrangement plan	Markings for identification of tanks on sides and bottom.	AP
Rudder arrangements	Z250 – Procedure	Measurement of bearing clearances.	FI
Impressed current system	Z030 – Arrangement plan		FI

103 For class notation **HOT**, additional documentation shall be submitted as required by Table C3.

Table C3 – Documentation requirements: Class notation HOT			
Object	*Documentation type*	*Additional description*	*Info*
Hull structure	H080 – Strength analysis	Cargo area, based on temperature distributions in the hull structure.	FI
	Z210 – Design basis	Covering heat balance, capacity calculations and temperature distribution in the hull girder system.	FI

104 For class notation **PLUS**, additional documentation shall be submitted as required by Table C4.

Table C4 – Documentation requirements: Class notation PLUS			
Object	*Documentation type*	*Additional description*	*Info*
Hull structure	H085 – Fatigue analysis	See CN 34.2.	FI

D. Ships built for in-water survey of the ship's bottom and related items

D 100 General

101 Ships built in accordance with the following requirements may be given the notation **BIS**.

102 The **BIS** notation indicates that the ship is prepared for in-water survey.

Guidance note 1:

The conditions under which in-water survey is allowed are given in Pt.7 Ch.1 Sec.1 [1].

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

Guidance note 2:

Means should be provided to enable the diver to confirm that the sea suction openings are clear.

Hinged sea suction grids will facilitate this operation, preferably with revolving weight balance or with a counter weight, and secured with bolts practical for dismantling and fitting while the ship is afloat.

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

D 200 On board documentation

201 The documentation required by Table C2 shall be available onboard.

D 300 Markings of ship’s sides and bottom

301 The underwater body shall be marked in such a way that the surveyor can identify the location of any observations made. Transverse and longitudinal reference lines of approximate length 300 mm and width 25 mm shall be applied as marking. The marks shall be made permanent welding or similar and painted in a contrasting colour.

Marking shall normally be placed as follows:

— at flat bottom in way of intersections of tank bulkheads or watertight floors and girders
— at ship’s sides in way of the positions of transverse bulkheads (the marking need not be extended more than 1 m above bilge plating)
— the intersection between tank top and watertight floors in way of ship’s sides
— all openings for sea suctions and discharge
— letter and number codes shall be applied on the shell for identification of tanks, sea suctions and discharges.

D 400 Rudder

401 Bearing materials shall be stainless steel, bronze or an approved type of synthetic material and shall satisfy the requirements in Ch.3 Sec.2.

402 For water lubricated bearings, arrangements shall be made for measuring of rudder stock and pintle clearances while the ship is afloat.

D 500 Tailshaft

501 The tailshaft shall be designed to minimum 5 years survey interval, ref. Pt.7 Ch.1 Sec.1 [1].

D 600 Thrusters

601 Thrusters shall have 5 year survey interval or alternatively the reduced scope survey, as required in Pt.7 Ch.1 Sec.5 [4]/[5], shall be possible while the ship is afloat.

SECTION 2 MATERIALS

A. General

A 100 Introduction

101 In this section requirements regarding the application of various structural materials as well as protection methods and materials are given.

A 200 Material certificates

201 Rolled steel and aluminium for hull structures are normally to be supplied with DNV's material certificates in compliance with the requirements given in Pt.2.

202 Requirements for material certificates for forgings, castings and other materials for special parts and equipment are stated in connection with the rule requirements for each individual part.

B. Hull structure steel

B 100 General

101 Where the subsequent rules for material grade are dependent on plate thickness, the requirements are based on the thickness as built.

Guidance note:

Attention should be drawn to the fact when the hull plating is being gauged at periodical surveys and the wastage considered in relation to reductions allowed by the Society, such allowed reductions are based on the nominal thicknesses required by the rules.

The under thickness tolerances acceptable for classification should be seen as the lower limit of a total «minus-plus» standard range of tolerances which could be met in normal production with a conventional rolling mill settled to produce in average the nominal thickness.

However, with modern rolling mills it might be possible to produce plates to a narrow band of thickness tolerances which could permit to consistently produce material thinner than the nominal thickness, satisfying at the same time the under thickness tolerance given in Pt.2 Ch.2 Sec.1.

Therefore in such a case the material will reach earlier the minimum thickness allowable at the hull gaugings.

It is upon the shipyard and owner, bearing in mind the above situation, to decide whether, for commercial reasons, stricter under thickness tolerances should be specified in the individual cases.

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

B 200 Material designations and classes

201 Hull materials of various strength groups will be referred to as follows:

— NV-NS denotes normal strength structural steel with yield point not less than 235 N/mm^2
— NV-27 denotes high strength structural steel with yield point not less than 265 N/mm^2
— NV-32 denotes high strength structural steel with yield point not less than 315 N/mm^2
— NV-36 denotes high strength structural steel with yield point not less than 355 N/mm^2
— NV-40 denotes high strength structural steel with yield point not less than 390 N/mm^2.

Normal and high strength steel may also be referred to as NS-steel and HS-steel respectively.

202 Hull materials of various grades will be referred to as follows:

— A, B, D and E denotes NS-steel grades
— AH, DH and EH denotes HS-steel grades. HS-steel may also be referred to by a combination of grade and strength group. In that case the letter H is substituted by one of the numbers indicated in 201, e.g. A 36-steel.

203 The material factor f_1 included in the various formulae for scantlings and in expressions giving allowable stresses, is dependent on strength group as follows:

— for NV-NS: f_1=1.00
— for NV-27: f_1=1.08
— for NV-32: f_1=1.28
— for NV-36: f_1=1.39
— for NV-40: f_1=1.47.

For A 34-steel (with yield point not less than 335 N/mm^2) the material factor may be taken as f_1 = 1.35.

204 In order to distinguish between the material grade requirements for different hull parts, various material classes are applied as defined in Table B1.

The steel grade is to correspond to the as-built plate thickness and material class.

Table B1 Material classes

Thickness in mm	*Class*			
	I	*II*	*III*	*IV*
t ≤ 15	A/AH	A/AH	A/AH	A/AH
15 < t ≤ 20	A/AH	A/AH	A/AH	B/AH
20 < t ≤ 25	A/AH	A/AH	B/AH	D/DH
25 < t ≤ 30	A/AH	A/AH	D/DH	D/DH
30 < t ≤ 35	A/AH	B/AH	D/DH	E/EH
35 < t ≤ 40	A/AH	B/AH	D/DH	E/EH
40 < t ≤ 50*)	B/AH	D/DH	E/EH	E/EH

*) Plating of Class III or IV and with a thickness between 50 mm < t ≤ 150 mm, shall be of grade E/EH.
For other cases, D/DH (according to Class II) will be minimum quality for thicknesses above 50 mm

B 300 Basic requirements

301 Materials in the various strength members are not to be of lower grade than those corresponding to the material classes and grades specified in Table B2 to Table B7. General requirements are given in Table B2, while additional minimum requirements are given in the following:

— Table B3: for ships, excluding liquefied gas carriers covered in Table B4, with length exceeding 150 m and single strength deck,
— Table B4: for membrane type liquefied gas carriers with length exceeding 150 m,
— Table B5: for ships with length exceeding 250 m,
— Table B6: for single side bulk carriers subjected to SOLAS regulation XII/6.4.3,
— Table B7: for ships with ice strengthening.

For strength members not mentioned in Tables B2 to B7, Class I may be applied.

302 Materials in local strength members shall not be of lower grades than those corresponding to the material class I. However, for heavy foundation plates in engine room, grade A may also be accepted for NS-steel with thickness above 40 mm.

Table B2 Material classes and grades for ships in general

Structural member category	*Material class/grade*
SECONDARY: A1. Longitudinal bulkhead strakes, other than that belonging to the Primary category A2. Deck plating exposed to weather, other than that belonging to the Primary or Special category A3. Side plating	— Class II within 0.4L amidships — Grade A/AH outside 0.4L amidships
PRIMARY: B1. Bottom plating, including keel plate B2. Strength deck plating, excluding that belonging to the Special category B3. Continuous longitudinal plating of strength members above strength deck, excluding hatch coamings B4. Uppermost strake in longitudinal bulkhead B5. Vertical strake (hatch side girder) and uppermost sloped strake in top wing tank	— Class III within 0.4L amidships — Grade A/AH outside 0.4L amidships
SPECIAL: C1. Sheer strake at strength deck *) C2. Stringer plate in strength deck *) C3. Deck strake at longitudinal bulkhead, excluding deck plating in way of inner-skin bulkhead of double-hull ships *)	— Class IV within 0.4L amidships — Class III outside 0.4L amidships — Class II outside 0.6L amidships
C4. Strength deck plating at outboard corners of cargo hatch openings in container carriers and other ships with similar hatch opening configurations	— Class IV within 0.4L amidships — Class III outside 0.4L amidships — Class II outside 0.6L amidships — Min. Class IV within the cargo region

Table B2 Material classes and grades for ships in general (Continued)	
Structural member category	*Material class/grade*
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 C5.1 Trunk deck and inner deck plating at corners of openings for liquid and gas domes in membrane type liquefied gas carriers	— Class IV within 0.6L amidships — Class III within rest of cargo region
C6. Bilge strake in ships with double bottom over the full breadth and length less than 150 m	— Class III within 0.6L amidships — Class II outside 0.6L amidships
C7. Bilge strake in other ships *)	— Class IV within 0.4L amidships — Class III outside 0.4L amidships — Class II outside 0.6L amidships
C8. Longitudinal hatch coamings of length greater than 0.15L including coaming top plate and flange C9. End brackets and deck house transition of longitudinal cargo hatch coamings	— Class IV within 0.4L amidships — Class III outside 0.4L amidships — Class II outside 0.6L amidships — Not to be less than Grade D/DH
*) Single strakes required to be of Class IV within 0.4L amidships are to have breadths not less than 800 + 5L (mm), need not be greater than 1800 (mm), unless limited by the geometry of the ship's design.	

Table B3 Minimum material grades for ships, excluding liquefied gas carriers covered in Table B4, with length exceeding 150 m and single strength deck *)	
Structural member category	*Material grade*
— Longitudinal plating of strength deck where contributing to the longitudinal strength — Continuous longitudinal plating of strength members above strength deck	Grade B/AH within 0.4L amidships
Single side strakes for ships without inner continuous longitudinal bulkhead(s) between bottom and the strength deck	Grade B/AH within cargo region
*) The requirements of Table B3 do not apply for ships where the strength deck is a double skin construction, and for ships with two continuous decks above 0.7D, measured from the baseline.	

Table B4 Minimum material grades for membrane type liquefied gas carriers with length exceeding 150 m *)		
Structural member category		*Material grade*
Longitudinal plating of strength deck where contributing to the longitudinal strength		Grade B/AH within 0.4L amidships
Continuous longitudinal plating of strength members above the strength deck	Trunk deck plating	Class III within 0.4L amidships
	— Inner deck plating — Longitudinal strength member plating between the trunk deck and inner deck	Grade B/AH within 0.4L amidships
*) Table B4 is applicable to membrane type liquefied gas carriers with deck arrangements as shown in Fig. 1. Table B4 may apply to similar ship types with a “double deck” arrangement above the strength deck.		

Table B5 Minimum material grades for ships with length exceeding 250 m	
Structural member category	Material grade
Shear strake at strength deck *)	Grade E/EH within 0.4L amidships
Stringer plate in strength deck *)	Grade E/EH within 0.4L amidships
Bilge strake *)	Grade D/DH within 0.4L amidships
*) Single strakes required to be of Grade E/EH and within 0.4L amidships are to have breadths not less than 800+5L (mm), need not be greater than 1800 (mm), unless limited by the geometry of the ship's design.	

Table B6 Minimum material grades for single-side skin bulk carriers subjected to SOLAS regulation XII/6.4.3	
Structural member category	*Material grade*
Lower bracket of ordinary side frame *) **)	Grade D/DH
Side shell strakes included totally or partially between the two points located to 0.125*l* above and below the intersection of side shell and bilge hopper sloping plate or inner bottom plate **)	Grade D/DH
*) The term “lower bracket” means webs of lower brackets and webs of the lower part of side frames up to the point of 0.125*l* above the intersection of side shell and bilge hopper sloping plate or inner bottom plate. **) The span of the side frame, *l*, is defined as the distance between the supporting structures.	

Table B7 Minimum material grades for ships with ice strengthening	
Structural member category	*Material grade*
Shell strakes in way of ice strengthening area for plates	Grade B/AH

(IACS UR S6)

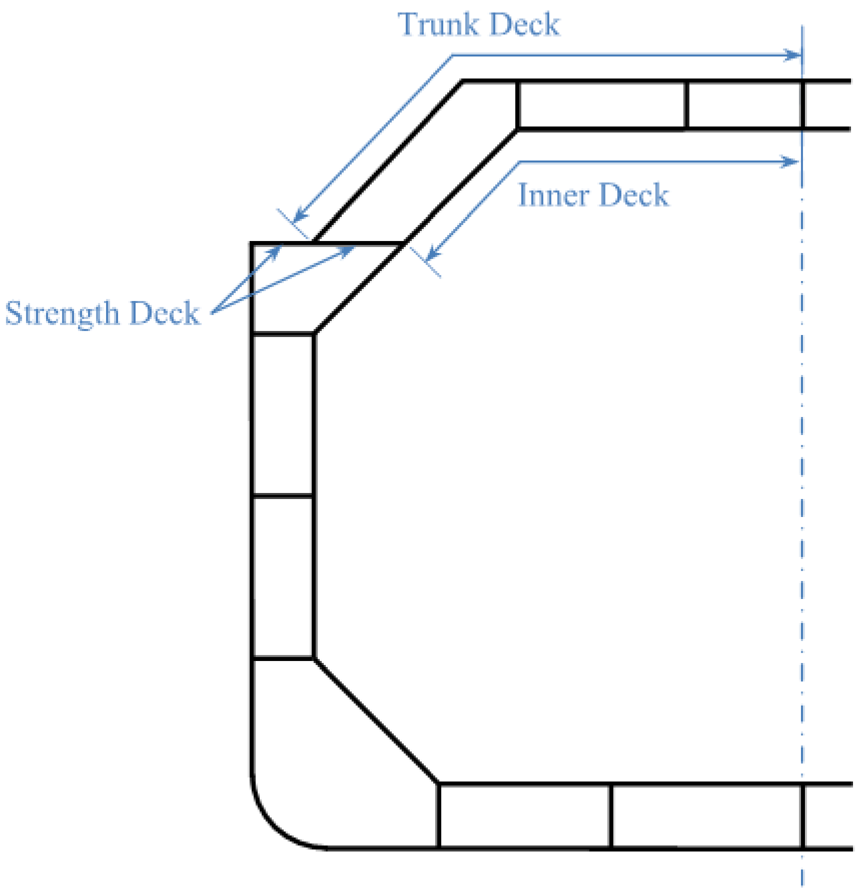


Fig. 1
Typical deck arrangement for membrane type liquefied natural gas carriers

303 For materials in:

— hull equipment and appendages (sternframes and rudders, anchoring and mooring equipment, masts and rigging, crane pedestals etc.), see Ch.3
— structure and equipment related to additional class notations, see Pt.5 and Pt.6
— hull structures related to installations for which no notation is available or requested, these will be considered and notation requirements usually maintained.

B 400 Requirements for low air temperatures

401 In ships intended to operate for longer periods in areas with low air temperatures (i.e. regular service during winter to Arctic or Antarctic waters), the materials in exposed structures will be specially considered. Applicable rule requirements are found in Pt.5 Ch.1 Sec.7.

B 500 Material at cross-joints

501 In important structural cross-joints where high tensile stresses are acting perpendicular to the plane of the plate, special consideration will be given to the ability of the plate material to resist lamellar tearing. For a special test, see Pt.2 Ch.2 Sec.1.

C. Alternative structural materials

C 100 Aluminium

101 Aluminium alloy for marine use may be applied in superstructures, deckhouses, hatch covers, hatch beams and sundry items, provided the strength of the aluminium structure is equivalent to that required for a steel structure.

102 For rolled products taking part in the longitudinal strength, alloys marked A shall be used. The alloy shall be chosen considering the stress level concerned.

103 In weld zones of rolled or extruded products (heat affected zones) the mechanical properties given for extruded products may in general be used as basis for the scantling requirements.

Note that for the alloy NV-A1MgSil the most unfavourable properties corresponding to -T4 condition shall be used.

104 Welding consumables giving a deposit weld metal with mechanical properties not less than those specified for the weld zones of the parent material shall be chosen.

105 The various formulae and expressions involving the factor f_1 may normally also be applied for aluminium alloys where:

$$f_1 = \frac{\sigma_f}{235}$$

σ_f = yield stress in N/mm^2 at 0.2% offset, σ_f shall not be taken greater than 70% of the ultimate tensile strength.

For minimum thickness requirements not involving the factor f_1 the equivalent minimum value for aluminium alloys may normally be obtained when the requirement is divided by $\sqrt{f_1}$.

106 For aluminium structures earthing to steel hull shall be in accordance with Pt.4 Ch.8.

C 200 Stainless steel

201 For clad steel and solid stainless steel due attention shall be given to the reduction of strength of stainless steel with increasing temperature.

For austenitic stainless steel and steel with clad layer of austenitic stainless steel the material factor f_1 included in the various formulae for scantlings and in expressions giving allowable stresses is given in 202 and 203.

202 For austenitic stainless steel the material factor f_1 can be taken as:

$$f_1 = \left[\left(3.9 + \frac{t-20}{650}\right) \sigma_f - 4.15\,(t-20) + 220 \right] 10^{-3}$$

σ_f = yield stress in N/mm^2 at 0.2% offset and temperature +20°C ($\sigma_{0.2}$).
t = cargo temperature in °C.

For end connections of corrugations, girders and stiffeners the factor is due to fatigue not to be taken greater than:

$$f_1 = 1.21 - 3.2\,(t-20)\,10^{-3}$$

203 For clad steel the material factor f_1 can be taken as:

$$f_1 = \frac{1.67\sigma_f - 1.37t}{1000} - 41.5\,\sigma_{fb}^{-0.7} + 1.6$$

σ_f = yield stress in N/mm^2 at 0.2% offset of material in clad layer and temperature +20°C ($\sigma_{0.2}$).
σ_{fb} = yield strength in N/mm^2 of base material.
t = cargo temperature in °C.

f_1 is in no case to be taken greater than that given for the base material in B203.

The calculated factor may be used for the total plate thickness.

204 For ferritic-austenitic stainless steel the material factor will be specially considered in each case.

Guidance note:

For ferritic-austenitic stainless steels with yield stress 450 N/mm^2, the following material factor will normally be accepted:

f_1 = 1.6 at + 20°C
= 1.36 at + 85°C

For end connection of corrugations, girders and stiffeners the factor should due to fatigue not be taken greater than:

f_1 = 1.39 at + 20°C
= 1.18 at + 85°C

For intermediate temperatures linear interpolation may be applied for the f_1 factor.

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C 300 Steel sandwich panel construction

301 Steel sandwich panel construction for marine use may be applied in structural panels provided the strength of the sandwich construction is equivalent to that required in the Society's rules for a stiffened steel structure and the fire safety is equivalent to that required in the Society's rules for a steel construction.

Guidance note:
For SOLAS vessels fire safety equivalence of steel sandwich panel needs being explicitly demonstrated and documented by an analysis according to Ch.II-2 Reg.17 of SOLAS when the construction deviates from the prescriptive requirements of the same Ch.II-2.

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

302 Verification of compliance with the Society's rules shall be demonstrated with the DNV Classification Notes No.30.11.

C 400 Concrete Barge

401 Concrete may be used as a construction material for vessels with class notation Barge, provided that requirements in Pt.5 Ch.7 Sec.14 D100 are complied with.

D. Corrosion additions for steel ships

D 100 General

101 In tanks for cargo oil and or water ballast the scantlings of the steel structures shall be increased by corrosion additions as specified in 200. In the following the term “cargo oil” will be used as a collective term for liquid cargoes which may be carried by oil carriers (see list of cargoes in appendix to Pt.5 Ch.3).

D 200 Corrosion additions

201 Plates, stiffeners and girders in tanks for water ballast and or cargo oil and of holds in dry bulk cargo carriers shall be given a corrosion addition t_k as stated in Table D1.

202 The requirements given in this item apply to vessels with the additional class notation **ESP**. Strength deck plates and stiffeners exposed to weather in the cargo area, not covered by 201, i.e. weather deck plate over void space and external stiffeners, should be given a corrosion addition t_k = 1.5 mm.

203 For members within or being part of the boundary of tanks for ballast water only, for which a corrosion protection system according to 204 is not fitted, the magnitude of the corrosion addition t_k is subject to special consideration.

204 It is assumed that tanks for ballast water only are protected by an effective coating or an equivalent protection system.

D 300 Class notation ICM increased corrosion margin

301 For the main class a corrosion addition t_k in mm as given in Table D1 is added to the reduced scantlings in ballast tanks, cargo oil tanks and cargo holds in bulk cargo carriers as specified in 200.

For an additional class notation **ICM** a further corrosion addition t_c in mm will be added in ballast tanks, cargo oil tanks and cargo holds in bulk cargo carriers. The following class notations may be chosen:

ICM(BT), ICM(BTu), ICM(BTs)	for ballast tanks
ICM(CT), ICM(CTu), ICM(CTs)	for cargo oil tanks
ICM(CH), ICM(CHu), ICM(CHs)	for cargo holds in bulk carriers

or combinations of these notations as e.g. **ICM(BT/CTu)** meaning all ballast tanks and upper part (above D/2) of all cargo oil tanks where:

BT All ballast tanks.
CT All cargo oil tanks.
CH All cargo holds in the bulk carrier.
u Upper part of the ship (above D/2).
s Strength deck of the ship and 1.5 m below.

The practical procedure in applying t_c in the rule scantling formula is outlined in the following items.

The corrosion addition t_c in mm is defined in Table D2.

Table D1 Corrosion addition t_k in mm

Internal members and plate boundary between spaces of the given category	*Tank/hold region*	
	Within 1.5 m below weather deck tank or hold top	*Elsewhere*
Ballast tank [1]	3.0	1.5
Cargo oil tank only	2.0	1.0 (0) [2]
Hold of dry bulk cargo carriers [4]	1.0	1.0 (3) [5]
Plate boundary between given space categories	*Tank/hold region*	
	Within 1.5 m below weather deck tank or hold top	*Elsewhere*
Ballast tank [1]/Cargo oil tank only	2.5	1.5 (1.0) [2]
Ballast tank [1]/Hold of dry bulk cargo carrier [4]	2.0	1.5
Ballast tank [1]/Other category space [3]	2.0	1.0
Cargo oil tank only/ Other category space [3]	1.0	0.5 (0) [2]
Hold of dry bulk cargo carrier [4] /Other category space [3]	0.5	0.5

1) The term ballast tank also includes combined ballast and cargo oil tanks, but not cargo oil tanks which may carry water ballast according to MARPOL 73/78 Annex I Reg. 18.
2) The figure in brackets refers to non-horizontal surfaces.
3) Other category space denotes the hull exterior and all spaces other than water ballast and cargo oil tanks and holds of dry bulk cargo carriers.
4) Hold of dry bulk cargo carriers refers to the cargo holds, including ballast holds, of vessels with class notations **Bulk Carrier** and **Ore Carrier**, see Pt.5 Ch.2 Sec.5 and Pt.5 Ch.2 Sec.12 respectively.
5) The figure in brackets refers to webs and bracket plates in lower part of main frames in bulk carrier holds.

302 The hull girder actual section modulus shall be based on the thickness t of plating, and web and flanges of stiffeners and girders taken as:

$$t = t_{actual} - t_c \quad \text{(mm)}.$$

303 The local scantlings of plates, stiffener webs/flanges and girder web/flanges where formulae are given in the rules with the corrosion addition (t_k), the total addition shall be taken as:

$$t'_k = t_k + t_c \quad \text{(mm)}.$$

304 For stiffeners where formulae are given in the rules with the w_k increase in section modulus for compensation of the corrosion addition (t_k), the w_k need not be additionally adjusted for the corrosion addition (t_c).

305 For web frames and girder systems where scantlings are based on a direct strength analysis, the allowable stresses in the rules are given with reference to reduced scantlings. The reduced thickness used in such analysis shall be:

$$t_{reduced} = t_{actual} - (t_k + t_c) \quad \text{(mm)}.$$

306 The throat thickness of continuous and intermittent fillet welding is given in Sec.11 with an addition of 0.5 t_k mm. The total corrosion addition shall be taken as:

$$(0.5\, t'_k) = 0.5\,(t_k + t_c) \quad \text{(mm)}.$$

Table D2 Corrosion addition t_c in mm

Internal members and plate boundary between spaces of the given category	*Tank/hold region*	
	Within 1.5 m below weather deck tank or hold top	*Elsewhere*
Ballast tank [1]	3.0	1.5
Cargo oil tank only	2.0	1.0
Hold of dry bulk cargo carriers [3]	1.0	1.0
Plate boundary between given space categories [4]	*Tank/hold region*	
	Within 1.5 m below weather deck tank or hold top	*Elsewhere*
Ballast tank [1]/Cargo oil tank only	2.5	1.5
Ballast tank [1]/Hold of dry bulk cargo carrier [3]	2.0	1.5
Ballast tank [1]/Other category space [2]	2.0	1.0
Cargo oil tank only/ Other category space [2]	1.0	0.5
Hold of dry bulk cargo carrier [3]/Other category space [2]	0.5	0.5

1) The term ballast tank also includes combined ballast and cargo oil tanks, but not cargo oil tanks which may carry water ballast according to MARPOL 73/78 Annex I Reg. 18.

2) Other category space denotes the hull exterior and all spaces other than water ballast and cargo oil tanks and holds of dry bulk cargo carriers.

3) Hold of dry bulk cargo carriers refers to the cargo holds, including ballast holds, of vessels with class notations **Bulk Carrier** and **Ore Carrier**, see Pt.5 Ch.2 Sec.5 and Pt.5 Ch.2 Sec.12 respectively.

4) For vessels with the notation **ICM(BT)**, **ICM(BTu)** or **ICM(BTs)**, cargo oil tanks and holds of dry bulk cargo carriers may be treated as "other category space".

307 The additional corrosion thickness t_c shall be given in the design drawings in the form of a general note.

Guidance note:

Example: Marking on the design drawing:

ICM( ) Plating, mm
Stiffeners web/flange, mm
Girders web/flange, mm

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SECTION 3 DESIGN PRINCIPLES

A. Subdivision and arrangement

A 100 General

101 The hull shall be subdivided into watertight compartments.

Guidance note:

The following requirements are considered to meet the relevant regulations of the International Convention on Load Lines, 1966 and SOLAS 1974 as amended. Attention should, however, be given to possible additional requirements of the Maritime Authorities in the country in which the ship shall be registered.

For passenger ships see Pt.5 Ch.2 Sec.2.

For dry cargo ships see also Pt.5 Ch.2 Sec.8.

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

A 200 Definitions

201 Symbols:

L_F = length in m as defined in Sec.1 B
P_F = perpendicular coinciding with the foreside of the stem on the waterline on which L_F is measured.
For ships with unconventional stem curvatures, e.g. a bulbous bow protuding the waterline, the position of P_F will be specially considered
H = height of superstructure in m
D_F = least moulded depth to the freeboard deck in m as defined in Sec.1 B.

A 300 Number of transverse watertight bulkheads.

301 The following transverse, watertight bulkheads shall be fitted in all ships:

— a collision bulkhead
— an after peak bulkhead
— a bulkhead at each end of the machinery space(s).

302 For ships without longitudinal bulkheads in the cargo region, the total number of watertight transverse bulkheads is normally not to be less than given in Table A1.

Table A1 Number of transverse bulkheads

Ship length in m	*Engine room*	
	Aft	*Elsewhere*
85 < L ≤ 105	4	5
105 < L ≤ 125	5	6
125 < L ≤ 145	6	7
145 < L ≤ 165	7	8
165 < L ≤ 190	8	9
190 < L ≤ 225	9	10
L > 225	specially considered	

303 After special consideration of arrangement and strength, the number of watertight bulkheads may be reduced. The actual number of watertight bulkheads will be entered in the «Register of Vessels classed with DNV».

304 Barges shall have a collision bulkhead and an after end bulkhead.

305 If the barge has discharging arrangements in the bottom, the regions having such bottom openings shall be bounded by watertight transverse bulkheads from side to side.

A 400 Position of collision bulkhead

401 Distance x_c from the perpendicular P_F to the collision bulkhead shall be taken between the following limits:

x_c (minimum) = $0.05\ L_F - x_r$ (m) for $L_F < 200$ m
= $10 - x_r$ (m) for $L_F \geq 200$ m

$$x_c \text{ (maximum)} = 0.08\ L_F - x_r \quad \text{(m)}$$

For ships with ordinary bow shape:

$$x_r = 0$$

For ships having any part of the underwater body extending forward of P_F, such as a bulbous bow, x_r shall be taken as the smallest of:

$$x_r = 0.5\ x_b \quad \text{(m)}$$
$$x_r = 0.015\ L_F \quad \text{(m)}$$
$$x_r = 3.0 \quad \text{(m)}$$

x_b = distance from P_F to the forward end of the bulbous bow, see Fig.1.

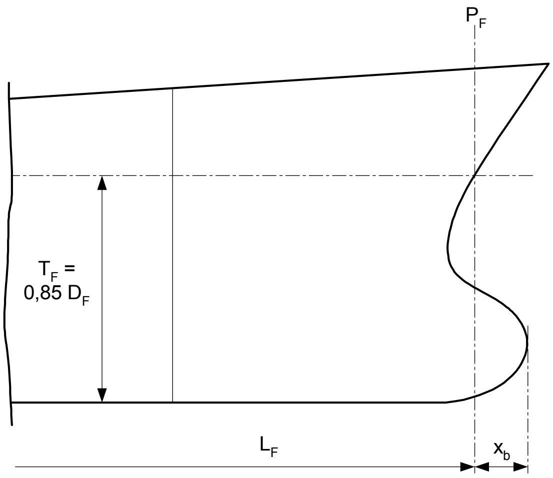

Fig. 1
Bulbous bow shape

402 An increase of the maximum distance given by 401 may be acceptable upon consideration in each case, provided a floatability and stability calculation shows that, with the ship fully loaded to summer draught on even keel, flooding of the space forward of the collision bulkhead will not result in any other compartments being flooded, nor in an unacceptable loss of stability.

403 Minor steps or recesses in the collision bulkhead may be accepted, provided the requirements to minimum and maximum distances from P_F are complied with.

404 In ships having a visor or doors in the bow and a sloping loading ramp forming part of the collision bulkhead above the freeboard deck, that part of the closed ramp which is more than 2.30 m above the freeboard deck may extend forward of the limits specified in 401, see Fig.2.

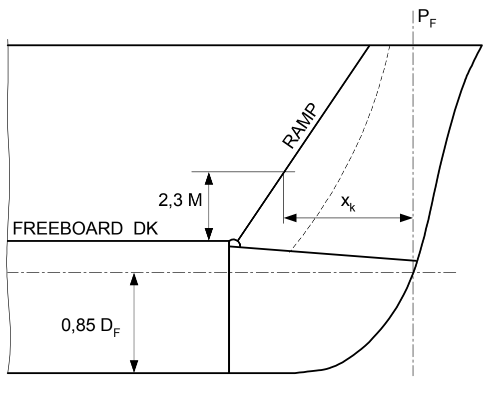

Fig. 2
Bow visor or door

The ramp shall be arranged for weathertight closing over its complete length.

The distance x_k in Fig.2 shall not be less than the minimum value of x_c as given in 401.

405 For barges the position of the collision bulkhead shall satisfy the minimum requirement to x_c as given in 401.

A 500 Height of watertight bulkheads

501 The watertight bulkheads are in general to extend to the freeboard deck. Afterpeak bulkheads may, however, terminate at the first watertight deck above the waterline at draught T.

For an afterpeak bulkhead also being a machinery bulkhead, see 503.

502 For ships having complete or long forward superstructures, the collision bulkhead shall extend weathertight to the next deck above the freeboard deck. The extension need not be fitted directly over the bulkhead below, provided the requirements for distances from P_F are complied with, and the part of the freeboard deck forming the step is made weathertight.

503 Bulkheads shall be fitted separating the machinery space from cargo and passenger spaces forward and aft and made watertight up to the freeboard deck. Afterpeak/machinery space bulkheads may terminate as given in 501 when the aft space is not utilised for cargo or passengers.

For ships without a long forward superstructure and for which the collision bulkhead has not been extended to the next deck above the freeboard deck, any openings within the forward superstructure giving access to spaces below the freeboard deck, shall be made weathertight.

504 For ships with a continuous deck below the freeboard deck and where the draught is less than the depth to this second deck, all bulkheads except the collision bulkhead may terminate at the second deck. In such cases the engine casing between second and upper deck shall be arranged as a watertight structure, and the second deck shall be watertight outside the casing above the engine room.

505 In ships with a raised quarter deck, the watertight bulkheads within the quarter deck region shall extend to this deck.

A 600 Opening and closing appliances.

601 Openings may be accepted in watertight bulkheads, except in that part of the collision bulkhead which is situated below the freeboard deck. However, See also 605.

602 Openings situated below the freeboard deck and which are intended for use when the ship is at sea, shall have watertight doors, which shall be closeable from the freeboard deck or place above the deck. The operating device shall be well protected and accessible.

603 Watertight doors are accepted in the engine room 'tween deck bulkheads, provided a signboard is fitted at each door stipulating that the door be kept closed while the ship is at sea.

This assumption will be stated in the appendix to classification certificate.

604 Openings in the collision bulkhead above the freeboard deck shall have weathertight doors or an equivalent arrangement. The number of openings in the bulkhead shall be reduced to the minimum compatible with the design and normal operation of the ship.

605 No door, manhole or ventilation duct or any other opening will be accepted in the collision bulkhead below the freeboard deck.

The collision bulkhead may, however, be pierced by necessary pipes to deal with fluids in the forepeak tank, provided the pipes are fitted with valves capable of being operated from above the freeboard deck. The valves are generally to be fitted on the collision bulkhead inside the forepeak. The valves may be fitted on the after side of the bulkhead provided that the valves are readily accessible under all service conditions and the space in which they are located is not a cargo space. See also Pt.4 Ch.6 Sec.3 A300.

A 700 Cofferdams and tank contents

701 The following dedicated tank types shall be separated from each other by cofferdams:

— tanks for mineral oil
— tanks for vegetable oil
— tanks for freshwater for human consumption.

Furthermore, cofferdams shall be arranged separating tanks carrying fresh water for human consumption from other tanks containing substances hazardous to human health.

Guidance note:
Normally tanks for fresh water and water ballast are considered non-hazardous.

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A 800 Forward compartment contents

801 In ships of 400 gross tonnage and above, compartments forward of the collision bulkhead shall not be arranged for carriage of oil or other liquid substances which are flammable.

A 900 Minimum bow height

901 Minimum bow height requirements are:

1) The bow height F_b, defined as the vertical distance at the forward perpendicular between the waterline corresponding to the assigned summer freeboard and the designed trim and the top of the exposed deck at side shall be not less than:

$$F_b = [6075(L_F/100) - 1875(L_F/100)^2 + 200(L_F/100)^3] \times [2.08 + 0.609C_B - 1.603C_{wf} - 0.0129(L_F/T_1)]$$

F_b = the minimum bow height (mm)
C_{wf} = water plane area coefficient forward of L/2
$= \dfrac{A_{wf}}{0.5L_F B}$
A_{wf} = water plane area forward of L/2 at draught T_1 (m^2)
T_1 = the draught at 85% of the least moulded depth, D_F.

2) Where the bow height required in paragraph (1) of this Regulation is obtained by sheer, the sheer shall extend for at least 15% of the length of the ship measured from the forward perpendicular. Where it is obtained by fitting a superstructure, such superstructure shall extend from the stem to a point at least 0.07 L abaft the forward perpendicular, and it shall be enclosed.
3) Ships which, to suit exceptional operational requirements, cannot meet the requirements of paragraphs (1) and (2) of this Regulation may be given special consideration.

(ICLL 39)

902 *Interpretations*

On ships to which timber freeboards are assigned Regulation 39 should relate to the summer load waterline and not to the timber summer load waterline.

(IACS LL43)

When calculating the bow height, the sheer of the forecastle deck may be taken into account, even if the length of the forecastle is less than 0.15 L, but greater than 0.07 L, provided that the forecastle height is not less than one half of standard height of superstructure as defined in Regulation 33 between 0.07 L and the forward terminal.

Where the forecastle height is less than one half of standard height of superstructure, as defined in Regulation 33, the credited bow height may be determined as follows (Figs. 3 and 4 illustrate the intention of 1 and 2 respectively):

1) When the freeboard deck has sheer extending from abaft 0.15 L, by a parabolic curve having its origin at 0.15 L abaft the forward terminal at a height equal to the midship depth of the ship, extended through the point of intersection of forecastle bulkhead and deck, and up to a point at the forward terminal not higher than the level of the forecastle deck. However, if the value of the height denoted h_t on Fig.3 is smaller than the value of the height denoted h_b, then h_t may be replaced by h_b in the available bow height.
2) When the freeboard deck has sheer extending for less than 0.15 L or has no sheer, by a line from the forecastle deck at side at 0.07 L extended parallel to the base line to the forward terminal.

(IACS LL38)

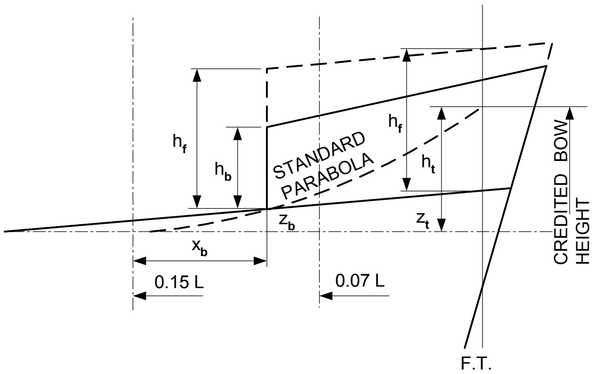

Fig. 3
Forecastle, procedure 1

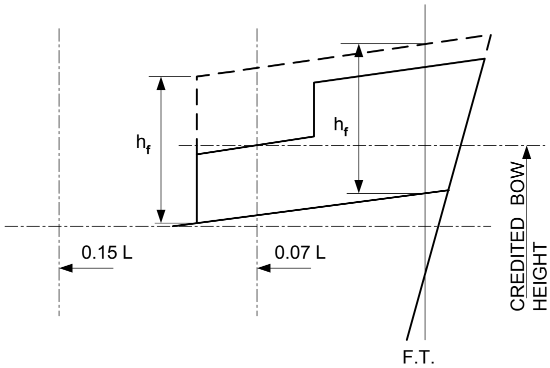

Fig. 4
Forecastle, procedure 2

h_f = half standard height of superstructure as defined in Regulation 33

$$h_t = Z_b\left(\frac{0.15L}{x_b}\right)^2 - Z_t$$

Guidance note:
ICLL 39 require additional reserve buoyancy in the fore end for all ships assigned a type B freeboard, other than oil tankers, chemical tankers and gas carriers

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A 1000 Access to and within narrow ballast tanks

1001 Vessels, except those exclusively intended for the carriage of containers, shall comply with 1002.

1002 Narrow ballast tanks (such as double-skin construction) shall be provided with permanent means of access, such as fixed platforms, climbing/foothold rails, ladders etc., supplemented by limited portable equipment to give safe and practical access to the internal structure for adequate inspection, including close-up survey as defined in Pt.7 Ch.1 Sec.3 [2] and Pt.7 Ch.1 Sec.4 [2].

Guidance note:
In order to obtain a practical arrangement it is recommended to provide for a fixed platform spacing of 3 to 5 metres.

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A 1100 Steering gear compartment

1101 The steering gear compartment shall be readily accessible and separated from machinery spaces.

(SOLAS Ch. II-1/29.13.1)

A 1200 Navigation bridge design

Guidance note:
It should be noted that the navigation bridge design is affected by requirements for navigation bridge visibility. Reference is made to SOLAS Ch.V Reg.22.

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A 1300 Oil fuel tank protection

Guidance note:
Oil fuel tank design is affected by requirements for fuel tank protection. Reference is made to MARPOL Annex I Reg. 12A.

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B. Structural design principles

B 100 Design procedure

101 Hull scantlings are in general based on the two design aspects, load (demand) and strength (capability). The probability distribution for the load and the strength of a given structure may be as illustrated in Fig.5.

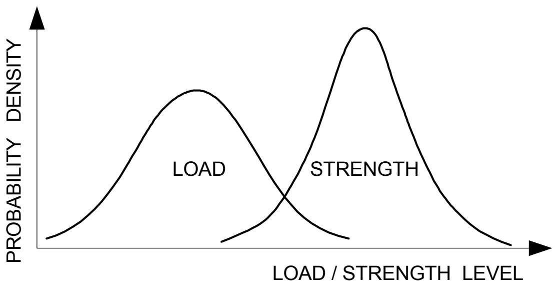


Fig. 5
Probability distribution

The rules have established design loads corresponding to the loads imposed by the sea and the containment of cargo, ballast and bunkers. The design loads are applicable in strength formulae and calculation methods where a satisfactory strength level is represented by allowable stresses and or usage factors.

102 The elements of the rule design procedure are shown in Fig.6 and further described in the following.

B 200 Loading conditions

201 Static loads are derived from loading conditions submitted by the builder or standard conditions prescribed in the rules. The standard conditions are expected to give suitable flexibility with respect to the loading of ordinary ship types.

202 Unless specifically stated, dry cargoes are assumed to be general cargo or bulk cargo (coal, grain) stowing at 0.7 t/m^3. Liquid cargoes are assumed to have density equal to or less than that of seawater.

203 Unless especially stated to be otherwise, or by virtue of the ship's class notation (e.g. **Container Carrier**) or the arrangement of cargo compartments, the ship's cargo and ballast conditions are assumed to be symmetric about the centreline. For ships for which unsymmetrical cargo or ballast condition(s) are intended, the effect of this shall be considered in the design.

204 The determination of dynamic loads is based on long term distribution of motions that the ship will experience during her operating life. The operating life is normally taken as 20 years, considered to correspond to a maximum wave response of 10^{-8} probability of exceedance in the North Atlantic.

Any pertinent effects of surge, sway, heave, roll, pitch and yaw in irregular seas are considered. A uniform probability is normally assumed for the occurrence of different ship-to-wave heading angles.

The effects of speed reduction in heavy weather are allowed for.

Wave-induced loads determined according to accepted theories, model tests or full scale measurements may be accepted as equivalent basis for classification.

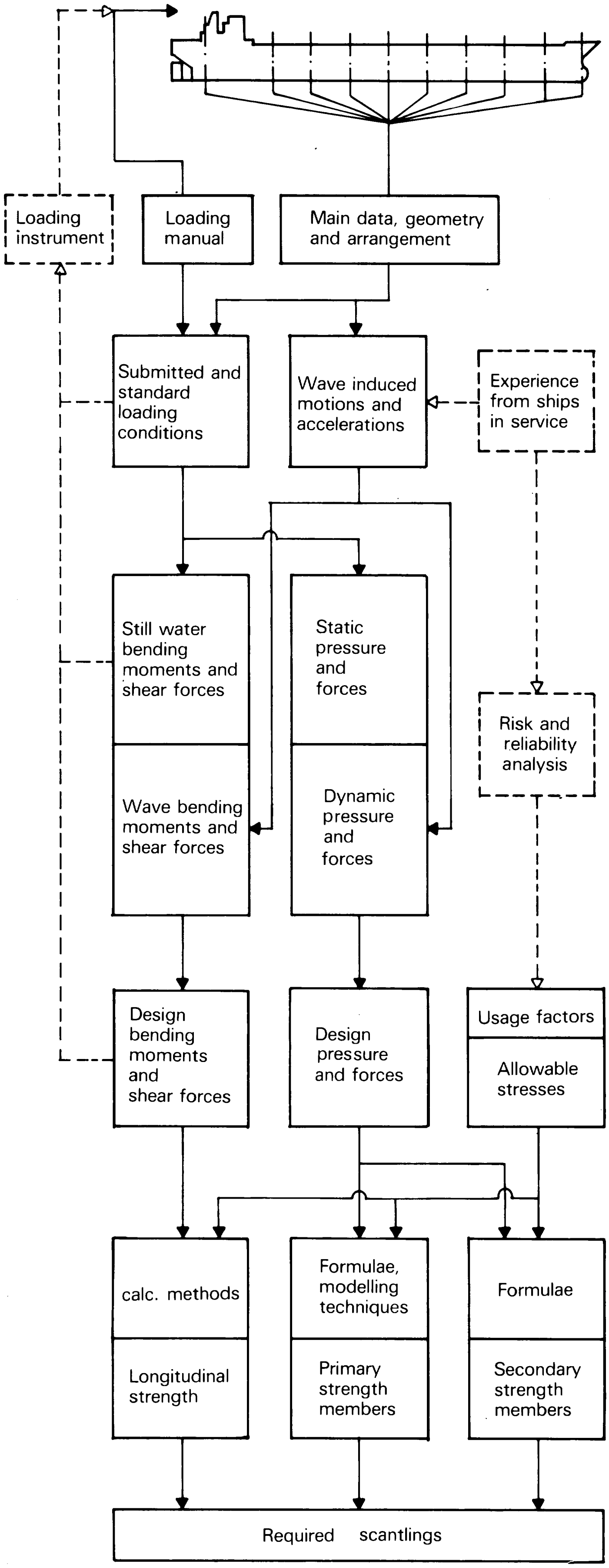


Fig. 6
Rule design procedure for ships

B 300 Hull girder strength

301 A minimum strength standard determined by the section modulus at bottom and deck is required for the hull girder cross-section amidships.

B 400 Local bending and shear strength

401 For plating exposed to lateral pressure the thickness requirement is given as function of nominal allowable bending stress as follows:

$$t = \frac{C\, k_a\, s \sqrt{p}}{\sqrt{\sigma}} + t_k \quad \text{(mm)}$$

C = factor depending on boundary conditions of plate field, normally taken as 15.8 for panels with equally spaced stiffeners.
k_a = correction factor for aspect ratio of plate field
= $(1.1 - 0.25\ s/\ l)^2$
= maximum 1.0 for $s/\ l = 0.4$
= minimum 0.72 for $s/\ l = 1.0$
s = stiffener spacing in m.
l = stiffener span in m.
p = design lateral pressure in kN/m^2.

The nominal allowable bending stress σ (in N/mm^2) shall be chosen so that the equivalent stress at the middle of the plate field will not exceed specified limits corresponding to the design pressure.

The equivalent stress is defined as:

$$\sigma_e = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1 \sigma_2 + 3\tau^2}$$

σ_1 and σ_2 are normal stresses perpendicular to each other.

τ is the shear stress in the plane of σ_1 and σ_2.

402 For stiffeners exposed to lateral pressure, the section modulus requirement is given as function of boundary conditions and nominal allowable bending stress.

The boundary conditions are included in a bending moment factor. The bending moment factor corresponds to m in the following expression:

$$M = \frac{q\, l^2}{m} \quad \text{(kNm)}$$

M is the expected bending moment.

q = pb
p = as specified in 401
b = effective load breadth of stiffener in m, for uniform pressure equal to stiffener spacing s
l = the length of the member in m.

m-values normally to be applied are given separately for each of the local structures.

For elastic deflections the m-value is derived directly from general elastic bending theory. In Table B1 m-values are given for some defined load and boundary conditions.

For plastic-elastic deflections the m-value is derived according to the following procedure:

— the pressure is increased until first yield occurs at one or both ends
— the pressure is further increased, considering yielding ends as simple supports.

This procedure involves a built-in safety in that the bending moment at a yielding support is not increased beyond the value corresponding to first yield.

The nominal allowable bending stress is combined with possible axial stresses so that the maximum normal stress will not exceed specified limits corresponding to the design pressure.

The sectional area requirement is given as a function of boundary conditions and nominal allowable shear stress.

The boundary conditions are included in a shear force factor, defined as k_s in the following expression:

$$Q = k_s\, P$$

Q is the expected shear force.

P is the total load force on the member.

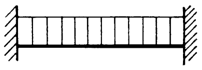
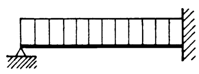
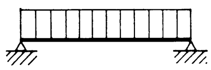
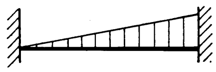
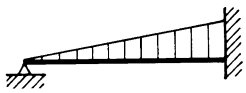
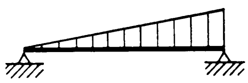
k_s-values normally to be applied are given separately for each of the local structures.

In Table B1 k_s-values are given for some defined load and boundary conditions.

403 Direct strength formulae for girders are limited to simple girders. The boundary conditions and the nominal allowable stresses are given in a similar way as for stiffeners.

For girder systems the stress pattern is assumed to be derived by direct computerised calculations. Allowable stresses corresponding to specified pressure combinations and indicated model fineness are given for the most common structural arrangements.

Table B1 Values of m and k_s

Load and boundary conditions	*Bending moment and shear force factors*		
Positions: 1 Support, 2 Field, 3 Support	1 m_1 ks_1	2 m_2 -	3 m_3 ks_3
	12.0 0.50	24.0 -	12.0 0.50
	- 0.38	14.2 -	8.0 0.63
	- 0.50	8.0 -	- 0.50
	15.0 0.30	23.3 -	10.0 0.70
	- 0.20	16.8 -	7.5 0.80
	- 0.33	7.8 -	- 0.67

B 500 Buckling strength

501 Requirements for structural stability are given to prevent buckling or tripping of structural elements when subjected to compressive stresses and shear stresses.

The critical buckling stress shall be checked for the various strength members based on general elastic buckling formulae, corrected in the plastic range. For plate elements subject to extreme loading conditions, compressive stresses above the elastic buckling strength may be allowed. For calculation of elastic and ultimate compressive strength, see Sec.13.

B 600 Impact strength

601 Ships designed for a small draught at F.P. may have to be strengthened to resist slamming. Requirements are given for bottom structures forward in a general form taking various structural arrangements into account, see Sec.6 H200. The draught upon which the slamming strength is based, will be stated in the appendix to the classification certificate. If the bottom scantlings are based on full ballast tanks in the forebody, this will also be stated.

In some cases impact loads from the sea on flat areas in afterbodies of special design may also have to be considered.

602 In ships with large bow flare and or large bow radius, strengthening may be required in the bow region above the summer load waterline. Requirements for structural arrangement and scantlings are given, see Sec.7 E200.

603 In large tanks for liquid cargo and or ballast special requirements for strengthening against sloshing impact loads will have to be considered, see Sec.4 C300.

B 700 Fatigue

701 In general the susceptibility of hull structures to fatigue cracking has been taken care of by special requirements to detail design. However in some cases e.g. where high tensile steel is applied in stiffening members subjected to high frequency fluctuating loads, a special calculation evaluating dynamic stresses, stress concentration factors and environment may have to be performed. For calculation of fatigue strength, see Sec.16.

B 800 Local vibrations

801 Vibrations in the hull structural elements are not considered in relation to the requirements for scantlings given in the rules. It is, however, assumed that special investigations are made to avoid harmful vibrations, causing structural failures (especially in afterbody and machinery space tank structures), malfunction of machinery and instruments or annoyance to crew and passengers.

B 900 Miscellaneous strength requirements

901 Requirements for scantlings of foundations, minimum plate thicknesses and other requirements not relating relevant load and strength parameters may reflect criteria other than those indicated by these parameters. Such requirements may have been developed from experience or represent simplifications considered appropriate by the Society.

B 1000 Reliability-based analysis of hull structures

1001 This item gives requirements for structural reliability analysis undertaken in order to document rule compliance, see Pt.1 Ch.1 Sec.1 B600.

1002 The method and procedures for evaluation of reliability are subject to the acceptance by the Society in each individual case. Acceptable procedures for reliability analyses are documented in the DNV Classification Note No. 30.6 «Structural Reliability Analysis of Marine Structures».

1003 Reliability analyses shall be based on level III reliability methods. These are methods that utilise probability of failure as a measure, and which therefore require a knowledge of the distribution of all uncertain parameters.

1004 For the purpose of these rules, level III reliability methods are mainly considered applicable to:

— unique design solutions
— novel designs where limited (or no) experience exists
— special case design problems
— calibration of level I methods to account for improved knowledge. (Level I methods are deterministic analysis methods that use only one characteristic value to describe each uncertain variable, i.e. the allowable stress method normally applied in the rules).

1005 Reliability analyses may be updated by utilisation of new information. Where such updating indicates that the assumptions upon which the original analysis was based are not valid, and the result of such non-validation is deemed to be essential to safety, the subject approval may be revoked.

1006 Target reliabilities shall be commensurate with the consequence of failure. The method of establishing such target reliabilities, and the values of the target reliabilities themselves, shall be approved by the Society in each separate case. To the extent possible, the minimum target reliabilities shall be established based upon calibration against well established cases that are known to have adequate safety.

Where well established cases do not exist, for example in the case of novel and unique design solutions, the minimum target reliability values shall be based upon one (or a combination) of the following considerations:

— transferable target reliabilities from “similar”, existing design solutions
— decision analysis
— internationally recognised codes and standards.

For further details, see DNV Classification Note No. 30.6.

C. Local design

C 100 Definition of span for stiffeners and girders

101 The effective span of a stiffener (l) or girder (S) depends on the design of the end connections in relation to adjacent structures. Unless otherwise stated the span points at each end of the member, between which the span is measured, is in general to be determined as shown in Fig.7 and Fig.8. When the adjacent structure is ineffective in support of the bracket, or when the end bracket does not comply with requirements in this section and is fitted for stiffening of supporting structures, the span point shall be defined by the intersection of the line defined by the stiffener face plate and the end support structure.

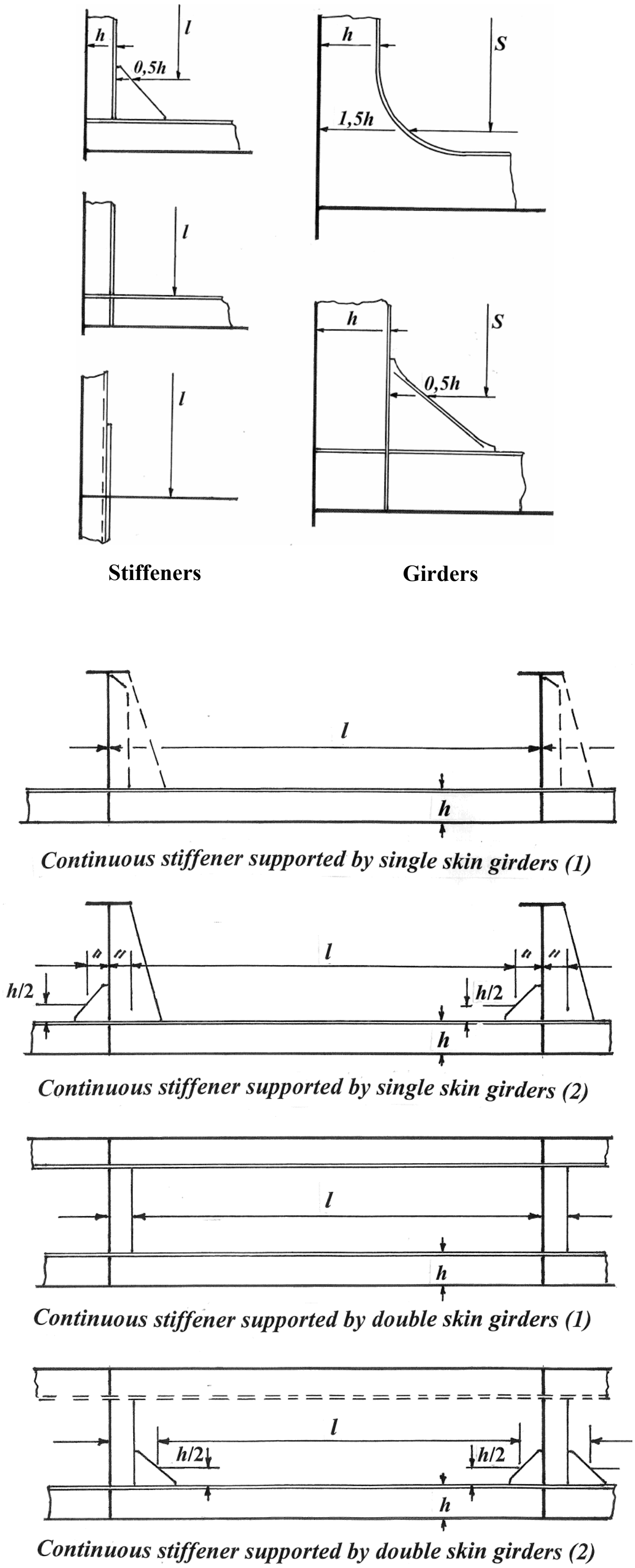


Fig. 7
Span points

C 200 End connections of stiffeners

201 Normally all types of stiffeners (longitudinals, beams, frames, bulkhead stiffeners) shall be connected at their ends. In special cases, however, sniped ends may be allowed, see 203. General requirements for the various types of end connections (with and without brackets, and with sniped ends) are given below.

Special requirements may be given for the specific structures in other sections.

Requirements for weld connections are given in Sec.11.

202 The scantlings of brackets for stiffeners not taking part in longitudinal strength may normally be taken as follows:

Thickness:

$$t_b = \frac{3 + k\sqrt{Z/w_k}}{\sqrt{f_1/f_1^1}} + t_k \quad \text{(mm)}$$

Z = required section modulus in cm^3 for the stiffener (smallest of connected stiffeners)
k = 0.2 for brackets with flange or edge stiffener
= 0.3 for brackets without flange or edge stiffener.

t_b is not be taken less than 6 mm, and, when flange or edge stiffener is provided, need not be taken greater than 13.5 mm.

w_k = corrosion factor as given in C1004
t_k = as given in Sec.2 D200, but need not be taken greater than 1.5 mm
f_1 = material factor for bracket
f_1^1 = material factor f_1 for stiffener.

Arm length:

The general requirement for arm length, see Fig.8 and 9, is given by:

$$a = c\sqrt{\frac{Z/w_k}{t_b - t_k}} \quad \text{(mm)}$$

Z as given above.

t_b = thickness of bracket in mm
c = 70 for brackets with flange or edge stiffener
= 75 for brackets without flange or edge stiffener.

The arm length, a, is in no case to be taken less than
$(1 + 1/\sin\phi_i)$ h, where i represents the angle between the stiffeners connected by the bracket, and h the depth of the lowest of the connected stiffeners. In addition the height of the bracket, h_b, see Fig.8 and 9, is not to be less than h.

Flange or edge stiffener shall be fitted when the edge length, l_b, exceeds 50 $(t_b - t_k)$, except when the depth of the bracket, defined as the distance from the root to the edge, d_b, is less than 22 $(t_b - t_k)$. The flange width is normally not to be taken less than:

$$W = 45\left(1 + \frac{Z}{2000}\right) \quad \text{(mm), minimum 50 mm.}$$

The connection between stiffener and bracket shall be so designed that the section modulus in way of the connection is not reduced to a value less than required for the stiffener.

If the flange transition between the stiffener and an integral bracket is knuckled, the flange shall be effectively supported in way of the knuckle. Alternatively the flange may be curved with radius not less than: $r = 0.4\, b_f^2/t_f$, where b_f and t_f represents the flange breadth and thickness respectively (see Fig.8).

Guidance note 1:

Shell stiffeners in the bow flare area, having an integral end bracket, are generally recommended to be tripping supported in way of the end bracket, also when the flange transition has been curved as described in 202.

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

Guidance note 2:

Note that end brackets for stiffeners may, as indicated in Fig.9, in general be arranged to be of the overlap type. End brackets of the type B, however, are only to be applied for locations where the bending moment capacity required for the bracket is reduced compared to the bending moment capacity of the stiffener, e.g. the upper end bracket of vertical stiffeners.

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

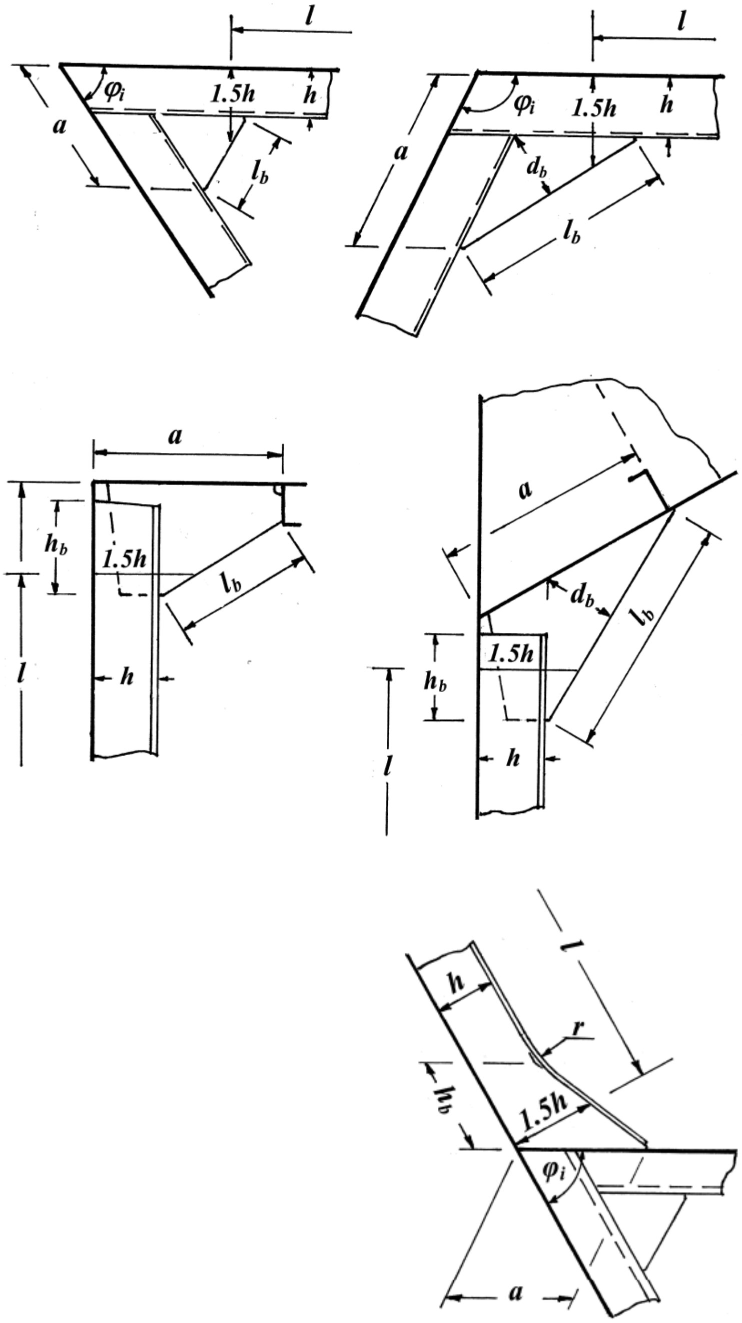


Fig. 8
Stiffener end brackets

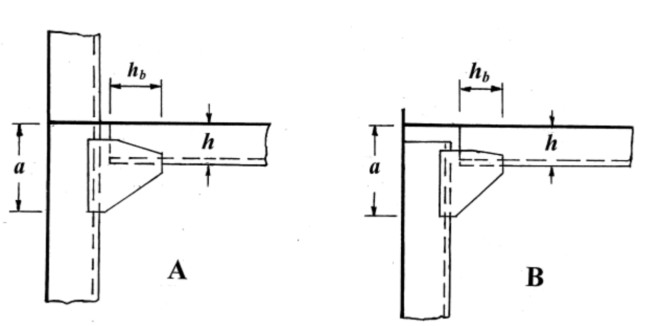


Fig. 9
Overlap end brackets

203 Bracketless end connections may be applied for longitudinals and other stiffeners running continuously through girders (web frames, transverses, stringers, bulkheads etc.), provided sufficient connection area is arranged for.

For longitudinals, see special requirements in Sec.6 and 8.

204 Stiffeners with sniped ends may be allowed where dynamic loads are small and where vibration is considered to be of little importance, provided the thickness of plating supported by the stiffener is not less than:

$$t = 1.25\sqrt{\frac{(l - 0.5s)\,s\,p}{f_1}} + t_k \qquad \text{(mm)}$$

l = stiffener span in m
s = stiffener spacing in m
p = pressure on stiffener in kN/m^2.

C 300 End connections of girders

301 Normally ends of single girders or connections between girders forming ring systems shall be provided with brackets. Brackets are generally to be made with a radius / be or well rounded at their toes. The free edge of the brackets shall be arranged with flange or edge stiffener. Scantlings and details are given below.

Bracketless connections may be applied provided adequate support of the adjoining face plates is arranged for.

302 The thickness of brackets on girders shall not be less than that of the girder web plate.

Flanges on girder brackets are normally to have a cross- sectional area not less than:

$$A = l\,t \quad (\text{cm}^2)$$

l = length of free edge of brackets in m. If l exceeds 1.5 m, 40% of the flange area shall be in a stiffener fitted parallel to the free edge and maximum 0.15 m from the edge
t = thickness of brackets in mm.

Where flanges are continuous, there shall be a smooth taper between bracket flange and girder face plate. If the flange is discontinuous, the face plate of the girder shall extend well beyond the toe of the bracket.

303 The arm length including depth of girder web may normally be taken as:

$$a = c\sqrt{\frac{Z/w_k}{t_b - t_k}} \qquad \text{(mm)}$$

Z = rule section modulus in cm^3 of the strength member to which the bracket is connected.
t = thickness of bracket in mm
t_k = as given in Sec.2 D200, but need not be taken greater than 1.5 mm
w_k = corrosion factor as given in C1004
c = 63 for bracket on bottom and deck girders
= 88 for brackets on girders other than bottom and deck girders. This requirement may be modified after special consideration.

304 At cross joints of bracketless connections the required flange area of free flanges may be gradually tapered beyond the crossing flange. For flanges in tension reduced allowable tensile stress shall be observed when lamellar tearing of flanges may occur.

The thickness of the web plate at the cross joint of bracketless connection (between girder 1 and 2) is normally given by the greater of (see Fig.10):

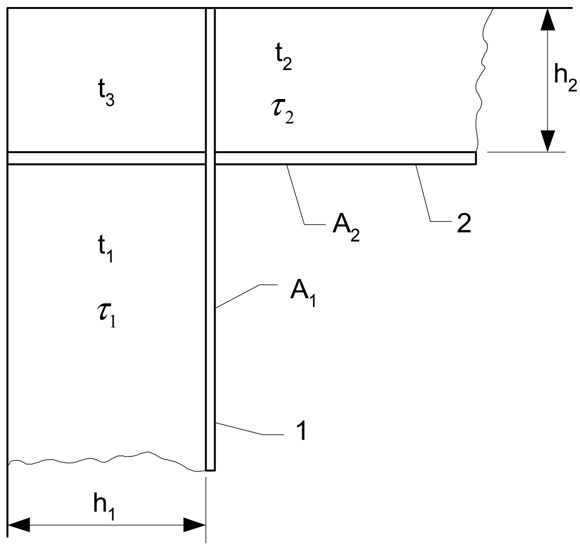


Fig. 10
Bracketless joint

$$t_3 = \left[\frac{\sigma_1 A_1}{h_2} - t_2 \frac{\tau_2}{100}\right] \frac{1}{f_{1t}} \quad \text{(mm)}$$

or

$$t_3 = \left[\frac{\sigma_2 A_2}{h_1} - t_1 \frac{\tau_1}{100}\right] \frac{1}{f_{1t}} \quad \text{(mm)}$$

A_1, A_2 = minimum required flange area in cm^2 of girder 1 and 2
h_1, h_2 = height in mm of girder 1 and 2
t_1, t_2 = minimum required thickness (outside the cross-joint) in mm of girder 1 and 2
τ_1, τ_2 = shear stress in N/mm^2 in girder 1 and 2
σ_1, σ_2 = bending stress in N/mm^2 in girder 1 and 2
f_{1t} = material factor for corner web plate.

C 400 Effective flange of girders

401 The section modulus of the girder shall be taken in accordance with particulars as given in the following. Structural modelling in connection with direct stress analysis shall be based on the same particulars when applicable. Note that such structural modelling will not reflect the stress distribution at local flange cut-outs or at supports with variable stiffness over the flange width. The local effective flange which may be applied in stress analysis is indicated for construction details in various DNV Classification Notes on “Strength Analysis of Hull Structures”.

402 The effective plate flange area is defined as the cross-sectional area of plating within the effective flange width. Continuous stiffeners within the effective flange may be included. The effective flange width b_e is determined by the following formula:

$$b_e = C\,b \quad \text{(m)}$$

C = as given in Table C2 for various numbers of evenly spaced point loads (r) on the span
b = sum of plate flange width on each side of girder, normally taken to half the distance from nearest girder or bulkhead

Table C2 Values of C								
a/b	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*≥ 7*
C (r ≥ 6)	0.00	0.38	0.67	0.84	0.93	0.97	0.99	1.00
C (r = 5)	0.00	0.33	0.58	0.73	0.84	0.89	0.92	0.93
C (r = 4)	0.00	0.27	0.49	0.63	0.74	0.81	0.85	0.87
C (r ≤ 3)	0.00	0.22	0.40	0.52	0.65	0.73	0.78	0.80

a = distance between points of zero bending moments
= S for simply supported girders
= 0.6 S for girders fixed at both ends
r = number of point loads.

403 For plate flanges having corrugations parallel to the girder, the effective width is as given in 402. If the corrugations are perpendicular to the direction of the girder, the effective width shall not be taken greater than 10% of the value derived from 402.

404 For effective width of plate flanges subject to elastic buckling, see Sec.13 and Appendix A.

405 The effective plate area shall not be less than the effective area of the face plate within the following regions:

— ordinary girders: total span
— continuous hatch side coamings and hatch end beams: length and breadth of the hatch, respectively, and an additional length of 1 m at each end of the hatch corners.

406 The effective area of curved face plates is given by:

$$A_e = k\, t_f\, b_f \quad (\text{mm}^2)$$

b_f = total face plate breadth in mm
k = flange efficiency coefficient, see also Fig.11

$$= k_1 \frac{\sqrt{r\, t_f}}{b}$$

= 1.0 maximum

$$k_1 = \frac{0.643\,(\sinh\beta\cosh\beta + \sin\beta\cos\beta)}{\sinh^2\beta + \sin^2\beta}$$

for symmetrical and unsymmetrical free flanges

$$= \frac{0.78\,(\sinh\beta + \sin\beta)(\cosh\beta - \cos\beta)}{\sinh^2\beta + \sin^2\beta}$$

for box girder flange with two webs

$$= \frac{1.56\,(\cosh\beta - \cos\beta)}{\sinh\beta + \sin\beta}$$

for box girder flange with multiple webs

$$\beta = \frac{1.285\, b}{\sqrt{r\, t_f}} \quad (\text{rad})$$

b = 0.5 ($b_f - t_w$) for symmetrical free flanges
= b_f for unsymmetrical free flanges
= $s - t_w$ for box girder flanges
s = spacing of supporting webs for box girder (mm)
t_f = face plate thickness in general (mm)
= t_w (maximum) for unsymmetrical free flanges
t_w = web plate thickness (mm)
r = radius of curved face plate (mm).

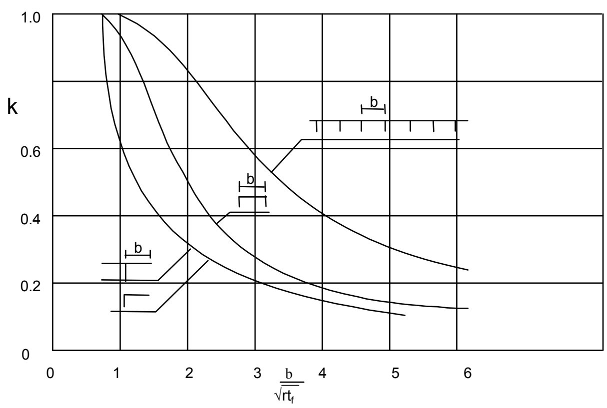


Fig. 11
Effective width of curved face plates for alternative boundary conditions

407 The effective flange area of curved face plates supported by radial brackets or of cylindrical longitudinally stiffened shells is given by:

$$A_e = \frac{3\,r\,t_f + k s_r^2}{3\,r\,t_f + s_r^2}\; t_f\, b_f \qquad (mm^2)$$

k, b_f, r, t_f is as given in 407, see also Fig.12.

s_r = spacing of radial ribs or stiffeners (mm).

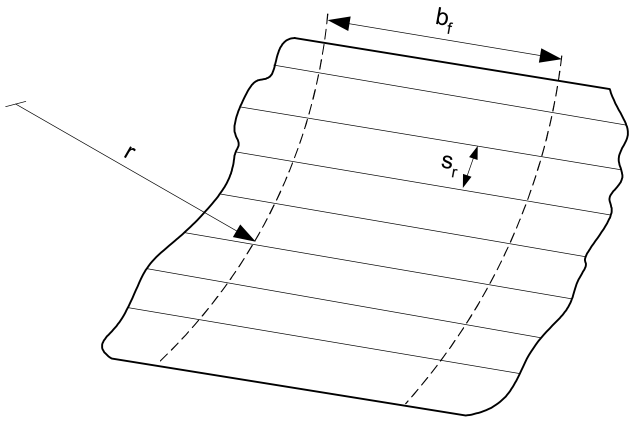


Fig. 12
Curved shell panel

C 500 Effective web of girders

501 The web area of a girder shall be taken in accordance with particulars as given below. Structural modelling in connection with direct stress analysis shall be based on the same particulars when applicable.

502 Holes in girders will generally be accepted provided the shear stress level is acceptable and the buckling strength is sufficient. Holes shall be kept well clear of end of brackets and locations where shear stresses are high. For buckling control, see Sec.13 B300.

503 For ordinary girder cross-sections the effective web area shall be taken as:

$$A_W = 0.01\, h_n\, t_w \quad (cm^2)$$

h_n = net girder height in mm after deduction of cut-outs in the cross-section considered
= $h_{n1} + h_{n2}$.

If an opening is located at a distance less than $h_w/3$ from the cross-section considered, h_n shall be taken as the smaller of the net height and the net distance through the opening. See Fig.13.

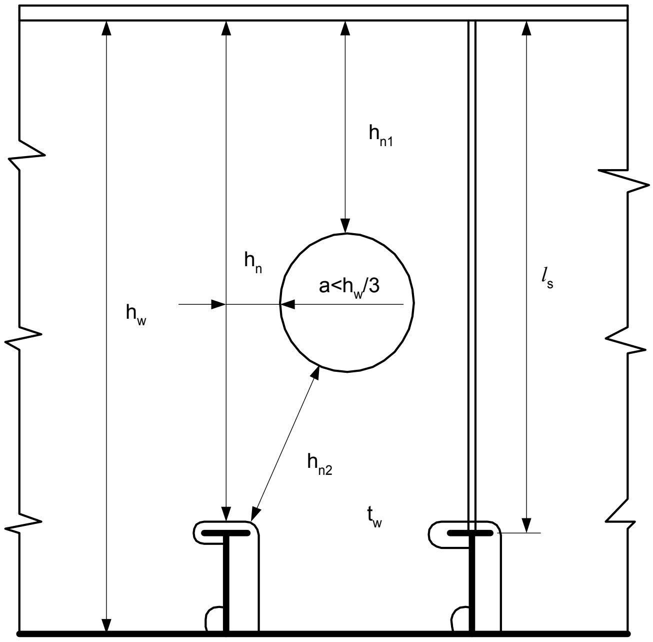


Fig. 13
Effective web area in way of openings

504 Where the girder flange is not perpendicular to the considered cross section in the girder, the effective web area shall be taken as:

$$A_W = 0.01\, h_n\, t_w + 1.3\, A_{Fl} \sin 2\theta \sin \theta \quad (\mathrm{cm}^2)$$

h_n = as given in 503
A_{Fl} = flange area in cm^2
θ = angle of slope of continuous flange
t_w = web thickness in mm.

See also Fig.14.

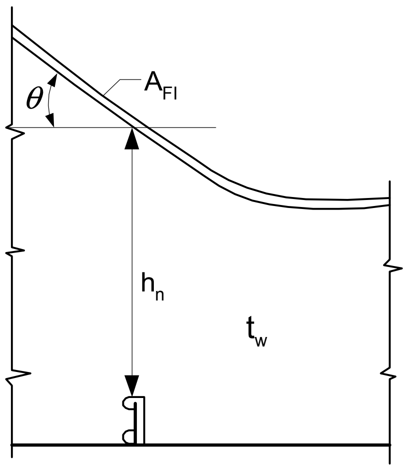


Fig. 14
Effective web area in way of brackets

C 600 Stiffening of girders.

601 In general girders shall be provided with tripping brackets and web stiffeners to obtain adequate lateral and web panel stability. The requirements given below are providing for an acceptable standard. The stiffening system may, however, be modified based on direct stress analysis and stability calculations according to accepted methods.

602 The spacing of stiffeners on the web plate is normally not to exceed:

$$s_v = \frac{5.4}{\tau}(t_w - t_k) \quad \text{(m)}$$

or

$$s_h = \frac{6.0}{\tau}(t_w - t_k) \quad \text{(m)}$$

s_v = spacing of stiffeners in m perpendicular to the girder flange
s_h = spacing of stiffeners in m parallel to the girder flange
t_w = web thickness in mm
τ = 90 f_1 N/mm^2 in general within 20% of the span from each end of the girder
= 60 f_1 N/mm^2 elsewhere.

τ may be adjusted after special consideration based on direct stress calculations.

603 Deep longitudinal bottom and deck girders are normally to be longitudinally stiffened. Unless special buckling analysis has been carried out, the following requirements shall be complied with:

— the spacing between the plate flange and the nearest stiffener shall not exceed:

$$s_h = 0.055\ (t_w - t_k) \quad \text{(m)}$$

For each successive stiffener spacing away from the plate flange s_h may be increased by 10%.

— below the transverse bulkhead verticals with adjoining brackets, the bottom girders shall have more closely spaced horizontal stiffeners or additional vertical stiffeners. The spacing of the stiffeners shall not exceed:

$$s_h = 0.045\ (t_w - t_k) \quad \text{(m)}$$

or

$$s_v = 0.060\ (t_w - t_k) \quad \text{(m)}$$

— stiffening arrangement will be specially considered with respect to docking.

604 The web plate of transverses shall be effectively stiffened. If the web plate is connected to the bottom longitudinals on one side only, vertical stiffeners shall be applied, or the free edge of the scallop shall be stiffened.

605 If the web stiffeners are in line with the intersecting longitudinals, frames or stiffeners, they shall be connected to the intersecting member.

Stiffeners on the web plate perpendicular to the flange may be sniped towards side, deck or bulkhead plating.

606 The web plate shall be specially stiffened at openings when the mean shear stress exceeds 60 N/mm^2. Stiffeners shall be fitted along the free edges of the openings parallel to the vertical and horizontal axis of the opening. Stiffeners may be omitted in one direction if the shortest axis is less than 400 mm, and in both directions if length of both axes is less than 300 mm. Edge reinforcement may be used as an alternative to stiffeners, see Fig.15. Scallops for longitudinals, frames or stiffeners deeper than 500 mm shall be stiffened along their free edge.

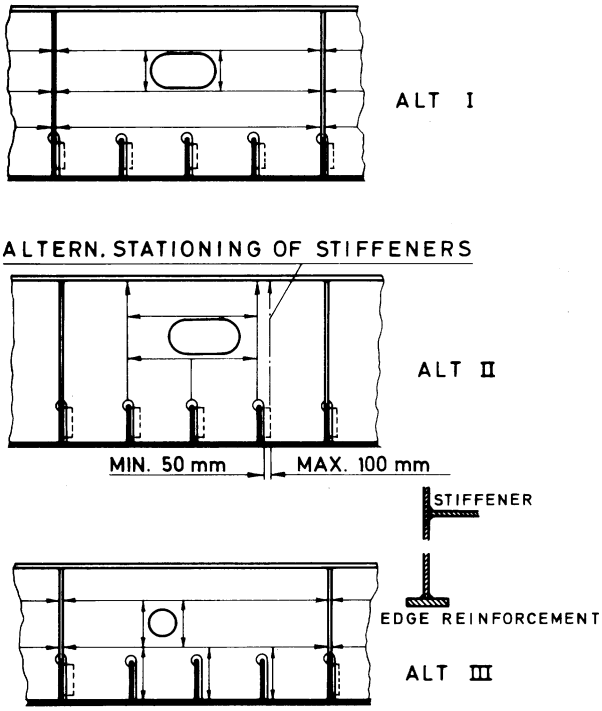


Fig. 15
Web plates with large openings

607 The spacing s_t of tripping brackets is normally not to exceed the values given in Table C3 valid for girders with symmetrical face plates. For girders with unsymmetrical face plates the spacing will be specially considered.

Table C3 Spacing between tripping brackets	
Girder type 1)	s_t *(m)*
Bottom transverse	0.02 b_f, maximum 6
Side and longitudinal bulkhead vertical 2)	0.012 b_f
Longitudinal girder, bottom 3)	0.014 b_f
Longitudinal girder, deck	0.014 b_f, maximum S
Deck transverse	0.02 b_f, maximum 6
Transverse wash bulkhead vertical	0.009 b_f
Transverse tight bulkhead vertical	0.012 b_f
Stringer	0.02 b_f, maximum 6

b_f = flange breadth in mm
S = distance between transverse girders in m.

1) For girders in tanks in the afterbody and machinery spaces s_t shall not exceed 0.012 b_f.
2) If the web of a strength member forms an angle with the perpendicular to the ship's side of more than 10°, s_t shall not exceed 0.007 b_f.
3) In general, tripping brackets shall be fitted at all transverses. For centre girder, tripping brackets are also to be fitted at halfway between transverses.

608 Tripping brackets on girders shall be stiffened by a flange or stiffener along the free edge if the length of the edge exceeds:

$$0.06\, t_t \quad \text{(m)}$$

t_t = thickness in mm of tripping bracket.

The area of the stiffening shall not be less than:

$$10\, l_t \quad (\text{cm}^2)$$

l_t = length in m of free edge.

The tripping brackets shall have a smooth transition to adjoining longitudinals or stiffeners exposed to large longitudinal stresses:

Tripping brackets shall be fitted as required in 607, and are further to be fitted near the toe of bracket, near rounded corner of girder frames and in line with any cross ties. The tripping brackets shall be fitted in line with longitudinals or stiffeners, and shall extend the whole height of the web plate. The arm length of the brackets along the longitudinals or stiffeners, shall not be less than 40% of the depth of the web plate, the depth of the longitudinal or stiffener deducted. The requirement may be modified for deep transverses.

609 Tripping brackets on the centre girder between the bottom transverses are at the bottom to extend to the second bottom longitudinal from the centre line.

On one side the bracket shall have the same depth as the centre girder, on the other side half this depth.

610 Hatch end beams supporting hatch side coamings are at least to have tripping brackets located in the centre line.

611 The moment of inertia of stiffeners perpendicular to the girder flange (including 400 mm plate flange) shall not be less than:

$$I_V = 0.1\ a\ s_v\ t_w^3 \quad (\text{cm}^4)$$

a = as given in Table C4
s_v = as given in 602
t_w = as given in 602.

Corrosion addition (t_k) shall be applied in tanks.

Table C4 Values of a

$\frac{s_v}{l_s}$	≥ 0.8	0.7	0.6	0.5	0.4	0.3
a	0.8	1.4	2.75	5.5	11.0	20.0

This requirement is not applicable to longitudinal girders in bottom and deck or transverse bulkhead vertical girders.

612 The moment of inertia of stiffeners parallel to the girder flange (including 400 mm plate flange) shall not be less than:

$$I_H = k\ A_S\ l_s^2 \quad (\text{cm}^4)$$

k = 2.5 in general
 = 3.3 for bottom and deck longitudinal girders
A_S = cross-sectional area in cm^2 of stiffener including 400 mm plate flange
l_s = length in m of stiffener.

For flat bar stiffeners the height/thickness-ratio shall not exceed 14.

613 The minimum thickness of tripping brackets and stiffeners is given in Sec.6 to Sec.9 covering the various local structures.

C 700 Reinforcement at knuckles

701 Whenever a knuckle in a main member (shell, longitudinal bulkhead etc.) is arranged, it is required that sufficient stiffening is provided for the support of the knuckle. The support of the knuckle may be provided by a member, which is aligned with the knuckle, and effectively attached to the primary support members crossing the knuckle, see Fig.16.

Where stiffeners intersect the knuckle as shown in Fig.16, effective support shall be provided for the stiffeners in way of the knuckle, e.g. as indicated in Fig.16.

When the stiffeners of the shell, inner shell or bulkhead intersect a knuckle at a narrow angle, it may be accepted to interrupt the stiffener at the knuckle, provided that proper end support in terms of carling, bracket or equivalent is fitted. Alternative design solution with, e.g. closely spaced carlings fitted across the knuckle between longitudinal members above and below the knuckle is generally not recommended.

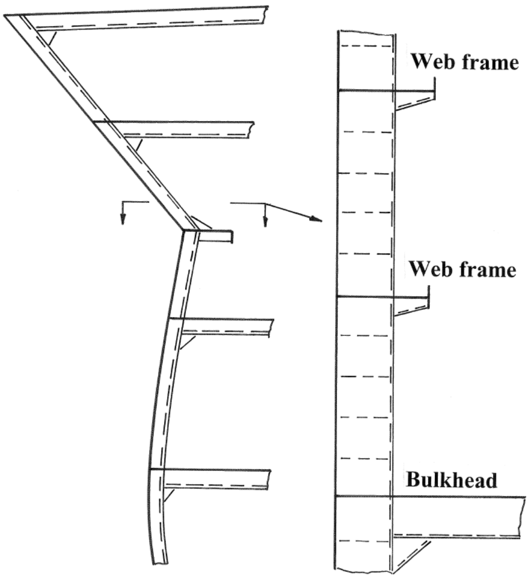


Fig. 16
Reinforcement at knuckle

702 When a stiffener or primary support member is knuckled within the length of the span, effective support shall be provided by fitting tripping bracket or equivalent for the support of the face plate, and tripping bracket or equivalent for supporting the knuckled web section, see Fig.17.

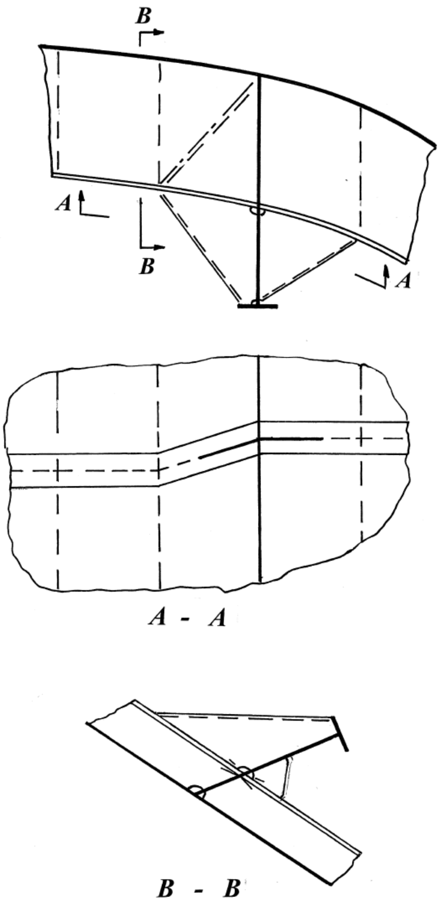


Fig. 17
Support arrangement for knuckled stringer

C 800 Continuity of local strength members

801 Attention is drawn to the importance of structural continuity in general.

802 Structural continuity shall be maintained at the junction of primary supporting members of unequal stiffness by fitting well rounded brackets.

Brackets shall not be attached to unsupported plating.

Brackets shall extend to the nearest stiffener, or local plating reinforcement shall be provided at the toe of the bracket.

803 Where practicable, deck pillars shall be located in line with pillars above or below.

804 Below decks and platforms, strong transverses shall be fitted between verticals and pillars, so that rigid continuous frame structures are formed.

C 900 Welding of outfitting details to hull

901 Generally connections of outfitting details to the hull shall be such that stress-concentrations are minimised and welding to highly stressed parts is avoided as far as possible.

Connections shall be designed with smooth transitions and proper alignment with the hull structure elements. Terminations shall be supported.

902 Equipment details as clips for piping, support of ladders, valves, anodes etc. shall be kept clear of the toe of brackets, edge of openings and other areas with high stresses.

Connections to topflange of girders and stiffeners shall be avoided if not well smoothened. Preferably supporting of outfittings shall be welded to the stiffener web.

903 All materials welded to the hull shell structure shall be of ship quality steel, or equivalent, preferably with the same strength group as the hull structure the item is welded to.

904 Gutterway bars on strength deck shall be arranged with expansion joints unless the height/thickness ratio complies with the formula

$$\frac{h}{t} < \frac{2}{3}\sqrt{1.28\,\frac{E}{\sigma_F}}$$

where

σ_F = minimum upper yield stress of material in N/mm^2. May be taken as 235 N/mm^2 for normal strength steel
E = as given in Sec.1 B101.

905 For welding of deck fittings to a rounded sheer strake, see also Sec.7 C206.

C 1000 Properties and selection of sections.

1001 The geometric properties (moment of inertia I and section modulus Z) of stiffeners, stringers and web frames may be calculated directly from the given dimensions, assuming that the web is attached to the plate flange at right angle. The effective attached plate flange for stringers and web frames is to be taken as given in 400, or plate obtained from published tables and curves. For stiffeners, the plate effective flange width may normally be taken equal to the stiffener spacing.

When the face plate or the web is knuckled within the length of the span, effective support by tripping bracket or equivalent is assumed provided in accordance with 702. Unsymmetrical face plates are generally assumed arranged straight between tripping supports. Curved symmetrical face plates may be assumed fully effective if the radius of curvature, r, is equal to or larger than r = 0.4 b_f^2/t_f, where b_f and t_f denote the breadth and the thickness of the face plate.

The plastic section modulus, including the effect of the angle between the stiffener web and the plate flange, φ_w see Fig.18 shall be determined as given in 1005.

1002 The requirement for standard section modulus and shear area are valid about an axis parallel to the plate flange. If the angle φ_w, see Fig.18, between the stiffener web and the plate flange is less than 75°, the requirement for standard section modulus and shear area may be determined by multiplying the rule requirement by 1/sin φ_w.

1003 Where several members in a group with some variation in requirement are selected as equal, the section modulus may be taken as the average of each individual requirement in the group. However, the requirement for the group shall not be taken less than 90% of the largest individual requirement.

1004 For stiffeners and primary support members, such as girders, stringers and web frames in tanks and in cargo holds of dry bulk cargo carriers, corrosion additions corresponding to the requirements given in Sec.2 D shall be applied. For built up sections the appropriate t_k-value may be added to the web and flange thickness after fulfilment of the modulus requirement.

For rolled sections the section modulus requirement may be multiplied by a corrosion factor w_k, given by the following approximation:

w_k = $1 + 0.05\,(t_{kw} + t_{kf})$ for flanged sections
= $1 + 0.06\,t_{kw}$ for bulbs

t_{kw} = corrosion addition t_k as given in Sec.2 D200 with respect to the profile web
t_{kf} = corrosion addition t_k as given in Sec.2 D200 with respect to the profile flange.

For flat bars the corrosion addition t_k may be added directly to the thickness.

1005 The net effective shear area of panel stiffeners with an inclined web in cm^2 is, away from web scallops, given by:

$$A_{sa} = (h + t_p)(t_w - t_k)\sin\varphi_w/100 \text{ (cm}^2\text{)}$$

The net effective plastic section modulus in cm^3 of the panel stiffener cross-section with an inclined web (and where the cross-sectional area of the attached plate flange exceeds the cross-sectional area of the stiffener) is given by:

$$Z_{pa} = \frac{h_w(h_w + t_p)(t_w - t_k)\sin\varphi_w}{2000} + \frac{A_{fn}\left((h_{fc} + t_p/2)\sin\varphi_w - b_w\cos\varphi_w\right)}{1000}$$

φ_w = angle between the stiffener web and the attached plate flange. For angles of φ_w in excess of 75°, the values of sin φ_w and cos φ_w may be taken equal to 1.0 and 0.0 respectively.
A_{fn} = net effective area of flange
= $(2\gamma - 1)\,(A_f - b_f t_k)$
A_f = cross-sectional area of flange in mm^2
= $b_f \times t_f$ in general
= may be taken as obtained from Table C5 for bulb profiles
= 0.0 for flat bar stiffeners

$$\beta = \frac{10^6\,(t_w - t_k)^2\,l^2}{80\,b_f^2\,(t_f - t_k)\,h_{fc}} + \frac{b_e}{b_f} \leq 0.5$$

$$\gamma = 0.25\left(1 + \sqrt{3 + 12\beta}\right)$$

= 1.0 for profiles of symmetrical cross-section and bulbs, and when mid-span tripping bracket is fitted.
b_f = breadth of flange in mm in general
= b_f^* as given in Table C5 for bulb profiles
= 0.0 for flat bar stiffeners
b_w = distance in mm, measured in the plane of flange and from mid-thickness of the web to the centre of the flange area, see also Fig.18.
= 0.0 for symmetrical flanges
= $(b_f - t_w)/2$ in rolled angle profiles
= may be taken as given in Table C5 for bulb profiles
h_{fc} = distance, measured in the plane of and from lower edge of the web to the level of the centre of the flange area, see also Fig.18.
= $h - t_f/2$ in general
= may be taken as given in Table C5 for bulb profiles
h_w = height of stiffener web in mm, see also Fig.18
l = span length of stiffener in m
t_f = thickness of flange in mm in general
= may be taken as given in Table C5 for bulb profiles
= 0.0 for flat bar stiffeners
t_k = as given in Sec.2 D200
t_p = thickness of attached plate in mm
t_w = web thickness of stiffener in mm.
b_e = as given in Fig.20.

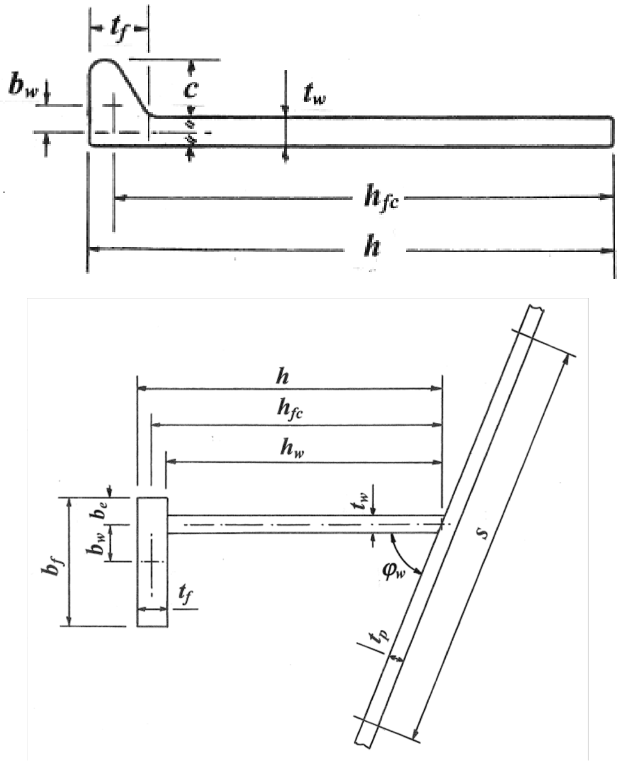


Fig. 18
Stiffener cross-section

Table C5a Characteristic flange data for DIN bulb profiles (see also Fig.18)						
h *(mm)*	C *(mm)*	t_f *(mm)*	b_f^* *(mm)*	$A_f - t_f \times t_w$ *(mm²)*	b_w *(mm)*	h_{fc} *(mm)*
200	28	28.8	69	577	10.9	188
220	31	32.1	76	715	12.1	206
240	34	35.4	84	867	13.3	225
260	37	38.7	92	1034	14.5	244
280	40	42.0	99	1216	15.8	263
300	43	45.3	107	1413	16.9	281
320	46	48.6	114	1624	18.1	300
340	49	52.0	122	1848	19.3	318
370	53.5	56.9	134	2215	21.1	346
400	58	61.9	145	2614	22.9	374
430	62.5	66.8	157	3047	24.7	402

Table C5b Characteristic flange data for JIS bulb profiles (see also Fig.18)						
h *(mm)*	C *(mm)*	t_f *(mm)*	b_f^* *(mm)*	A_f *(mm²)*	b_w *(mm)*	h_{fc} *(mm)*
180	23	24.3	46	635	9.0	170
200	26.5	27.9	53	814	10.4	188
230	30	31.5	60	1030	11.7	217
250	33	34.5	66	1250	12.9	235

Fig. 19
Bulb profiles (DIN and JIS Standard)

C 1100 Cold formed plating

1101 For important structural members, e.g. corrugated bulkheads and hopper knuckles, the inside bending radius in cold formed plating shall not be less than 4.5 times the plate thickness for carbon-manganese steels and 2 times the plate thickness for austenitic- and ferritic-austenitic (duplex) stainless steels, corresponding to 10% and 20% theoretical deformation, respectively.

1102 For carbon-manganese steels the allowable inside bending radius may be reduced below 4.5 times the plate thickness providing the following additional requirements are complied with:

a) The steel is killed and fine grain treated, i.e. grade NV D/DH or higher.

b) The material is impact tested in the strain-aged condition and satisfies the requirements stated herein. The deformation shall be equal to the maximum deformation to be applied during production, calculated by the formula $t/(2R + t)$, where t is the thickness of the plate material and R is the bending radius. Ageing shall be carried out at 250°C for 30 minutes. The average impact energy after strain ageing shall be at least 27 J at 20°C.

c) 100% visual inspection of the deformed area shall be carried out. In addition, random check by magnetic particle testing shall be carried out.

d) The bending radius is in no case to be less than 2 times the plate thickness.

SECTION 4 DESIGN LOADS

A. General

A 100 Introduction

101 In this section formulae for wave induced ship motions and accelerations as well as lateral pressures are given.

The given design wave coefficient is also a basic parameter for the longitudinal strength calculations.

102 The ship motions and accelerations in B are given as extreme values (i.e. probability level = 10^{-8}).

103 Design pressures caused by sea, liquid cargoes, dry cargoes, ballast and bunkers as given in C are based on extreme conditions, but are modified to equivalent values corresponding to the stress levels stipulated in the rules. Normally this involves a reduction of the extreme values given in B to a 10^{-4} probability level.

104 Impact pressures caused by the sea (slamming, bow impact) are not covered by this section. Design values are given in the sections dealing with specific structures.

A 200 Definitions

201 Symbols:

p = design pressure in kN/m^2
ρ = density of liquid or stowage rate of dry cargo in t/m^3.

202 The load point for which the design pressure shall be calculated is defined for various strength members as follows:

a) For plates:
midpoint of horizontally stiffened plate field.
Half of the stiffener spacing above the lower support of vertically stiffened plate field, or at lower edge of plate when the thickness is changed within the plate field.

b) For stiffeners:
midpoint of span.
When the pressure is not varied linearly over the span the design pressure shall be taken as the greater of:

$$p_m \text{ and } \frac{p_a + p_b}{2}$$

p_m, p_a and p_b are calculated pressure at the midpoint and at each end respectively.

c) For girders:
midpoint of load area.

B. Ship motions and accelerations

B 100 General

101 Accelerations in the ship's vertical, transverse and longitudinal axes are in general obtained by assuming the corresponding linear acceleration and relevant components of angular accelerations as independent variables. The combined acceleration in each direction may be taken as:

$$a_c = \sqrt{\sum_{m=1}^{n} a_m^2}$$

n = number of independent variables.

Transverse or longitudinal component of angular acceleration considered in the above expression shall include the component of gravity acting simultaneously in the same direction.

102 The combined effects given in the following may deviate from the above general expression due to practical simplifications applicable to hull structural design or based on experience regarding phasing between certain basic components.

B 200 Basic parameters

201 The acceleration, sea pressures and hull girder loads have been related to a wave coefficient as given in Table B1.

Table B1 Wave coefficient C_W	
L	C_W
L ≤ 100	0.0792 L
100 < L < 300	$10.75 - [\,(300 - L)/100\,]^{3/2}$
300 ≤ L ≤ 350	10.75
L > 350	$10.75 - [\,(L - 350)/150\,]^{3/2}$

The above formulae are illustrated in Fig.1.

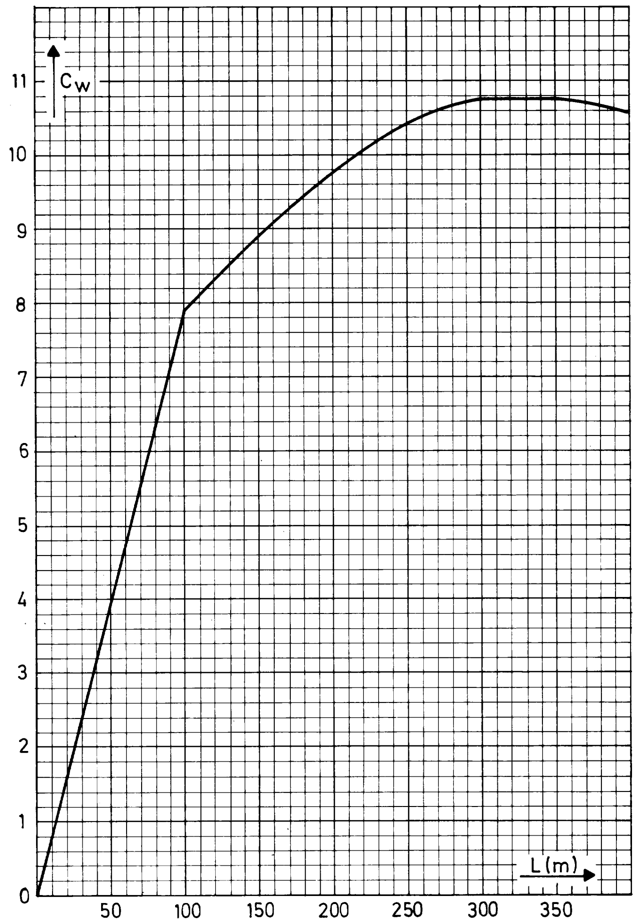


Fig. 1
Wave coefficient

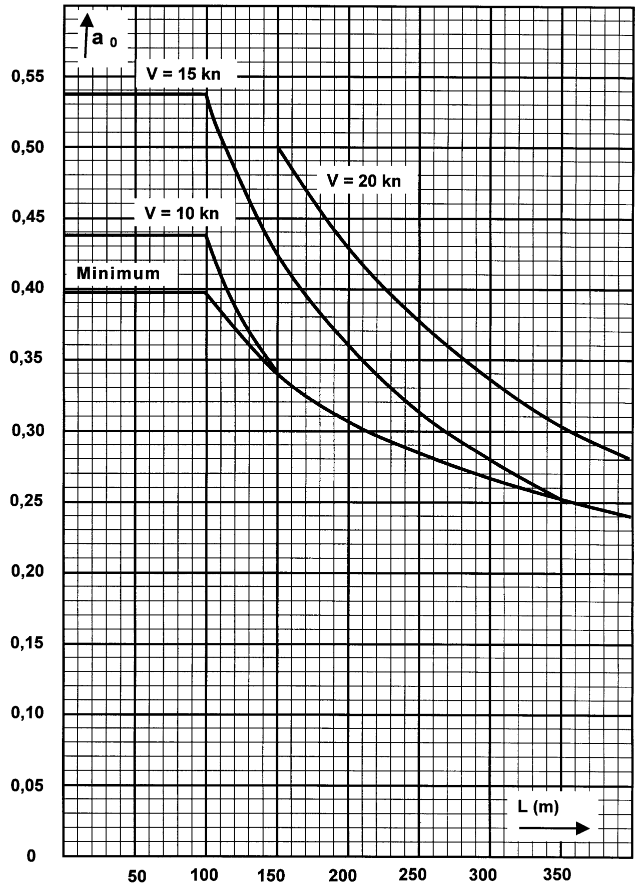


Fig. 2
Acceleration parameter

202 For ships with restricted service, C_W may in general be reduced as follows:

— service area notation **R0**: No reduction
— service area notation **R1**: 10%
— service area notation **R2**: 20%
— service area notation **R3**: 30%
— service area notation **R4**: 40%
— service area notation **RE**: 50%.

203 A common acceleration parameter is given by:

$$a_0 = \frac{3C_W}{L} + C_V C_{V1}$$

$$C_V = \frac{\sqrt{L}}{50}, \quad \text{maximum } 0{,}2$$

$$C_{V1} = \frac{V}{\sqrt{L}}, \quad \text{minimum } 0{,}8$$

Values of a_0 according to the above formula may also be found from Fig.2.

B 300 Surge, sway/yaw and heave accelerations

301 The surge acceleration is given by:

$$a_x = 0.2\, g_0\, a_0 \sqrt{C_B} \qquad (\mathrm{m/s^2})$$

302 The combined sway/yaw acceleration is given by:

$$a_y = 0.3\ g_0\ a_0 \quad (\mathrm{m/s^2})$$

303 The heave acceleration is given by:

$$a_z = 0.7\, g_0 \frac{a_0}{\sqrt{C_B}} \qquad (m/s^2)$$

B 400 Roll motion and acceleration

401 The roll angle (single amplitude) is given by:

$$\phi = \frac{50c}{B + 75} \qquad (rad)$$

c = $(1.25 - 0.025\, T_R)\, k$
k = 1.2 for ships without bilge keel
= 1.0 for ships with bilge keel
= 0.8 for ships with active roll damping facilities
T_R = as defined in 402, not to be taken greater than 30.

402 The period of roll is generally given by:

$$T_R = \frac{2k_r}{\sqrt{GM}} \qquad (s)$$

k_r = roll radius of gyration in m
GM = metacentric height in m.

The values of k_r and GM to be used shall give the minimum realistic value of T_R for the load considered.

In case k_r and GM have not been calculated for such condition, the following approximate design values may be used:

k_r = 0.39 B for ships with even transverse distribution of mass
= 0.35 B for tankers in ballast
= 0.25 B for ships loaded with ore between longitudinal bulkheads
GM = 0.07 B in general
= 0.12 B for tankers and bulk carriers.
= 0.05 B for container ship with B < 32.2 m
= 0.08 B for container ship with B > 40.0 m
with interpolation for B in between.

403 The tangential roll acceleration (gravity component not included) is generally given by:

$$a_r = \phi \left(\frac{2\pi}{T_R}\right)^2 R_R \qquad (m/s^2)$$

R_R = distance in m from the centre of mass to the axis of rotation.

The roll axis of rotation may be taken at a height z m above the baseline.

z = the smaller of $\left[\frac{D}{4} + \frac{T}{2}\right]$ and $\left[\frac{D}{2}\right]$

404 The radial roll acceleration may normally be neglected.

B 500 Pitch motion and acceleration

501 The pitch angle is given by:

$$\theta = 0.25 \frac{a_0}{C_B} \qquad (rad)$$

502 The period of pitch may normally be taken as:

$$T_P = 1.8 \sqrt{\frac{L}{g_0}} \qquad (s)$$

503 The tangential pitch acceleration (gravity component not included) is generally given by:

$$a_p = \theta \left[\frac{2\pi}{T_P}\right]^2 R_P \quad (m/s^2)$$

T_P = period of pitch
R_P = distance in m from the centre of mass to the axis of rotation.

The pitch axis of rotation may be taken at the cross- section 0.45 L from A.P. z meters above the baseline.

z = as given in 403.

With T_P as indicated in 502 the pitch acceleration is given by:

$$a_p = 120\ \theta \frac{R_P}{L} \quad (m/s^2)$$

504 The radial pitch acceleration may normally be neglected.

B 600 Combined vertical acceleration

601 Normally the combined vertical acceleration (acceleration of gravity not included) may be approximated by:

$$a_v = \frac{k_v\, g_0\, a_0}{C_B} \quad (m/s^2)$$

k_v = 1.3 aft of A.P.
= 0.7 between 0.3 L and 0.6 L from A.P.
= 1.5 forward of F.P.

Between mentioned regions k_v shall be varied linearly, see Fig.3.

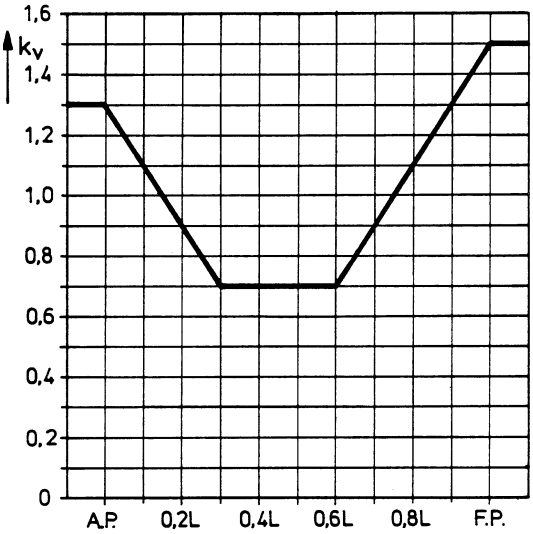


Fig. 3
Acceleration distribution factor

If for design purposes a constant value of a_v within the cargo area is desirable, a value equal to 85% of the maximum a_v within the same area may be used.

602 For evaluation of concentrated loads the acceleration along the ship's vertical axis (acceleration of gravity not included) shall be taken as the combined effect of heave, pitch and roll calculated as indicated in 100, i.e.:

$$a_v = \max \begin{cases} \sqrt{a_{rz}^2 + a_z^2} \\ \sqrt{a_{pz}^2 + a_z^2} \end{cases} \quad (m/s^2)$$

a_z = as given in 303
a_{rz} = vertical component of the roll acceleration given in 403
a_{pz} = vertical component of the pitch acceleration given in 503.

Note that a_{rz} and a_{pz} are equal to a_r and a_p using the horizontal projection of R_R and R_P respectively.

B 700 Combined transverse acceleration

701 Acceleration along the ship's transverse axis is given as the combined effect of sway/yaw and roll calculated as indicated in 100, i.e.:

$$a_t = \sqrt{a_y^2 + (g_0 \sin\phi + a_{ry})^2} \qquad (m/s^2)$$

a_{ry} = transverse component of the roll acceleration given in 403.

Note that a_{ry} is equal to a_r using the vertical projection of R_R, i.e. z_p - z. z_p is the vertical coordinate of the centre of mass. z is given in 403.

B 800 Combined longitudinal accelerations

801 Acceleration along the ship's longitudinal axis is given as the combined effect of surge and pitch calculated as indicated in 100, i.e.:

$$a_l = \sqrt{a_x^2 + (g_0 \sin\theta + a_{px})^2} \qquad (m/s^2)$$

a_{px} = longitudinal component of pitch acceleration given in 503.

Note that a_{px} is equal to a_p using the vertical projection of R_P, i.e. z_p - z. z_p is the vertical coordinate of the centre of mass. z is given in 403.

C. Pressures and forces

C 100 General

101 The external and internal pressures considered to influence the scantling of panels are:
— static and dynamic sea pressures
— static and dynamic pressures from liquids in a tank
— static and dynamic pressures from dry cargoes, stores and equipment.

102 The design sea pressures are assumed to be acting on the ship's outer panels at full draught.

103 The internal pressures are given for the panel in question irrespectively of possible simultaneous pressure from the opposite side. For outer panels sea pressure at ballast draught may be deducted.

104 The gravity and acceleration forces from heavy units of cargo and equipment may influence the scantlings of primary strength members.

C 200 Sea pressures

201 The pressure acting on the ship's side, bottom and weather deck shall be taken as the sum of the static and the dynamic pressure as:

— for load point below summer load waterline:

p_1 = 10 h_0 + p_{dp} [1)] (kN/m^2)

— for load point above summer load waterline:

p_2 = a (p_{dp} – (4 + 0.2 k_s) h_0) [1)] (kN/m^2)
= minimum 6.25 + 0.025 L_1 for sides
= minimum 5 for weather decks.

The pressure p_{dp} is taken as:

$$p_{dp} = p_l + 135\frac{y}{B+75} - 1.2\,(T - z) \qquad (kN/m^2)$$

$p_l = k_s C_W + k_f$

$= (k_s C_W + k_f)\left(0.8 + 0.15\frac{V}{\sqrt{L}}\right)$ if $\frac{V}{\sqrt{L}} > 1.5$

$k_s = 3C_B + \frac{2.5}{\sqrt{C_B}}$ at AP and aft

= 2 between 0.2 L and 0.7 L from AP

$= 3C_B + \frac{4.0}{C_B}$ at FP and forward.

Between specified areas k_s shall be varied linearly.

a = 1.0 for ship's sides and for weather decks forward of 0.15 L from FP, or forward of deckhouse front, whichever is the foremost position
= 0.8 for weather decks elsewhere

h_0 = vertical distance from the waterline at draught T to the load point (m)

z = vertical distance from the baseline to the load point, maximum T (m)

y = horizontal distance from the centre line to the load point, minimum B/4 (m)

C_W = as given in B200

k_f = the smallest of T and f

f = vertical distance from the waterline to the top of the ship's side at transverse section considered, maximum 0.8 C_W (m)

L_1 = ship length, need not be taken greater than 300 (m).

1) For ships with service restrictions, p_2 and the last term in p_1 may be reduced by the percentages given in B202. C_W should not be reduced.

202 The sea pressure at minimum design draught which may be deducted from internal design pressures shall be taken as:

$$p = 10\,(T_M - z) \quad (\text{kN/m}^2)$$
$$= \text{minimum } 0$$

T_M = minimum design draught in m normally taken as 0.35 T for dry cargo vessels and 2 + 0.02 L for tankers

z = vertical distance in m from the baseline to the load point.

203 The design pressure on watertight bulkheads (compartment flooded) shall be taken as:

$$p = 10\,h_b \quad (\text{kN/m}^2)$$

h_b = vertical distance in metres from the load point to the deepest equilibrium waterline in damaged condition obtained from applicable damage stability calculations.

204 The design pressure on inner bottom (double bottom flooded) shall not be less than:

$$p = 10\,T \quad (\text{kN/m}^2).$$

C 300 Liquids in tanks

301 Tanks for crude oil or bunkers are normally to be designed for liquids of density equal to that of sea water, taken as ρ = 1.025 t/m^3 (i.e. $\rho\, g_0 \approx 10$). Tanks for heavier liquids may be approved after special consideration. Vessels designed for 100% filling of specified tanks with a heavier liquid will be given the notation **HL(ρ)**, indicating the highest cargo density applied as basis for approval. The density upon which the scantling of individual tanks are based, will be given in the appendix to the classification certificate.

302 The pressure in full tanks shall be taken as the greater of:

$$p = \rho\,(g_0 + 0.5\,a_v)\,h_s \quad (\text{kN/m}^2) \qquad [1]$$

$$p = \rho\,g_0\,[0.67(h_s + \phi b) - 0.12\sqrt{H b_t \phi}] \quad (\text{kN/m}^2) \qquad [2]$$

$$p = \rho\,g_0\,[0.67(h_s + \theta l) - 0.12\sqrt{H l_t \theta}] \quad (\text{kN/m}^2) \qquad [3]$$

$$p = 0.67\,(\rho\,g_0\,h_p + \Delta p_{dyn}) \quad (\text{kN/m}^2) \qquad [4]$$

$$p = \rho\,g_0\,h_s + p_0 \quad (\text{kN/m}^2) \qquad [5]$$

a_v = vertical acceleration as given in B600, taken in centre of gravity of tank.

ϕ = as given in B400

θ = as given in B500

H = height in m of the tank

ρ = density of ballast, bunkers or liquid cargo in t/m^3, normally not to be taken less than 1.025 t/m^3 (i.e. $\rho\,g_0 \approx 10$)

b = the largest athwartship distance in m from the load point to the tank corner at top of the tank which is situated most distant from the load point. For tank tops with stepped contour, the uppermost tank corner will normally be decisive

b_t = breadth in m of top of tank

l = the largest longitudinal distance in m from the load point to the tank corner at top of tank which is situated most distant from the load point. For tank tops with stepped contour, the uppermost tank corner will normally be decisive

l_t = length in m of top of tank

h_s = vertical distance in m from the load point to the top of tank, excluding smaller hatchways.

h_p = vertical distance in m from the load point to the top of air pipe

p_0 = 25 kN/m^2 in general

= 15 kN/m^2 in ballast holds in dry cargo vessels

= tank pressure valve opening pressure when exceeding the general value.

Δp_{dyn} = calculated pressure drop according to Pt.4 Ch.6 Sec.4 K201.

For calculation of girder structures the pressure [4] shall be increased by a factor 1.15.

The formulae normally giving the greatest pressure are indicated in Figs. 4 to 6 for various types.

For sea pressure at minimum design draught which may be deduced from formulae above, see 202.

Formulae [2] and [3] are based on a 2% ullage in large tanks.

Guidance note 1:

With respect to the definition of h_s, hatchways may be considered small to the extent that the volume of the hatchway is negligible compared to the minimum ullage of the tank. Hatchways for access only may generally be defined as small with respect to the definition of h_s.

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

Guidance note 2:

If the pressure drop according to Pt.4 Ch.6 Sec.4 K201 is not available, Δp_{dyn} may normally be taken as 25 kN/m^2. for ballast tanks and zero for other tanks. If arrangements for the prevention of overpumping of ballast tanks in accordance with Pt.4 Ch.6 Sec.4 K200 are fitted, p_{dyn} may be taken as zero.

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Guidance note 3:

When a ship is designed with VCS notation (high-high level alarm) or provided with equivalent systems to prevent overflow through air pipes, the tank pressure for liquid cargo, based on air pipe height h_p, may be omitted.

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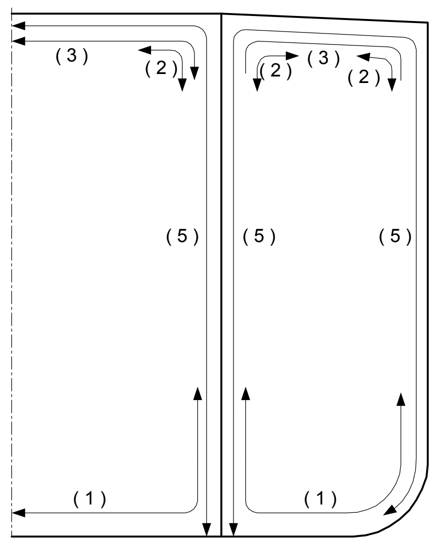

Fig. 4
Section in cargo tanks

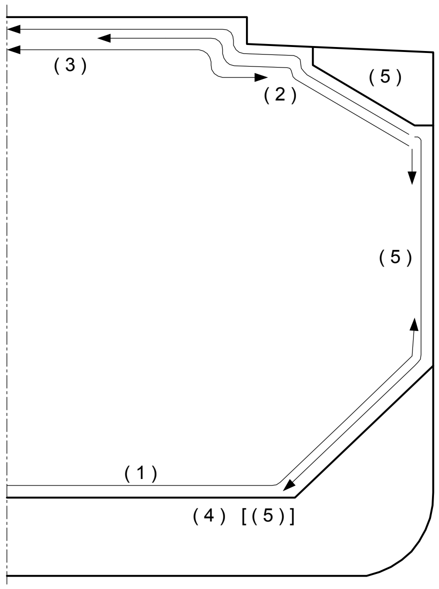

Fig. 5
Section in bulk cargo hold

303 Tanks with l_b < 0.13 L and b_b < 0.56 B shall have scantlings for unrestricted filling height.

For strength members located less than 0.25 l_b away from wash and end bulkheads the pressure shall not be taken less than:

$$p = \rho\left[4 - \frac{L}{200}\right] l_b \quad (kN/m^2)$$

l_b = distance in m between transverse tank bulkheads or fully effective transverse wash bulkheads at the height at which the strength member is located (α_t < 0.2).

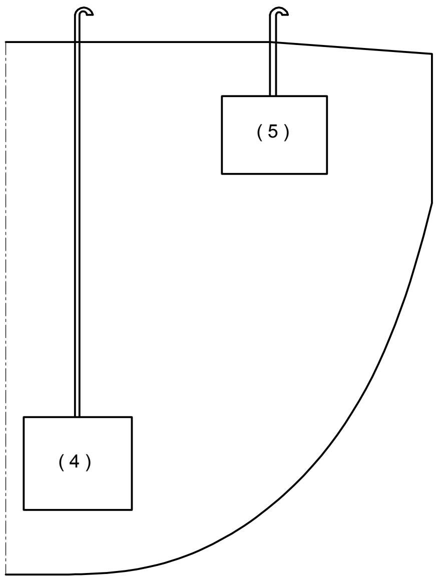

Fig. 6
Section in engine room

For strength members located less than 0.25 b_b away from longitudinal wash bulkheads and tank sides the pressure shall not be taken less than:

$$p = \rho\left[3 - \frac{B}{100}\right] b_b \quad (kN/m^2)$$

b_b = distance in m between tank sides or fully effective longitudinal wash bulkheads at the height at which the strength member is located (α_l < 0.2)

If the wash bulkheads are not fully effective (α_t > 0.2 α_l > 0.2). l_b and b_b may be substituted by l_s and b_s given in 306.
α_t and α_l are defined in 306.

304 The minimum sloshing pressure on webframes and girder panels in cargo and ballast tanks, except ballast tanks in double side and double bottom, shall be taken as 20 kN/m^2. In double side and double bottom ballast tanks the minimum sloshing pressure shall be taken as 12 kN/m^2.

In long or wide tanks with many webframes or girders the sloshing pressure on the frames or girders near to the wash or end bulkheads shall be taken as:

$$p = p_{bhd}\left(1 - \frac{s}{l_s}\right)^2 \quad (\text{kN/m}^2) \text{ for webframes}$$

$$p = p_{bhd}\left(1 - \frac{s}{b_s}\right)^2 \quad (\text{kN/m}^2) \text{ for longitudinal griders.}$$

p_{bhd} = sloshing pressure on wash or end bulkheads as given in 306
s = distance in m from bulkhead to webframe or girder considered.

l_s and b_s as given in 306.

305 Tanks with free sloshing breadth b_s > 0.56 B will be subject to specified restrictions on maximum GM. In addition such tanks and or tanks with a sloshing length such that 0.13 L < l_s < 0.16 L may be designed for specified restrictions in filling height.

Maximum allowable GM, cargo density and possible restrictions on filling heights will be stated in the appendix to the classification certificate.

The sloshing pressures (p) given in 306 and 309 shall be considered together with the normal strength formulae given in Sec.7, Sec.8 and Sec.9.

The impact pressures (p_i) given in 307, 308, 309, and 310 shall be used together with impact strength formulae given in Sec.9 E400.

b_s and l_s as given in 306.

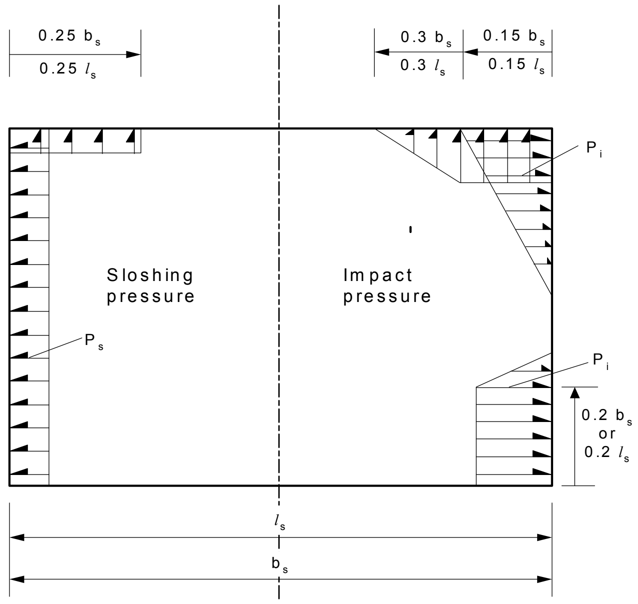

Fig. 7
Pressure distribution

306 *Sloshing pressure*

For strength members located less than 0.25 l_s away from transverse wash and end bulkheads the pressure shall not be taken less than (see Fig.7):

$$p = \rho g_0 l_s k_f\left[0.4 - \left(0.39 - \frac{1.7\, l_s}{L}\right)\frac{L}{350}\right] \quad (\text{kN/m}^2)$$

For strength members located less than 0.25 b_s from longitudinal wash bulkheads and tank sides the pressure shall not be taken less than:

$$p = 7 \rho g_0 k_f \left(\frac{b_s}{B} - 0.3 \right) GM^{0.75} \quad (kN/m^2)$$

k_f = $1 - 2\left(0.7 - \frac{h}{H}\right)^2$, maximum = 1

$$\left(\frac{h}{H}\right)_{max} = 1$$

h = filling height (m)
H = tank height (m) within 0.15 l_s or 0.15 b_s
GM = maximum GM including correction for free surface effect. $GM_{minimum}$ = 0.12 B (m)

l_s = effective sloshing length in m given as:

$= \frac{(1 + n_t \alpha_t)(1 + \beta_t n_2)\, l}{(1 + n_t)(1 + n_2)}$ for end bulkheads

$= \frac{[1 + \alpha_t(n_t - 1)](1 + \beta_t n_2)\, l}{(1 + n_t)(1 + n_2)}$ for wash bulkheads

b_s = effective sloshing breadth in m given as:

$= \frac{(1 + n_l \alpha_l)(1 + \beta_l n_4)\, b}{(1 + n_l)(1 + n_4)}$ for tank sides

$= \frac{[1 + \alpha_l(n_l - 1)](1 + \beta_l n_4)\, b}{(1 + n_l)(1 + n_4)}$ for wash bulkhead

l = tank length in m
b = tank breadth in m
n_t = number of transverse wash bulkheads in the tank with $\alpha_t < 0.5$
α_t = ratio between openings in transverse wash bulkhead and total transverse area in the tank below considered filling height, see Fig.8.

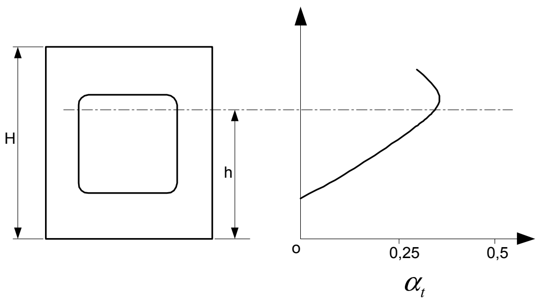

Fig. 8
Wash bulkhead coefficient

If no restriction to filling height, h is taken as 0.7 H.

n_2 = number of transverse web-ring frames in the tank over the length:

$$\frac{l}{(1 + n_t)}$$

β_t = ratio between openings in web-ring frames and total transverse area in the tank below considered filling height, see Fig.9.

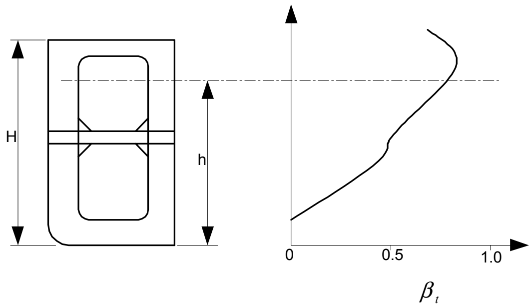

Fig. 9
Webframe coefficient

If no restriction to filling height, h is taken as 0.7 H.

n_l = number of longitudinal wash bulkheads in the tank with $\alpha_l < 0.5$
α_l = similar to α_t but taken for longitudinal wash bulkhead
n_4 = number of longitudinal ring-girders in the tank between the breadth $\frac{b}{(1 + n_l)}$

β_l = similar to β_t taken for longitudinal ring-girders.

307 *Impact pressure in upper part of tanks.*

Tanks with free sloshing length $0.13\ L < l_s < 0.16\ L$ or with free sloshing breadth $b_s > 0.56\ B$ will generate an impact pressure on horizontal and inclined surfaces adjacent to vertical surfaces in upper part of the tank due to high liquid velocities meeting these surfaces. For horizontal or inclined panels (deck, horizontal stringers etc.) the impact pressure on upper parts of the tank may be taken as:

Within 0.15 l_s from transverse wash or end bulkheads:

$$p_i = \rho g_0 k_f \left(\frac{220\ l_s}{L} - 7.5 \right) \sin^2 \gamma \quad (\text{kN/m}^2)$$

$$\text{for} \quad \frac{l_s}{L} < \frac{350 + L}{3550}$$

$$= \rho\ g_0\ k_f \left(25 + \frac{L}{13} \right) \left(0.5 + \frac{l_s}{L} \right) \sin^2 \gamma \quad (\text{kN/m}^2)$$

$$\text{for} \quad \frac{l_s}{L} > \frac{350 + L}{3550}$$

Within 0.15 b_s from longitudinal wash bulkheads and tank sides:

$$p_i = \frac{240\ \rho\ g_0\ k_f}{B} \left(\frac{b_s}{B} - 0.3 \right) GM^{1.5} \sin^2 \gamma$$

Outside 0.15 l_s and 0.15 b_s the pressure may be reduced to zero at 0.3 l_s and 0.3b_s, respectively, see Fig.7.
In tank corners within 0.15 l_s and 0.15 b_s the impact pressure shall not be taken smaller than p_i (transversely) or p_i (longitudinally) + 0.4 p_i (transversely).
The reflected impact pressure on vertical surfaces adjacent to horizontal or inclined surfaces above will have an impact pressure linearly reduced to 50% of the pressure above, 0.1 l_s or 0.1 b_s m below.

l_s, b_s and GM are as given in 306.

k_f = $1 - 4 \left(0.6 - \frac{h}{H} \right)^2$, maximum =1,

$$\left(\frac{h}{H} \right)_{max} = 1$$

h = maximum allowable filling height (m)
H = tank height (m) within 0.15 l_s or 0.15 b_s
γ = angle between considered panel and the vertical.

308 *Impact pressure in lower part of smooth tanks*

In larger tanks (l_s > 0.13 L or b_s > 0.56 B) with double bottom and which have no internal transverse or longitudinal girders restraining the liquid movement at low minimum filling heights ($2 < h < 0.2\, l_s$ or $2 < h < 0.2\, b_s$) the impact pressure on vertical and inclined tank surfaces shall not be taken less than:

$$p_i = 1.42\, \rho\, g_0\, k\, l_s \sin^2 \delta \quad (\text{kN/m}^2)$$

on transverse bulkheads up to a height of 0.2 l_s

$$p_i = 1.5\, \rho\, g_0\, b_s \sin^2 \delta \quad (\text{kN/m}^2)$$

on longitudinal bulkheads up to a height of 0.2 b_s

The impact pressure may be reduced to zero 1 metre above the heights given, see Fig.7.

In tank corners at outermost side of transverse bulkheads the impact pressure within 0.15 b_s shall not be taken smaller than:

$$p_i \text{ (longitudinally)} + 0.4\, p_i \text{ (transversely)}$$

If the tank is arranged with a horizontal stringer within the height $h < 0.2\, l_s$ or $h < 0.2\, b_s$ a reflected impact pressure of the same magnitude as on adjacent transverse or longitudinal bulkhead shall be used on the under side of the stringer panel.

l_s and b_s are free sloshing length and breadth in m at height considered, as given in 306.

k = 1 for L < 200
  = 1.4 – 0.002L for L > 200
δ = angle between the lower boundary panel and the horizontal.

309 For tanks with upper panels higher than L/20 m above lowest seagoing waterline the sloshing and impact pressures given in 306 and 307 shall be multiplied by the following magnification factors:

$1 + 6\, z_e/L$ for longitudinal sloshing
$1 + 7.5\, z_e\, GM/B^2$ for transverse sloshing
$1 + 18\, z_e/L$ for longitudinal impact
$1 + 17.5\, z_e\, GM/B^2$ for transverse impact

z_e = $z_t - T_s - L/20$ (m)
z_t = distance from baseline to panel consider (m)
T_S = lowest seagoing draught (m)
  = 0.50 T may normally be used.

310 For tanks with smooth boundaries (no internal structural members) with tank bottom higher than the D/2, the low filling impact pressure as given in 308 shall be multiplied by the following magnification factor:

$$\left(1 + \frac{2\, z_i\, \theta}{l_s}\right)^2 \quad \text{in longitudinal direction}$$

$$\left(1 + \frac{2\, z_i\, \phi}{b_s}\right)^2 \quad \text{in transverse direction}$$

θ and ϕ = pitch and rolling angle given in B400 and B500
z_i = distance from panel considered to D/2 in m.

C 400 Dry cargoes, stores, equipment and accommodation

401 The pressure on inner bottom, decks or hatch covers shall be taken as:

$$p = \rho\, (g_0 + 0.5\, a_v)\, H \quad (\text{kN/m}^2)$$

a_v = as given in B600
H = stowage height in m.

Standard values of ρ and H are given in Table C1.

If decks (excluding inner bottom) or hatch covers are designed for cargo loads heavier than the standard loads given in Table C1 the notation **DK(+)** or **HA(+)** respectively, will be assigned. The design cargo load in t/m^2 will be given for each individual cargo space in the appendix to the classification certificate.

402 When the weather deck or weather deck hatch covers are designed to carry deck cargo the pressure is in general to be taken as the greater of p according to 201 and 401.

In case the design stowage height of weather deck cargo is smaller than 2.3 m, combination of loads may be required after special consideration.

Table C1 Standard load parameters

Decks	*Parameters*	
	ρ	*H*
Sheltered deck, sheltered hatch covers and inner bottom for cargo or stores	0.7 t/m^3 1)	vertical distance in m from the load point to the deck above. For load points below hatch- ways H shall be measured to the top of coaming.
	ρ H	
Weather deck and weather deck hatch covers in-tended for cargo	1.0 t/m^2 for L = 100 m 1.3 t/m^2 for L > 150 m at superstructure deck. 1.75 t/m^2 for L > 150 m at freeboard deck. For vessels corresponding to 100 m < L < 150 m, the standard value of ρ H is obtained by linear interpolation.	
Platform deck in machinery space	1.6 t/m^2	
Accommodation decks	0.35 t/m^2, when not directly calculated, including deck's own mass. Minimum 0.25 t/m^2.	

1) If $\Sigma\rho$H for cargo spaces exceeds the total cargo capacity of the vessel, ρ may be reduced after special consideration in accordance with specified maximum allowable load for individual decks. When the deck's own mass exceeds 10% of the specified maximum allowable loads, the ρH shall not be taken less than the combined load of deck mass and maximum allowable deck load.

403 The pressure from bulk cargoes on sloping and vertical sides and bulkheads shall be taken as:

$$p = \rho\,(g_0 + 0.5\,a_v)\,K\,h_c \quad (kN/m^2)$$

K = $\sin^2\alpha \tan^2(45 - 0.5\,\delta) + \cos^2\alpha$
 = $\cos\alpha$ minimum
α = angle between panel in question and the horizontal plane in degrees
a_v = as given in B600
δ = angle of repose of cargo in degrees, not to be taken greater than 20° for light bulk cargo (grain etc.), and not greater than 35° for heavy bulk cargo (ore)
h_c = vertical distance in m from the load point to the highest point of the hold including hatchway in general. For sloping and vertical sides and bulkheads, h_c may be measured to deck level only, unless the hatch coaming is in line with or close to the panel considered.

C 500 Deck cargo units. Deck equipment

501 The forces acting on supporting structures and securing systems for heavy units of cargo, equipment or structural components (including cargo loads on hatch covers) are normally to be taken as:

— vertical force alone: $P_V = (g_o + 0.5\,a_v)\,M$ (kN)

— vertical force in combination with transverse force:
$P_{VC} = g_o\,M$ (kN)

— transverse force in combination with vertical force:
$P_{TC} = 0.67\,a_t\,M$ (kN)

— vertical force in combination with longitudinal force:
$P_{VC} = (g_o + 0.5\,a_v)\,M$ (kN),

acting downwards at vessels ends together with downward pitch, acting in 60° - 90° phasing with P_{LC} amidships, where heave part of P_{VC} is prevailing

— longitudinal force in combination with vertical force:
$P_{LC} = 0.67\,a_l\,M$ (kN)

M = mass of unit in t
a_v = as given in B600
a_t = as given in B700
a_l = as given in B800

— P_{TC} and P_{LC} may be regarded as not acting simultaneously, except when the stress σ_L C > 0.6 σ_{TC}, in which case $\sigma_{LC} + 0.4\,\sigma_{TC}$ shall be substituted for σ_{LC}.

502 Regarding forces acting on cargo containers, their supports and lashing systems, reference is made to Pt.5 Ch.2 Sec.6.

SECTION 5 LONGITUDINAL STRENGTH

A. General

A 100 Introduction

101 In this section the requirements regarding the longitudinal hull girder scantlings with respect to bending and shear are given.

102 The wave bending moments and shear forces are given as the design values with a probability of exceedance of 10^{-8}.

These values are applied when determining the section modulus and the shear area of the hull girder and in connection with control of buckling and ultimate strength. Reduced values will have to be used when considering combined local and longitudinal stresses in local elements, see B204.

103 The buckling strength of longitudinal members is not covered by this section. Requirements for such control are given in Sec.13.

104 For ships with small block coefficient, high speed and large flare the hull girder buckling strength in the forebody may have to be specially considered based on the distribution of still water and vertical wave bending moments indicated in B100 and B200 respectively. In particular this applies to ships with length L > 120 m and speed V > 17 knots.

105 For narrow beam ships the combined effects of vertical and horizontal bending of the hull girder may have to be specially considered as indicated in C300.

106 For ships with large deck openings (total width of hatch openings in one transverse section exceeding 65% of the ship's breadth or length of hatch opening exceeding 75% of hold length) the longitudinal strength including torsion may be required to be considered as given in Pt.5 Ch.2 Sec.6 B200. For ships with block coefficient $C_B < 0.7$ the longitudinal/local strength outside of the midship region may, subject to special consideration in each case, be taken according to Pt.5 Ch.2 Sec.6 B.

107 In addition to the limitations given in 104 to 106, special considerations will be given to vessels with the following proportions:

$L/B \leq 5$
$B/D \geq 2.5$.

A 200 Definitions

201 Symbols:

I_N = moment of inertia in cm^4 about the transverse neutral axis
I_C = moment of inertia in cm^4 about the vertical neutral axis
C_W = wave coefficient as given in Sec.4 B
S_N = first moment of area in cm^3 of the longitudinal material above or below the horizontal neutral axis, taken about this axis
z_n = vertical distance in m from the baseline or deckline to the neutral axis of the hull girder, whichever is relevant
z_a = vertical distance in m from the baseline or deckline to the point in question below or above the neutral axis, respectively
M_S = design stillwater bending moment in kNm as given in B100
Q_S = design stillwater shear force in kN as given in B100
M_W = rule wave bending moment in kNm as given in B200
Q_W = rule wave shear force in kN as given in B200
M_{WH} = rule wave bending moment about the vertical axis as given in B205
M_{WT} = rule wave torsional moment as given in B206.

202 Terms:

Effective longitudinal bulkhead is a bulkhead extending from bottom to deck and which is connected to the ship's side by transverse bulkheads both forward and aft.

Loading manual is a document which describes:

— the loading conditions on which the design of the ship has been based, including permissible limits of still water bending moment and shear force and shear force correction values and, where applicable, permissible limits related to still water torsional moment [1)] and lateral loads
— the results of calculations of still water bending moments, shear forces and still water torsional moments if unsymmetrical loading conditions with respect to the ships centreline

— the allowable local loadings for the structure (hatch covers, decks, double bottom, etc.).

1) Permissible torsional still water moment limits are generally applicable for ships with large deck openings as given in 106 and class notation **CONTAINER** or **Container Carrier**.

For bulk carriers of 150 m in length and above, additional requirements as given in Pt.5 Ch.2 Sec.5 A also apply.

A *Loading computer system* is a system, which unless stated otherwise is digital, by means of which it can be easily and quickly ascertained that, at specified read-out points, the still water bending moments, shear forces, and the still water torsional moments and lateral loads, where applicable, in any load or ballast condition will not exceed the specified permissible values.

Guidance note:
The term "Loading computer system" covers the term "Loading instrument" as commonly used in IACS UR S1.

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An operation manual is always to be provided for the loading instrument. Single point loading instruments are not acceptable.

Category I ships. Ships with large deck openings where combined stresses due to vertical and horizontal hull girder bending and torsional and lateral loads have to be considered.

Ships liable to carry non-homogeneous loadings, where the cargo and or ballast may be unevenly distributed. Ships less than 120 m in length, when their design takes into account uneven distribution of cargo or ballast, belong to Category II.

Chemical tankers and gas carriers.

Category II Ships. Ships with arrangement giving small possibilities for variation in the distribution of cargo and ballast, and ships on regular and fixed trading pattern where the Loading Manual gives sufficient guidance, and in addition the exception given under Category I.

B. Still water and wave induced hull girder bending moments and shear forces

B 100 Stillwater conditions

101 The design stillwater bending moments, M_S, and stillwater shear forces, Q_S, shall be calculated along the ship length for design cargo and ballast loading conditions as specified in 102.

For these calculations, downward loads are assumed to be taken as positive values, and shall be integrated in the forward direction from the aft end of L. The sign conventions of Q_S and M_S are as shown in Fig.1.

(IACS UR S11.2.1.1 Rev.7)

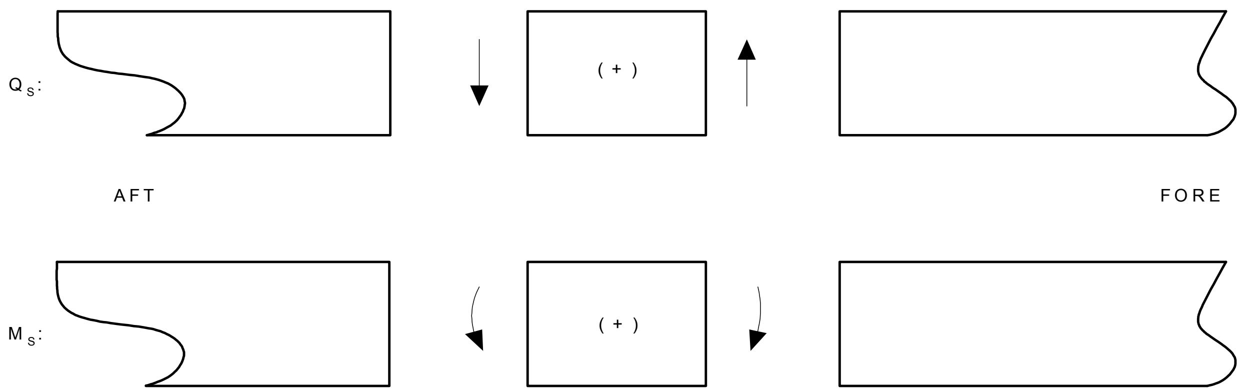

Fig. 1
Sign Conventions of Q_S and M_S

102 In general, the following design cargo and ballast loading conditions, based on amount of bunker, fresh water and stores at departure and arrival, shall be considered for the M_S and Q_S calculations. Where the amount and disposition of consumables at any intermediate stage of the voyage are considered more severe, calculations for such intermediate conditions shall be submitted in addition to those for departure and arrival conditions. Also, where any ballasting and or deballasting is intended during voyage, calculations of the intermediate condition just before and just after ballasting and or deballasting any ballast tank shall be submitted and where approved included in the loading manual for guidance.

Cargo ships, container carriers, roll-on/roll-off and refrigerated carriers, ore carriers and bulk carriers:

— homogenous loading conditions at maximum draught
— ballast conditions
— special loading conditions, e.g. container or light load conditions at less than the maximum draught, heavy cargo, empty holds or non-homogenous cargo conditions, deck cargo conditions, etc. where applicable
— docking condition afloat
— for vessels with **BC-A**, **BC-B**, **BC-C** or **BC-B*** notation, loading conditions as specified in Pt.5 Ch.2 Sec.5 A.

Oil tankers:

— homogenous loading conditions (excluding dry and clean ballast tanks) and ballast or part-loaded conditions
— any specified non-uniform distribution of loading
— mid-voyage conditions relating to tank cleaning or other operations where these differ significantly from the ballast conditions
— docking condition afloat
— for oil carriers complying with the requirements for the segregated ballast tanks as stipulated in Pt.5 Ch.3 Sec.3 B, the ballast conditions shall in addition to the segregated ballast condition include one or more relevant conditions with additional ballast in cargo tanks.

Chemical and product tankers:

— conditions as specified for oil tankers
— conditions for high density or segregated cargo where these are included in the approved cargo list.

Liquefied gas carriers:

— homogenous loading conditions for all approved cargoes
— ballast conditions
— cargo condition where one or more tanks are empty or partially filled or where more than one type of cargo having significantly different densities is carried
— harbour condition for which an increased vapour pressure has been approved
— docking condition afloat.

Combination carriers:

— conditions as specified for oil tankers and cargo ships.

For smaller ships the stillwater bending moments and shear forces may have to be calculated for ballast and particular non-homogeneous load conditions after special considerations.

Also short voyage or harbour conditions including loading and unloading transitory conditions shall be checked where applicable.

Guidance note:

It is advised that the ballast conditions determining the scantlings are based on the filling of ballast in as few cargo tanks as practicable, and it is important that the conditions will allow cleaning of all cargo tanks with the least possible shifting.

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(IACS UR S11.2.1.2 Rev.7)

103 Ballast loading conditions involving partially filled peak and or other ballast tanks at departure, arrival or during intermediate conditions are not permitted to be used as design conditions unless:

— design stress limits are satisfied for all filling levels between empty and full and
— for bulk carriers, Pt.5 Ch.2 Sec.8 C, as applicable, is complied with for all filling levels between empty and full.

To demonstrate compliance with all filling levels between empty and full, it will be acceptable if, in each condition at departure, arrival and where required by 102 any intermediate condition, the tanks intended to be partially filled are assumed to be:

— empty
— full
— partially filled at intended level.

Where multiple tanks are intended to be partially filled, all combinations of empty, full or partially filled at intended level for those tanks shall be investigated.

However, for conventional Ore Carriers with large wing water ballast tanks in cargo area, where empty or full ballast water filling levels of one or maximum two pairs of these tanks lead to the ship's trim exceeding one of the following conditions, it is sufficient to demonstrate compliance with maximum, minimum and intended partial filling levels of these one or maximum two pairs of ballast tanks such that the ship's condition does not exceed any of these trim limits. Filling levels of all other wing ballast tanks shall be considered between empty and full. The trim conditions mentioned above are:

— trim by stern of 3% of the ship's length, or
— trim by bow of 1.5% of ship's length, or
— any trim that cannot maintain propeller immersion (I/D) not less than 25%.

where:

I = the distance from propeller centreline to the waterline
D = propeller diameter.

See Fig.2.

The maximum and minimum filling levels of the above mentioned pairs of side ballast tanks shall be indicated in the loading manual.

(IACS UR S11.2.1.3 Rev.7)

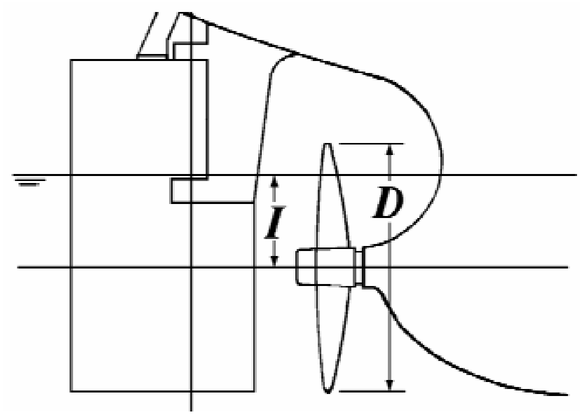


Fig. 2

104 In cargo loading conditions, the requirements given in 103 applies to peak tanks only.

(IACS UR S11.2.1.4 Rev.7)

105 Requirements given in 103 and 104 are not applicable to ballast water exchange using the sequential method. However, bending moment and shear force calculations for each de-ballasting or ballasting stage in the ballast water exchange sequence are to be included in the loading manual or ballast water management plan of any vessel that intends to employ the sequential ballast water exchange method.

(IACS UR S11.2.1.5 Rev.7)

106 The design stillwater bending moments amidships (sagging and hogging) are normally not to be taken less than:

$$M_S = M_{SO} \quad \text{(kNm)}$$

M_{SO} = $-0.065\, C_{WU}\, L^2\, B\, (C_B + 0.7)$ (kNm) in sagging
= $C_{WU}\, L^2\, B\, (0.1225 - 0.015\, C_B)$ (kNm) in hogging
C_{WU} = C_W for unrestricted service.

Larger values of M_{SO} based on cargo and ballast conditions shall be applied when relevant, see 102.

For ships with arrangement giving small possibilities for variation of the distribution of cargo and ballast, M_{SO} may be dispensed with as design basis.

107 When required in connection with stress analysis or buckling control, the stillwater bending moments at arbitrary positions along the length of the ship are normally not to be taken less than:

$$M_S = k_{sm}\, M_{SO} \quad \text{(kNm)}$$

M_{SO} = as given in 106
k_{sm} = 1.0 within 0.4 L amidships
= 0.15 at 0.1 L from A.P. or F.P.
= 0.0 at A.P. and F.P.

Between specified positions k_{sm} shall be varied linearly.

Values of k_{sm} may also be obtained from Fig.3.

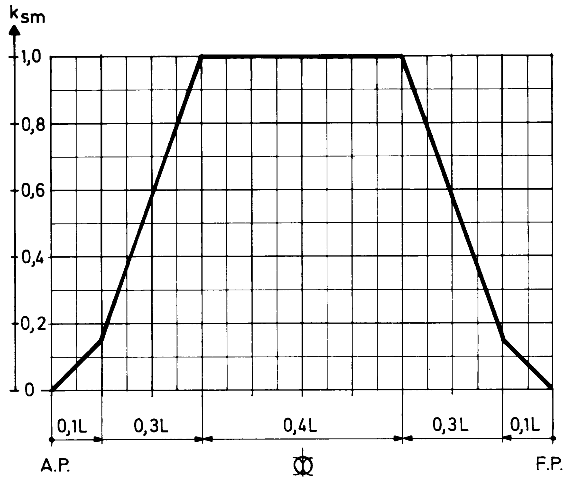


Fig. 3
Stillwater bending moment

The extent of the constant design bending moments amidships may be adjusted after special consideration.

108 The design values of stillwater shear forces along the length of the ship are normally not to be taken less than:

$$Q_S = k_{sq}\, Q_{SO} \quad \text{(kN)}$$

$$Q_{SO} = 5\frac{M_{SO}}{L} \quad \text{(kN)}$$

M_{SO} = design stillwater bending moments (sagging or hogging) given in 106.
Larger values of Q_S based on load conditions ($Q_S = Q_{SL}$) shall be applied when relevant, see 102. For ships with arrangement giving small possibilities for variation in the distribution of cargo and ballast, Q_{SO} may be dispensed with as design basis

k_{sq} = 0 at A.P. and F.P.
= 1.0 between 0.15 L and 0.3 L from A.P.
= 0.8 between 0.4 L and 0.6 L from A.P.
= 1.0 between 0.7 L and 0.85 L from A.P.

Between specified positions k_{sq} shall be varied linearly.

Sign convention to be applied:

— when sagging condition positive in forebody, negative in afterbody
— when hogging condition negative in forebody, positive in afterbody.

B 200 Wave load conditions

201 The rule vertical wave bending moments amidships are given by:

$$M_W = M_{WO} \quad \text{(kNm)}$$

M_{WO} = $-0.11\, \alpha C_W L^2 B (C_B + 0.7)$ (kNm) in sagging
= $0.19\, \alpha C_W L^2 B C_B$ (kNm) in hogging

α = 1.0 for seagoing conditions
= 0.5 for harbour and sheltered water conditions (enclosed fjords, lakes, rivers).

C_B is not be taken less than 0.6.

202 When required in connection with stress analysis or buckling control, the wave bending moments at arbitrary positions along the length of the ship are normally not to be taken less than:

$$M_W = k_{wm}\, M_{WO} \quad \text{(kNm)}$$

M_{WO} = as given in 201

k_{wm} = 1.0 between 0.40 L and 0.65 L from A.P.
= 0.0 at A.P. and F.P.

For ships with high speed and or large flare in the forebody the adjustments to k_{wm} as given in Table B1, limited to the control for buckling as given in Sec.13, apply.

Table B1 Adjustments to k_{wm}

Load condition	*Sagging and hogging*		*Sagging only*	
C_{AV}	≤ 0.28	≥ 0.32 1)		
C_{AF}			≤ 0.40	≥ 0.50
k_{wm}	No adjust ment	1.2 between 0.48 L and 0.65 L from A.P. 0.0 at F.P. and A.P.	No adjust ment	1.2 between 0.48 L and 0.65 L from A.P. 0.0 at F.P. and A.P.
1) Adjustment for C_{AV} not to be applied when $C_{AF} \geq 0.50$.				

$$C_{AV} = \frac{c_v V}{\sqrt{L}}$$

$$C_{AF} = \frac{c_v V}{\sqrt{L}} + \frac{A_{DK} - A_{WP}}{L z_f}$$

c_v = $\frac{\sqrt{L}}{50}$, maximum 0.2
A_{DK} = projected area in the horizontal plane of upper deck (including any forecastle deck) forward of 0.2 L from F.P.
A_{WP} = area of waterplane forward of 0.2 L from F.P. at draught T
z_f = vertical distance from summer load waterline to deckline measured at F.P.

Between specified C_A-values and positions k_{wm} shall be varied linearly. Values of k_{wm} may also be obtained from Fig.4.

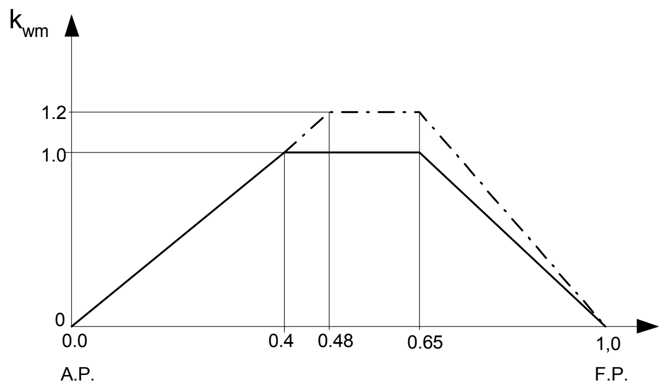


Fig. 4
Wave bending moment distribution

203 The rule values of vertical wave shear forces along the length of the ship are given by:

Positive shear force, to be used when positive still water shear force:

$$Q_{WP} = 0.3\,\beta\,k_{wqp}\,C_W\,L\,B\,(C_B + 0.7) \quad \text{(kN)}$$

Negative shear force, to be used when negative still water shear force:

$$Q_{WN} = -\,0.3\,\beta\,k_{wqn}\,C_W\,L\,B\,(C_B + 0.7) \quad \text{(kN)}$$

Positive shear force when there is a surplus of buoyancy forward of section considered, see also Fig.1.

Negative shear force when there is a surplus of weight forward of section considered.

β = 1.0 for seagoing conditions
= 0.5 for harbour and sheltered water conditions (enclosed fjords, lakes, rivers)
k_{wqp} = 0 at A.P. and F.P.
= $1.59\,C_B/(C_B + 0.7)$ between 0.2 L and 0.3 L from A.P.
= 0.7 between 0.4 L and 0.6 L from A.P.
= 1.0 between 0.7 L and 0.85 L from A.P.

k_{wqn} = 0 at A.P. and F.P.
= 0.92 between 0.2 L and 0.3 L from A.P.
= 0.7 between 0.4 L and 0.6 L from A.P.
= 1.73 $C_B/(C_B + 0.7)$ between 0.7 L and 0.85 L from A.P.
C_W = as given in 201.

For ships with high speed and or large flare in the forebody, the adjustments given in Table B2 apply.

Table B2 Adjustments to k_{wq}				
Load condition	*Sagging and hogging*		*Sagging only*	
C_{AV}	≤ 0.28	≥ 0.32 1)		
C_{AF}			≤ 0.40	≥ 0.50
Multiply k_{wq} by	1.0	1.0 aft of 0.6 L from A.P. 1.2 between 0.7 L and 0.85 L from A.P.	1.0	1.0 aft of 0.6 L from A.P. 1.2 between 0.7 L and 0.85 L from A.P.
1) Adjustment for C_{AV} not to be applied when $C_{AF} \geq 0.50$.				

C_{AV} = as defined in 202
C_{AF} = as defined in 202.

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

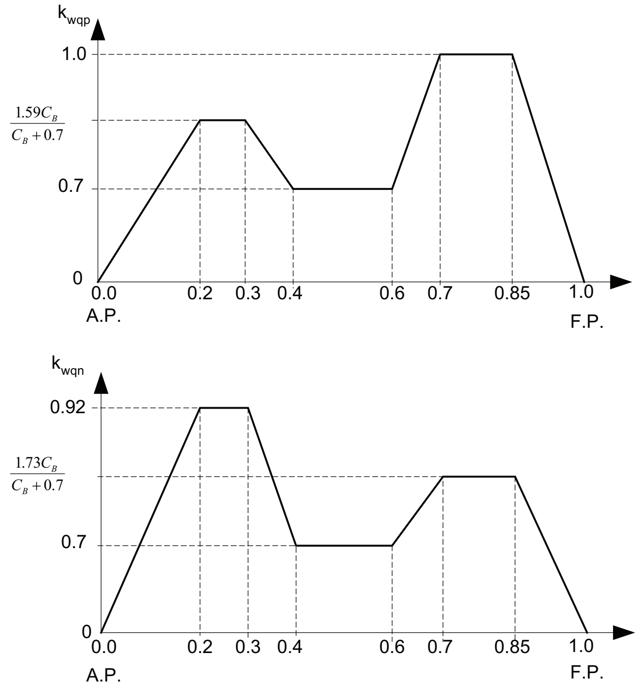


Fig. 5
Wave shear force distribution

204 When hull girder stresses due to wave loads are combined with local stresses in girder systems, stiffeners and plating in accordance with Sec.12, the wave bending moments and shear forces may be reduced as follows:

$$M_{WR} = 0.59\ M_W$$
$$Q_{WR} = 0.59\ Q_W$$

205 The rule horizontal wave bending moments along the length of the ship are given by:

$$M_{WH} = 0.22\ L^{9/4}\ (T + 0.3\ B)\ C_B\ (1 - \cos\ (360\ x/L))\ \text{(kNm)}$$

x = distance in m from A.P. to section considered.

206 The rule wave torsional moments along the length of the ship due to the horizontal wave- and inertia forces and the rotational wave- and inertia moment loads are given by:

$$M_{WT} = K_{T1}\ L^{5/4}\ (T + 0.3\ B)\ C_B\ z_e \pm K_{T2}\ L^{4/3}\ B^2\ C_{SWP}\ \ \text{(kNm)}$$

K_{T1} = 1.40 sin (360 x/L)
K_{T2} = 0.13 (1 – cos (360 x/L))

C_{SWP} = $A_{WP}/(LB)$
A_{WP} = water plane area of vessel in m^2 at draught T
z_e = distance in m from the shear centre of the midship section to a level 0.7 T above the base line
x = distance in m from A.P. to section considered.

C. Bending strength and stiffness

C 100 Midship section particulars

101 When calculating the moment of inertia and section modulus, the effective sectional area of continuous longitudinal strength members is in general the net area after deduction for openings as given in E.

The effective sectional area of strength members between hatch openings in ships with twin or triple hatchways shall be taken as the net area multiplied by a factor 0.6 unless a higher factor is justified by direct calculations.

Superstructures which do not form a strength deck shall not be included in the net section. This applies also to deckhouses, bulwarks and non-continuous hatch side coamings.

For definition of strength deck, see Sec.1 B205.

102 The rule section modulus generally refers to the baseline and the deckline.

103 Continuous trunks, longitudinal hatch coamings and above deck longitudinal girders shall be included in the longitudinal sectional area provided they are effectively supported by longitudinal bulkheads or deep girders. The deck modulus is then to be calculated by dividing the moment of inertia by the following distance, provided this is greater than the distance to the deck line at side:

$$z = (z_n + z_a)\left[0.9 + 0.2\frac{y_a}{B}\right], \quad \text{minimum } z_n$$

y_a = distance in m from the centre line of the ship to the side of the strength member.

y_a and z_a shall be measured to the point giving the largest value of z.

104 The main strength members included in the hull section modulus calculation shall extend continuously through the cargo region and sufficiently far towards the ends of the ship.

105 Longitudinal bulkheads shall terminate at an effective transverse bulkhead, and large transition brackets shall be fitted in line with the longitudinal bulkheads.

C 200 Extent of high strength steel (HS-steel)

201 The vertical extent of HS-steel used in deck or bottom shall not be less than:

$$z_{hs} = z_n \frac{f_2 - f_3}{f_2}$$

f_2 = stress factor, for the bottom given in Sec.6 and for the deck in Sec.8
f_3 = material factor (general symbol f_1) for the members located more than z_{hs} from deck or bottom, see Fig.6.

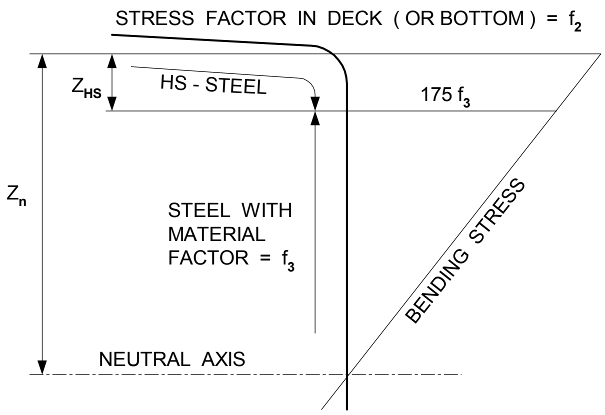


Fig. 6
Vertical extent of HS-steel

For narrow beam ships the vertical extent of HS-steel may have to be increased after special consideration.

202 The longitudinal extent of HS-steel used in deck or bottom shall not be less than x_{hs} as indicated in Fig.7.

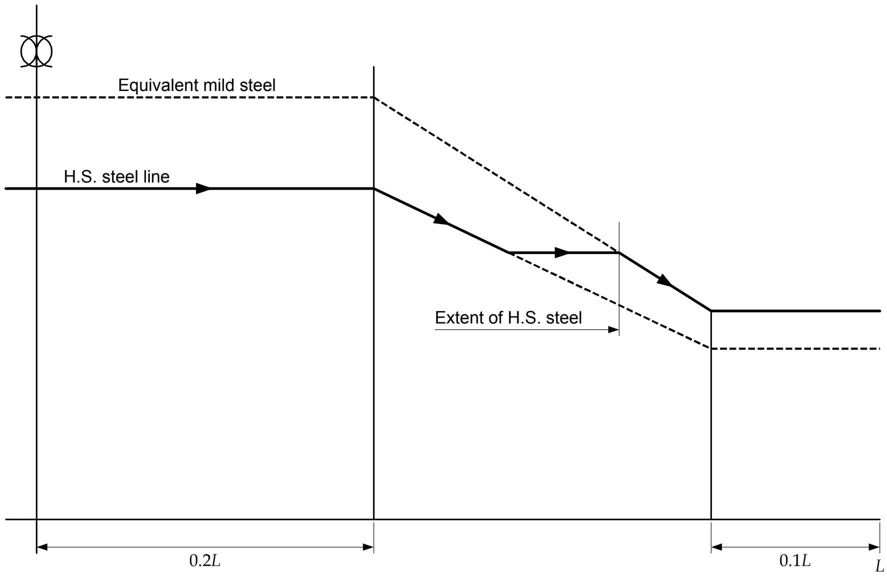


Fig. 7
Longitudinal extent of HS-steel

x_{hs} (minimum) implies that the midship scantlings shall be maintained outside 0.4 L amidships to a point where the scantlings equal those of an identical ship built of normal strength steel over the full length. x_{hs} (general) implies that the scantlings outside 0.4 L may be gradually reduced as if HS-steel was used over the full length. Where material strength group changes, however, continuity in scantlings shall be maintained.

C 300 Section modulus

301 The requirements given in 302 and 303 will normally be satisfied when calculated for the midship section only, provided the following rules for tapering are complied with:

a) Scantlings of all continuous longitudinal strength members shall be maintained within 0.4 L amidships.
   In special cases, based on consideration of type of ship, hull form and loading conditions, the scantlings may be gradually reduced towards the ends of the 0.4 L amidship part, bearing in mind the desire not to inhibit the vessel's loading flexibility.
b) Scantlings outside 0.4 L amidships are gradually reduced to the local requirements at the ends, and the same material strength group is applied over the full length of the ship.

The section modulus at other positions along the length of the ship may have to be specially considered for ships with small block coefficient, high speed and large flare in the forebody or when considered necessary due to structural arrangement, see A106.

In particular this applies to ships of length L > 120 m and speed V > 17 knots.

302 As a minimum, hull girder bending strength checks are to be carried out at the following locations:

— In way of the forward end of the engine room.
— In way of the forward end of the foremost cargo hold.
— At any locations where there are significant changes in hull cross-section.
— At any locations where there are changes in the framing system.

Buckling strength of members contributing to the longitudinal strength and subjected to compressive and shear stresses is to be checked, in particular in regions where changes in the framing system or significant changes in the hull cross-section occur. The buckling evaluation criteria used for this check is determined by each Classification Society.

Continuity of structure is be maintained throughout the length of the ship. Where significant changes in structural arrangement occur adequate transitional structure is to be provided.

For ships with large deck openings such as containerships, sections at or near to the aft and forward quarter length positions are to be checked. For such ships with cargo holds aft of the superstructure, deckhouse or engine room, strength checks of sections in way of the aft end of the aft-most holds, and the aft end of the deckhouse or engine room are to be performed.

303 The midship section modulus about the transverse neutral axis shall not be less than:

$$Z_O = \frac{C_{WO}}{f_1} L^2 B (C_B + 0.7) \quad (cm^3)$$

C_{WO} = $10.75 - [(300 - L)/100]^{3/2}$ for $L < 300$
= 10.75 for $300 \leq L \leq 350$
= $10.75 - [(L - 350)/150]^{3/2}$ for $L > 350$

Values of C_{WO} are also given in Table C1.

C_B is in this case not to be taken less than 0.60.

Table C1 Values for C_{WO}

L	C_{WO}	L	C_{WO}	L	C_{WO}
		160	9.09	260	10.50
		170	9.27	280	10.66
		180	9.44	300	10.75
		190	9.60	350	10.75
100	7.92	200	9.75	370	10.70
110	8.14	210	9.90	390	10.61
120	8.34	220	10.03	410	10.50
130	8.53	230	10.16	440	10.29
140	8.73	240	10.29	470	10.03
150	8.91	250	10.40	500	9.75

For ships with restricted service, C_{WO} may be reduced as follows:

— service area notation **R0**: No reduction
— service area notation **R1**: 5%
— service area notation **R2**: 10%
— service area notation **R3**: 15%
— service area notation **R4**: 20%
— service area notation **RE**: 25%.

304 The section modulus requirements about the transverse neutral axis based on cargo and ballast conditions are given by:

$$Z_O = \frac{|M_S + M_W|}{\sigma_l} 10^3 \quad (cm^3)$$

σ_l = 175 f_1 N/mm^2 within 0.4 L amidship
= 125 f_1 N/mm^2 within 0.1 L from A.P. or F.P.

Between specified positions σ_l shall be varied linearly.

305 The midship section modulus about the vertical neutral axis (centre line) is normally not to be less than:

$$Z_{OH} = \frac{5}{f_1} L^{9/4} (T + 0.3B) C_B \quad (cm^3)$$

The above requirement may be disregarded provided the combined effects of vertical and horizontal bending stresses at bilge and deck corners are proved to be within 195 f_1 N/mm^2.

The combined effect may be taken as:

$$\sigma_s + \sqrt{\sigma_w^2 + \sigma_{wh}^2}$$

σ_s = stress due to M_S
σ_w = stress due to M_W
σ_{wh} = stress due to M_{WH}, the horizontal wave bending moment as given in B205.

306 The stress concentration factor due to fatigue control of scallops e.g. in way of block joints shall not be greater than:
- for scallops in deck

$$K_{ga} = \frac{\sigma_d Z_{deck}}{240 (M_{W,hog} - M_{W,sag})}$$

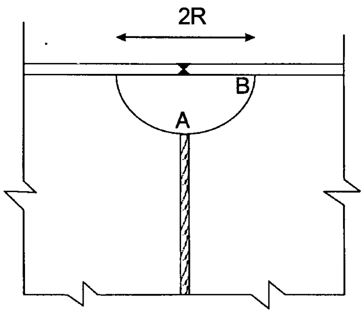
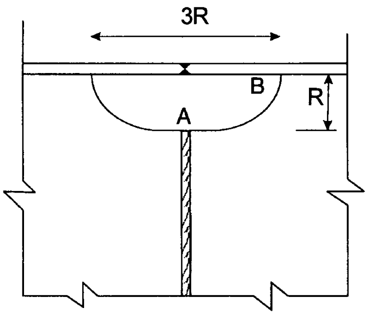
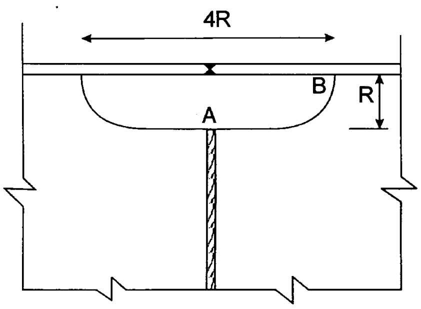
- for scallops in bottom

$$K_{ga} = \frac{\sigma_d Z_{bottom}}{240 (M_{W,hog} - M_{W,sag})}$$

σ_d = permissible single amplitude dynamic stress in (N/mm^2)
= 110 c, in general
c = 1.0 for uncoated cargo and ballast tanks
= 1.15 for fully coated tanks and fuel tanks
= 1.28 for dry cargo holds and void spaces
Z_{deck} = midship section modulus in cm^3 at deck as built
Z_{bottom} = midship section modulus in cm^3 at bottom as built
$M_{W,}$ hog = the rule vertical wave hogging bending moment amidship, as defined in B201
$M_{W,}$ sag = the rule vertical wave sagging bending moment amidship, as defined in B201.

Stress concentration factors for scallops are given in Table C2.

Table C2 Stress concentration factors K_{ga} for scallops

Structure	*Point A*	*Point B*
	1.67	1.2
	1.13	1.2
	1.07	1.2
For scallops without transverse welds, the K-factor at B will be governing for the design		

C 400 Moment of inertia

401 The midship section moment of inertia about the transverse neutral axis shall not be less than:

$$I = 3\ C_W\ L^3\ B\ (C_B + 0.7) \quad (cm^4)$$

D. Shear strength

D 100 General

101 The shear stress in ship's sides and longitudinal bulkheads shall not exceed 110 f_1 N/mm^2. In addition the plate panels shall be checked for adequate shear and combined buckling strength as outlined in Sec.13 B300 and B500.

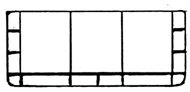
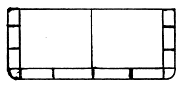
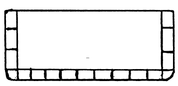
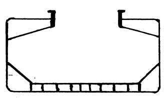
102 The thickness requirements given below apply unless smaller values are proved satisfactory by an accepted method of direct stress calculation, including a shear flow calculation and a calculation of bottom load distribution.

Acceptable calculation methods are outlined in DNV Classification Notes on «Strength Analysis of Hull Structures» for various ship types.

103 The thickness requirements for side shell (or combined thickness of inner and outer shell when double skin) and possible longitudinal bulkhead are given by:

$$t = \frac{|\Phi(Q_S + Q_W) \pm 0.5\Delta Q_S|}{\tau} \frac{S_N}{I_N} 10^2 \quad (mm)$$

Φ = shear force distribution factor as given in Table D1

Table D1 Shear force distribution factor	
	$\Phi_S = 0.109 + 0.0911 \frac{A_S}{A_L}$ $\Phi_L = 0.391 - 0.0911 \frac{A_S}{A_L}$
	$\Phi_S = 0.338 + 0.0167 \frac{A_S}{A_C}$ $\Phi_C = 0.324 - 0.0334 \frac{A_S}{A_C}$
	$\Phi_S = 0.5$
	$\Phi_S = 0.5$

For these and other arrangements Φ may be taken from a direct shear flow calculation.

ΔQ_S = shear force correction due to shear carrying longitudinal bottom members (girders or stiffeners) and uneven transverse load distribution
= 0 when $Q_S = k_{sq}\ Q_{SO}$, as given in B107
= $\Delta\ Q_{SL}$ when $Q_S = Q_{SL}$, i.e. based on cargo and ballast conditions

ΔQ_{SL} is given in 300 for ships with two LBHD.

ΔQ_{SL} is given in 400 for ships with centre line BHD.

ΔQ_{SL} is given in 400 for ships without LBHD.

ΔQ_{SL} is given in 200 for bulk and OBO carriers.

For other arrangements ΔQ_S will be specially considered.

τ = 110 f_1 N/mm^2, provided the buckling strength (see 101) does not require smaller allowable stress.

I_N / S_N may normally be taken as 90 D at the neutral axis.

A_S = mean shear area in cm^2 of the side shell or double skin in the side tank under consideration, taken as the total cross-sectional area of the plating over the depth D

A_L = mean shear area in cm^2 of the longitudinal bulkhead in the side tank under consideration, taken as the total cross-sectional area of the bulkhead plating between bottom and deck for plane bulkheads. For corrugated bulkheads the area to be reduced with the relation between projected length and expanded length of the corrugations

A_C = mean shear area in cm^2 of the centre line bulkhead in the tank under consideration, taken as the total cross-sectional area of the bulkhead plating between bottom and deck for plane bulkheads. For corrugated bulkheads the area shall be reduced with the relation between projected length and expanded length of the corrugations.

104 Minimum shear area at fore end of machinery spaces (machinery aft) shall be based on fully loaded condition at arrival. Minimum shear area at after end of fore peak shall be based on light ballast condition with fore peak filled, or fully loaded condition at arrival, whichever gives the largest shear area. If a deep tank is positioned between the forward cargo hold/cargo tank and the fore peak, the shear area at after end of the deep tank shall be based on a light ballast condition with both fore peak and deep tank filled, or fully loaded condition at arrival, whichever gives the largest shear area.

For ships where fore peak and any deep tank are not intended to carry ballast when the ship is in light ballast condition, the shear force determining scantlings will be specially considered.

D 200 Ships with single or double skin and without other effective longitudinal bulkheads

201 The thickness of side shell shall not be less than given by the formula in 103. When $Q_S = Q_{SL}$, the shear force transmitted directly to one transverse bulkhead from the hold in question may be expressed as follows:

$$\Delta Q_{SL} = C_p(P_H + \sum(K_N P_N)) - C_D T_1 \quad \text{(kN)}$$

P_H = cargo or ballast in t for the hold in question
P_N = bunker or ballast (t) in double bottom tank no. N (port and starboard) situated below considered hold
T_1 = draught in m at the middle of hold
C_P = load correction factor in kN/t
C_D = buoyancy correction factor in kN/m

$K_N = \dfrac{V_H A_N'}{H A_N A_B'}$ to be calculated for each filled tank

H = height of hold in m
V_H = volume of hold in m^3
A_N = horizontal cross-sectional area (m^2) (port and starboard) at level of inner bottom tank N
A_N ' = horizontal cross-sectional area (m^2) (port and starboard) at level of inner bottom of that part of the double bottom tank no. N which is situated within the length of the considered hold
A_B ' = sum of all A_N '.

The Δ Q-value shall be deducted from the peak-values of the conventional shear force curve in way of loaded hold between empty holds or empty hold between loaded holds as shown in Fig.8. For other loading conditions the sign convention shall be applied in a similar manner.

For practical purposes C_P and C_D may be taken as constants independent of cargo filling height and draught respectively.

The following values may be used:

$$C_P = \frac{9.81\, C\, B_{DB}\, L_H\, H}{V_H} \quad \text{(kN/t)}$$

$C_D = 10\, C\, B_{DB}\, L_H$ (kN/m)

$$C = \frac{B}{2.2(B + L_H)} \quad \text{(for conventional designs)}$$

B_{DB} = breadth of the flat part of the double bottom in m
L_H = length of hold in m.

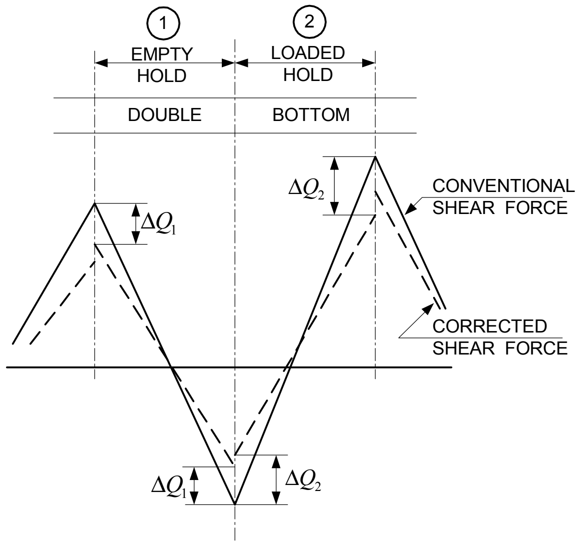


Fig. 8
Shear force correction

202 For shell plates completely within a top wing tank or a hopper tank, the thickness requirements calculated from the formula in 103 may be divided by 1.2.

D 300 Ships with two effective longitudinal bulkheads

301 Between fore bulkhead in after cargo tank/hold and after bulkhead in fore cargo tank/hold, the sum of thickness at 0.5 D of ship's sides and longitudinal bulkheads is normally not to be less than:

$$\Sigma t = \frac{2.7(LB)^{1/3}}{f_1} + \Sigma t_k \quad \text{(mm)}$$

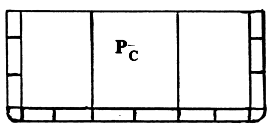
of which the thickness of each longitudinal bulkhead at 0.5 D shall not be less than:

$$t = \frac{0.6\,(LB)^{1/3}}{f_1} + t_k \quad \text{(mm)}$$

Above 0.5 D the thickness of the longitudinal bulkhead plating may be linearly reduced to 90% at deck.

Outside the region between fore bulkhead in after cargo tank and after bulkhead in fore cargo tank, the sum of thicknesses of ship's sides and longitudinal bulkheads can be varied linearly to give the shear area required by 104 at fore end of machinery spaces and after end of fore peak or adjacent deep tank.

302 The thickness of the double side and the longitudinal bulkhead shall not be less than given by the formula in 103. Above 0.5 D the thickness of the plating may be linearly reduced to 90% at deck.

	Load in double bottom in centre tank to be included in P_C

When $Q_S = Q_{SL}$ the shear force correction due to load distribution is given by:

— for the double side:

$$\Delta Q_{SL} = 0.5 P_C \left[\left(1 - \frac{s}{l_c}\right)(1 - C_T)\,\frac{r}{r+1} - 2\Phi_S\right] \quad \text{(kN)}$$

— for the longitudinal bulkhead:

$$\Delta Q_{SL} = 0.5\,P_C\left[\left(1-\frac{s}{l_c}\right)\frac{(1-C_T)}{r+1}-2\Phi_L\right] \quad \text{(kN)}$$

C_T = fraction of the centre tank load going through longitudinal girders directly to the transverse bulkhead found by a direct calculation. A value of NL/(NL+NB) may otherwise be used
P_C = resulting force in kN due to difference between tank contents and buoyancy along the centre tank length l_c. P_C is always to be taken positive. If the loading P_C is variable along the length, the P_C term shall be calculated specially for each part loading
l_c = distance in m between oiltight transverse bulkheads in the centre tank
l = distance in m between oiltight transverse bulkheads in the side tank
s = distance in m between floors in the centre tank
NL = number of longitudinal girders in centre tank
NB = number of transverse floors in centre tank
Φ_S = as given in 103
Φ_L = as given in 103.

r expresses the ratio between the part of loading from the wash bulkheads and the transverses in the centre tank which is carried to the ship's side, and the part which remains in the longitudinal bulkhead. For preliminary calculations, r may be taken as 0.5.

r may be derived from the following formula:

$$r = \frac{1}{\dfrac{A_L}{A_S}+\dfrac{2(N_s+1)bA_L}{l(N_sA_T+R)}}$$

b = mean span of transverses in the side tank in m (including length of brackets)
A_T = shear area of a transverse wash bulkhead in the side tank in cm^2, taken as the smallest area in a vertical section
N_S = number of wash bulkheads in the side tank along the length l.

R is an expression for the total efficiency of the girder frames in the side tank, given by the formula:

$$R = \left(\frac{n}{2}-1\right)\frac{A_R}{\gamma} \qquad (cm^2)$$

n = number of girder frames along the tank length l
A_R = shear area in cm^2 of a transverse girder frame in the side tank, taken as the sum of the shear areas of transverses and cross ties

$$\gamma = 1+\frac{300b^2A_R}{I_R}$$

I_R = moment of inertia in cm^4 of a transverse girder frame in the side tank, taken as the sum of the moment of inertia of transverses and cross ties.

Plus or minus sign before the ΔQ_S-term in the expressions for plate thickness depends on whether inclination of the shear force curve increases or decreases due to the loading in the centre tank. For the longitudinal bulkheads this relation is indicated in Table D2.

Table D2 Shear force correction for longitudinal bulkhead

The ship has over the length:	*The centre tank has over the length:*	*Inclination of the shear force curve:*
excess in buoyancy	excess in buoyancy	increases
excess in buoyancy	excess in weight	decreases
excess in weight	excess in weight	increases
excess in weight	excess in buoyancy	decreases

For the side shell the change in inclination is contrary to that given in Table D2.

At the middle point of l the shear force curve is supposed to remain unchanged.

If the turning of the shear force curve leads to an increased shear force, plus sign shall be used, otherwise minus sign. An example where the slope increases for the longitudinal bulkhead and decreases for the side shell, is shown in Fig.9.

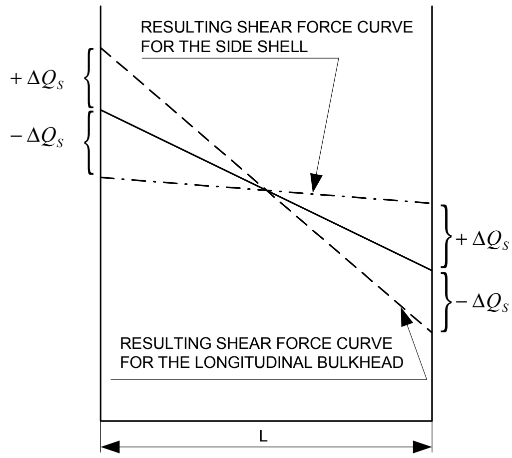


Fig. 9
Shear force correction

D 400 Ships with number of effective longitudinal bulkheads different from two

401 The sum of thicknesses at 0.5 D of ship's sides and longitudinal bulkhead(s) shall not be less than:

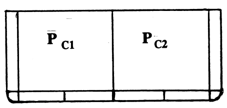
$$\Sigma t = \frac{2.6\,(LB)^{1/3}}{f_1}(0.8 + 0.1n) + \Sigma t_k \quad \text{(mm)}$$

n = number of longitudinal bulkheads.

Above 0.5 D the thickness of the longitudinal bulkhead plating may be linearly reduced to 90% at deck.

The requirement applies to the region between fore bulkhead in after cargo tank and after bulkhead in fore cargo tank. Outside this region, the sum of thicknesses may be varied linearly to give the shear area required by 103 at fore end of machinery spaces and after end of fore peak or adjacent deep tank.

402 For ships with double sides and a centre line bulkhead the thickness of centre line bulkhead and the double side shall not be less than given by the formula in 103. Above 0.5 D the thickness of the plating may be linearly reduced to 90% at deck.

	$P_C = P_{C1} + P_{C2}$ Load in the double bottom below the centre tanks to be included in P_C

When $Q_S = Q_{SL}$, the shear force correction due to load distribution is given by:

— for the double side:

$$\Delta Q_{SL} = P_C\left(0.3\left(1 - \frac{s}{l_c}\right)(1 - C_T) - \Phi_S\right) \quad \text{(kN)}$$

— for the centre line bulkhead:

$$\Delta Q_{SL} = P_C\left(0.4\left(1 - \frac{s}{l_c}\right)(1 - C_T) - \Phi_C\right) \quad \text{(kN)}$$

P_C = resulting force in kN due to difference between tank contents and buoyancy along the centre tank length l_c. P_C is always to be taken positive. If the loading P_C is variable along the length, the P_C term shall be calculated specially for each part loading

C_T = fraction of the centre tank load going through the side girders to the transverse bulkhead found by a direct calculation

A value of NL/(NL+NB) may otherwise be used.

l_c = distance in m between oiltight transverse bulkheads in the centre tank

s = distance in m between floors in the centre tank

NL = number of longitudinal girders in one centre tank

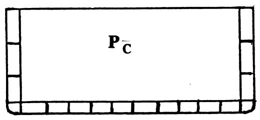
NB = number of transverse floors in the centre tank

Φ_S = as given in 103
Φ_C = as given in 103.

Plus or minus sign before the ΔQ_S -term in the expression for plate thickness depends on whether the expression in the ( ) after P_C in the formula above is a +value or a -value. A +value gives increased inclination of the shear force curve and hence an increased shear force in the end of the tank where the shear force is highest.

403 For ships with double sides and no longitudinal bulkheads the thickness of the double side shall not be less than given by the formula in 103.

Above 0.5 D the thickness of the double side plating may be linearly reduced to 90% at deck.

	Load in double bottom below centre tank to be included in P_C

When $Q_S = Q_{SL}$, the shear force correction due to load distribution is given by:

— for the double side:

$$\Delta Q_{SL} = C_T \, P_C \quad \text{(kN)}$$

P_C = resulting force in kN due to difference between tank contents and buoyancy along the centre tank length l_c. P_C is always to be taken positive. If the loading P_C is variable along the length, the term P_C shall be calculated specially for each part loading
C_T = fraction of the centre tank load going to the transverse bulkhead found by a direct calculation. A value of $0.5\, b/(b + l_c)$ may otherwise be used
b = breadth in m of the inner bottom between the inner sides
l_c = distance in m between oiltight transverse bulkheads in the centre tank
s = distance in m between floors in the centre tank

The shear force correction ΔQ_S for the ship side may be taken according to the principles outlined in Fig.8, always giving a decreased inclination of the shear force curve.

D 500 Strengthening in way of transverse stringers

501 The local thickness of ship's sides and longitudinal bulkheads supporting stringers on transverse bulkheads shall not be less than:

$$t = \frac{P_{STR}}{240\, f_1\, b_{str}} + 0.75\, t_r \quad \text{(mm)}$$

P_{STR} = stringer supporting force in kN based on design loads in accordance with Sec.4. At longitudinal bulkheads P_{STR} shall be taken as the sum of forces at each side of the bulkhead when acting simultaneously in the same direction
b_{str} = largest depth of stringer in m at support, brackets included
t_r = rule thickness in accordance with 103, with full value of Q_W.

The strengthened area shall extend not less than 0.5 m forward and aft of the stringer including brackets, and not less than 0.2 b_{str} above and below the stringer.

E. Openings in longitudinal strength members

E 100 Positions

101 The keel plate is normally not to have openings. In the bilge plate, within 0.6 L amidships, openings shall be avoided as far as practicable. Any necessary openings in the bilge plate shall be kept clear of the bilge keel.

102 Openings in strength deck within 0.6 L amidships (for «open» ships within cargo hold region) are as far as practicable to be located inside the line of large hatch openings. Necessary openings outside this line shall be kept well clear of ship's side and hatch corners. Openings in lower decks shall be kept clear of main hatch corners and other areas with high stresses.

103 Openings in side shell, longitudinal bulkheads and longitudinal girders shall be located not less than twice the opening breadth below strength deck or termination of rounded deck corner.

104 Small openings are generally to be kept well clear of other openings in longitudinal strength members.

Edges of small unreinforced openings shall be located a transverse distance not less than four times the opening breadth from the edge of any other opening.

E 200 Deduction-free openings

201 When calculating the midship section modulus openings exceeding 2.5 m in length or 1.2 m in breadth and scallops, where scallop welding is applied, shall be deducted from the sectional areas of longitudinal members.

202 Smaller openings (manholes, lightening holes, single scallops in way of seams etc.) need not to be deducted provided that the sum of their breadths or shadow area breadths in one transverse section does not reduce the section modulus at deck or bottom by more than 3% and provided that the height of lightening holes, draining holes and single scallops in longitudinals or longitudinal girders does not exceed 25% of the web depth, for scallops maximum 75 mm.

203 A deduction-free sum of smaller openings breadths in one transverse section in the bottom or deck area equal to

$$0.06\ (B - \Sigma\ b)$$

may be considered equivalent to the above reduction in section modulus.

B = breadth of ship
Σ b = sum of breadths of large openings.

204 When calculating deduction-free openings, the openings are assumed to have longitudinal extensions as shown by the shaded areas in Fig.10, i.e. inside tangents at an angle of 30° to each other.

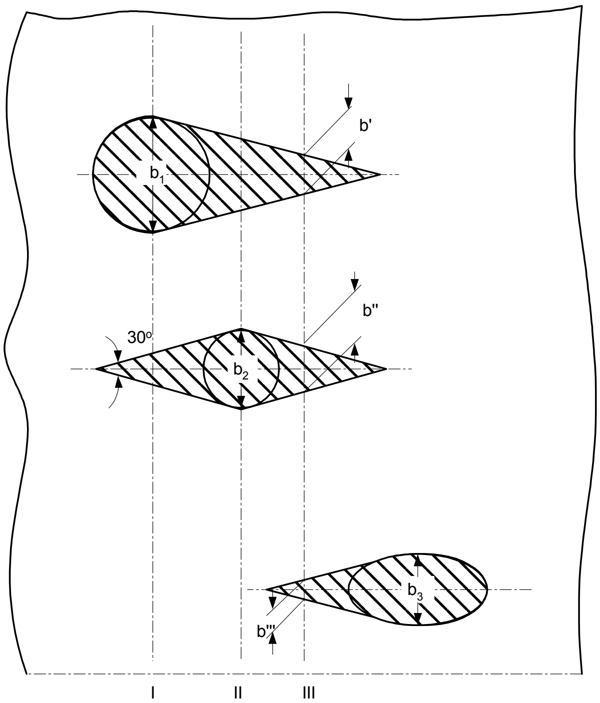


Fig. 10
Deduction-free openings

Example for transverse section III:

$$\Sigma\ b_{III} = b^{I} + b^{II} + b^{III}$$

205 It is assumed that the deduction-free openings are arranged approximately symmetric about the ship's centre line, and that the openings do not cut any longitudinal or girder included in the midship section area. Openings in longitudinals are normally to be of elliptical shape or equivalent design and are normally to be kept clear of the connecting weld. When flush openings are necessary for drainage purposes, the weld connections shall end in soft toes.

E 300 Compensations

301 Compensation for not deduction-free openings may be provided by increased sectional area of longitudinals or girders, or other suitable structure. The area of any reinforcement as required in 400 shall not be included in the sectional area of the compensation.

E 400 Reinforcement and shape of smaller openings

401 In strength deck and outer bottom within 0.6 L amidships (for «open» ships within the total cargo hold region), circular openings with diameter equal to or greater than 0.325 m shall have edge reinforcement. The cross-sectional area of edge reinforcements shall not be less than:

$$2.5\ b\ t \quad (\text{cm}^2)$$

b = diameter of opening in m
t = plating thickness in mm.

The reinforcement is normally to be a vertical ring welded to the plate edge. Alternative arrangements may be accepted but the distance from plating edge to reinforcement is in no case to exceed 0.05 b.

402 In areas specified in 401 elliptical openings with breadth greater than 0.5 m shall have edge reinforcement if their length/breadth ratio is less than 2. The reinforcement shall be as required in 401 for circular openings, taking b as the breadth of the opening.

403 In areas specified in 401 rectangular and approximately rectangular openings shall have a breadth not less than 0.4 m. For corners of circular shape the radius shall not be less than:

$$R = 0.2\ b$$

b = breadth of opening.

The edges of such rectangular openings shall be reinforced as required in 401.

For corners of streamlined shape, as given by Fig.11 and Table E1, the transverse extension of the curvature shall not be less than:

$$a = 0.15\ b \quad (\text{m})$$

Edge reinforcement will then generally not be required. For large hatch openings, see 500.

404 Openings in side shell in areas subjected to large shear stresses shall be of circular shape and shall have edge reinforcement as given in 401 irrespective of size of opening.

E 500 Hatchway corners

501 For corners with rounded shape, the radius is within 0.6 L amidships generally not to be less than:

$$r = 0.03\left(1.5 + \frac{l}{b}\right)(B - b) \quad (\text{m})$$

b = breadth of hatchway in m
l = longitudinal distance in m between adjacent hatchways.

$\frac{l}{b}$ need not be taken greater than 1.0.

(B – b) shall not be taken less than 7.5 m, and need not be taken greater than 15 m.

For local reinforcement of deck plating at circular corners, see Sec.8 A405.

When a corner with double curvature is adopted, further reduction in radius will be considered.

For corners of streamlined shape, as given by Fig.11 and Table E1, the transverse extension of the curvature shall not be less than:

$$a = 0.025\left(1.5 + \frac{l}{b}\right)(B - b) \quad (\text{m})$$

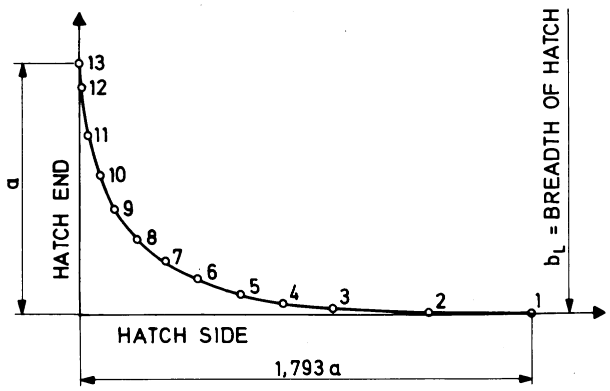


Fig. 11
Streamlined deck corner

Table E1 Ordinates of streamlined corner		
Point	*Abscissa x*	*Ordinate y*
1	1.793 a	0
2	1.381 a	0.002 a
3	0.987 a	0.021 a
4	0.802 a	0.044 a
5	0.631 a	0.079 a
6	0.467 a	0.131 a
7	0.339 a	0.201 a
8	0.224 a	0.293 a
9	0.132 a	0.408 a
10	0.065 a	0.548 a
11	0.022 a	0.712 a
12	0.002 a	0.899 a
13	0	1.000 a

502 Alternative hatch corner designs (e.g. key hole) may be accepted subject to special consideration in each case.

E 600 Miscellaneous

601 Edges of openings shall be smooth. Machine flame cut openings with smooth edges may be accepted. Small holes shall be drilled.

Hatch corners may in special cases be required to be ground smooth. Welds to the deck plating within the curved hatch corner region are as far as possible to be avoided.

602 Studs for securing small hatch covers shall be fastened to the top of a coaming or a ring of suitable thickness welded to the deck. The studs shall not penetrate the deck plating.

603 The design of the hatch corners will be specially considered for ships with very large hatch openings («open» ships), where additional local stresses occur in the hatch corner area due to torsional warping effects and transverse bulkhead reactions.

F. Loading guidance information

F 100 General

101 All ships covered by Reg. 10 of the International Convention on Load Lines shall be provided with an approved loading manual.

The requirements given in this subsection are considered to fulfil Reg. 10(1) of the International Convention on Load Lines for all classed ships of 65 m in length and above. However, a loading manual, considering longitudinal strength, is not required for a category II ship with length less that 90 m where the maximum dead-weight does not exceed 30% of the maximum displacement.

102 If a loading computer system is installed onboard a ship, the system shall be approved in accordance with requirements in Pt.6 Ch.9.

103 All ships of category I (see A202) are in addition to the loading manual to be provided with a loading computer system approved and certified for calculation and control of hull strength in accordance with the requirements given in Pt.6 Ch.9.

F 200 Conditions of approval of loading manuals

201 The approved loading manual shall be based on the final data of the ship. The loading manual should contain the design loading and ballast conditions, subdivided into departure and arrival conditions, and ballast exchange at sea conditions, where applicable, upon which the approval of hull scantlings is based, see B100. Possible specifications are:

— draught limitations (in ballast etc.)
— load specifications for cargo decks
— cargo mass- and cargo angle of repose restrictions
— cargo density- and filling heights for cargo tanks
— restrictions to GM-value.

(IACS UR S1, Annex 1 to requirements Rev.5)

202 The loading manual must be prepared in a language understood by the users. If this language is not English a translation into English shall be included.

203 In case of modifications resulting in changes to the main data of the ship, a new approved loading manual shall be issued.

F 300 Condition of approval of loading computer systems

301 With respect to the approval of the loading computer system, see Pt.6 Ch.9.

SECTION 6 BOTTOM STRUCTURES

A. General

A 100 Introduction

101 The requirements in this section apply to bottom structures.

102 The formulae given for plating, stiffeners and girders are based on the structural design principles outlined in Sec.3 B. In most cases, however, fixed values have been assumed for some variable parameters such as:

— aspect ratio correction factor for plating
— bending moment factor m for stiffeners and girders.

Where relevant, actual values for these parameters may be chosen and inserted in the formulae.

Direct stress calculations based on said structural design principles and as outlined in Sec.12 will be considered as alternative basis for the scantlings.

A 200 Definitions

201 Symbols:

L = rule length in m [1)]
B = rule breadth in m [1)]
D = rule depth in m [1)]
T = rule draught in m [1)]
C_B = rule block coefficient [1)]
V = maximum service speed in knots on draught T
L_1 = L but need not be taken greater than 300 m
t = rule thickness in mm of plating
Z = rule section modulus in cm^3 of stiffeners and simple girders
k_a = correction factor for aspect ratio of plate field
= $(1.1 - 0.25\ s/l)^2$
= maximum 1.0 for $s/l = 0.4$
= minimum 0.72 for $s/l = 1.0$
s = stiffener spacing in m, measured along the plating
l = stiffener span in m, measured along the topflange of the member. For definition of span point, see Sec.3 C100. For curved stiffeners l may be taken as the cord length
w_k = section modulus corrosion factor in tanks, see Sec.3 C1004
= 1.0 in other compartments
σ = nominal allowable bending stress in N/mm^2 due to lateral pressure
p = design pressure in kN/m^2 as given in B
f_1 = material factor [2)]
= 1.0 for NV-NS steel [2)]
= 1.08 for NV-27 steel [2)]
= 1.28 for NV-32 steel [2)]
= 1.39 for NV-36 steel [2)]
= 1.47 for NV-40 steel [2)]
f_{2b} = stress factor below the neutral axis of the hull girder depending on surplus in midship section modulus and maximum value of the actual still water bending moments:

$$f_{2b} = \frac{5.7(M_S + M_W)}{Z_B}$$

Z_B = midship section modulus in cm^3 at bottom as built
M_S = normally to be taken as the largest design still water bending moment in kNm. M_S shall not be taken less than 0.5 M_{SO}. When actual design moment is not known, M_s may be taken equal to M_{SO}
M_{SO} = design still water bending moment in kNm given in Sec.5 B
M_W = rule wave bending moment in kNm given in Sec.5 B. Hogging or sagging moment to be chosen in relation to the applied still water moment.

1) For details see Sec.1 B.

2) For details see Sec.2 B to C.

Guidance note:

In special cases a more detailed evaluation of the actual still water moment M_S to be used may be allowed. The simultaneous occurring of a certain local load on a structure and the largest possible -value in the same area of the hull girder may be used as basis for estimating f_{2B}.

Example: Inner bottom longitudinal in a loaded hold of a bulk carrier with **BC-A**-notation. Local load from Table B1: P_4. M_S may be taken as maximum hogging still water moment in particular hold for **BC-A**-condition (maximum local stress in compression at longitudinal flange in middle of hold). M_S/M_{SO} in no case to be taken less than 0.5.

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

A 300 Structural arrangement and details

301 The engine room is normally to have a double bottom.

302 Double bottoms within the cargo region are normally to be longitudinally stiffened in ships with length L > 150 m

303 Single bottoms within the cargo region are normally to be longitudinally stiffened.

304 When the bottom or inner bottom is longitudinally stiffened:

— the longitudinals shall be continuous through transverse members within 0.5 L amidships in ships with length L > 150 m
— the longitudinals may be cut at transverse members within 0.5 L amidships in ships with length 50 m < L < 150 m. In that case continuous brackets connecting the ends of the longitudinals shall be fitted.
— the longitudinals may be welded against the floors in ships with length L < 50 m, and in larger ships outside 0.5 L amidships.

305 Manholes shall be cut in the inner bottom, floors and longitudinal girders to provide access to all parts of the double bottom. The vertical extension of lightening holes shall not exceed one half of the girder height. The edges of the manholes shall be smooth. Manholes in the inner bottom plating shall have reinforcement rings.

Manholes are normally not to be cut in floors or girders under large pillars or stool structures.

Manhole covers in the inner bottom plating in cargo holds shall be effectively protected.

The diameter of the lightening holes in the bracket floors shall not be greater than 1/3 of the breadth of the brackets.

306 To ensure the escape of air and water from each frame space to the air pipes and suctions, holes shall be cut in the floors and longitudinal girders. The air holes shall be placed as near to the inner bottom as possible.

The drain holes shall be placed as near to the bottom as possible. The total area of the air holes shall be greater than the area of the filling pipes.

307 The access opening to pipe tunnel shall be visible above the floor plates and shall be fitted with a rigid, watertight closure.

A notice plate shall be fitted stating that the access opening to the pipe tunnel shall be kept closed. The opening shall be regarded as an opening in watertight bulkhead.

308 The bilge keel and the flat bar to which it is attached, shall not terminate abruptly. Ends shall be tapered, and internal stiffening shall be provided. Butts in the bilge keel and the flat bar shall be well clear of each other and of butts in the shell plating. The flat bar shall be of the same material strength as the bilge strake to which it is attached and of the material class according to Sec.2 as a bilge strake. The bilge keel shall be of the same material strength as the bilge strake to which it is attached.

309 Weld connections shall satisfy the general requirements given in Sec.11.

310 For end connections of stiffeners and girders, see Sec.3 C.

A 400 Bottom arrangement

401 For passenger vessels and cargo ships other than tankers a double bottom shall be fitted, extending from the collision bulkhead to the afterpeak bulkhead, as far as is practicable and compatible with the design and proper working of the ship.

402 The depth of the double bottom is given in D100. The inner bottom shall be continued out to the ship's side in such a manner as to protect the bottom to the turn of the bilge.

403 Small wells constructed in the double bottom, in connection with the drainage arrangements of holds, shall not extend in depth more than necessary. In no case shall the vertical distance from the bottom of such a well to a plane coinciding with the keel line be less than 500 mm. Other wells (e.g. for lubricating oil under main engines) may be permitted if the arrangement gives protection equivalent to that afforded by a double bottom complying with this regulation.

404 A double bottom need not be fitted in way of watertight compartments used exclusively for the carriage of liquids, provided the safety of the ship in the event of a bottom damage is not thereby impaired.

For oil tankers, see Pt.5 Ch.3 Sec.3, for chemical carriers, see Pt.5 Ch.4 Sec.3, and for liquefied gas carriers, see Pt.5 Ch.5 Sec.3.

(SOLAS CH.II-1).

405 Any part of the ship that is not fitted with a double bottom in accordance with 401 to 404 shall be capable of withstanding bottom damages. Ref.SOLAS Reg.II-1/9.8.

Guidance note:

Bottom arrangements regulated under SOLAS Convention that are not in compliance with Reg.II-1/9 are subject to acceptance by the Administration.

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

406 Subject to agreement with the Society, the requirements in 401 to 405 may be specially considered for vessels not regulated under the SOLAS convention.

B. Design loads

B 100 Local loads on bottom structures

101 All generally applicable local loads on bottom structures are given in Table B1, based upon the general loads given in Sec.4. In connection with the various local structures, reference is made to this table, indicating the relevant loads in each case.

B 200 Total loads on double bottom

201 In connection with direct stress calculations on double bottom structures, total loads shall be taken as differences between internal and external pressures.

These loads are specified in Sec.12.

Table B1 Design loads

Structure	*Load type*	*p (kN/m²)*
Outer bottom	Sea pressure	$p_1 = 10\ h_0 + p_{dp}$ (kN/m²) 1)
	Net pressure in way of cargo tank or deep tank	$p_2 = \rho\,(g_0 + 0.5\ a_v)\ h_s - 10\ T_M$ $p_3 = \rho\ g_0\ h_s + p_0 - 10\ T_M$
Inner bottom	Dry cargo in cargo holds	$p_4 = \rho\,(g_0 + 0.5\ a_v)\ H_C$
	Ballast in cargo holds	$p_5 = (10 + 0.5a_v)h_s$ $p_6 = 6.7(h_s + \phi b) - 1.2\sqrt{H\,\phi b_t}$ 2) $p_7 = 0.67(10h_p + \Delta p_{dyn})$ $p_8 = 10h_s + p_0$
	Liquid cargo in tank above	$p_9 = \rho\,(g_0 + 0.5a_v)\ h_s$ $p_{10} = \rho g_0 [0.67(h_s + \phi b) - 0.12\sqrt{H\,\phi b_t}]$ 2) $p_{11} = 0.67(10h_p + \Delta p_{dyn})$ $p_{12} = \rho g_0 h_s + p_0$
Inner bottom, floors and girders	Pressure on tank boundaries in double bottom	$p_{13} = 0.67\ (10\ h_p + \Delta\ p_{dyn})$ $p_{14} = \rho\ g_0 h_s + p_0$
	Flooded condition	$p_{15} = 10h_b$

1) For ships with service restrictions the last term in p_1 may be reduced by the percentages given in Sec.4 B202.
2) p_6 and p_{10} to be used in tanks/holds with largest breadth > 0.4 B.

T_M = minimum design draught in m amidships, normally taken as 0.35 T for dry cargo vessels and 2 + 0.02 L for tankers
p_{dp} = as given in Sec.4 C201
y = horizontal distance in m from Ship's centre line to point considered, minimum B/4

C_W = wave coefficient as given in Sec.4 B200
a_v = vertical acceleration as given in Sec.4 B600
ϕ = roll angle in radians as given in Sec.4 B400
h_0 = vertical distance from the waterline at draught T to the load point (m)
h_s = vertical distance in m from load point to top of tank
h_p = vertical distance in m from the load point to the top of air pipe
h_b = vertical distance in metres from the load point to the deepest equilibrium waterline in damaged condition obtained from applicable damage stability calculations. The deepest equilibrium waterline in damaged condition should be indicated on the drawing of the bulkhead in question. The vertical distance shall not be less than up to the bulkhead deck
H = height in m of tank
H_C = stowage height in m of dry cargo. Normally the height to 'tween deck or top of cargo hatchway to be used in combination with a standard cargo density $\rho_c = 0.7$ t/m^3
ρ_c = dry cargo density in t/m^3, if not otherwise specified to be taken as 0.7
ρ = density of liquid cargo in t/m, normally not to be taken less than 1.025 t/m^2 (i.e. $\rho\, g_0 \approx 10$)
b = the largest athwartship distance in m from the load point to the corner at top of the tank/hold most distant from the load point
b_t = breadth in m of top of tank/hold
p_0 = 25 in general
= 15 in ballast hold of dry cargo vessels
= pressure valve opening pressure when exceeding the general value.
Δp_{dyn} = as given in Sec.4 C300.

C. Plating and stiffeners

C 100 General

101 In this sub-section requirements to laterally loaded plating and stiffeners are given, and in addition the scantlings and stiffening of double bottom floors and girders. For single bottom and peak tank girders, see F and G.

C 200 Keel plate

201 A keel plate shall extend over the complete length of the ship. The breadth shall not be less than:

$$b = 800 + 5\,L \quad \text{(mm)}.$$

202 The thickness shall not be less than:

$$t = 7.0 + \frac{0.05 L_1}{\sqrt{f_1}} + t_k \quad \text{(mm)}$$

The thickness is in no case to be less than that of the adjacent bottom plate.

C 300 Bottom and bilge plating

301 The breadth of strakes in way of longitudinal bulkhead and bilge strake, which shall be of steel grade higher than A-grade according to Ch.1 Sec.2, shall not be less than:

$$b = 800 + 5\,L \quad \text{(mm)}.$$

302 The thickness requirement corresponding to lateral pressure is given by:

$$t = \frac{15.8 k_a s \sqrt{p}}{\sqrt{\sigma}} + t_k \quad \text{(mm)}$$

p = p_1 to p_3 (when relevant) in Table B1
σ = $175 f_1 - 120 f_{2b}$, maximum $120 f_1$ when transverse frames, within 0.4 L
= $120 f_1$ when longitudinals, within 0.4 L
= $160 f_1$ within 0.1 L from the perpendiculars.

Between specified regions the σ-value may be varied linearly.

f_{2b} = stress factor as given in A 200

303 The longitudinal and combined buckling strength shall be checked according to Sec.13.

304 The thickness shall not be less than:

$$t = 5.0 + \frac{0.04 L_1}{\sqrt{f_1}} + t_k \quad \text{(mm)}$$

305 Between the midship region and the end regions there shall be a gradual transition in plate thickness.

306 The thickness of the bilge plate shall not be less than that of the adjacent bottom and side plates, whichever is the greater.

307 If the bilge plate is not stiffened, or has only one stiffener inside the curved part, the thickness shall not be less than:

$$t = \frac{\sqrt[3]{R^2 l p}}{900} + t_k$$

R = radius of curvature (mm)
l = distance between circumferential stiffeners, i.e. bilge brackets (mm)
p = $10 (h_0 + B \phi/2 + 0.088 C_B (B/2 + 0.8 C_W))$ (kN/m^2)
 = $2 p_1 - 10 h_0$ (minimum)
ϕ = roll angle in radians as given in Sec.4 B400.
C_W = wave coefficient as given in Sec.4 B200.

In case of longitudinal stiffening positioned outside the curvature, R is substituted by:

$$R_1 = R + 0.5 (a + b)$$

See Fig.1.

The lengths a and b are normally not to be greater than s/3.

C 400 Inner bottom plating

401 The thickness requirement corresponding to lateral pressure is given by:

$$t = \frac{15.8 k_a s \sqrt{p}}{\sqrt{\sigma}} + t_k \quad \text{(mm)}$$

p = p_4 to p_{15} (whichever is relevant) as given in Table B1
σ = $200 f_1 - 110 f_{2b}$, maximum $140 f_1$ when transverse frames, within 0.4 L
 = $140 f_1$ when longitudinals, within 0.4 L
 = $160 f_1$ within 0.1 L from the perpendiculars
 = $220 f_1$ for flooded condition.

Between specified regions the σ-value may be varied linearly.

f_{2b} = stress factor as given in A200.

402 The thickness shall not be less than:

$$t = t_0 + \frac{0.03 L_1}{\sqrt{f_1}} + t_k \quad \text{(mm)}$$

t_0 = 7.0 in holds below dry cargo hatchway opening if ceiling is not fitted.
 = 6.0 elsewhere in holds if ceiling is not fitted
 = 5.0 in general if ceiling is fitted.
 = 5.0 in void spaces, machinery spaces and tanks.

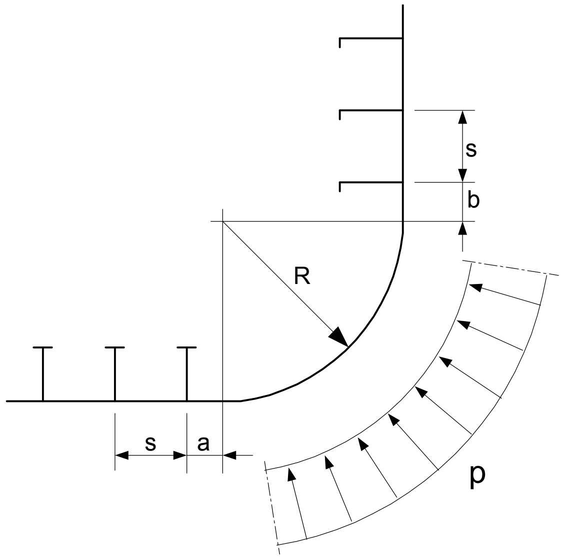


Fig. 1
Bilge without longitudinal stiffening

403 The longitudinal and combined buckling strength shall be checked according to Sec.13.

C 500 Plating in double bottom floors and longitudinal girders

501 The thickness requirement of floors and longitudinal girders forming boundaries of double bottom tanks is given by:

$$t = \frac{15.8\, k_a s \sqrt{p}}{\sqrt{\sigma}} + t_k \quad \text{(mm)}$$

p = p_{13} to p_{15} (when relevant) as given in Table B1
p = p_1 for sea chest boundaries (including top and partial bulkheads)
σ = allowable stress, for longitudinal girders within 0.4 L given by:

Transversely stiffened	*Longitudinally stiffened*
190 f_1 – 120 $f_{2b,}$ maximum 130 f_1	130 f_1

σ = 160 f_1 within 0.1 L from the perpendiculars and for floors in general
= 120 f_1 for sea chest boundaries (including top and partial bulkheads)
= 220 f_1 for flooded condition
f_{2b} = stress factor as given in A200.

Between specified regions of longitudinal girders the σ-value may be varied linearly.

502 The thickness of longitudinal girders, floors, supporting plates and brackets shall not be less than:

$$t = 6.0 + \frac{k}{\sqrt{f_1}} + t_k \quad \text{(mm)}$$

k = 0.04 L_1 for centre girder up to 2 m above keel plate
= 0.02 L_1 for other girders and remaining part of centre girder
= 0.05 L_1 for sea chest boundaries (including top and partial bulkheads).

503 The buckling strength of girders shall be checked according to Sec.13.

C 600 Transverse frames

601 The section modulus requirement of bottom and inner bottom frames is given by:

$$Z = \frac{0.63\, l^2 s\, p\, w_k}{f_1} \quad (\text{cm}^3)$$

p = p_1 to p_{15} (when relevant) as given in Table B1.

602 Struts fitted between bottom and inner bottom frames are in general not to be considered as effective supports for the frames.

The requirements given in 601, however, may be reduced after special consideration. When bottom and inner bottom frames have the same scantlings, a Z-reduction of 35% will be accepted if strut at middle length of span.

603 The thickness of web and flange shall not be less than the larger of:

$t = 4.5 + k + t_k$ (mm)

$= 1.5 + \frac{h_w \sqrt{f_1}}{g} + t_k$

$k = 0.015\ L_1$
$= 5.0$ maximum
$h_w =$ web height in mm
$g = 75$ for flanged profile webs
$= 41$ for bulb profiles
$= 22$ for flat bar profiles.

C 700 Bottom longitudinals

701 The section modulus requirement is given by:

$$Z = \frac{83\, l^2\, s\, p\, w_k}{\sigma} \quad (\text{cm}^3)$$

$p = p_1$ to p_3 (when relevant) as given in Table B1
$\sigma =$ allowable stress (maximum 160 f_1) given by:

— within 0.4 L:

Single bottom	*Double bottom*
$225\ f_1 - 130\ f_{2b}$	$225\ f_1 - 130\ f_{2b} - 0.7\ \sigma_{db}$

For bilge longitudinals the allowable stress σ shall be taken as $225\ f_1 - 130\ f_2\ (z_n - z_a)/z_n$, where z_n, z_a are taken as defined in Sec.7 A201.

— within 0.1 L from perpendiculars: $\sigma = 160\ f_1$

Between specified regions the σ- value may be varied linearly.

$\sigma_{db} =$ mean double bottom stress at plate flanges, normally not to be taken less than:
$= 20\ f_1$ for cargo holds in general cargo vessels
$= 50\ f_1$ for holds for ballast
$= 85\ f_1\ b/B$ for tanks for liquid cargo
$f_{2b} =$ stress factor as given in A200
$b =$ breadth of tank at double bottom.

Longitudinals connected to vertical girders on transverse bulkheads shall be checked by a direct stress analysis, see Sec.12 C.

702 The buckling strength of longitudinals shall be checked according to Sec.13.

703 The thickness of web and flange shall not be less than the larger of:

$t = 4.5 + k + t_k$ (mm)

$= 1.5 + \frac{h_w \sqrt{f_1}}{g} + t_k$

$k = 0.015\ L_1$
$= 5.0$ maximum
$h_w =$ web height in mm
$g = 75$ for flanged profile webs
$= 41$ for bulb profiles
$= 22$ for flat bar profiles.

704 Struts fitted between bottom and inner bottom longitudinals are in general not to be considered as effective supports for the longitudinals. The requirements given in 701, however, may be reduced after special consideration. When bottom and inner bottom longitudinals have the same scantlings, a Z-reduction of 35% will be accepted if strut at middle length of span.

705 A longitudinal shall be fitted at the bottom where the curvature of the bilge plate starts.

C 800 Inner bottom longitudinals

801 The section modulus requirement is given by:

$$Z = \frac{83\, l^2 s\, p\, w_k}{\sigma} \quad (cm^3)$$

p = p_4 to p_{15} (whichever is relevant) as given in Table B1
σ = $225 f_1 - 100 f_{2B} - 0.7\, \sigma_{db}$ within 0.4 L (maximum 160 f_1)
= 160 f_1 within 0.1 L from the perpendiculars
= 220 f_1 for flooded condition.

Between specified regions the σ-value may be varied linearly.

σ_{db} = mean double bottom stress at plate flanges, normally not to be taken less than:
= 20 f_1 for cargo holds in general cargo vessels
= 50 f_1 for holds for ballast
= 85 f_1 b/B for tanks for liquid cargo
f_{2b} = stress factor as given in A200
b = breadth of tank at double bottom.

802 The thickness of web and flange shall not be less than the larger of:

$$t = 4.5 + k + t_k \quad (mm)$$

$$= 1.5 + \frac{h_w \sqrt{f_1}}{g} + t_k$$

k = 0.015 L_1
= 5.0 maximum
h_w = web height in mm
g = 75 for flanged profile webs
= 41 for bulb profiles
= 22 for flat bar profiles.

803 Struts fitted between bottom and inner bottom longitudinals are in general not to be considered as effective supports for the longitudinals. The requirements given in 801, however, may be reduced after special consideration. When bottom and inner bottom longitudinals have the same scantlings, a Z-reduction of 35% will be accepted if strut at middle length of span.

804 The buckling strength shall be checked according to Sec.13.

C 900 Stiffening of double bottom floors and girders

901 The section modulus requirement of stiffeners on floors and longitudinal girders forming boundary of double bottom tanks is in general given by:

$$Z = \frac{100\, l^2 s\, p\, w_k}{\sigma} \quad (cm^3)$$

When longitudinally stiffened, the required section modulus is given by:

$$Z = \frac{83\, l^2 s\, p\, w_k}{\sigma} \quad (cm^3)$$

p = p_{13} to p_{15} as given in Table B1
p = p_1 for sea chest boundaries (including top and partial bulkheads)
σ = $225 f_1 - 110 f_{2b}$, maximum 160 f_1 for longitudinal stiffeners within 0.4 L
= 160 f_1 for longitudinal stiffeners within 0.1 L from perpendiculars and for transverse and vertical stiffeners in general.
= 120 f_1 for sea chest boundaries (including top and partial bulkheads).
= 220 f_1 for flooded condition.

Between specified regions of longitudinal stiffeners the σ-value may be varied linearly.

f_{2b} = stress factor as given in A200.

902 Stiffeners in accordance with the requirement in 901 are assumed to have end connections. When Z is increased by 40%, however, stiffeners other than longitudinals may be sniped at ends if the thickness of plating supported by the stiffener is not less than:

$$t = 1.25\sqrt{\frac{(l - 0.5s)\,s\,p}{f_1}} + t_k \quad \text{(mm)}$$

903 The thickness of web and flange shall not be less than given in 603.

904 In double bottoms with transverse stiffening the longitudinal girders shall be stiffened at every transverse frame.

905 The longitudinal girders shall be satisfactorily stiffened against buckling.

906 In double bottoms with longitudinal stiffening the floors shall be stiffened at every longitudinal.

D. Arrangement of double bottom

D 100 General

101 Where a double bottom is required to be fitted the inner bottom shall be continued out to the ship side in such a manner as to protect the bottom to the turn of bilge. Such protection will be deemed satisfactory if the inner bottom is not lower at any part than a plane parallel with the keel line and which is located not less than a vertical distance h measured from the keel line, as calculated by the formula:

$$h = 1000 \cdot B/20 \text{ (mm), minimum 760 mm}$$

The height, h, need not be taken more than 2000 mm.

The height shall be sufficient to give good access to all parts of the double bottom. For ships with a great rise of floors, the minimum height may have to be increased after special consideration.

102 Under the main engine, girders extending from the bottom to the top plate of the engine seating, shall be fitted. The height of the girders shall not be less than that of the floors. If the engine is bolted directly to the inner bottom, the thickness of the plating in way of the engine shall be at least twice the rule thickness of inner bottom plating.

Engine holding-down bolts shall be arranged as near as practicable to floors and longitudinal girders.

Guidance note:

The thickness of the top plate of seatings for main engine and reduction gear should preferably not be less than:

P_S (kW) [1]	t (mm)
≤ 1000	25
$1000 < P_S \le 1750$	30
$1750 < P_S \le 2500$	35
$2500 < P_S \le 3500$	40
$P_S > 3500$	45
1) P_S = maximum continuous output of propulsion machinery.	

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

D 200 Double bottom with transverse framing

201 Side girders shall be fitted so that the distance between the side girders and the centre girder or the margin plate or between the side girders themselves does not exceed 4 metres. In the engine room, side girders are in all cases to be fitted outside the engine seating girders.

202 The floor spacing is normally not to be greater than given in Table D1. In the engine room floors shall be fitted at every frame. In way of thrust bearing and below pillars, additional strengthening shall be provided.

Table D1 Plate floors

Draught in m	*Under deep tanks* [1]	*Clear of deep tanks and machinery space* [2]
T ≤ 2	Every 4th frame	Every 6th frame
2 < T ≤ 5.4	Every 3rd frame	Every 5th frame
5.4 < T ≤ 8.1	Every 3rd frame	Every 4th frame
T > 8.1	Every 2nd frame	Every 3rd frame
1) With height greater than 0.7 times the distance between the inner bottom and the main deck.		
2) The distance between plate floors shall not exceed 3 metres.		

203 Supporting plates for the transverse bottom frames shall be fitted at the centre girder and the margin plate on frames without floors. The breadth shall be at least one frame spacing, and the free edge shall be provided with a flange.

D 300 Double bottom with longitudinals

301 Side girders shall normally be fitted so that the distance between the side girders and the centre girder or the margin plate or between the side girders themselves does not exceed 5 metres. In the engine room, one side girder is in all cases to be fitted outside the engine seating girders.

For double bottom girder systems below cargo holds and tanks, see E100.

302 The floor spacing is normally not to be greater than 3.6 m. In way of deep tanks with height exceeding 0.7 times the distance between the inner bottom and the main deck, the floor spacing is normally not to exceed 2.5 m. In the engine room, floors shall be fitted at every second side frame. Bracket floors shall be fitted at intermediate frames, extending to the first ordinary side girder outside the engine seating. In way of thrust bearing and below pillars additional strengthening shall be provided.

303 Supporting plates shall be fitted at the centre girder. The free edge of the supporting plates shall be provided with flange. The breadth of the supporting plate shall be at least one longitudinal spacing.

The spacing is normally not to exceed two frame spacings. Between supporting plates on the centre girder, docking brackets shall be fitted.

Alternative arrangements of supporting plates and docking brackets require special consideration of local buckling strength of centre girder/duct keel and local strength of docking longitudinal subject to the forces from docking blocks.

E. Double bottom girder system below cargo holds and tanks

E 100 Main scantlings

101 In addition to fulfilling the minimum and local requirements given in C and D, the main scantlings of the girder system below cargo holds and tanks for cargo or ballast are normally to be based on a direct strength analysis as outlined in Sec.12. The distance between floors and side girders given in D200 and D300 may then be modified.

Special attention shall be given to the relative deflection between the transverse bulkhead and the nearest floor.

In dry Cargo ships with homogeneous loading only, the scantlings may be based on the local and minimum requirements in C and D.

F. Single bottom girders

F 100 Main scantlings

101 The main scantlings of single bottom girder system in tanks for liquid cargo and ballast shall be based on a direct stress analysis as outlined in Sec.12. The loads given in B shall be used as basis for such calculations.

F 200 Local scantlings

201 The thickness of web plates, flanges, brackets and stiffeners is generally not to be less than:

$$t = 6.0 + \frac{k L_1}{\sqrt{f_1}} + t_k \quad \text{(mm)}$$

k = 0.04 for centre girder plating up to 2 m above keel plate
= 0.02 for other girders and remaining part of centre girder
= 0.01 for stiffeners on girders.

The thickness of girders is in addition not to be less than:

$$t = 15\,s + t_k \quad \text{(mm)}$$

s = web stiffener spacing in m.

202 The thickness of the web plates is in addition to be checked for buckling according to Sec.13, with respect to in-plane compressive and shear stresses.

203 Girder flanges shall have:

a thickness not less than 1/30 of the flange width when the flange is symmetrical, and not less than 1/15 of the flange width when the flange width is asymmetrical.

204 The end connections and stiffening of single bottom girder systems shall be as given in Sec.3 C.

G. Girders in peaks

G 100 Arrangement

101 Girders in fore and after peaks supporting longitudinals or transverse frames, are normally to have spacing not exceeding 1.8 m. Heavy intersecting girders or bulkheads at distances generally not exceeding the smaller of 0.125 B and 5 m shall support the girders mentioned above.

102 In the after peak of single screw ships, the floors shall be of such a height that their upper edge is well above the sterntube.

G 200 Scantlings

201 The thickness of web plates, brackets and stiffeners is generally not to be less than:

$$t = 5.0 + \frac{k}{\sqrt{f_1}} + t_k \quad \text{(mm)}$$

k = $0.03\ L_1$ for web plates and brackets (maximum 6)
= $0.01\ L_1$ for stiffeners on web plates.

The thickness of girders and floors is in addition not to be less than:

$$t = 12\ s + t_k \quad \text{(mm)}$$

s = stiffener spacing in m.

202 Girder flanges shall have:

- a thickness not less than 1/30 of the flange width when the flange is symmetrical, and not less than 1/15 of the flange width when the flange width is asymmetrical
- a width not less than 1/20 of the distance between tripping brackets.

G 300 Details

301 For end connections and stiffening of girders in general, see Sec.3 C.

302 The height of stiffeners, h, on the floors and girders in after peak tanks (not void spaces) are to be not less than:

h = $80.0\ l_s$ mm, for flat bar stiffeners
h = $70.0\ l_s$ mm, for bulb profiles and flanged stiffeners
l_s = length of stiffener as shown in Fig.2, in m, need not be taken greater than 5 m.

303 Stiffeners on the floors and girders above the propeller[1)] in after peak tanks (not void spaces) are to be provided with end brackets as follows:

- brackets shall be fitted at the both ends when l_{s-t} exceeds 4 m,
- brackets shall be fitted at one end when l_{s-t} exceeds 2.5 m.
- l_{s-t} = total length of stiffener as shown in Fig. 2, in m.

1) "Above the propeller" means between the forward edge of the rudder and the after end of the propeller boss and within the diameter of the propeller in transverse direction.

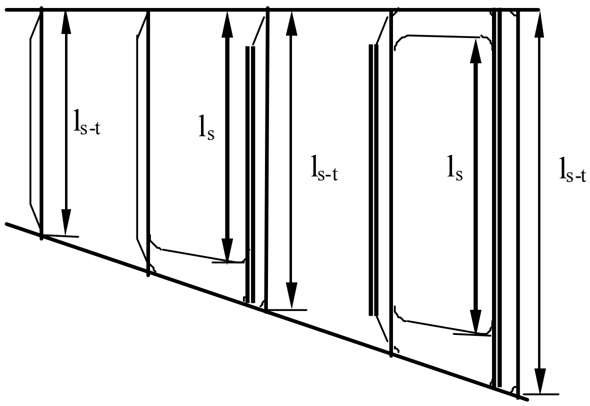


Fig. 2
Stiffening of floors and girders in after peak tank

H. Special requirements

H 100 Vertical struts

101 Where bottom and inner bottom longitudinals or frames are supported by vertical struts, the sectional area of the strut shall not be less than:

$$A = \frac{k\, l\, s\, T}{f_1} \quad (\text{cm}^2)$$

k = 0.7 in way of ballast tanks
= 0.6 elsewhere
l = stiffener span in m disregarding the strut.

The moment of inertia of the strut shall not be less than:

$$I = 2.5\, h_{db}^2\, A \quad (\text{cm}^4)$$

h_{db} = double bottom height in m.

H 200 Strengthening against slamming

201 The bottom forward shall be strengthened according to the requirements given in the following. For ships with service restriction notations the strengthening will be specially considered.

202 The strengthening is to be based on the minimum forward draught in a departure/arrival ballast condition where ballast is carried in dedicated ballast tanks only.

203 The design slamming pressure shall be taken as:

$$p_{sl} = \frac{c_1 c_2}{T_{BF}} B_B \left(0.56 - \frac{L}{1250} - \frac{x}{L}\right) \quad (\text{kN/m}^2)$$

c_1 = $L^{1/3}$ for $L \leq 150$ m

c_1 = $\left(225 - \frac{L}{2}\right)^{1/3}$ for $L > 150$ m

c_2 = $1675\left(1 - \frac{20T_{BF}}{L}\right)$

T_{BF} = design ballast draught in m at F.P.
B_B = the breadth of the bottom in m at the height $0.15T_{BF}$ above the baseline measured at the cross section considered.
B_B shall not be taken greater than the smaller of $1.35\, T_{BF}$ and $0.55\sqrt{L}$
x = longitudinal distance in m from F.P. to cross section considered, but need not be taken smaller than x_1

x_1 = $\left(1.2 - (C_B)^{1/3} - \frac{L}{2500}\right)L$

The assumed variation in design slamming pressure is shown in Fig.3.

204 If the ship on the design ballast draught T_{BF} is intended to have full ballast tanks in the forebody and the load from the ballast will act on the bottom panel, the slamming pressure (p_{sl}) may be reduced by 14 h kN/m^2 where h is the height in m of the ballast tank.

205 The thickness of the bottom plating below 0.05 T_{BF} from keel shall not be less than:

$$t = \frac{0.9\, k_a\, k_r\, s\, \sqrt{p_{sl}}}{\sqrt{f_1}} + t_k \qquad \text{(mm)}$$

k_r = correction factor for curved plates with stiffening direction at right angle to axis of curvature

$= \left(1 - 0.5\,\frac{s}{r}\right)$

r = radius of curvature in m
p_{ls} = as given in 203 or 204.

206 Above the area given in 205 the thickness may be gradually reduced to the ordinary requirement at side. For vessels with rise of floor, however, reduction will not be accepted below the bilge curvature.

207 The section modulus of longitudinals or transverse stiffeners supporting the bottom plating defined in 205 and 206 shall not be less than:

$$Z = \frac{0.15\, l^2\, s\, p_{sl}\, w_k}{f_1} \qquad (\text{cm}^3)$$

The shear area shall not be less than:

$$A_S = \frac{0.03\,(l - 0.5s)\, s\, p_{sl}}{f_1} + 10\, h\, t_k \qquad (\text{cm}^2)$$

p_{sl} = as given in 203 or 204.
h = stiffener height in m.

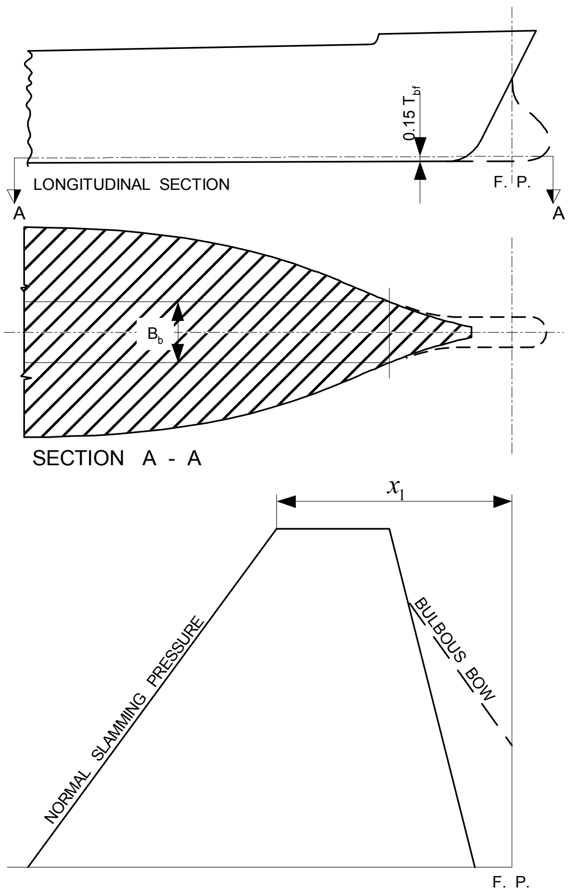


Fig. 3
Design slamming pressure

208 The net connection area of continuous stiffeners at girders shall satisfy the following expression:

$$1.7\, f_{1F}\, A_F + f_{1W}\, A_W \geq 2\, f_{1S}\, (A_S - 10\, ht_k)$$

A_F = connection area at flange in cm^2
A_W = connection area at web in cm^2
A_S = as given in 207
f_{1F} = material factor f_1 for top stiffener welded to flange
f_{1W} = material factor f_1 for shear connection
f_{1S} = material factor f_1 for the bottom stiffener.

209 In the bottom below 0.05 T_{BF} the spacing of stiffeners on web plates or bulkheads is near the shell plating not to exceed:

$$s_w = 0.09\, t \quad (m)$$

t = thickness of web or bulkhead plating in mm.

210 Flanged primary members supporting stiffeners in part of the bottom, e.g. typical primary members in duct keel, shall satisfy the criteria in 207.

211 The sum of the products of shear area and the corresponding material factor f_1 at end supports of all girders within a typical bottom area (between heavy supporting structures such as bulkheads and ship's sides) shall not be less than:

$$\sum_n A_{si} f_{1i} = c_3\, l\, b\, p_{sl} \quad (cm^2)$$

A_{si} = shear area of end support member #i
f_{1i} = material factor f_1 for end support member #i
n = number of girders.

$$c_3 = 0.05\left(1 - \frac{10\, l\, b}{LB}\right), \text{ minimum } 0.025$$

p_{sl} = as given in 203 or 204.

l and b is the length and the breadth in m respectively of the loaded area supported by the girder or girder system. p_{sl} is taken at the middle of the girder system considered.

212 The design ballast draught forward will be stated in the appendix to the classification certificate.

H 300 Strengthening for grab loading and discharging - Optional class - special features notation IB-X

301 Vessels with inner bottom, and adjacent bulkheads over a width (measured along the plate) of 1.5 m, and strengthened in accordance with the requirement given in 303 may have the notation **IB-X** assigned, where **X** denotes areas especially strengthened, as specified below:

IB-1 Strengthening of inner bottom.
IB-2 Strengthening of inner bottom, and lower part of transverse bulkhead.
IB-3 Strengthening of inner bottom, and lower part of transverse and longitudinal bulkhead.

302 The requirement given in 301 does not apply to vessels with **CSR** notation.

303 The plate thickness shall not be less than:

$$t = 9.0 + \frac{12s}{\sqrt{f_1}} + t_k \quad (mm)$$

H 400 Docking

401 The bottom scantlings required in this section are considered to give ample strength for the safe docking of ships with length less than 120 metres and of normal design.

402 For ships of special design, particularly in the afterbody, and for large vessels (docking weight exceeding 70 t/m) the expected docking conditions and docking block arrangements shall be evaluated and checked by a special calculation. The docking arrangement plan, giving calculated forces from docking blocks, shall be submitted for information.

Guidance note:

Size and number of docking blocks should be estimated on the basis of a design pressure in blocks normally not exceeding 2 N/mm^2. With centre line girder the docking blocks should be supported by the innermost longitudinals, which should be dimensioned for 1/4 of the reaction force from the blocks. With a symmetric duct keel the distance between the duct keel girders should be less than the expected transverse length of the docking blocks.

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

SECTION 7 SIDE STRUCTURES

A. General

A 100 Introduction

101 The requirements in this section apply to ship's side structure.

102 The formula are given for plating, stiffeners and girders are based on the structural design principles outlined in Sec.3 B. In most cases, however, fixed values have been assumed for some variable parameters such as:

— aspect ratio correction factor for plating
— bending moment factor m for stiffeners and girders.

Where relevant, actual values of these parameters may be chosen and inserted in the formulae.

Direct stress calculations based on said structural principles and as outlined in Sec.12 will be considered as alternative basis for the scantlings.

A 200 Definitions

201 Symbols:

L = rule length in m [1)]
B = rule breadth in m [1)]
D = rule depth in m [1)]
T = rule draught in m [1)]
C_B = rule block coefficient [1)]
V = maximum service speed in knots on draught T
L_1 = L but need not be taken greater than 300 m
t = rule thickness in mm of plating
Z = rule section modulus in cm^3 of stiffeners and simple girders
k_a = correction factor for aspect ratio of plate field
= $(1.1 - 0.25\ s/l)^2$
= maximum 1.0 for $s/l = 0.4$
= minimum 0.72 for $s/l = 1.0$
s = stiffener spacing in m, measured along the plating
l = stiffener span in m, measured along the top flange of the member. For definition of span point, see Sec.3 C100. For curved stiffeners l may be taken as the cord length.
For main frames in bulk carriers, see special definition of l in Pt.5 Ch.2 Sec.8 Fig.1
S = girder span in m. For definition of span point, see Sec.3 C100
z_n = vertical distance in m from the baseline or deckline to the neutral axis of the hull girder, whichever is relevant
z_a = vertical distance in m from the baseline or deckline to the point in question below or above the neutral axis, respectively
f_1 = material factor
= 1.0 for NV-NS steel [2)]
= 1.08 for NV-27 steel [2)]
= 1.28 for NV-32 steel [2)]
= 1.39 for NV-36 steel [2)]
= 1.47 for NV-40 steel [2)]
f_{2b} = stress factor below neutral axis of hull girder as defined in Sec.6 A200
f_{2d} = stress factor above neutral axis of hull girder as defined in Sec.8 A200
w_k = section modulus corrosion factor in tanks, see Sec.3 C1004
= 1.0 in other compartments
σ = nominal allowable bending stress in N/mm^2 due to lateral pressure
p = design pressure in kN/m^2 as given in B.

1) For details see Sec.1 B.

2) For details see Sec.2 B and C.

202 The load point where the design pressure shall be calculated is defined for various strength members as follows:

a) For plates: midpoint of horizontally stiffened plate field.
Half of the stiffener spacing above the lower support of vertically stiffened plate field, or at lower edge of plate when the thickness is changed within the plate field.

b) For stiffeners: midpoint of span.
When the pressure is not varied linearly over the span, the design pressure shall be taken as the greater of:

$$p_m \text{ and } \frac{p_a + p_b}{2}$$

p_m, p_a and p_b are calculated pressures at the midpoint and at each end respectively.

c) For girders: midpoint of load area.

203 The lower span of the side frame in way of longitudinally stiffened single bottom is defined as follows (see Fig.1):

$$l = l_2 - 0.3\ r - 1.5\ (h - a) \quad (m)$$

l_2 = vertical distance in m between the bottom and lowest side stringer
r = bilge radius in m
h = largest depth of bilge bracket in m measured at right angles to the flange
a = depth of frame in m

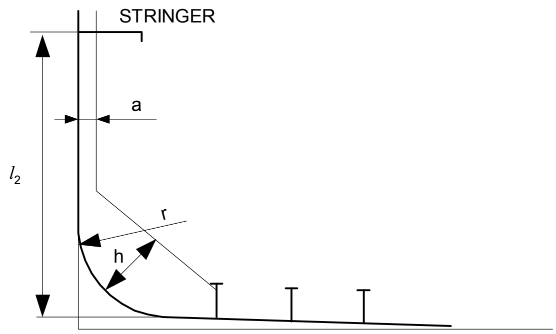


Fig. 1
Lower span of side frame

A 300 Structural arrangement and details

301 The ship's side may be longitudinally or vertically stiffened.

Guidance note:
It is advised that longitudinal stiffeners are used near bottom and strength deck in ships with length L> 150 m.

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

302 Within 0.5 L amidships, in the area 0.15 D above the bottom and 0.15 D below strength deck, the continuity of the longitudinals shall be as required for bottom and deck longitudinals respectively.

303 Weld connections shall satisfy the general requirements given in Sec.11.

304 For end connections of stiffeners and girders, see Sec.3 C.

B. Design loads

B 100 Local loads on side structures

101 All generally applicable local loads on side structures are given in Table B1, based upon the general loads given in Sec.4. In connection with the various local structures, reference is made to this table, indicating the relevant loads in each case.

Table B1 Design loads

Load type		*P (kN/m²)*
External	Sea pressure below summer load waterline	$p_1 = 10\ h_0 + p_{dp}$ 1)
	Sea pressure above summer load waterline	$p_2 = (p_{dp} - (4 + 0.2\ k_s)\ h_0)$ 1) minimum $6.25 + 0.025\ L_1$
Internal	Ballast, bunker or liquid cargo in side tanks in general	$p_3 = \rho\ (g_0 + 0.5\ a_v)\ h_s - 10\ h_b$ $p_4 = \rho\ g_0\ h_s - 10\ h_b + p_o$ $p_5 = 0.67\ (\rho\ g_0\ h_p + \Delta\ p_{dyn}) - 10\ h_b$
	Above the ballast waterline at ballast, bunker or liquid cargo tanks with a breadth > 0.4 B	$p_6 = \rho g_0[0.67(h_s + \phi b) - 0.12\sqrt{H\ \phi b_t}]$
	Above the ballast waterline and towards ends of tanks for ballast, bunker or liquid cargo with length > 0.15 L	$p_7 = \rho g_0[0.67(h_s + \theta l) - 0.12\sqrt{H \theta\ l_t}]$
	In tanks with no restriction on their filling height 2)	$p_8 = \rho\left[3 - \frac{B}{100}\right] b_b$

1) For ships with service restrictions, p_2 and the last term in p_1 may be reduced by the percentages given in Sec.4 B202.
2) For tanks with free breadth b_s > 0.56 B the design pressure will be specially considered according to Sec.4 C305.

h_0 = vertical distance in m from the waterline at draught T to the load point
T = rule draught in m, see Sec.1 B
z = vertical distance from the baseline to the load point, maximum T (m)
p_{dp}, k_s = as given in Sec.4 C201
L_1 = ship length, need not be taken greater than 300 (m)
a_v = vertical acceleration as given in Sec.4 B600
h_s = vertical distance in m from load point to top of tank, excluding smaller hatchways.

h_p = vertical distance in m from the load point to the top of air pipe
h_b = vertical distance in m from the load point to the minimum design draught, which may normally be taken as 0.35 T for dry cargo vessels and 2 + 0.02 L for tankers. For load points above the ballast waterline $h_b = 0$
p_o = 25 in general
= 15 in ballast holds in dry cargo vessels
= tank pressure valve opening pressure when exceeding the general value
ρ = density of ballast, bunker or liquid cargo in t/m³, normally not to be taken less than 1.025 t/m³ (i.e. $\rho\ g_0 \approx 10$)
Δp_{dyn} = as given in Sec.4 C300
H = height in m of tank
b = the largest athwartship distance in m from the load point to the tank corner at the top of tank/ hold most distant from the load point, see Fig.2
b_t = breadth in m of top of tank/hold
l = the largest longitudinal distance in m from the load point to the tank corner at top of tank most distant from the load point
l_t = length in m of top of tank
ϕ = roll angle in radians as given in Sec.4 B400
θ = pitch angle in radians as given in Sec.4 B500
b_b = distance in m between tank sides or effective longitudinal wash bulkhead at the height at which the strength member is located.

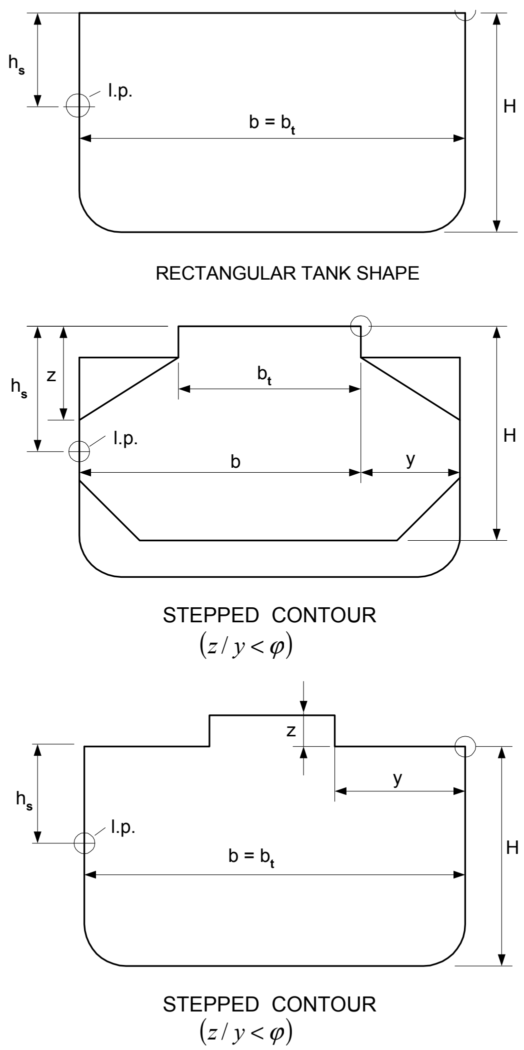


Fig. 2
Tank shapes

C. Plating and stiffeners

C 100 Side plating, general

101 The thickness requirement corresponding to lateral pressure is given by:

$$t = \frac{15.8 k_a s \sqrt{p}}{\sqrt{\sigma}} + t_k \quad \text{(mm)}$$

p = $p_1 - p_8$, whichever is relevant, as given in Table B1

σ = 140 f_1 for longitudinally stiffened side plating at neutral axis, within 0.4 L amidship

= 120 f_1 for transversely stiffened side plating at neutral axis, within 0.4 L amidship.

Above and below the neutral axis the σ-values shall be reduced linearly to the values for the deck and bottom plating, assuming the same stiffening direction and material factor f_1 as for the plating considered

= 160 f_1 within 0.05 L from F.P. and 0.1 L from A.P.

Between specified regions the σ-value may be varied linearly.

102 The thickness is not for any region of the ship to be less than:

$$t = 5.0 + \frac{k L_1}{\sqrt{f_1}} + t_k \quad \text{(mm)}$$

k = 0.04 up to 4.6 m above the summer load waterline. For each 2.3 m above this level the k-value may be reduced by 0.01 (k (minimum) = 0.01)

= 0.06 for plating connected to the sternframe.

103 The thickness of the side plating between a section aft of midships where the breadth at the load waterline exceeds 0.9 B and a section forward of midships where the load waterline breadth exceeds 0.6 B, and taken from the lowest ballast waterline to 0.25 T (minimum 2.2 m) above the summer load line, shall not be less than:

$$t = 31\,(s + 0.7)\left(\frac{BT}{\sigma_f^2}\right)^{\frac{1}{4}} + t_k \quad \text{(mm)}$$

σ_f = minimum yield stress in N/mm^2 as given in Sec.2 B200.

104 The thickness of side plating is also to satisfy the buckling strength requirements given in Sec.13, taking into account also combination of shear and compressive in-plane stresses where relevant.

105 If the end bulkhead of a superstructure is located within 0.5 L amidships, the side plating should be given a smooth transition to the sheer strake below.

C 200 Sheer strake at strength deck

201 The breadth shall not be less than:

$$b = 800 + 5\,L \text{ (mm), maximum 1800 mm.}$$

202 The thickness shall not be less than:

$$t = \frac{t_1 + t_2}{2} \quad \text{(mm)}$$

t_1 = required side plating in mm
t_2 = strength deck plating in mm
t_2 shall not be taken less than t_1.

203 The thickness of sheer strake shall be increased by 30% on each side of a superstructure end bulkhead located within 0.5 L amidships if the superstructure deck is a partial strength deck.

204 Cold rolling and bending of rounded sheer strakes are not accepted when the radius of curvature is less than 15 t.

205 When it is intended to use hot forming for rounding of the sheer strake, all details of the forming and heat treatment procedures shall be submitted to the Society for approval. Appropriate heat treatment subsequent to the forming operation will normally be required.

Where the rounded sheer strake towards ends forward and aft transforms into a square corner, line flame heating may be accepted to bend the sheer strake.

206 The welding of deck fittings to rounded sheer strakes shall be kept to a minimum within 0.6 L amidships. Subject to the surveyor's consent, such welding may be carried out provided:

— when cold formed, the material is of grade NV D or a grade with higher impact toughness
— the material is hot formed in accordance with 205.

The weld joints shall be subjected to magnetic particle inspection.

The design of the fittings shall be such as to minimise stress concentrations, with a smooth transition towards deck level.

207 Where the sheer strake extends above the deck stringer plate, the top edge of the sheer strake shall be kept free from notches and isolated welded fittings, and shall be ground smooth with rounded edges. Drainage openings with smooth transition in the longitudinal direction may be allowed.

208 Bulwarks are in general not to be welded to the top of the sheer strake within 0.6 L amidships. Such weld connections may, however, be accepted upon special consideration of design (i.e. expansion joints), thickness and material grade.

C 300 Longitudinals

301 The section modulus requirement is given by:

$$Z = \frac{83\,l^2 s\,p\,w_k}{\sigma} \quad (\text{cm}^3)\text{, minimum 15 cm}^3$$

p = $p_1 - p_8$, whichever is relevant, as given in Table B1

σ = allowable stress given by:

$$\sigma = 225 f_1 - 130 f_2 \frac{z_n - z_a}{z_n}$$

, maximum 160 f_1

within 0.4 L amidships.

Within 0.1 L from perpendiculars:

$$\sigma = 160 f_1$$

Between specified regions the σ-value may be varied linearly.

For longitudinals $\sigma = 160 f_1$ may be used in any case in combination with heeled condition pressures p_6 and p_8.

f_2 = stress factor f_{2b} as given in Sec.6 A200 below the neutral axis
= stress factor f_{2d} as given in Sec.8 A200 above the neutral axis.

302 The thickness of web and flange shall not be less than the larger of

$t = 4.5 + k + t_k$ (mm)

$= 1.5 + \frac{h_w \sqrt{f_1}}{g} + t_k$

k = 0.01 L_1 in general
= 0.015 L_1 in peaks and in cargo oil tanks and ballast tanks in cargo area
h_w = web height in mm
g = 75 for flanged profile webs
= 41 for bulb profiles
= 22 for flat bar profiles.

303 Longitudinals supported by side verticals subject to relatively large deflections shall be checked by a direct strength calculation, see Sec.12 C. Increased bending stresses at transverse bulkheads shall be evaluated and may be absorbed by increased end brackets.

304 The buckling strength of longitudinals shall be checked according to Sec.13.

C 400 Main frames

401 Main frames are frames located outside the peak tanks, connected to the floors, double bottom or hopper tanks and extended to the lowest deck, stringer or top wing tank on the ship side.

402 The section modulus requirement is given by:

$$Z = \frac{C l^2 s p w_k}{f_1}$$

p = $p_1 - p_8$, whichever is relevant, as given in Table B1
C = 0.37 when external pressure ($p_1 - p_2$) is used
= 0.43 when internal pressure ($p_3 - p_8$) is used
l = corresponding to full length of frame including brackets.

403 The thickness of web and flange shall not be less than given in 302.

404 The requirement given in 402 is based on the assumption that effective brackets are fitted at both ends. The length of brackets shall not be less than:

— 0.12 *l* for the lower bracket.
— 0.07 *l* for the upper bracket.

The section modulus of frame, including bracket, at frame ends shall not be less than as given in 402 with l equal to total span of frame including brackets and applying C-factors as given below.

Upper end:

C = 0.56 when external pressure ($p_1 - p_2$) is used
C = 0.64 when internal pressure ($p_3 - p_8$) is used.

Lower end:

C = 0.74 when external pressure ($p_1 - p_2$) is used
C = 0.86 when internal pressure ($p_3 - p_8$) is used.

When the length of the free edge of the bracket is more than 40 times the plate thickness, a flange shall be fitted, the width being at least 1/15 of the length of the free edge.

For single deck vessels e.g. gas carriers, the end connection of main frames may alternatively be based on a direct calculation where the rotation of upper and lower ends are taken into account.

405 Brackets may be omitted provided the frame is carried through the supporting member and the section modulus as given in 402 is increased by 50% and inserting total span in the formula.

406 The section modulus for a main frame shall not be less than for the 'tween deck frame above.

407 In ships without top wing tank, frames at hatch end beams shall be reinforced to withstand the additional bending moment from the deck structure.

408 Main frames made of angles or bulb profiles having a span $l > 5$ m shall be supported by tripping brackets at the middle of the span.

Forward of 0.15 L from F.P., see also E100.

C 500 'Tween deck frames and vertical peak frames

501 'Tween deck frames are frames between the lowest deck or the lowest stringer on the ship's side and the uppermost superstructure deck between the collision bulkhead and the after peak bulkhead.

502 If the lower end of 'tween deck frames is not welded to the bracket or the frame below, the lower end shall be bracketed above the deck. For end connections, see also Sec.3 C200.

503 The section modulus shall not be less than the greater of:

$$Z = \frac{0.55\, l^2 s\, p\, w_k}{f_1} \quad (\text{cm}^3)$$

and

$$Z = k\sqrt{\frac{L}{f_1}} \quad (\text{cm}^3)$$

k = 6.5 for peak frames
 = 4.0 for 'tween deck frames
p = $p_1 - p_8$, whichever is relevant, as given in Table B1.

504 The thickness of web and flange shall not be less than given in 302.

D. Girders

D 100 General

101 The thickness of web plates, flanges, brackets and stiffeners of girders shall not be less than:

$$t = 5.0 + \frac{k}{\sqrt{f_1}} + t_k \quad (\text{mm})$$

k = $0.01\, L_1$ in general
 = $0.02\, L_1$ for girder webs, flanges and brackets in cargo oil tanks and ballast tanks in cargo area
 = $0.03\, L_1$ (= 6.0 maximum) for girder webs, flanges and brackets in peaks.

The thickness of girder web plates in single skin construction is in addition not to be less than:

$$t = 12\, s + t_k \quad (\text{mm})$$

s = spacing of web stiffening in m.

102 The buckling strength of web plates subject to in- plane compressive and shear stresses shall be checked according to Sec.13.

103 In the after peak, engine and boiler room, side verticals are normally to be fitted at every 5th frame.

104 Verticals in the engine room and verticals less than 0.1 L from the perpendiculars shall have a depth not less than:

$$h = 2\, L\, S \text{ (mm), maximum } 200\, S.$$

Verticals with moment of inertia equivalent to a girder with height h and flange breadth in accordance with 105 are also acceptable. If the side verticals are fitted closer than required by 103, the required moment of inertia may be reduced correspondingly.

105 Girder flanges shall have a thickness not less than 1/30 of the flange width when the flange is symmetrical, and not less than 1/15 of the flange width when the flange is asymmetrical.

For girders in engine room the total flange width shall not be less than 35 S mm.

106 Transverse bulkheads or side verticals with deck transverses shall be fitted in the 'tween deck spaces to ensure adequate transverse rigidity.

107 Vertical peak frames shall be supported by stringers or perforated platforms at a vertical distance not exceeding 2.25 + L/400 metres.

108 The end connections and stiffening of girders shall be arranged as given in Sec.3 C.

Stiffeners on girders in the after peak shall have end connections.

D 200 Simple girders

201 The section modulus requirement is given by:

$$Z = \frac{100\, S^2\, b\, p\, w_k}{\sigma} \quad (\mathrm{cm}^3)$$

p = $p_1 - p_4$
= 1.15 p_5
= $p_6 - p_8$, whichever is relevant, as given in Table B1.
b = loading breadth in m

σ = $190\, f_1 - 130\, f_2 \frac{z_n - z_a}{z_n}$,
maximum 160 f_1 for continuous longitudinal girders within 0.4 L amidships
= 160 f_1 for other girders.

Between specified regions the σ-value may be varied linearly.

For longitudinal girders σ= 160 f_1 may be used in any case in combination with heeled condition pressures p_6 and p_8.

f_2 = stress factor f_{2b} as given in Sec.6 A200 below the neutral axis
= stress factor f_{2d} as given in Sec.8 A200 above the neutral axis.

The above requirement applies about an axis parallel to the ship's side.

202 The web area requirement (after deduction of cut-outs) at the girder ends is given by:

$$A = \frac{k\, S\, b\, p}{f_1} + 10\, h\, t_k \quad (\mathrm{cm}^2)$$

k = 0.06 for continuous horizontal girders and upper end of vertical girders
= 0.08 for lower end of vertical girders
b = as given in 201
h = girder height in m
p = $p_1 - p_7$, whichever is relevant, as given in Table B1.

The web area at the middle of the span shall not be less than 0.5 A.

The above requirement apply when the web plate is perpendicular to the ship's side.

For oblique angles the requirement shall be increased by the factor 1 / cos θ, where θ is the angle between the web plate of the girder and the perpendicular to the ship's side.

D 300 Complex girder systems

301 In addition to fulfilling the general local requirements given in 100, the main scantlings of girders being parts of a complex system may have to be based on a direct stress analysis as outlined in Sec.12.

D 400 Cross ties

401 The buckling strength shall satisfy the requirements given in Sec.13.

402 Cross ties may be regarded as effective supports for side vertical when:

— the cross tie extends from side to side

— the cross tie is supported by other structures which may be considered rigid when subjected to the maximum expected axial loads in the cross tie
— the load condition may be considered symmetrical with respect to the cross tie.

403 Side verticals may be regarded as individual simple girders between cross ties, provided effective cross ties, as defined in 402, are positioned as follows:

Side verticals with 1 cross tie:
The cross tie is located 0.36 l – 0.5 l from the lower end.

Side verticals with 2 cross ties:
The lower cross tie is located 0.21 l – 0.30 l from the lower end.
The upper cross tie is located 0.53 l – 0.58 l from the lower end.

l = total span of side vertical.

Side verticals with more than 2 cross ties or with cross ties not located as given above, will be specially considered. On stringers, the cross ties are assumed to be evenly spaced.

E. Special requirements

E 100 Strengthening against bow impact

101 The bow region as referred to in the following is normally to be taken as the region forward of a position 0.1L abaft F.P. and above the summer load waterline.

102 The effect of bow impact loads is in general to be evaluated for all ships. Normally only ships with well rounded bow lines and or flare will need strengthening.

The impact pressure given in 103 applies to areas away from knuckles, anchor bolster etc. that may obstruct the water flow during wave impacts. In way of such obstructions, additional reinforcement of the shell plate by fitting carlings or similar shall generally be considered.

103 The design bow impact pressure shall be taken as:

$$p_{sl} = C(2.2 + C_f)(0.4V\sin\beta + 0.6\sqrt{L})^2 \text{ (kN/m}^2\text{)}$$

C = 0.18 (C_W – 0.5 h_o), maximum 1.0
C_W = wave coefficient as given in Sec.4 B200
h_o = vertical distance (m) from the waterline at draught T to point considered
C_f = 1.5 tan ($\alpha + \gamma$)
= 4.0, maximum
γ = 0.4 ($\phi\cos\beta + \theta\sin\beta$)
ϕ, θ = as given in, in radians, Sec.4 B
α = flare angle in radians taken as the angle between the side plating and a vertical line, measured at the point considered
β = angle in radians between the waterline and a longitudinal line, measured at the point considered. With reference to Fig. 3, the flare angle α may normally be taken in accordance with:

$$\tan\alpha = \frac{a_1 + a_2}{h_d}$$

If there is significant difference between a_1 and a_2, more than one plane between the design waterline and upper deck (forecastle deck if any) may have to be considered.

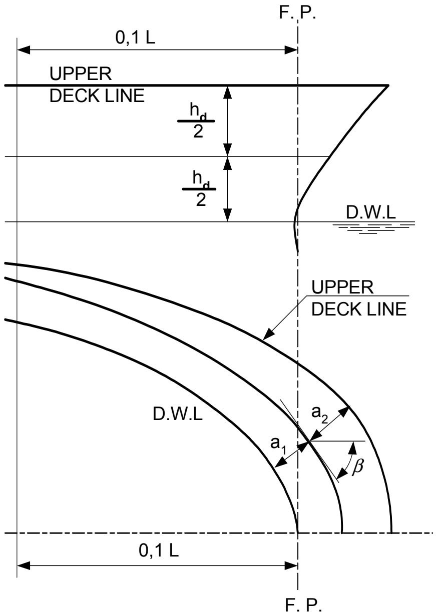


Fig. 3
Bow region

104 The thickness of shell plating in the bow region shall not be less than:

$$t = \frac{13.8\ k_a\ s\ \sqrt{p_{sl}}}{\sqrt{\sigma_f}} + t_k \quad \text{(mm)}$$

k_a = $(k_{a1} - 0.25k_{a2})^2$
k_{al} = 1.1 in general
= $1.95\left(\frac{s}{R}\right)^{0.25}$
within cylindrical and conical bow shell regions with vertical or radial stiffening. The value of k_{al} is, however, not to be taken less than 1.1 and need not be taken larger than 1.16.
R = radius of curvature of shell plating in m
k_{a2} = s/l, but need not be taken < 0.4, and is not to be taken > 1.0
l = length of plate field in m
σ_f = minimum upper yield stress of material in N/mm^2 and shall not be taken less than the limit to the yield point given in Sec.2 B201
p_{sl} = as given in 103
s = stiffener spacing in m.

105 The net effective shear area A_{sa}, as defined in Sec.3 C1005, of stiffeners supporting the shell plating in the bow region is not to be less than As, as given under:

$$A_s = \frac{12.5\ l\ s\ p}{\sigma_f} \quad (\text{cm}^2)$$

l = stiffener span in m as given in A201
p = 0.5 p_{sl} but is not to be taken less than 2 p_2 as given in Table B1
p_{sl} = as given in 103
σ_f = as defined in 104.

The net effective plastic section modulus for the stiffener fitted, Z_{pa}, as determined according to in Sec.3 C1005, is not to be less than Z_p, given below:

$$Z_p = \frac{160\ s\, l^2\ p}{\left(1+\frac{n_s}{2}\right)\sigma_f} + \frac{n_s\left(1-\sqrt{1-\left(A_s / A_{sa}\right)^2}\right)\sin\varphi_w\, h_w\left(h_w+t_p\right)\left(t_w-t_k\right)}{8000} \quad (\text{cm}^3)$$

l = stiffener span (m) as given in A201
n_s = number of bending effective end supports of stiffener
= 2, 1 or 0 (see Guidance Note)
A_s = as given above
A_{sa} = net effective web area in cm^2 of the stiffener fitted, as determined in accordance with Sec.3 C1005.
φ_w = angle between stiffener web and shell plate

h_w, t_p, t_w, t_k are as defined in Sec.3 C1005 for the stiffener fitted.

Guidance note:

Stiffener end supports may be considered bending effective except where the stiffener is terminated at the support without being attached to an aligned member or a supported end bracket.

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

106 Outside the bow region the requirements, as calculated in 104 and 105, are to be gradually decreased to the ordinary requirements at 0.15 L from F.P. and at the ballast waterline.

However, if the flare angle, α, at 0.15 L from F.P., is greater than 40°, the bow region in 101 is extended to 0.15 L from F.P. with gradually decrease to 0.2 L from F.P.

107 The web thickness of shell stiffeners or breast hooks, stringers and web frames in lieu of shell stiffeners shall not be less than:

$$t_w = 0.025\left(\frac{p\ s\ h_w^2}{\sin\varphi_w}\right)^{0.33} + t_k \quad (\text{mm})$$

p = as given in 105
s = load breadth of considered member in m
φ_w = angle between member web and shell plate
h_w = web height.

or distance in mm between shell plating and the nearest parallel web or breast hook stiffener.

108 Shell stiffeners shall be connected to supports, e.g. stringers, web frames, decks or bulkheads. The connection area is generally obtained through fitting support members such as collar plate, lugs, end brackets or web stiffener. The net connection area of the support members fitted is given by:

$$a = \sum_n 0.01 k_\tau (t_i - t_k) h_i \quad (\text{cm}^2)$$

where

h_i = effective dimension of connection area of member #i
t_i = thickness of connection area #i
k_τ = 1.0 in general
= 1.7 for members where critical stress response is axial stress
n = number of end connection members

The net end connection area fitted, a is normally not to be less than a_o, given by:

$$a_0 = \frac{9.5(l_1 + l_2 - s)\, sp}{\sin\varphi_w \sigma_f}$$

where

l_1, l_2 = the full length of the stiffener to the adjacent primary member supports, see Fig.5
p = 0.5 p_{sl}

φ_w = angle between support member and the shell plate.

For the support members the throat thickness of double fillet welds connecting the shell stiffener and the member i, t_w, is given by:

$$t_w = \frac{(t_i - t_k) a_0 \sigma_f}{450 a f_w} + 0.5 t_k$$

f_w = as given in Sec.11 C103.

End brackets of shell stiffeners are to be arranged with flange or edge stiffener in accordance with Sec.3 C200.

109 Girder systems in the bow shall be designed to have structural continuity. Aligned support members are in general to be fitted in decks, platforms and bulkheads providing end support for stringers and web frames supporting shell stiffeners.

The main stiffening direction for stringers and web frames, platforms and bulkheads is generally to be parallel to the web direction of the shell stiffeners being supported.

In way of end supports of primary members supporting shell stiffeners (i.e. stringers and web frames), web stiffening parallel to the flange shall be provided as necessary for ensuring the buckling strength of the member, as outlined in 111.

End brackets are generally to be arranged with flange or edge stiffener.

Tripping brackets are generally to be fitted in way of end brackets of girders. At positions where the flange and or the web of frames and girders are knuckled, support shall be provided as necessary for ensuring the effectiveness of the knuckled members.

One-sided girder flanges are generally to be straight between supports.

110 The plate thickness of members which support shell stiffeners, e.g. stringers, web frames, and decks or bulkheads fitted in lieu of a stringer or a web frame, shall not be less than:

$$t = \frac{f_p\, f_s\, p\, s_b}{\sin \varphi_w\, \sigma} - t_s + t_k \qquad \text{(mm)}$$

f_p = $(h - h_p)/h$
f_s = $\cos \varphi_s$ with respect to the stress component perpendicular to the stiffening direction of the plate field considered.
= $\sin \varphi_s$ with respect to the stress component parallel to the stiffening direction of the plate field considered.

$$t_s = \frac{0.09\, \sigma_f\, A_{ns}}{s_w\, \sigma}$$

A_{ns} = net cross-sectional area in cm^2 of the stiffening members which are parallel to the stress component considered.
= 0 if such stiffening members are not fitted.
h = depth in m of the stringer, web frame, and deck or bulkhead fitted in lieu of a stringer or a web frame, measured at right angle to its line of intersection with the shell. In a deck or bulkhead the depth need not be measured further than to the ship's centreline and need not be taken larger than the length, h_m. See also Fig.4 for illustration.
h_m = distance measured on the side shell between the members which support the deck or the bulkhead.
h_p = distance, measured in the plane of the member, from the side shell to the mid point of the plate field considered. In way of plate fields adjacent to the shell, with stiffening aligned with the shell frames, the length h_p is not to be taken larger than the depth of the shell frames plus half the arm length of any bracket fitted on the shell frames. See also Fig.4 for illustration.
s_w = spacing in m of the stiffening members parallel with the stress component considered.
σ = $0.9\sigma_c$
σ_c = the critical buckling stress as given in Sec.13 B102 of the supporting plate member with respect to the stress component considered, i.e. parallel or perpendicular to the stiffeners fitted.
σ_f = as defined in 104.
p = as given in 105.
s_b = breadth of shell in m supported by considered stringer, web frame, and deck or bulkhead fitted in lieu of a stringer or a web frame.
φ_w = angle between the stringer, web frame, deck or bulkhead and the shell plate.
φ_s = angle, measured in the plane of the member considered, between the side shell and the direction of the stiffeners of the plate field considered.

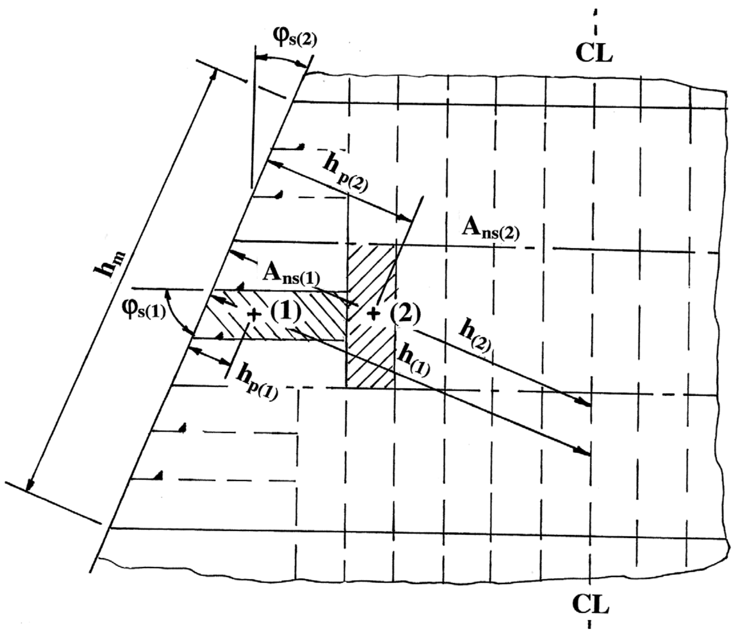


Fig. 4
Deck supporting shell frames

111 The section modulus of primary members supporting shell stiffeners (i.e. stringers and web frames) shall not to be less than:

$$Z = \frac{110 S^2 b p w_k}{\sin\varphi_w \, \sigma_f} \quad (cm^3)$$

The web area at each end support of primary members supporting shell stiffeners shall not to be less than:

$$A = \frac{12.5 n s b p}{\sin\varphi_w \, \sigma_f} + \frac{h t_k}{100} \quad (cm^2)$$

b = breadth of load area supported by the stringer or web frame in m
= 0.5 ($l_1 + l_2$), see Fig.6.
h = girder height in mm
n = number of stiffeners located within the span length S
s = spacing of shell stiffeners in m as defined in A201
S = span of stringer or web frame as given in A201
φ_w = angle between web and shell plate, see Fig.5
p = 0.4 p_{sl}, but shall not to be taken less than 2 p_2 as given in Table B1
p_{s1} = as given in 103
σ_f = as defined in 104.

At the end supports of primary members supporting shell stiffeners, the shear and axial stress response of the web shall to be assessed with respect to web buckling in accordance with Sec.13. In the assessment of the primary member, the shear stress, of the web plate may be taken as:

$$\tau = \frac{600 n s b p}{\sin\varphi_w \, h(t_w - t_k)} \quad (N/mm^2)$$

The normal stress of the web plate at the face plate may be assumed given by:

$$\sigma = \frac{100 S^2 b p w_k}{\sin\varphi_w Z_f} \quad (N/mm^2)$$

Z_f = section modulus in cm^3 of primary member as fitted
t_w = web plate thickness in mm of the primary member as fitted.

At the attached plate flange, the normal stress of the web may with respect to the buckling check in general be taken equal to zero.

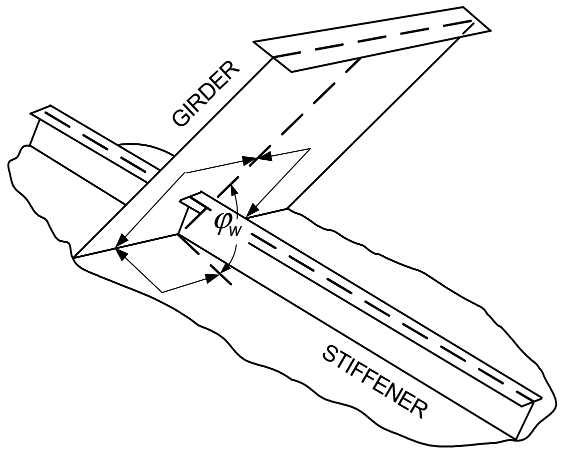


Fig. 5
The web angle φ_w of stringers and web frames

112 Stringers and web frames supporting shell stiffeners shall be effectively connected to supports, e.g. stringers, web frames, decks or bulkheads. The connection area is generally given by the sum of the cross-sectional areas of the support structure that contribute to the support of the structure supported. The net connection area of the support fitted is given by:

$$a = \sum_n 0.01 k_\tau (t_i - t_k) h_i \quad (cm^2)$$

where

h_i = effective dimension of connection area #i
t_i = thickness of connection area #i
k_τ = 1.0 in general
= 1.7 for members where critical stress response is axial stress
n = number of support areas.

The net connection area, a is normally not to be less than a_o, given by:

$$a_0 = \frac{9.5(n_1 + n_2)s l p}{\sin\varphi_w \sigma_f} \quad (cm^2)$$

where

l = the load length of the shell stiffeners that are supported by the stringer or web frame
n_1, n_2 = number of shell stiffeners supported by the stringer or web frame within the spans adjacent to the support considered, see Fig.6
p = 0.4 p_{sl}
φ_w = angle between web of support member and shell plate.

For the support members the throat thickness of double fillet welds connecting the stringer or web frame and the support area i, t_w, is given as:

$$t_w = \frac{(t_i - t_k) a_0 \sigma_f}{450 a f_w} + 0.5 t_k$$

f_w = as given in Sec.11 C103.

End brackets of stringers and web frames shall be arranged with edge stiffener in accordance with Sec.3 C200.

113 Alternative to the requirements in 110 and 111, and in special cases where e.g. a grillage like primary stiffening system is arranged, the scantling requirements to stringers and web frames of the flared bow shell and the supporting bulkhead and deck structures of the bow may be required to be based on direct strength analysis.

When direct calculation of the bow structure subjected to impact loading is undertaken, a mean impact pressure = 0.375 p_{sl} is generally to be assumed. This pressure may be required to be applied alternatively on one or both bow sides. In the structure analysis, the nominal equivalent stress, σ_e, as given in Sec.12 B400 shall not exceed the yield stress, σ_f, as given in 103. The nominal shear stress shall, in addition, not exceed 90% of the shear yield stress, given as $0.9\sigma_f/\sqrt{3}$.

In the buckling control, the usage factors, η_x and η_y, as given in Sec.13 B400 and B500, may be taken equal to 1.0.

p_{sl} = as given in 103.

Guidance note:

When direct calculation is undertaken for the scantling assessment of a stringer or an equivalent member which is supporting shell stiffeners, the structure model should preferably extend from the stringer or equivalent member below to the stringer or equivalent member above the member to be considered by the assessment.

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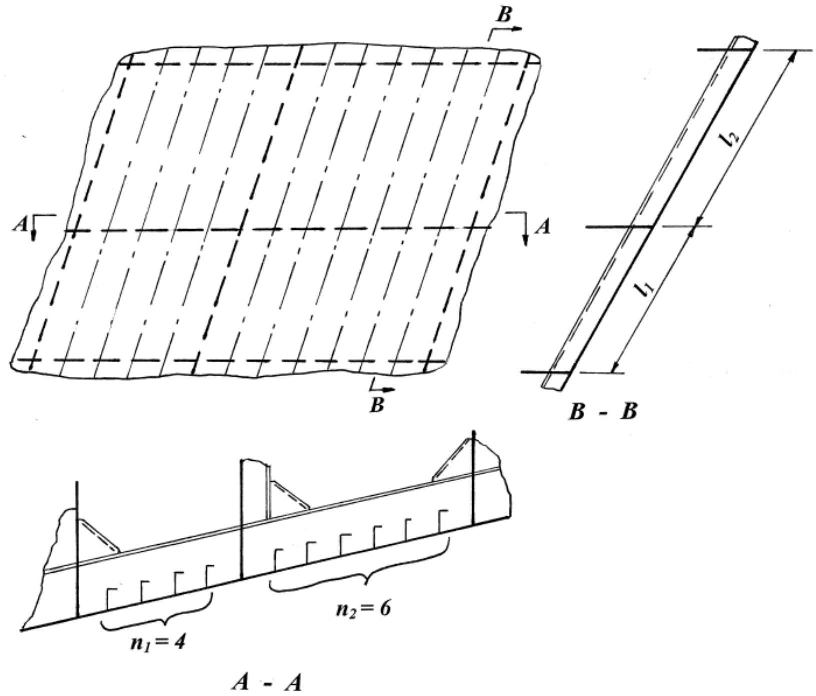


Fig. 6
Primary member supporting shell stiffeners

E 200 Stern slamming

201 Vessels where the flare angle of the lower shell is larger than 60°, typically container ships, cruise ships, ro-ro and car carriers, are to be strengthened according to 202 and 203.

202 The stern slamming requirements are in general applicable aft of 0.1L forward of A.P. The strengthening of plates and stiffeners against stern slamming is to be according to 104 and 105 with respect to the impact pressure given in 203.

The shear area and the section modulus of the girders or and web frames supporting shell stiffeners are to be strengthened in accordance with 111 using p = $0.4p_{sl}$ given in 203.

203 The design stern slamming pressure shall be taken as:

$$p_{sl} = 2.2CL\left(0.6 + \frac{1.65a_0(0.55L - X)\sin^3\alpha}{C_B L}\right)^2$$

Not to be taken greater than:

$$p_{sl} = 2.2CL\left(0.6 + \frac{1.65a_0\sin^3\alpha}{2C_B}\right)^2$$

C = $0.18\,(C_W - 2\,h_o)$, maximum 1.0 (minimum 0.0)

C_W = wave coefficient as given in Sec.4 B200

h_o = vertical distance (positive downwards) in m from the waterline T_{BA} to the shell at the position considered.

T_{BA} = design minimum ballast draught in m at A.P.

X = distance from A.P. to position considered (m)
a_0 = a_0 from Sec.4 B203, with C_{V1}= 0.8
α = flare angle as defined in E103.

E 300 Strengthening against liquid impact pressure in larger tanks

301 If the ship side forms boundary of larger ballast or cargo tanks with free sloshing length $l_s > 0.13$ L and or breadth
$b_s > 0.56$ B, the side structure shall have scantlings according to Sec.9 E400 for impact loads referred to in Sec.4 C305.

E 400 Fatigue control of longitudinals, main frames and 'tween deck frames

401 Longitudinals in tanks shall have a section modulus not less than:

$$Z = \frac{83\, s\, l^2 p_d w_k}{\sigma_d} \qquad (\text{cm}^3)$$

p_d = single amplitude dynamic pressure in kN/m^2
= $5 [\, \kappa + (T - z) \,]$ $\qquad (T - z)_{max} = \kappa$

$$\kappa = \frac{B}{2}\,\frac{\phi}{2} + \frac{B}{32}\left(1 + \frac{z}{T}\right) \qquad z_{max} = T \text{ for } \kappa$$

σ_d = permissible single amplitude fluctuating dynamic stress

$$= \frac{110c}{K} \qquad (\text{N/mm}^2)$$

c = 1.0 for uncoated cargo and ballast tanks
= 1.1 for fully coated tanks and fuel tanks
z = distance from base-line to considered longitudinal (m)
K = stress concentration factor as given in Fig.7
ϕ = rolling angle in radians.

For designs giving larger deflections between transverse bulkheads and the side verticals smooth two-sided brackets (armlength = 1.2 – 1.5 times profile height) shall be arranged on the top of the longitudinals at the transverse bulkheads unless the strength is verified by a special fatigue analysis. Such an analysis shall be based on calculating the additional stress:

σ_δ = fluctuating single amplitude dynamic stresses in the longitudinal due to relative deflection between the supports calculated for the dynamic pressure p_d.

This stress shall be deducted from 110 c/K to obtain the allowable stress σ_d in the formula for Z.

402 Main frames in tanks are at their welded end support to have a section modulus not less than:

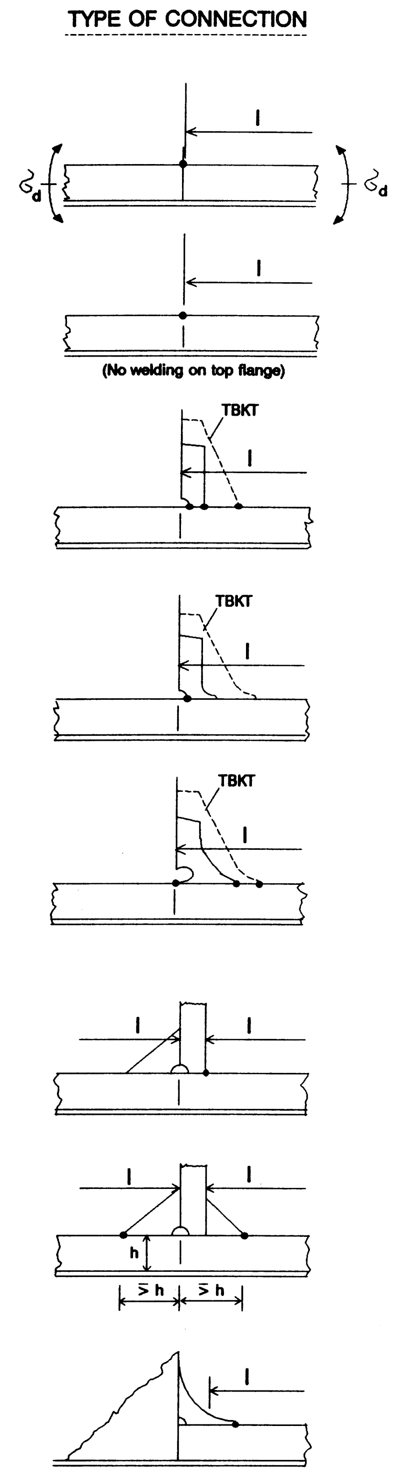
$$Z = \frac{83\, s\, l^2 p_d w_k}{\sigma_d} \qquad (\text{cm}^3)$$

p_d, σ_d and K are as given in 401.

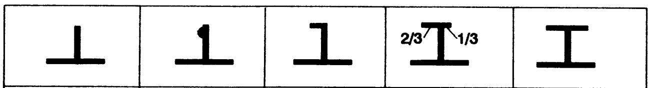
403 'Tween deck frames in tanks shall have a section modulus at their welded end supports not less than:

$$Z = \frac{83\, s\, l^2 p_d w_k}{\sigma_d} \qquad (\text{cm}^3)$$

p_d, σ_d and K are as given in 401.



K - factors



1.4	1.9	2.5	2.0	1.5
1.2	1.4	1.7	1.5	1.3
1.4 (1.6)	1.9 (2.1)	2.5 (2.7)	2.0	1.5
1.4 (1.6)	1.9 (2.1)	2.5 (2.7)	2.0	1.5
[1.3]	[1.7]	[2.2]	[1.8]	[1.4]
1.4 (1.6)	1.9 (2.1)	2.5 (2.7)	2.0	1.5
[1.2] 1.3 (1.4)	[1.4] 1.6 (1.8)	[1.7] 1.9 (2.1)	[1.5] 1.7	[1.3] 1.4
[1.3] 1.5 (1.7)	[2.0] 2.2 (2.4)	[2.4] 2.6 (2.8)	[2.2] 2.4	[1.9] 2.1

K factors refer to indicated notch positions

( ) denotes overlap welded stiffener or bracket

[ ] denotes soft nose at notch point

Fig. 7
Stress concentration factors

SECTION 8 DECK STRUCTURES

A. General

A 100 Introduction

101 The requirements in this section apply to ship's deck structure.

102 The formulae given for plating, stiffeners and girders are based on the structural design principles outlined in Sec.3 B. In most cases, however, fixed values have been assumed for some variable parameters such as:

— aspect ratio correction factor for plating
— bending moment factor m for stiffeners and girders.

Where relevant, actual values for these parameters may be chosen and inserted in the formulae.

Direct stress calculations based on said structural principles and as outlined in Sec.12 will be considered as alternative basis for the scantlings.

A 200 Definitions

201 Symbols:

L = rule length in m [1)]
B = rule breadth in m [1)]
D = rule depth in m [1)]
T = rule draught in m [1)]
C_B = rule block coefficient [1)]
V = maximum service speed in knots on draught T
L_1 = L but need not be taken greater than 300 m
t = rule thickness in mm of plating
Z = rule section modulus in cm^3 of stiffeners and simple girders
k_a = correction factor for aspect ratio of plate field
= $(1.1 - 0.25\ s/l)^2$
= maximum 1.0 for $s/l = 0.4$
= minimum 0.72 for $s/l = 1.0$
s = stiffener spacing in m, measured along the plating
l = stiffener span in m, measured along the topflange of the member. For definition of span point, see Sec.3 C100. For curved stiffeners l may be taken as the cord length
S = girder span in m. For definition of span point, see Sec.3 C100
z_n = vertical distance in m from the baseline or deckline to the neutral axis of the hull girder, whichever is relevant
z_a = vertical distance in m from the baseline or deckline to the point in question below or above the neutral axis, respectively
w_k = section modulus corrosion factor in tanks, see Sec.3 C1004
σ = nominal allowable bending stress in N/mm^2 due to lateral pressure
p = design pressure in kN/m^2 as given in B
f_1 = material factor
= 1.0 for NV-NS steel [2)]
= 1.08 for NV-27 steel [2)]
= 1.28 for NV-32 steel [2)]
= 1.39 for NV-36 steel [2)]
= 1.47 for NV-40 steel [2)]
f_{2d} = stress factor above the neutral axis of the hull girder, depending on surplus in midship section modulus and maximum value of the actual still water moments:

$$f_{2d} = \frac{5,7(M_S + M_W)}{Z_D}$$

Z_D = midship section modulus in cm^3 at deck as built
M_S = normally to be taken as the largest design still water bending moment in kNm. M_S shall not be taken less than 0.5 M_{SO}. When actual design moment is not known, M_S may be taken equal to M_{SO}

M_{SO} = design still water bending moment in kNm given in Sec.5 B
M_W = rule wave bending moment in kNm given in Sec.5 B. Hogging or sagging moment to be chosen in relation to the applied still water moment.

1) For details see Sec.1 B.
2) For details see Sec.2 B and C.

Guidance note:
In special cases a more detailed evaluation of the actual still water moment M_S to be used may be allowed. The simultaneous occurrence of a certain local load on a structure and the largest possible M_S-value in the same area of the hull girder may be used as basis for estimating f_{2d}.

Example: Deck longitudinals. External load (p_1 or p_2 in Table B1) gives maximum local stress in compression, and M_S may be taken as maximum sagging moment. Internal load (p_7 to p_{10} in Table B1) gives maximum load stress in tension, and M_S may be taken as maxim hogging moment.

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A 300 Structural arrangement and details

301 Dry cargo ships with length L > 150 m are normally to have deck longitudinals in the strength deck clear of hatchway openings.

302 In tankers the deck is normally to be longitudinally stiffened in the cargo tank region.

303 When the strength deck is longitudinally stiffened:

— the longitudinals shall be continuous at transverse members within 0.5 L amidships in ships with length L > 150 m
— the longitudinals may be cut at transverse members within 0.5 L amidships in ships with length corresponding to 50 m < L < 150 m. In that case continuous brackets connecting the ends of the longitudinals shall be fitted
— the longitudinals may be welded against the transverse members in ships with length L ≤ 50 m and in larger ships outside 0.5 L amidships.

304 Transverse beams are preferably to be used in deck areas between hatches. The beams shall be efficiently supported by longitudinal girders. If longitudinals are used, the plate thickness shall be increased so that the necessary transverse buckling strength is achieved, or transverse buckling stiffeners shall be fitted intercostally. The stiffening of the upper part of a plane transverse bulkhead (or stool tank) shall be such that the necessary transverse buckling strength is achieved.

Transverse beams shall extend to the second deck longitudinal from the hatch side. Where this is impracticable, stiffeners or brackets shall be placed intercostally in extension of beams.

305 If hatch coaming corners with double curvature or hatch corners of streamlined shape are not adopted, the thickness of deck plates in strength deck at hatch corners shall be increased by 25%, maximum 5 mm.

The longitudinal extension of the thicker plating shall not be less than 1.5 R and not more than 3 R on both sides of the hatch end. The transverse extension outside line of hatches shall be at least 2 R.

For shape and radius of corners in large hatch openings, see Sec.5.

R = corner radius.

306 The seam between the thicker plating at the hatch corner and the thinner plating in the deck area between the hatches shall be located at least 100 mm inside the point at which the curvature of the hatch corner terminates.

If the difference between the deck plate thickness at the hatch corners and in the deck area between hatches is greater than
1/2 of the thickest plate, a transition plate shall be laid between the thick plating and the thin deck area plating. The material strength group of the transition plate is typically to be of an intermediate strength group to that of the connecting plates.

307 Weld connections shall satisfy the general requirements given in Sec.11.

308 For end connections of stiffeners and girders, see Sec.3 C.

A 400 Construction and initial testing of watertight decks, trunks etc.

401 Watertight decks, trunks, tunnels, duct keels and ventilators shall be of the same strength as watertight bulkheads at corresponding levels (see Table B1, p_{13}) The means for making them watertight, and the arrangements adopted for closing openings in them shall satisfy the requirements of this section and Ch.3 Sec.6. Watertight ventilators and trunks shall be carried at least up to the bulkhead deck in passenger ships and up to the freeboard deck in cargo ships.

402 Where a ventilation trunk passing through a structure penetrates the bulkhead deck, the trunk shall be capable of withstanding the water pressure that may be present within the trunk, after having taken into account the maximum heel angle allowable during intermediate stages of flooding, in accordance with SOLAS Ch. II-1/8.5.

403 Where all or part of the penetration of the bulkhead deck is on the main ro-ro deck, the trunk shall be capable of withstanding impact pressure due to internal water motions (sloshing) of water trapped on the ro-ro deck.

404 In ships constructed before 1 July 1997, the requirements of paragraph 2 shall apply not later than the date of the first periodical survey after 1 July 1997.

405 After completion, a hose or flooding test shall be applied to watertight decks and a hose test to watertight trunks, tunnels and ventilators.
(SOLAS Ch. II-1/19)

B. Design loads

B 100 Local loads on deck structures

101 All generally applicable local loads on deck structures are given in Table B1, based upon the general loads given in Sec.4. In connection with the various local structures reference is made to this table, indicating the relevant loads in each case.

Table B1 Design loads

Structure	*Load type*	*p (kN/m²)*
Weather decks 1)	Sea pressure	$p_1 = a(p_{dp} - (4 + 0,2k_s)h_0)$ 2), minimum 5.0
	Deck cargo	$p_2 = (g_0 + 0.5\ a_v)\ q$
Cargo 'tweendecks	Deck cargo	$p_3 = \rho_c\ (g_0 + 0.5\ a_v)\ H_C$
Platform deck in machinery spaces	Machinery and equipment	$p_4 = 1.6\ (g_0 + 0.5\ a_v)$
Accommodation decks	Accommodation in general	$p_5 = 0.35\ (g_0 + 0.5\ a_v)$, see also Sec.4 C401
Deck as tank bottom in general	Ballast, bunker or liquid cargo	$p_6 = \rho\ (g_0 + 0.5\ a_v)\ h_s$ $p_7 = 0.67\ (\rho\ g_0\ h_p + \Delta\ p_{dyn})$ $p_8 = \rho\ g_0\ h_s + p_0$
Deck as tank top in general		$p_7 = 0.67\ (\rho\ g_0\ h_p + \Delta\ p_{dyn})$ $p_8 = \rho\ g_0\ h_s + p_0$
Deck as tank boundary in tanks with breadth > 0.4 B		$p_9 = \rho g_0[0.67(h_s + \phi b) - 0.12\sqrt{H\phi b_t}]$
Deck as tank boundary towards ends of tanks with length > 0.15 L		$p_{10} = \rho g_0[0.67(h_s + \theta l) - 0.12\sqrt{H\theta l_t}]$
Deck as tank boundary in tanks with breadth > 0.4 B 3)		$p_{11} = \rho\left(3 - \frac{B}{100}\right) b_b$
Deck as tank boundary in tanks with length > 0.1 L 4)		$p_{12} = \rho\left(4 - \frac{L}{200}\right) l_b$
Watertight decks submerged in damaged condition 5)	Sea pressure	$p_{13} = 10\ h_b$

1) On weather decks combination of the design pressures p_1 and p_2 may be required for deck cargo with design stowage height less than 2.3 m.

2) For ships with service restrictions p_1 may be reduced with the percentages given in Sec.4 B202. C_W should not be reduced

3) To be used for strength members located less than 0.25 b_b away from tank sides in tanks with no restrictions on their filling height. For tanks with free breadth (no longitudinal wash bulkheads) b_b > 0.56 B the design pressure will be specially considered according to Sec.4 C305

4) To be used for strength members located less than 0.25 l_b away from tank ends in tanks with no restrictions on their filling height. For tanks with free length (no transverse wash bulkheads or transverse web frames in narrow tanks) l_b > 0.13 L the design pressure will be specially considered according to Sec.4 C305

5) The strength may be calculated with allowable stresses for plating, stiffeners and girders increased by 60 f_1.

a = 1.0 for weather decks forward of 0.15 L from FP, or forward of deckhouse front, whichever is the foremost position
= 0.8 for weather decks elsewhere

p_{dp}, k_s = as given in Sec.4 C201

h_0 = vertical distance in m from the waterline at draught T to the deck

a_v = vertical acceleration as given in Sec.4 B600
q = deck cargo load in t/m^2 as specified.Weather decks above cargo holds in dry cargo ships are normally to be designed for a minimum cargo load:
q_{min} = 1.0 for ships with L = 100 m
= 1.3 for ships with L > 150 m when superstructure deck
= 1.75 for ships with L > 150 m when freeboard deck.
For ships with length between 100 and 150 m the q-value may be varied linearly.
When it is specially stated that no deck cargo shall be carried, the q_{min} may be discarded
ρ_c = dry cargo density in t/m^3, if not otherwise specified to be taken as 0.7, see also Sec.4 C401
ρ = density of ballast, bunker or liquid cargo in t/m^3, normally not to be less than 1.025 (i.e. $\rho\, g_0 \approx 10$)
H_C = stowage height in m of dry cargo. Normally the 'tweendeck height or height to top of cargo hatchway to be used
h_s = vertical distance in m from the load point to top of tank, excluding smaller hatchways
h_p = vertical distance in m from the load point to the top of air pipe
h_b = vertical distance in metres from the load point to the deepest equilibrium waterline in damaged condition obtained from applicable damage stability calculations. The deepest equilibrium waterline in damaged condition should be indicated on the drawing of the deck in question.
The vertical distance shall not be less than up to the bulkhead deck.
Δp_{dyn} = as given in Sec.4 C300
p_0 = 25 in general
= 15 in ballast holds in dry cargo vessels
= tank pressure valve opening pressure when exceeding the general value
H = height in m of tank
b = the largest athwartship distance in m from the load point to the tank corner at the top of tank/ hold most distant from the load point
b_t = breadth in m of top of tank/hold
b_b = distance in m between tank sides or effective longitudinal wash bulkhead at the height at which the strength member is located
l = the largest longitudinal distance in m from the load point to the tank corner at top of tank most distant from the load point
l_t = length in m of top of tank
l_b = distance in m between transverse tank bulkheads or effective transverse wash bulkheads at the height at which the strength member is located. Transverse webframes covering part of the tank cross section (e.g. wing tank structures in tankers) may be regarded as wash bulkheads
ϕ = roll angle in radians as given in Sec.4 B400
θ = pitch angle in radians as given in Sec.4 B500.

C. Plating and stiffeners

C 100 Strength deck plating

101 The breadth of stringer plate and strakes in way of possible longitudinal bulkheads which shall be of grade B, D or E shall not be less than:

$$b = 800 + 5\,L \quad \text{(mm), maximum 1800 mm.}$$

102 The thickness requirement corresponding to lateral pressure is given by:

$$t = \frac{15.8 k_a\, s \sqrt{p}}{\sqrt{\sigma}} + t_k \qquad \text{(mm)}$$

p = $p_1 - p_{13}$, whichever is relevant, as given in Table B1
σ = allowable stress within 0.4 L, given by:

Transversely stiffened	*Longitudinally stiffened*
$175\, f_1 - 120\, f_{2d}$, maximum $120\, f_1$	$120\, f_1$

σ = 160 f_1 within 0.1 L from the perpendiculars and within line of large deck openings.

Between specified regions the σ-value may be varied linearly.

f_{2D} = stress factor as given in A 200.

103 The longitudinal buckling strength shall be checked according to Sec.13.

104 The thickness shall not be less than:

$$t = t_0 + \frac{k L_1}{\sqrt{f_1}} + t_k \quad \text{(mm)}$$

t_0 = 5.5 for unsheathed weather and cargo decks
= 5.0 for accommodation decks and for weather and cargo decks sheathed with wood or an approved composition
k = 0.02 in vessels with single continuous deck
= 0.01 in vessels with two continuous decks above 0.7 D from the baseline
= 0.01 as minimum for weather decks forward of 0.2 L from F.P.
= 0 in vessels with more than two continuous decks above 0.7 D from the baseline.

105 If the end bulkhead of a long superstructure is located within 0.5 L amidships, the stringer plate shall be increased in thickness for a length of 3 m on each side of the superstructure end bulkhead. The increase in thickness shall be 20%.

C 200 Plating of decks below or above strength deck

201 The thickness requirement corresponding to lateral pressure is given by the formula in 102 when σ= 160 f_1.

202 The thickness of steel decks shall not be less than:

$$t = t_0 + \frac{k L_1}{\sqrt{f_1}} + t_k \quad \text{(mm)}$$

t_0 = as given in 104
k = 0.01 for 'tween deck above 0.7 D in vessels with two continuous decks above 0.7 D from the baseline and first tier of superstructure or deckhouse in vessels with single continuous deck when more than 50% of 0.4 L amidships is covered
= 0.01 for forecastle decks forward of 0.2 L from F.P.
= 0 for other decks.

C 300 Longitudinals

301 The section modulus requirement is given by:

$$Z = \frac{83\, l^2 s\, p\, w_k}{\sigma} \quad (\text{cm}^3), \quad \text{minimum } 15 \text{ cm}^3$$

p = $p_1 - p_{13}$, whichever is relevant, as given in Table B1.
σ = allowable stress, within 0.4 L midship given in Table C1
= 160 f_1 for continuous decks within 0.1 L from the perpendiculars and for other deck longitudinals in general.

Between specified regions the σ-value shall be varied linearly.

For longitudinals σ= 160 f_1 may be used in any case in combination with heeled condition pressures p_9 and sloshing load pressures, p_{11} and p_{12}.

For definition of other parameters used in the formula, see A200.

302 The buckling strength of longitudinals shall be checked according to Sec.13.

303 The web and flange thickness shall not be less than the larger of:

t = $4.5 + k + t_k$ (mm)

= $1.5 + \frac{h_w \sqrt{f_1}}{g} + t_k$

k = $0.01\ L_1$ in general
= $0.015\ L_1$ in peaks and for boundaries of cargo oil tanks and ballast tanks in cargo area
= 0.5 for accommodations decks above strength deck
h_w = web height in mm
g = 75 for flanged profile webs
= 41 for bulb profiles
= 22 for flat bar profiles
t_k = corrosion addition, see Sec.1B
peaks = extent is defined in Sec.1B.

For definition of other parameters used in the formula, see A200.

304 Longitudinals supported by deck transverses subject to relatively large deflections shall be checked by direct strength calculation, see Sec.12 C. Increased bending stresses at transverse bulkheads shall be evaluated and may be absorbed by increased end brackets.

C 400 Transverse beams.

401 The section modulus requirement is given by:

$$Z = \frac{0.63\, l^2\, s\, p\, w_k}{f_1} \quad (\text{cm}^3), \quad \text{minimum } 15\ \text{cm}^3$$

p = $p_1 - p_{13}$, whichever is relevant, as given in Table B1.

402 The thickness of web and flange shall not be less than given in 303.

403 For end connections, see Sec.3 C200.

404 For beam-panel buckling, see Sec.13 C501.

Table C1	
Deck	σ
Strength deck, long superstructures and effective deckhouses above strength deck	$225\ f_1 - 130\ f_{2d}$, maximum 160 f_1
Continuous decks below strength deck	$225 f_1 - 130 f_{2d} \frac{z_n - z_a}{z_n}$ maximum 160 f_1

D. Girders

D 100 General

101 The thickness of web plates, flanges, brackets and stiffeners of girders shall not be less than:

$$t = 5.0 + \frac{k}{\sqrt{f_1}} + t_k \quad (\text{mm})$$

k = $0.01\ L_1$ in general
= $0.02\ L_1$ for girder webs, flanges and brackets in cargo oil tanks and ballast tanks in cargo area
= $0.03\ L_1$ (= 6.0 maximum) for girder webs, flanges and brackets in peaks.

The thickness of girder web plates is in addition not to be less than:

$$t = 12\ s + t_k \quad (\text{mm})$$

s = spacing of web stiffening in m.

102 The buckling strength of web plates subject to in- plane compressive and shear stresses shall be checked according to Sec.13.

103 Longitudinal deck girders above tanks shall be fitted in line with transverse bulkhead verticals.

The flange area shall be at least 1/7 of the sectional area of the web plate, and the flange thickness shall be at least 1/30 of the flange width. For flanges subject to compressive stresses the thickness shall be taken as 0.1 b_f, b_f being the flange width when asymmetric and half the flange width when symmetric.

104 Deck transverses shall be fitted in the lowest deck in engine room, in line with the side verticals. The depth of the deck transverses shall be at least 50% of the depth of the side verticals, web thickness and face plate scantlings being as for side verticals.

105 The thickness of girder stiffeners and brackets shall not be less than given in 102.

106 The end connections and stiffening of girders shall be arranged as given in Sec.3 C.

D 200 Simple girders

201 The section modulus requirement for simple girders is given by:

$$Z = \frac{100\, S^2\, b\, p\, w_k}{\sigma} \quad (\text{cm}^3)$$

p = $p_1 - p_6$
= 1.15 p_7
= $p_8 - p_{13}$, whichever is relevant, as given in Table B1.
b = loading breadth in m

σ = $190 f_1 - 130 f_{2d} \frac{z_n - z_a}{z_n}$, maximum 160 f_1

for continuous longitudinal girders within 0.4 L amidships
= 160 f_1 for transverse girders and longitudinal girders within 0.1 L from perpendiculars.

Between specified regions the σ-value may be varied linearly. For longitudinal girders σ = 160 f_1 may be used in any case in combination with heeled condition pressures p_9 and p_{11}.

f_{2d} = stress factor as given in A 200.

202 The web area requirement (after deduction of cut-outs) at the girder ends is given by:

$$A = \frac{0.07\, S\, b\, p}{f_1} + 10\, h\, t_k \quad (\text{cm}^2)$$

p = as given in 201
b = as given in 201
h = girder height in m.

The web area at the middle of the span shall not be less than 0.5 A.

203 For stiffness in connection with panel buckling, see Sec.13 C502.

D 300 Complex girder systems

301 In addition to fulfilling the general local requirements given in 100, the main scantlings of deck girders being part of complex girder systems in holds or tanks for heavy cargo or liquids may have to be based on a direct stress analysis as outlined in Sec.12.

E. Special requirements

E 100 Transverse strength of deck between hatches

101 In ships with large hatch openings, it shall be examined that the effective deck area between hatches is sufficient to withstand the transverse load acting on the ship's sides. Bending and shear stresses may also arise as result of loading on the transverse bulkhead supported by the deck area, and also as result of displacements caused by torsion in the hull girder. Reinforcements to reduce the additional stresses will be considered in each case. The effective area is defined as:

— deck plating
— transverse beams
— deck transverses

— hatch end beams (after special consideration)
— cross section of stool tank at top of transverse bulkhead
— cross section of transverse bulkhead (if plane or horizontally corrugated) down to base of top wing tank, or to 0.15 D from deck.

When calculating the effective area, corrosion additions shall be deducted.

The compressive stress shall not exceed 120 f_1 N/mm^2 nor 80% of the critical buckling stress of the deck, bulkhead and stool tank plating.

The buckling strength of stiffeners and girders shall be examined.

E 200 Strength of deck outside large hatches

201 The strength of deck and ship's side in way of long and wide hatches as given in Sec.5 A106 is, as applicable, to be examined by direct calculation of bending moments, torsional moments, shear forces and deflections due to loads caused by the sea and the deck cargo as given in Pt.5 Ch.2 Sec.6 C.

E 300 Pillars in tanks

301 Solid pillars shall be used.

302 Where the hydrostatic pressure may give tensile stresses in the pillars, their sectional area shall not be less than:

$$A = 0.07\, A_{DK}\, p_t \quad (\mathrm{cm}^2)$$

A_{DK} = deck area in m^2 supported by the pillar
p_t = design pressure p in kN/m^2 giving tensile stress in the pillar.

Doubling plates at ends are not allowed.

E 400 Strengthening against liquid impact pressure in larger tanks

401 If the deck forms boundary of larger ballast or cargo tanks with free sloshing length $l_s > 0.13$ L and or breadth $b_s > 0.56$ B, the deck structure shall have scantlings according to Sec.9 E400 for impact loads referred to in Sec.4 C305.

SECTION 9 BULKHEAD STRUCTURES

A. General

A 100 Introduction

101 The requirements in this section apply to bulkhead structures.

102 The formulae given for plating, stiffeners and girders are based on the structural design principles outlined in Sec.3 B. In most cases, however, fixed values have been assumed for some variable parameters such as:

— aspect ratio correction factor for plating
— bending moment factor m for stiffeners and girders.

Where relevant, actual values for these parameters may be chosen and inserted in the formulae. Direct stress calculations based on said structural principles and as outlined in Sec.12 will be considered as alternative basis for the scantlings.

A 200 Definitions

201 Symbols:

L = rule length in m [1)]
B = rule breadth in m [1)]
D = rule depth in m [1)]
T = rule draught in m [1)]
C_B = rule block coefficient [1)]
L_1 = L, but need not be taken greater than 300 m
t = rule thickness in mm of plating
Z = rule section modulus in cm^3 of stiffeners and simple girders
k_a = correction factor for aspect ratio of plate field
= $(1.1 - 0.25\ s/l)^2$
= maximum 1.0 for $s/l = 0.4$
= minimum 0.72 for $s/l = 1.0$
s = stiffener spacing in m, measured along the plating. For corrugations, see 203
l = stiffener span in m, measured along the topflange of the member. For definition of span point, see Sec.3 C100. For curved stiffeners l may be taken as the cord length
S = girder span in m. For definition of span point, see Sec.3 C100
z_n = vertical distance in m from the baseline or deckline to the neutral axis of the hull girder, whichever is relevant
z_a = vertical distance in m from the baseline or deckline to the point in question below or above the neutral axis, respectively
f_1 = material factor
= 1.0 for NV-NS steel [2)]
= 1.08 for NV-27 steel [2)]
= 1.28 for NV-32 steel [2)]
= 1.39 for NV-36 steel [2)]
= 1.47 for NV-40 steel [2)]
f_{2b} = stress factor below neutral axis of hull girder as defined in Sec.6 A200
f_{2d} = stress factor above neutral axis of hull girder as defined in Sec.8 A200
w_k = section modulus corrosion factor in tanks, see Sec.3 C1004
= 1.0 in other compartments
σ = nominal allowable bending stress in N/mm^2 due to lateral pressure
p = design pressure in kN/m^2 as given in B.

1) For details see Sec.1 B.
2) For details see Sec.2 B and C.

202 The load point where the design pressure shall be calculated is defined for various strength members as follows:

— For plates: Midpoint of horizontally stiffened plate field.
  Half of the stiffener spacing above the lower support of vertically stiffened plate field, or at lower edge of plate when the thickness is changed within the plate field.
— For stiffeners: Midpoint of span.
  When the pressure is not varied linearly over the span, the design pressure shall be taken as the greater of:

$$p_m \quad \text{and} \quad \frac{p_a + p_b}{2}$$

p_m, p_a and p_b are calculated pressures at the midpoint and at each end respectively.

— For girders: Midpoint of load area.

203 For corrugated bulkheads the following definition of spacing applies (see Fig.1):

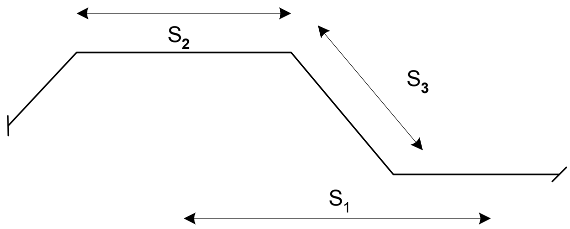


Fig. 1
Corrugated bulkhead

s = s_1 for section modulus calculations
= 1.05 s_2 or 1.05 s_3 for plate thickness calculations in general
= s_2 or s_3 for plate thickness calculation when 90° corrugations.

A 300 Structural arrangement and details

301 Number and location of transverse watertight bulkheads shall be in accordance with the requirements given in Sec.3.

302 The peak tanks shall have centre line wash bulkheads when the breadth of the tank is greater than 2/3 of the moulded breadth of the ship.

303 Within 0.5 L amidships, in the areas 0.15 D above the bottom and 0.15 D below the strength deck, the continuity of bulkhead longitudinals shall be as required for bottom and deck longitudinals respectively.

304 Weld connections shall satisfy the general requirements given in Sec.11.

305 For end connections of stiffeners and girders, see Sec.3 C.

306 "Stern tubes shall be enclosed in a watertight space (or spaces) of moderate volume". (SOLAS Ch.II-1/11.9) In case the stern tube terminates at an afterpeak bulkhead also being a machinery space bulkhead, a pressurized stern tube sealing system may be accepted as an alternative to the watertight enclosure.

B. Design loads

B 100 Local loads on bulkhead structures

101 All generally applicable local loads on bulkhead structures are given in Table B1, based upon the general loads given in Sec.4. In connection with the various local structures reference is made to this table, indicating the relevant loads in each case.

Table B1 Design loads

Structure		*Load type*	*p (kN/m²)*
Watertight bulkheads		Sea pressure when flooded or general dry cargo minimum	$p_1 = 10\ h_b$
Cargo hold bulkheads		Dry bulk cargo	$p_2 = \rho_c\ (g_0 + 0.5\ a_v)\ K\ h_c$
Tank bulkheads in general		Ballast, bunker or liquid cargo	$p_3 = \rho\ (g_0 + 0.5\ a_v)\ h_s$ $p_4 = 0.67\ (\rho\ g_0\ h_p + \Delta\ p_{dyn})$ $p_5 = \rho\ g_0\ h_s + p_0$
Longitudinal bulkheads as well as transverse bulkheads at sides in wide tanks	In tanks with breadth > 0.4 B	Ballast, bunker or liquid cargo	$p_6 = \rho g_0 [0,67(h_s + \phi b) - 0,12 \sqrt{H\ \phi\ b_t}]$
Longitudinal bulkheads as well as transverse bulkheads at sides in wide tanks	Note 1)	Ballast, bunker or liquid cargo	$p_7 = \rho\left[3 - \frac{B}{100}\right] b_b$
Transverse bulkheads and longitudinal bulkheads at ends in long tanks	In tanks with length > 0.15 L	Ballast, bunker or liquid cargo	$p_8 = \rho g_0 [0,67(h_s + \theta l) - 0,12 \sqrt{H\ \theta\ l_t}]$
Transverse bulkheads and longitudinal bulkheads at ends in long tanks	Note 2)	Ballast, bunker or liquid cargo	$p_9 = \rho\left[4 - \frac{L}{200}\right] l_b$
Longitudinal wash bulkheads		Ballast, bunker or liquid cargo	$p_7 = \rho\left[3 - \frac{B}{100}\right] b_b$
Transverse wash bulkheads		Ballast, bunker or liquid cargo	$p_9 = \rho\left[4 - \frac{L}{200}\right] l_b$

1) To be used for strength members located less than 0.25 b_b away from tank sides in tanks with no restrictions on their filling height. For tanks with free breadth (no longitudinal wash bulkheads) b_b > 0.56 B the design pressure will be specially considered according to Sec.4 C305.

2) To be used for strength members located less than 0.25 l_b away from tank ends in tanks with no restrictions on their filling height. For tanks with free length (no transverse wash bulkheads or transverse web frames in narrow tanks) l_b > 0.13 L the design pressure will be specially considered according to Sec.4 C305.

h_b = vertical distance in metres from the load point to the deepest equilibrium waterline in damaged condition obtained from applicable damage stability calculations. The deepest equilibrium waterline in damaged condition should be indicated on the drawing of the bulkhead in question.
The vertical distance shall not be less than up to the bulkhead deck

a_v = vertical acceleration in m/s² as given in Sec.4 B600

ρ_c = dry cargo density in t/m³ if not otherwise specified to be taken as 0.7

ρ = density of ballast, bunker or liquid cargo in t/m³, normally not to be taken less than 1.025 (i.e. $\rho g_0 \approx 10$)

K = $\sin^2 \alpha \tan^2 (45 - 0.5\ \delta) + \cos^2 \alpha$
= $\cos \alpha$ minimum

α = angle between panel in question and the horizontal plane in degrees

δ = angle of repose of cargo in degrees, not to be taken greater than 20° for light bulk cargo (coal, grain) and not greater than 35° for heavy bulk cargo (ore)

h_s = vertical distance in m from the load point to the top of tank or hatchway excluding smaller hatchways

h_c = vertical distance in m from the load point to the highest point of the hold including hatchway in general. For sloping and vertical sides and bulkheads, h_c may be measured to deck level only, unless the hatch coaming is in line with or close to the panel considered.
In dry cargo 'tweendecks, h_c may be taken to the nearest deck above

h_p = vertical distance in m from the load point to the top of air pipe

Δp_{dyn} = as given in Sec.4 C300

H = height in m of tank

p_0 = 25 in general
= 15 in ballast holds in dry cargo vessels
= tank pressure valve opening pressure when exceeding the general value

b = the largest athwartship distance in m from the load point to the tank corner at the top of tank/ hold most distant from the load point

b_t = breadth in m of top of tank/hold

l = the largest longitudinal distance in m from the load point to the tank corner at top of tank most distant from the load point

l_t = length in m of top of tank
ϕ = roll angle in radians as given in Sec.4 B400
θ = pitch angle in radians as given in Sec.4 B500
b_b = distance in m between tank sides or effective longitudinal wash bulkhead at the height at which the strength member is located
l_b = distance in m between transverse tank bulkheads or effective transverse wash bulkheads at the height at which the strength member is located. Transverse webframes covering part of the tank cross section (e.g. wing tank structures in tankers) may be regarded as wash bulkheads.

C. Plating and stiffeners

C 100 Bulkhead plating

101 The thickness requirement corresponding to lateral pressure is given by:

$$t = \frac{15.8 k_a s \sqrt{p}}{\sqrt{\sigma}} + t_k \quad \text{(mm)}$$

p = $p_1 - p_9$, whichever is relevant, as given in Table B1
σ = 160 f_1 for longitudinally stiffened longitudinal bulkhead plating at neutral axis irrespective of ship length
= 140 f_1 for transversely stiffened longitudinal bulkhead plating at neutral axis within 0.4 L amidships, may however be taken as 160 f_1 when p_6 or p_7 are used.
Above and below the neutral axis the σ-values shall be reduced linearly to the values for the deck and bottom plating, assuming the same stiffening direction and material factor as for the plating considered
= 160 f_1 for longitudinal bulkheads outside 0.05 L from F.P. and 0.1 L from A.P. and for transverse bulkheads in general
= 220 f_1 for watertight bulkheads except the collision bulkhead, when p_1 is applied.

Between specified regions the σ-value may be varied linearly.

In corrugated bulkheads formed by welded plate strips, the thickness in flange and web plates may be differing. The thickness requirement then is given by the following modified formula:

$$t = \sqrt{\frac{500 s^2 p}{\sigma} - t_n^2} + t_k \quad \text{(mm)}$$

t_n = thickness in mm of neighbouring plate (flange or web), not to be taken greater than t.

102 The thickness shall not be less than:

$$t = 5.0 + \frac{k L_1}{\sqrt{f_1}} + t_k \quad \text{(mm)}$$

k = 0.03 for longitudinal bulkheads except double skin bulkheads in way of cargo oil tanks and ballast tanks in liquid cargo tank areas
= 0.02 in peak tanks and for transverse and double skin longitudinal bulkheads in way of cargo oil tanks and ballast tanks in liquid cargo tank areas
= 0.01 for other bulkheads.

103 The thickness of longitudinal bulkhead plating is also to satisfy the buckling strength requirements given in Sec.13, taking into account combined shear and in- plane compressive stresses where relevant.

104 In longitudinal bulkheads within the cargo area the thickness shall not be less than:

$$t = \frac{1000 s}{120 - 3\sqrt{L_1}} + t_k \quad \text{(mm)}$$

105 The buckling strength of corrugation flanges at the middle length of corrugations shall be controlled according to Sec.13, taking k_l in Sec.13 B201 equal to 5.

Usage factors to be applied:

η = 0.80 for cargo tank bulkheads, cargo hold bulkheads when exposed to dry cargo or ballast pressure, and collision bulkheads
= 1.0 for watertight bulkheads.

106 For plates in afterpeak bulkhead in way of sterntube, increased thickness or doubling may be required.

107 For wash bulkhead plating, requirement for thicknesses may have to be based on the reaction forces imposed on the bulkhead by boundary structures.

C 200 Longitudinals

201 The section modulus requirement for stiffeners and corrugations is given by:

$$Z = \frac{83\, l^2 s\, p\, w_k}{\sigma} \quad (\text{cm}^3), \text{ minimum } 15 \text{ cm}^3$$

p = $p_1 - p_9$, whichever is relevant, as given in Table B1

σ = $225 f_1 - 130 f_2 \frac{z_n - z_a}{z_n}$, maximum 160 f_1

within 0.4 L amidships

= 160 f_1 within 0.1 L from perpendiculars.

Between specified regions the σ-value may be varied linearly. For longitudinals σ= 160 f_1 may be used in any case in combination with heeled condition pressures p_6 to p_7 and with sloshing pressure p_9.

The allowable stress may be increased by 60 f_1 for watertight bulkheads, except the collision bulkhead, when p_1 is applied.

f_2 = stress factor f_{2b} as given in Sec.6 A200 below the neutral axis
= stress factor f_{2d} as given in Sec.8 A200 above the neutral axis.

202 The web and flange thickness shall not be less than the larger of:

t = $4.5 + k + t_k$ (mm)

= $1.5 + \frac{h_w \sqrt{f_1}}{g} + t_k$

k = 0.01 L_1 in general
= 0.015 L_1 in peak tanks and in cargo oil tanks and ballast tanks in cargo area
h_w = web height in mm
g = 75 for flanged profile webs
= 41 for bulb profiles
= 22 for flat bar profiles.

203 Longitudinals supported by vertical girders subject to relatively large deflections shall be checked by a direct strength calculation, see Sec.12 C. Increased bending stresses at transverse bulkheads shall be evaluated and may be absorbed by increased end brackets.

204 The buckling strength of longitudinals shall be checked according to Sec.13.

C 300 Vertical and transverse stiffeners on tank, wash, dry bulk cargo, collision and watertight bulkheads

301 Transverse bulkheads for ballast and bulk cargo holds are normally built with strength members only in the vertical direction (corrugations or double plane bulkheads), having unsupported spans from deck to inner bottom. In larger ships, stool tanks are often arranged at the lower and upper end of the bulkhead. The scantlings of such bulkheads are normally to be based on a direct calculation, taking into account the reactions and supporting effect from double bottom and deck structure, see Sec.12.

302 The section modulus requirement for simple stiffeners and corrugations is given by:

$$Z = \frac{1000\, l^2 s\, p\, w_k}{\sigma m} \quad (\text{cm}^3)$$

p = $p_1 - p_9$, whichever is relevant, as given in Table B1
σ = 160 f_1 for tank, cargo and collision bulkheads (see also 105)
= 220 f_1 for watertight bulkheads (see also 105)
m = 7.5 for vertical stiffeners simply supported at one or both ends
= 10 for transverse stiffeners and vertical stiffeners which may be considered fixed at both ends
= 10 for horizontal corrugations fixed at ends

= 13 for vertical corrugation, upper end if fixed
= 20 for vertical corrugation, upper end if flexible
= m_s for vertical corrugation, lower end to stool

= $\frac{8m_s}{m_s - 4}$ for vertical corrugation at middle of span

m(max) = 13

$$m_s = 7.5\left[1 + \frac{4 b_c\left(H_S + \frac{h_{db}}{2}\right)}{b_s l_{db}}\right]$$

b_c = breadth of stool in m where corrugation is welded in
b_s = breadth of stool in m at inner bottom
H_S = height of stool in m
h_{db} = height of double bottom in m
l_{db} = length of cargo hold double bottom between stools in m not to be taken larger than 6 H_S or 6 h_{db} if no stool.

The m-value may be adjusted for members with boundary condition not corresponding to the above specification or a direct calculation including the supporting boundary structure may be done, see Sec.12.

303 The thickness of web and flanges shall not be less than given in 202. For corrugations the flanges shall have thickness satisfying buckling as given in 105.

304 Brackets are normally to be fitted at ends of non-continuous stiffeners. For end connections, see also Sec.3 C200.

305 If brackets are not welded in line with the corrugation webs, the end plating in upper and lower stool shall have a thickness not less than 0.8 times the corrugation flange thickness. The section modulus is then to be based on the corrugation flange only as the web will not be supported. For corrugations arranged with a slanting plate the effect of the slanting plate may be taken into consideration. This effect will increase the section modulus Z of the corrugation on the side where the slanting plate is fitted and hence reduce the nominal stresses. A maximum increased Z of 15% may be accepted. Tank bulkheads in oil and chemical carriers normally need brackets in line with corrugation webs. The stool sides or floors in the double bottom shall have thickness corresponding to the forces coming from the corrugation flanges with the allowable stresses as given in 302 and controlled for buckling as given in Sec.13.

D. Girders

D 100 General

101 The thickness of web plates, flanges, brackets and stiffeners of girders shall not be less than:

$$t = 5.0 + \frac{k}{\sqrt{f_1}} + t_k \quad \text{(mm)}$$

k = 0.01 L_1 in general
= 0.02 L_1 for girder webs, flanges and brackets in cargo oil tanks and ballast tanks in cargo area
= 0.03 L_1 (= 6.0 maximum) for girder webs, flanges and brackets in peaks

The thickness of girder web plates is in addition not to be less than:

$$t = 12 s + t_k \quad \text{(mm)}$$

s = spacing of web stiffening in m.

102 The buckling strength of web plates subject to in- plane compressive and shear stresses shall be checked according to Sec.13.

103 The end connections and stiffening of girders shall be arranged as given in Sec.3 C.

D 200 Simple girders

201 The section modulus requirement for simple girders is given by:

$$Z = \frac{100\, S^2\, b\, p\, w_k}{\sigma} \quad (cm^3)$$

p = $p_1 - p_3$
= $1.15\, p_4$
= $p_5 - p_9$, whichever is relevant, as given in Table B1.
b = loading breadth in m

σ = $190 f_1 - 130 f_2 \frac{z_n - z_a}{z_n}$, minimum 160 f_1

for continuous longitudinal girders within 0.4 L amidships
= 160 f_1 for other girders.

The allowable stress may be increased by 60 f_1 (40 f_1 for longitudinal girders within 0.4 L amidships) for watertight bulkheads, except the collision bulkhead, when p_1 is applied.

Between specified regions the σ-value may be varied linearly. For longitudinal girders σ = 160 f_1 may be used in any case in combination with heeled condition pressures p_6 and p_7.

f_2 = stress factor f_{2b} as given in Sec.6 A200 below the neutral axis
= stress factor f_{2d} as given in Sec.8 A200 above the neutral axis.

202 The web area requirement (after deduction of cut-outs) at the girder ends is given by:

$$A = \frac{c\, k\, S\, b\, p}{f_1} + 10\, h\, t_k \quad (cm^2)$$

p = as given in 201
k = 0.06 for stringers and upper end of vertical girders
= 0.08 for lower end of vertical girders
c = 0.75 for watertight bulkheads, except the collision bulkhead, when p_1 is applied
= 1.0 in all other cases
b = as given in 201
h = girder height in m.

The web area at the middle of the span shall not be less than 0.5 A.

D 300 Complex girder systems

301 In addition to fulfilling the general local requirements given in 100, the main scantlings of bulkhead girders being parts of complex girder systems in holds or tanks for heavy cargo or liquids, may have to be based on a direct stress analysis as outlined in Sec.12.

E. Special requirements

E 100 Shaft tunnels

101 In ships with engine room situated amidships, a watertight shaft tunnel shall be arranged. Openings in the forward end of shaft tunnels shall be fitted with watertight sliding doors capable of being operated from a position above the load waterline.

102 The thickness of curved top plating may be taken as 90% of the requirement to plane plating with the same stiffener spacing.

103 If ceiling is not fitted on top plating under dry cargo hatchway openings, the thickness shall be increased by 2 mm.

104 The shaft tunnel may be omitted in ships with service restriction notation **R2**, **R3** and **R4** provided the shafting is otherwise effectively protected. Bearings and stuffing boxes shall be accessible.

E 200 Corrugated bulkheads

201 The lower and upper ends of corrugated bulkheads and those boundaries of vertically corrugated bulkheads connected to ship sides and other bulkheads shall have plane parts of sufficient width to support the adjoining structures.

202 Girders on corrugated bulkheads are normally to be arranged in such a way that application of the bulkhead as girder flange is avoided.

203 End connections for corrugated bulkheads terminating at deck or bottom shall be carefully designed. Supporting structure in line with corrugation flanges shall be arranged below an inner bottom.

E 300 Supporting bulkheads

301 Bulkheads supporting decks shall be regarded as pillars. The compressive loads and buckling strength shall be calculated as indicated in Sec.13 assuming:

i = radius of gyration in cm of stiffener with adjoining plate. Width of adjoining plate shall be taken as 40 t, where t = plate thickness

Local buckling strength of adjoining plate and torsional buckling strength of stiffeners shall be checked

302 Section modulus requirement to stiffeners:

$$Z = 2\, l^2\, s \quad (\text{cm}^3)$$

303 The distance between stiffeners shall not be greater than 2 frame spacings, and shall not exceed 1.5 m.

304 The plate thickness shall not be less than 7.5 mm in the lowest hold and 6.5 mm in 'tween decks.

305 On corrugated bulkheads, the depth of the corrugations shall not be less than 150 mm in the lower holds and 100 mm in the upper 'tween deck.

E 400 Strengthening against liquid impact pressure in larger tanks

401 Tanks with free sloshing length $l_s > 0.13$ L and or breadth $b_s > 0.56\, Bp_i$ shall be strengthened for the impact pressure as given in Sec.4 C305.

402 Plating subjected to impact pressure p_i. The thickness shall not be less than:

$$t = \frac{0.9\, k_a\, s \sqrt{p_i}}{\sqrt{f_1}} + t_k \quad (\text{mm})$$

403 Stiffeners supporting plating subjected to impact pressure p_i. The section modulus shall not be taken less than:

$$Z = \frac{0.5\, l\, l_p\, s\, p_i\, k_p\, w_k}{f_1} \quad (\text{cm}^3)$$

The shear area at each end shall not be less than:

$$A_S = \frac{0.05\, l\, (l_p - s)\, s\, p_i\, k_p}{l_p f_1} + 10\, h\, t_k \quad (\text{cm}^2)$$

l_p = loaded length of stiffener, maximum l, but need not be taken greater than 0.1 l_s or 0.1 b_s, respectively, for longitudinal or transverse impact pressure
k_p = correction factor for resulting impact pressure

= $1.1 - 10\, \frac{l}{l'_s}$, minimum 0.35.

l'_s = l_s or b_s as defined in Sec.4 C306
h = height in m of stiffener.

If the impact pressure is acting on the stiffener side, the stiffener web thickness shall not be less than:

$$t = 5 + \frac{s\, p_i}{100 f_1} + t_k \quad (\text{mm})$$

The throat thickness of continuous fillet welding of the stiffener to the plating when impact pressure is acting on the stiffener side shall not be less than:

$$t = \frac{s\, p_i}{120} + \frac{t_k}{2} \quad (\text{mm})$$

A proper fit up between stiffener and plating is assumed.

The net connection area of continuous stiffeners at girders shall satisfy the following expression:

$$1.7\ A_F + A_W = 2\ A_S$$

A_F = connection area at flange in cm^2
A_W = connection area at web in cm^2.

404 Girders supporting stiffeners subjected to impact pressure p_i.
The section modulus shall not be less than:

$$Z = \frac{0.5\ S\ S_p\ b\ p_i\ k_p\ w_k}{f_1} \qquad (cm^3)$$

The shear area at each end shall not be taken less than:

$$A_S = \frac{0.05\ S\ b\ p_i\ k_p}{f_1} + 10\ h\ t_k \qquad (cm^2)$$

S_p = loaded length of girder, maximum S, but need not be taken greater than 0.1 l_s or 0.1 b_s, respectively, for longitudinal or transverse impact pressure
k_p = correction factor for impact pressure

= $1.1 - 10\frac{b}{l'_s}$, minimum 0.25 for horizontals
= $1.1 - 10\frac{S_p}{l'_s}$, minimum 0.25 for verticals

l'_s = l_s or b_s as defined in Sec.4 C306
h = height in m of girder web
b = loading breadth of girder in m.

The web thickness is in no case to be less than:

$$t = 6.5 + \frac{0.2\sqrt{p_i}}{\sqrt{f_1}} + t_k \qquad (mm)$$

The throat thickness of continuous fillet welding of girder webs to the plating subjected to impact pressure is acting on the girder web side shall not be less than:

$$t = \frac{s\ p_i}{120} + \frac{t_k}{2} \qquad (mm)$$

A proper fit up between stiffener and plating is assumed.

The spacing of stiffeners on the web plate for girders in the tank where impact pressure occurs shall not be taken greater than:

$$s = \frac{1.2(t - t_k)}{\sqrt{p_i}} \qquad (m)$$

p_i = impact pressure at panel near girder.

SECTION 10 SUPERSTRUCTURE ENDS, DECKHOUSE SIDES AND ENDS, BULWARKS

A. General

A 100 Introduction

101 In this section the requirements applicable to superstructure end bulkheads, deckhouse sides and ends and bulwarks are collected. The requirements for sides of superstructures and decks above superstructures and deckhouses are given in Sec.7 and 8 respectively.

Requirements for protection of crew as given by ICLL Regulation 25 supplemented by relevant IACS interpretations are also included (see Ch.3 Sec.8). Other relevant requirements given in the ICLL regulations are included in Ch.3 Sec.6.

A 200 Definitions

201 Symbols:

L = rule length in m, see Sec.1 B
B = rule breadth in m, see Sec.1 B
C_B = rule block coefficient, see Sec.1 B
t = rule thickness in mm of plating
Z = rule section modulus in cm^3 of stiffeners and simple girders
L_1 = L, but need not be taken greater than 300 m
k_a = correction factor for aspect ratio of plate field
= $(1.1 - 0.25\ s/\ l)^2$
= maximum 1.0 for $s/\ l = 0.4$
= minimum 0.72 for $s/\ l = 1.0$
s = stiffener spacing in m, measured along the plating
l = stiffener span in m, measured along the topflange of the member. For definition of span point, see Sec.3 C100. For curved stiffeners l may be taken as the cord length
f_1 = material factor
= 1.0 for NV-NS steel 1)
= 1.08 for NV-27 steel 1)
= 1.28 for NV-32 steel 1)
= 1.39 for NV-36 steel 1)
= 1.47 for NV-40 steel 1)
σ = nominal allowable bending stress in N/mm^2 due to lateral pressure
p = design pressure in kN/m^2 as given in C.

1) For details see Sec.2 B and C.

202 *Superstructure* is defined as a decked structure on the freeboard deck, extending from side to side of the ship or with the side plating not inboard of the shell plating more than 4% of the breadth (B).

203 *Deckhouse* is defined as a decked structure above the strength deck with the side plating being inboard of the shell plating more than 4% of the breadth (B).

Long deckhouse = deckhouse having more than 0.2 L of its length within 0.4 L amidships.

Short deckhouse = deckhouse not defined as a long deckhouse.

B. Structural arrangement and details

B 100 Structural continuity

101 In superstructures and deckhouses aft, the front bulkhead shall be in line with a transverse bulkhead in the hull below or be supported by a combination of partial transverse bulkheads, girders and pillars. The after end bulkhead is also to be effectively supported. As far as practicable, exposed sides and internal longitudinal and transverse bulkheads shall be located above tank bulkheads and or deep girder frames in the hull structure and shall be in line in the various tiers of accommodation. Where such structural arrangement in line is not possible, there shall be other effective support.

102 Sufficient transverse strength shall be provided by means of transverse bulkheads or girder structures.

103 At the break of superstructures, which have no set-in from the ship's side, the side plating of poop and bridge shall extend beyond the ends of the superstructure, and shall be gradually reduced in height down to the sheer strake. The transition shall be smooth and without local discontinuities. A substantial stiffener shall be fitted at the upper edge of plating, which extends beyond the superstructure. The plating is also to be additionally stiffened.

104 The end bulkheads of long superstructures shall be effectively supported by bulkheads or heavy girders below deck.

105 In long deckhouses, openings in the sides shall have well rounded corners. Horizontal stiffeners shall be fitted at the upper and lower edge of large openings for windows.

Openings for doors in the sides shall be substantially stiffened along the edges, and the side plates forming coamings below and above the doors, shall be continuous and extended well beyond the door openings. The thickness shall be increased locally or doubling plates shall be fitted.

The connection area between deckhouse corners and deck plating shall be increased locally.

Deck girders shall be fitted below long deckhouses in line with deckhouse sides. The girders shall extend three frame spaces forward and aft of the deckhouse ends. The depth of the girders shall not be less than that of the beams plus 100 mm. Girders shall be stiffened at the lower edge. The girder depth at ends may be equal to the depth of the beams.

Guidance note:

Expansion of long deckhouse sides should be taken into account by setting in parts of the sides towards the centre line of the ship.

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

106 Casings situated within 0.5 L amidships shall be stiffened longitudinally at the strength deck (e.g. at the lower edge of the half beams) to avoid buckling due to longitudinal compression forces.

B 200 Connections between steel and aluminium

201 To prevent galvanic corrosion a non-hygroscopic insulation material shall be applied between steel and aluminium when bolted connection.

202 Aluminium plating connected to steel boundary bar at deck is as far as possible to be arranged on the side exposed to moisture.

203 A rolled compound (aluminium/steel) bar may be used in a welded connection after special approval.

204 Direct contact between exposed wooden materials, e.g. deck planking, and aluminium shall be avoided.

205 Bolts with nuts and washers are either to be of stainless steel or cadmium plated or hot galvanized steel. The bolts shall be fitted with sleeves of insulating material. The spacing is normally not to exceed 4 times the bolt diameter.

206 For earthing of insulated aluminium superstructures, see Pt.4 Ch.8.

B 300 Miscellaneous

301 Companionways situated on exposed decks shall be of steel and efficiently stiffened.

302 Bulwark plates are in general not to be welded to side plating or deck plating (see also Sec.7 C208).

Long bulwarks shall have expansion joints within 0.6 L amidships.

303 Where bulwarks on exposed decks form wells, ample provision shall be made for freeing the decks of water.

304 Weld connections shall satisfy the general requirements given in Sec.11.

C. Design loads

C 100 External pressure

101 The design sea pressure for the various end and side structures is given in Table C1.

Table C1 Design loads		
Structure		*p (kN/m²)*
Unprotected front bulkheads	General	$p_1 = 5.7\ a\ (k\ C_W - h_o)\ c$
	Minimum lowest tier	$p_2 = 12.5 + 0.05\ L_1$
	Minimum elsewhere	$p_3 = 6.25 + 0.025\ L_1$
Unprotected sides in deckhouses		$p_4 = p_{dp} - (4 + 0.2\ k_s)\ h_o$, minimum p_3
Unprotected aft end bulkheads		$p_5 = 0.85\ p_4$, minimum p_3
1) For ships with service restrictions, p_1 and p_4 may be reduced with the percentages given in Sec.4 B202. C_W should not be reduced.		
2) The minimum design pressure for sides and aft end of deckhouses 1.7 C_W (m) above S.W.L. may be reduced to 2.5 kN/m².		

a $= 2.0 + \frac{L}{120}$ maximum 4.5 for the lowest tier front

$= 1.0 + \frac{L}{120}$ maximum 3.5 for 2nd tier front

$= 0.5 + \frac{L}{150}$ maximum 2.5 for 3rd tier front and above

k $= 1.3 - 0.6\frac{x}{L}$ for $\frac{x}{L} \le 0.5$

k $= 0.3 + 1.4\frac{x}{L}$ for $\frac{x}{L} > 0.5$

x = longitudinal distance in m from A.P. to the load point
h_o = vertical distance in m from the waterline at draught T to the load point

c $= 0.3 + 0.7\frac{b_1}{B_1}$

b_1 = breadth of deckhouse at position considered
B_1 = maximum breadth of ship on the weather deck at position considered

$\frac{b_1}{B_1}$ shall not be taken less than 0.25.

For unprotected parts of machinery casings c shall not be taken less than 1.0.

C_W = wave coefficient as given in Sec.4 B200
p_{dp}, k_s = as given in Sec.4 C201

D. Scantlings

D 100 End bulkheads of superstructures and deckhouses, and exposed sides in deckhouses

101 The thickness requirement for plating corresponding to lateral external pressure is given by:

$$t = \frac{15.8 k_a s \sqrt{p}}{\sqrt{\sigma}} \quad \text{(mm)}$$

p = $p_1 - p_5$, whichever is relevant, as given in Table C1
σ = 160 f_1 N/mm².

102 The thickness shall not be less than:

— for the lowest tier:

$$t = 5 + 0.01 L \text{ (mm), maximum 8 mm}$$

— for higher tiers:

$$t = 4 + 0.01 L \text{ (mm), maximum 7 mm, minimum 5 mm.}$$

103 The section modulus requirement for stiffeners is given by:

$$Z = \frac{100 l^2 s p}{\sigma} \quad (cm^3)$$

p = as given in 101
σ = 160 f_1 for longitudinals, vertical and transverse stiffeners in general
= 90 $f_1 \sigma$ for longitudinals at strength deck in long deckhouse within 0.4 L amidships. The value may be increased linearly to the general value at the first deck above the strength deck and at 0.1 L from the perpendiculars.

104 Front stiffeners shall be connected to deck at both ends with a connection area not less than:

$$a = \frac{0.07}{f_1} l s p \quad (cm^2)$$

Sniped ends may be allowed, however, for stiffeners above the 3rd tier provided the formula in Sec.3 C204 is fulfilled.

Side and after end stiffeners in the lowest tier of erections shall have end connections.

105 Deck beams under front and aft ends of deckhouses shall not be scalloped for a distance of 0.5 m from each side of the deckhouse corners.

D 200 Protected casings

201 The thickness of plating shall not be less than:

t = 8.5 s minimum 6.0 mm in way of cargo holds
= 6.5 s minimum 5.0 mm in way of accommodation.

202 The section modulus of stiffeners shall not be less than:

$$Z = \frac{3 l^2 s}{f_1} \quad (cm^3)$$

l = length of stiffeners in m, minimum 2.5 m.

203 Casings supporting one or more decks above shall be adequately strengthened.

D 300 Bulwarks

301 The thickness of bulwark plates shall not be less than required for side plating in a superstructure in the same position, if the height of the bulwarks is 1.8 m.

If the height of the bulwark is 1 metre or less the thickness need not be greater than 6.0 mm.

For intermediate heights, the thickness of the bulwark may be found by interpolation.

302 A strong bulb section or similar shall be continuously welded to the upper edge of the bulwark. Bulwark stays shall be spaced not more than 2 m apart, and shall be in line with transverse beams or local transverse stiffening, alternatively the toe of stay may be supported by a longitudinal member. The stays shall have sufficient width at deck level. The deck beam shall be continuously welded to the deck in way of the stay. Bulwarks on forecastle decks shall have stays fitted at every frame where the flare is considerable.

Stays of increased strength shall be fitted at ends of bulwark openings. Openings in bulwarks should not be situated near the end of superstructures.

D 400 Aluminium deckhouses

401 The strength of aluminium deckhouses shall be related to that required for steel deckhouses, see below.

The scantlings shall be based on the mechanical properties of the applied alloy. See Sec.2 C.

402 The minimum thicknesses given in 102 and 201 shall be increased by 1 mm.

403 For the section moduli requirements given in 100 and 200, f_1 need not be taken less than 0.6.

SECTION 11 WELDING AND WELD CONNECTIONS

A. General

A 100 Introduction

101 In this section requirements related to welding and various connection details are given.

A 200 Definitions

201 Symbols:

t_k = see Sec.1 B101.

B. Types of welded joints

B 100 Butt joints

101 For panels with plates of equal thickness, the joints are normally to be butt welded with edges prepared as indicated in Fig.1.

102 For butt welded joints of plates with thickness difference exceeding 4 mm, the thicker plate is normally to be tapered. The taper is generally not to exceed 1: 3. After tapering, the end preparation may be as indicated in 101 for plates of equal thickness.

103 All types of butt joints are normally to be welded from both sides. Before welding is carried out from the second side, unsound weld metal shall be removed at the root by a suitable method.

104 Butt welding from one side against permanent backing will only be permitted after special consideration when the stress level is low.

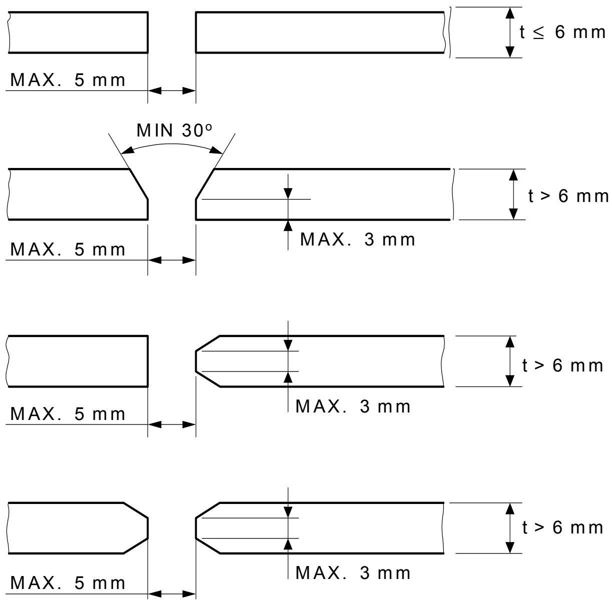


Fig. 1
Manually welded butt joint edges

B 200 Lap joints and slot welds

201 Various types of overlapped joints are indicated in Fig.2.

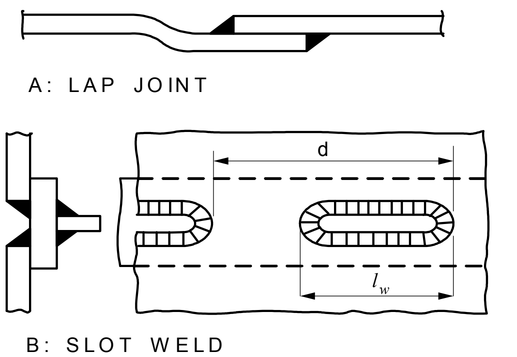


Fig. 2
Lap joints and slot welds

Type “A” (lap joint) may be used for connections dominated by shear- or in plane stresses acting parallel to the weld. Such overlaps will normally not be accepted for connections with high in plane stresses transverse to the weld. Stresses above 0.5* yield are taken as high in this context. Type “B” (slot weld) may be used for connection of plating to internal webs, where access for welding is not practicable.

Type “C” (filled slot weld) for plates subject to larger in plane transverse stresses where type “B” slot welding is not acceptable.

Type “B” and “C” joints shall not be used in case of pressure from abutting plate side or in tank boundaries.

For requirements to size of slot welds, see C600.

B 300 Tee or cross joints

301 The connection of girder and stiffener webs to plate panel as well as plating abutting on another plate panel, is normally to be made by fillet welds as indicated in Fig.3.

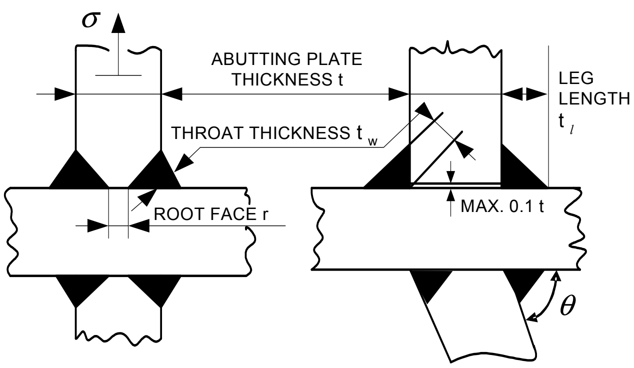


Fig. 3
Tee or cross joints

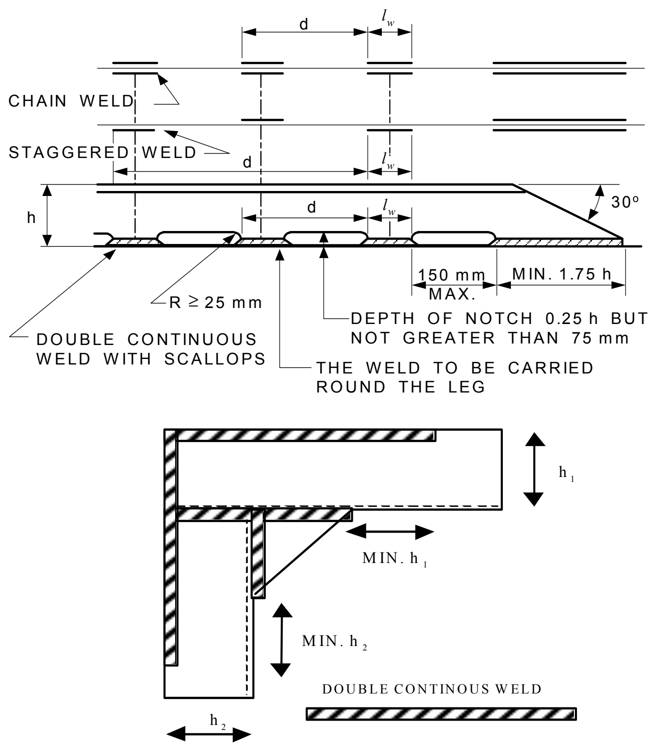
For fillet weld with opening angle θ (see Fig.3.) less than 75 deg., the net requirement in C103, C202 and C302 shall be increased by a factor $\sqrt{2}\cos(\theta/2)$.

Where the connection is highly stressed or otherwise considered critical, the edge of the abutting plate may have to be bevelled to give partial or full penetration welding, see also 304. For penetration welds, root face r and throat thickness t_w are defined as shown in Fig.3. In case of partial penetration welding with an abutting plate bevelled only at one side, the fillet weld at opposite side should not be less than 80% of that required for a double continuous fillet weld according to C103 and C202.

Where the connection is moderately stressed, intermittent welds may be used. With reference to Fig.4, the various types of intermittent welds are as follows:

— chain weld
— staggered weld
— scallop weld (closed).

For size of welds, see C500.



Extent of double continuous welds at end connections of stiffeners when otherwise connected through intermittent welding

Fig. 4
Intermittent welds

One side continuous fillet welding could be accepted for stiffeners in dry spaces where it is not affected by tank pressure, concentrated loads and excessive vibration such as under winch, cranes, davits and machineries. The size for one side continuous welding shall be of the intermittent fillet required by C501.

Where intermittent welding or one sided continuous welding is permitted, double continuous welds to be applied for each ends in accordance with C103.

302 Double continuous welds are required in the following connections irrespective of the stress level:

— weathertight, watertight and oil tight connections
— connections in foundations and supporting structures for machinery
— all connections in after peak
— connections in rudders, except where access difficulties necessitate slot welds
— connections at supports and ends of stiffeners, pillars, cross ties and girders
— centre line girder to keel plate.

303 Where intermittent welds are accepted, scallop welds shall be used in tanks for water ballast, cargo oil or fresh water. Chain and staggered welds may be used in dry spaces and tanks arranged for fuel oil only.

When chain and staggered welds are used on continuous members penetrating oil- and watertight boundaries, the weld termination towards the tank boundary shall be closed by a scallop, see Fig.5.

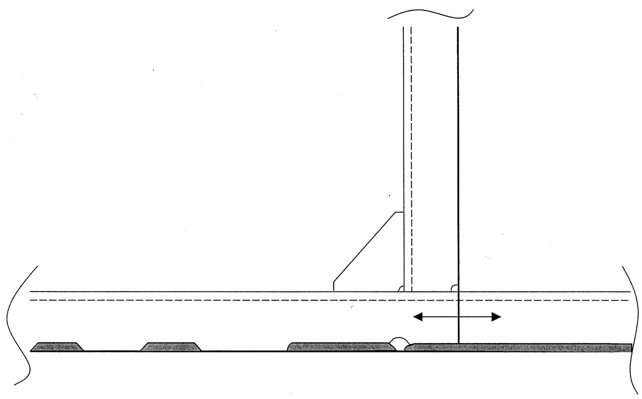


Fig. 5
Weld termination towards tank boundary

304 Full penetration welds are in any case to be used in the following connections:

— rudder horns and shaft brackets to shell structure
— rudder side plating to rudder stock connection areas
— end brackets of hatch side coamings both to deck and coaming side. For brackets of thickness above 20 mm, partial penetration weld can be applied except for the last 150 mm of the bracket toe to deck
— edge reinforcements or pipe penetrations both to strength deck (including sheer strake) and bottom plating within 0.6 L amidships when the transverse dimension of opening exceeds 300 mm, see Fig.6. For machine cut holes, partial penetration with root face r = t/3 may be accepted
— abutting plate panels (see Fig.3) forming boundaries to sea below summer load waterline. For thickness t above 12 mm, partial penetration weld with root face r = t/3 may be accepted and
— lower end of vertical corrugated bulkheads that are situated in the cargo area and arranged without lower stool.

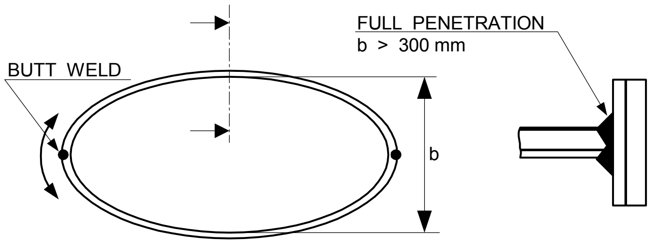


Fig. 6
Deck and bottom penetrations

C. Size of weld connections

C 100 Continuous fillet welds, general

101 Unless otherwise stated, it is assumed that the welding consumables used will give weld deposit with yield strength σ_{fw} as follows:

σ_{fw} = 355 N/mm^2 for welding of normal strength steel
= 375 N/mm^2 for welding of the high strength steels NV-27, NV-32 and NV-36
= 390 N/mm^2 for welding of high strength steel NV-40.

If welding consumables with deposits of lower yield strength than specified above are used, the σ_{fw}-value shall be stated on the drawings submitted for approval. The yield strength of the weld deposit is in no case to be less than required in Pt.2 Ch.3.

102 When deep penetrating welding processes are applied, the required throat thicknesses may be reduced by 15% of that required in C103 provided sufficient weld penetration is demonstrated.

Guidance note:

An electrode is considered to be of deep penetration type when the penetration is at least 4 mm when welding a fillet weld with a maximum gap of 0.25 mm. The electrode shall be type approved as a deep penetration electrode.

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

103 The throat thickness of double continuous fillet welds shall not be less than:

$$t_w = \frac{C\ t_0\sqrt{f_1}}{f_w} + 0.5t_k \text{ (mm), minimum as given in C104}$$

C = weld factor given in Table C1
t_0 = net thickness in mm of abutting plate, corrosion addition not included
= $t - t_k$, where:
t = gross thickness of abutting plate in mm (see Fig.3)
t_k = corrosion addition in mm, see Sec.2 D

f_1 = material factor as defined in Sec.2 B203 of abutting plate
f_w = material factor for weld deposit

$$= \left(\frac{\sigma_{fw}}{235}\right)^{0.75} \text{maximum } (2\ f_1)^{0.5}$$

σ_{fw} = yield strength in N/mm^2 of weld deposit

When welding consumables with deposits as assumed in 101 are used, f_w may be taken as follows dependent on parent material:

f_w = 1.36 for NV-NS
= 1.42 for NV-27, NV-32 and NV-36
= 1.46 for NV-40.

Table C1 Weld factor C

Item	*60% of span*	*At ends*
Local buckling stiffeners	0.14	0.14
Stiffeners, frames, beams or longitudinals to shell, deck, oil tight or water tight girders or bulkhead plating, except in after peaks	0.16	0.26
Web plates of non-watertight girders except in after peaks	0.20	0.32
Girder webs and floors in double bottom and double hull below summer load waterline. Stiffeners and girders in after peaks	0.26	0.43
Swash bulkheads Perforated decks	0.32	
Watertight centre line girder to bottom plating and inner bottom plating Boundary connection of ballast tanks and liquid cargo tanks Hatch coamings at corners and transverse hatch end brackets to deck. Strength deck plating to shell Scuppers and discharges to deck	0.52	
Fillet welds subject to compressive stresses only	0.25	
All other welds not specified above or in 200 to 400, e.g. boundary connection of watertight compartments and fuel oil tanks	0.43	

1) Welding of longitudinals of flat-bar type may normally be according to 104.

104 The throat thickness of fillet welds is in no case to be taken less than given in Table C2:

Table C2 Minimum throat thickness	
Plate thickness (web thickness) t_0 (mm) [3)]	*Minimum throat thickness (mm) [1)]*
$t_0 \leq 4$	2.0
$4 < t_0 \leq 6.5$	2.5
$6.5 < t_0 \leq 9.0$	2.75
$9.0 < t_0 \leq 12.5$	3.0
$t_0 > 12.5$	$0.21\ t_0$, minimum 3.25 [2)]

1) Corrosion addition 0.5 t_k to be added where relevant, see Sec.2 D. The values may be reduced by 10% for local buckling stiffeners (sniped ends).
2) 0.18 t_0, minimum 3.0 when automatic deep penetration welding is applied.
3) Net thickness of abutting plate as defined in 103 with the following reductions:

t_0 = $0.5\ (25 + t - t_k)$ for net plate thicknesses $(t - t_k)$ above 25 mm
t_0 = $25 + 0.25\ (t - t_k - 25)$ for longitudinals of flat-bar type with net plate thickness $(t - t_k)$ above 25 mm

C 200 Fillet welds and penetration welds subject to high tensile stresses

201 In structural parts where high tensile stresses act through an intermediate plate (see Fig.3) increased fillet welds or penetration welds shall be used. Examples of such structures are:

— transverse bulkhead connection to the double bottom
— vertical corrugated bulkhead connection to the top of stool tank
— stool tanks to inner bottom and hopper tank
— structural elements in double bottoms below bulkhead and stooltanks
— transverse girders in centre tanks to longitudinal bulkheads.

202 In case full penetration welding is not used the throat thickness of double continuous welds shall not be less than:

$$t_w = C_1\ t_o + 0.5\ t_k \quad \text{(mm)}$$

$$C_1 = \frac{1.36}{f_w}\left[0.2 + \left(\frac{\sigma}{270} - 0.25\right)\frac{r}{t_0}\right]$$

σ = calculated maximum tensile stress in abutting plate in N/mm^2
r = root face in mm (see Fig.3)
t_o = net thickness in mm of abutting plate, corrosion addition not included, as given in 103
f_w = as given in 103.

Typical design values for C_1 are given in Table C3.

Table C3 Values of C_1			
Plate material	σ	C_1	
		Fillet weld: $r = t_o$	Partial penetration weld with root face: *$r = t_o/3$*
NS	160	0.54	0.31
NV-32	205	0.68	0.35
NV-36	222	0.74	0.37

C 300 End connections of girders, pillars and cross ties

301 The weld connection area of bracket to adjoining girders or other structural parts shall be based on the calculated normal and shear stresses. Double continuous welding shall be used. Where large tensile stresses are expected, welding according to 200 shall be applied.

The section modulus of the weld area at the end connection of simple girders shall satisfy the requirement for section modulus given for the girder in question.

302 Where high shear stresses in web plates, double continuous boundary fillet welds shall have throat thickness not less than:

$$t_w = \frac{t_0\,\tau}{2\tau_w} + 0.5t_k \quad \text{(mm)}$$

τ = calculated shear stress in N/mm^2
τ_w = 100 f_w when calculated shear stress (τ) is average shear stress in web plate
τ_w = 115 f_w when calculated shear stress (τ) is local shear stress in web plate
t_o = net thickness of abutting plate, corrosion addition not included, as given in 103
f_w = as given in 103.

303 End connection of pillars and cross ties shall have a weld area not less than:

$$a = \frac{kP}{f_w} + a_k \quad (cm^2)$$

P = axial load in pillar of cross tie (kN)
a_k = corrosion addition corresponding to t_k
f_w = as given in 103
k = 0.05 when pillar in compression only
= 0.14 when pillar in tension.

C 400 End connections of stiffeners

401 Stiffeners may be connected to the web plate of girders in the following ways:

— welded directly to the web plate on one or both sides of the frame
— connected by single- or double-sided lugs
— with stiffener or bracket welded on top of frame
— a combination of the above.

In locations with great shear stresses in the web plate, a double-sided connection or a stiffening of the unconnected web plate edge is normally required. A double-sided connection may be taken into account when calculating the effective web area.

402 The connection area at supports of stiffeners is normally not to be less than:

$$a_o = c\, k\, (l - 0.5\, s)\, s\, p \quad (cm^2)$$

c = factor as given in Table C4
k = $r_1\, r_2$
r_1 = 0.125 when pressure acting on stiffener side
= 0.1 when pressure acting on opposite side
r_2 = $1.0/f_1$ for stiffeners with mainly loading from one side (pressure ratio less than 0.3 or greater than 3.3)
= 1.0 for stiffeners with loading from two sides
f_1 = material factor of abutting plate as defined in Sec.2 B203
l = distance between girder web plates in m
s = spacing between stiffeners in m
p = design pressure in kN/m^2.

Corrosion addition as specified in Sec.2 D200 is not included in the formulae for a_o, and shall be added where relevant.

Weld area shall not be less than:

$$a = \frac{1.15\, a_0 \sqrt{f_1}}{f_w} + a_k \quad (cm^2)$$

a_k = corrosion addition corresponding to t_k
f_w = as given in 103.

Table C4 Values of c

Type of connection (see figure)	*Stiffener/bracket on top of stiffener*		
	None	*Single- sided*	*Double- sided*
a	1.00	1.25	1.00
b	0.90	1.15	0.90
c	0.80	1.00	0.80

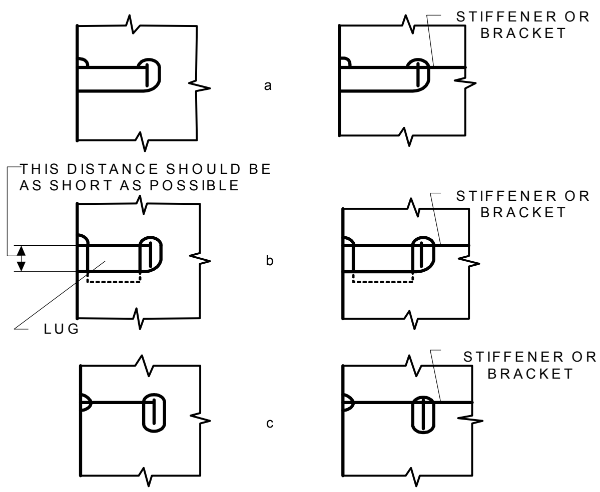


Fig. 7
End connections

403 Various standard types of connections are shown in Fig.7.

Other types of connection will be considered in each case.

Guidance note:

In ballast and cargo tanks the connection types b or c should be used for longitudinals on ship sides, unless double-sided brackets are arranged, see also Sec.7 E400.

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

404 Connection lugs shall have a thickness not less than 75% of the web plate thickness.

405 Lower ends of peak frames shall be connected to the floors by a weld area not less than:

$$a = 0.105\, l\, s\, p + a_k \quad (\text{cm}^2)$$

l, s, p and a_k = as given in 402.

406 For stiffeners which may be sniped at the ends according to the requirements given in Sec.3 C202, the required connection area is satisfied by the plating.

407 Bracketed end connections as mentioned below, shall have a weld area not less than:

$$a = \frac{kZ}{h} + a_k \quad (\text{cm}^2)$$

Z = net section modulus of stiffener in cm^3, corrosion addition not included
h = stiffener height in mm
k = 24 for connections between supporting plates in double bottoms and transverse bottom frames or reversed frames
= 25 for connections between the lower end of main frames and brackets (Minimum weld area = 10 cm^2)
= 15 for brackets fitted at lower end of 'tween deck frames, and for brackets on stiffeners
= 10 for brackets on 'tween deck frames carried through the deck and overlapping the underlying bracket
a_k = corrosion addition corresponding to t_k.

408 Brackets between transverse deck beams and frames or bulkhead stiffeners shall have a weld area not less than:

$$a = 0.41\sqrt{Z\, t_b} + a_k \quad (\text{cm}^2)$$

t_b = net thickness in mm of bracket
Z = as defined in 407
a_k = as defined in 407.

409 The weld area of brackets to longitudinals shall not be less than the sectional area of the longitudinal. Brackets shall be connected to bulkhead by a double continuous weld.

C 500 Intermittent welds

501 The throat thickness of intermittent fillet welds shall not be less than:

$$t_w = \frac{C\ t_0 \sqrt{f_1}}{f_w} \frac{d}{l_w} + 0.5\, t_k \quad \text{(mm)}$$

C, t_0, f_1 and f_w are as given in 103. C-values given in Table C1 for 60% of span may be applied.

d = distance, in mm, between successive welds, see Fig.4
l_w = length, in mm, of weld fillet, not to be less than 75 mm, see Fig.4.

502 In addition to the minimum requirements in 501, the following apply:

— for chain intermittent welds and scallop welds the throat thickness shall not exceed 0.6 t_0
— for staggered intermittent welds the throat thickness shall not exceed 0.75 t_0.

Double continuous welds to be applied at ends, see Fig.4

C 600 Slot welds

601 Slots shall have a minimum length of 75 mm and, normally, a width of twice the plate thickness. The ends shall be well rounded, see Fig.2. The distance d between slots shall not exceed 3 *l*, maximum 250 mm.

602 Fillets welds in slots shall have a throat thickness as given by the formula in 501 with:

t_0 = net thickness of adjoining web plate
d = distance between slots, see Fig.2
l = length of slots.

603 Slot weld is not acceptable for areas with high in plane stresses transversely to the slots.

SECTION 12 DIRECT STRENGTH CALCULATIONS

A. General

A 100 Introduction

101 In the preceding sections the scantlings of various primary and secondary hull structures have been given explicitly, based on design principles outlined in Sec.3 B. In some cases direct strength or stress calculations have been referred to in the text.

This section describes loads, acceptance criteria and required documentation of direct strength calculations. Loading conditions and specific scope of analysis are given in Pt.5 for the different class notations. Instructions related to model and model extent for such analysis are described in detail in DNV classification notes for the considered type of vessel.

A 200 Application

201 The application of direct stress analysis is governed by:

- required as part of rule scantling determination.
  When simplified formulations do not take into account special stress distributions, boundary conditions or structural arrangements with sufficient accuracy, direct stress analysis has been required in the rules. These analyses may be performed by finite element analyses or beam analyses if finite element analysis has not been specifically required elsewhere in the rules.
- as supplementary basis for the scantlings.

202 For ships where direct calculations for the midship region based on finite element methods are required in the rules, such analysis shall be performed with a scope sufficient for attaining results as listed below:

- relative deflections of deep supporting members such as floors, frames and girders
- stresses in transverse bulkheads
- stresses in longitudinal bottom, side, bulkhead and deck girders
- stresses in transverse bottom, side, bulkhead and deck girders
- stresses in girders and stringers on transverse bulkheads
- stresses in brackets in connection with longitudinal and transverse or vertical girders located on bottom, side, deck or bulkhead structures
- stresses in stiffeners where the stiffeners' supports are subjected to large relative deflections
- stresses in brackets in connection with longitudinal and transverse stiffeners located on bottom, side, decks or bulkhead structures.

The stresses shall not exceed the acceptance criteria given in B400.

Hull girder normal stresses and hull girder shear stresses shall not be considered directly from the analysis unless special boundary conditions and loads are applied to represent the hull girder shear forces and hull girder bending moments correctly.

Further descriptions of such calculations are given in subsections D, E and F.

A 300 Documentation

301 When direct strength analyses are submitted for information, such analyses shall be supported by documentation satisfactory for verifying results obtained from the analyses.

302 The documentation for verification of input shall contain a complete set of information to show the assumptions made and that the model complies with the actual structure. The documentation of the structure may be given as references to drawings with their drawing numbers, names and revision numbers. Deviations in the model compared with the actual geometry according to these drawings shall be documented.

303 The modelled geometry, material parameters, plate thickness, beam properties, boundary conditions and loads shall be documented preferably as an extract directly from the generated model.

304 Reaction forces and displacements shall be presented to the extent necessary to verify the load cases considered.

305 The documentation of results shall contain all relevant results such as:

- type of stress (element/nodal, membrane/surface, normal/ shear/equivalent)
- magnitude
- unit
- load case
- name of structure

— structural part presented.

306 Evaluation of the results with respect to the acceptance criteria shall be submitted for information.

B. Calculation methods

B 100 General

101 For girders which are parts of a complex 2- or 3-dimensional structural system, a complete structural analysis may have to be carried out to demonstrate that the stresses are acceptable when the structure is loaded as described in 300.

102 Detailed requirements for the extent of direct calculations have (as applicable) been given in Pt.5 for the various class notations. These requirements may, subject to special consideration in each case, be required to be applied also for ships of related types, even if the particular class notation has not been requested.

103 Calculation methods and computer programs applied shall take into account the effects of bending, shear, axial and torsional deformations. The calculations shall reflect the structural response of the 2- or 3-dimensional structure considered, with due attention to:

— boundary conditions
— shear area and moment of inertia variation
— effective flange
— effect of relative support deflections
— effects of bending, shear and axial deformations
— influence of end brackets.

For deep girders, bulkhead panels, bracket zones, etc. where results obtained by applying beam theory are unreliable, finite element analysis or equivalent methods shall be applied.

104 The objectives of analyses together with their applicable acceptance criteria are described in C to F for the following levels of calculations:

— global analysis
— cargo hold/tank analysis
— frame and girder analysis
— local structure analysis.

105 For structures as decks, bulkheads, hatch covers, ramps etc., a direct calculation may generally be undertaken as a frame and girder analysis as described in E, supplemented by local structure analyses as described in F, if necessary.

106 Corrosion additions, t_k, shall be deducted from the material thickness.

107 Areas representing girder flanges shall be adjusted for effective width in accordance with Sec.3 C400.

108 The element mesh fineness and element types used in finite element models shall be sufficient to allow the model to represent the deformation pattern of the actual structure with respect to matters such as:

— effective flange (shear lag)
— bending deformation of beam structures
— three-dimensional response of curved regions.

Acceptable calculation methods, including mesh fineness in finite element models are given in relevant DNV Classification Notes. The acceptance criteria given in 400 are closely related to the procedures given in the DNV Classification Notes.

B 200 Computer program

201 The calculations specified in the requirements shall be carried out by computer programs supplied by, or recognised by the Society. Programs applied where reliable results have been demonstrated to the satisfaction of the Society are regarded as recognised programs.

B 300 Loading conditions and load application

301 The calculations shall be based on the most severe realistic loading conditions with the ship:

— fully loaded
— partly loaded
— ballasted
— during loading/discharging.

302 General design loads are given in Sec.4 and design loads for specific structures are given in Sec.6 and Ch.3 Sec.8.

303 Local dynamic loads shall be taken at a probability of exceedance of 10^{-4}, when used together with acceptance criteria as given in 400.

304 For sea-going conditions realistic combinations of external and internal dynamic loads shall be considered.

305 For harbour conditions, only static loads need to be considered. Harbour conditions with asymmetric loading are relevant to the extent that they do not result in unrealistic heeling.

306 External sea pressures in the upright seagoing condition shall be taken in accordance with Sec.4 C200 with h_0 defined as follows.

h_0 = vertical distance in m from the waterline considered to the load-point.

307 In harbour conditions, the external sea pressure, p shall be taken as:

$$p = 10\ h_0\ (\text{kN/m}^2)$$

308 The external sea pressures, p, in heeled conditions are normally to be taken as:

p = $10\,(T_a - z) + 6.7\,y \tan(\varphi/2)$ (kN/m²)
on submerged side
p = $10\,(T_a - z) - 10\,y \tan(\varphi/2)$ (kN/m²)
on emerged side
= 0 minimum.

T_a = actual considered draught in m
z = vertical distance in m from base line
y = transverse distance in m from centre line
φ = as given in Sec.4 B.

309 The liquid pressure in tanks in the upright condition is normally to be taken as given in Sec.4 C300 (5).

310 In heeled condition, the liquid pressure in tanks, p, shall be taken as:

$$p = g_0 \rho (h_s + 0.5\varphi b - 0.1\sqrt{\varphi H b_t})\quad (\text{kN/m}^2)$$

ρ = liquid density in t/m³
h_s = height in m from load point to top of hold (including hatch coaming) or tank with the vessel on even keel
b = athwartships distance in m with the vessel on even keel from load point to the point which represents the top of the tank when the ship is heeled to an angle of 0.5 φ
H = height of hold (including hatch coaming) or tank in m with the vessel on even keel
b_t = breadth of top of tank or hold in meter with the vessel on even keel
φ = as given in Sec.4 B.

311 Pressures and forces from cargo and heavy units are generally to be taken as given in Sec.4, C400 and C500. The pressure from dry bulk cargoes is, however, generally to be taken as:

$$p = \rho\,(g_0 + 0.5\,a_v)\,K\,h_c\quad (\text{kN/m}^2)$$

K = $\sin^2\alpha \tan^2(45 - 0.5\,\delta) + \cos^2\alpha$
$\cos\alpha$ minimum
ρ = stowage rate of cargo in t/m³
α = angle between panel in question and the horizontal plane in degrees
a_v = as given in Sec.4 B, generally
= 0 in static loading conditions
δ = angle of repose of cargo in degrees
h_c = vertical distance in m from the load point to the hold boundary above, in general. When a partly filled hold is considered, the h_c shall be measured to the cargo surface, taking due consideration of the untrimmed conical shape of the cargo volume within the hold
= as given in Sec.9 B100 for cargo bulkhead structures.

For watertight bulkheads between cargo holds, the pressure load, p, shall be taken as given in Sec.9 B100.

312 The mass of deck structures is generally to be included when greater than 5% of the applied loads. Vertical acceleration shall be included when relevant.

B 400 Acceptance criteria

401 The expressions related to nominal stress components are defined as follows:

Hull girder stresses consist of nominal normal and shear stresses. Hull girder *normal* stresses are those stresses resulting from hull-girder bending and may generally be determined by a simple beam method, disregarding shear lag and effects of small deck openings etc. Hull girder *shear* stresses are those shear stresses caused by the unbalanced forces in the vertical, horizontal and longitudinal directions along the vessel, that are transferred to the hull girder with the vessel in an equilibrium condition. The hull girder may be defined as effective longitudinal material such as bottom, inner bottom, decks, side and longitudinal bulkheads.

Transverse or longitudinal bottom, side, bulkhead or deck girder nominal stresses consist of normal and shear stresses. These stresses shall be determined by performing a 3-dimensional finite element analysis or a beam analysis. Transverse or longitudinal bottom, side, bulkhead or deck girder *normal* stresses are those stresses resulting from bending of large stiffened panels between longitudinal and transverse bulkheads due to local loads in a cargo hold or tank. The nominal normal stresses of girders shall include the effect of shear lag and effectivity of curved and unsymmetrical flanges. Transverse or longitudinal bottom, side, bulkhead or deck girder *shear* stresses are those stresses caused by an unbalanced force within a tank or a hold and carried in girders as mentioned, to the girder supports. The nominal shear stress of girders is generally defined as the mean shear stress of the effective shear carrying areas of the girder web.

Stiffener nominal stresses are those stresses resulting from local bending of longitudinals between supporting members, i.e. floors and girders web frames etc. The stresses include those due to local load on the stiffener and those due to relative deflections of the supporting ends. The stiffener stress may be regarded as a nominal bending stress without consideration of effective width of flanges and warping of unsymmetrical stiffeners.

402 The final thickness of the considered structure shall not be less than the minimum thickness given in Sec.6 and Ch.3 Sec.8, regardless of the acceptance criteria presented in the following.

403 The equivalent stress σ_e, taken as the local bending stresses combined with in plane stresses, in the middle of a local plate field shall not exceed 245 f_1 N/mm^2. The local bending in the middle of the plate field shall not exceed 160 f_1 N/mm^2. σ_e is defined in 409.

404 The allowable nominal stresses may be taken as given in Table B1. Buckling strength with usage factors as given in Sec.13 is generally to be complied with.

405 The allowable nominal girder stresses in a flooded condition may be taken as 220 f_1 for normal stresses and 120 f_1 for shear stresses.

406 The longitudinal combined stress taken as the sum of hull girder and longitudinal bottom, side or deck girder bending stresses, is normally not to exceed 190 f_1 N/mm^2. The hull girder stresses may in general be calculated as given in Sec.5 C300, applying relevant combinations of hogging and sagging stresses, and with wave bending moments taken as given in Sec.5 B204.

407 During preliminary strength calculations of longitudinal stiffeners in double bottom the values of longitudinal bottom girder stresses may normally be taken as follows:

Normal stress, light bulk cargoes:

$$\sigma = 20\ f_1\ (\text{N/mm}^2)$$

Normal stress, ballast condition:

$$\sigma = 50\ f_1\ (\text{N/mm}^2)$$

Normal stress, liquid cargo condition:

$$\sigma = \frac{85\ b\ f_1}{B} \qquad (\text{N/mm}^2)$$

b = breadth of double bottom in m between supporting side and or bulkheads.

Higher local normal stresses than given above may be accepted provided the combined stress including hull girder stress and longitudinal bottom girder stress, as given in Table B1 and 402, are complied with.

408 The allowable stresses given in Table B1 assume that appropriate considerations and conditions are taken with respect to the model definition and result analysis. In particular the following should be noted:

1) Calculated stresses based on constant stress elements may have to be considered with respect to the stress variation within each element length.
2) The allowable nominal stresses, given in Table B1, do not refer to local stress concentrations in the structure or to local modelling deficiencies in finite element models. The allowable stresses do neither refer to areas where the model is not able to describe the structure's response properly due to geometrical simplifications or insufficiencies of the element representation.

3) The allowable shear stresses given in Table B1 may be used directly to assess shear stresses in girder webs clear of openings not represented in the model. In way of areas with openings, the nominal shear stress is normally to be derived as given in Sec.3 C500, based on the integrated shear force over the girder web height.
4) Equivalent stresses for girder webs of longitudinal structures shall not be considered in relation to the allowable limits given in Table B1, unless global forces and moments are applied.
5) Peak stresses obtained by fine mesh finite element calculations may exceed the values stated above in local areas close to stress concentration points. The allowable peak stress is subject to special consideration in each case.

409 The equivalent stress is defined as follows:

$$\sigma_e = \sqrt{\sigma_x^2 + \sigma_y^2 - \sigma_x \sigma_y + 3\tau^2}$$

σ_x = nominal normal stress in x-direction
σ_y = nominal normal stress in y-direction
τ = shear stress in the x-y-plane.

Table B1 Allowable nominal stresses

Structure	*Seagoing or harbour condition*	*Type of stress*				*Normal stress σ (N/mm²)*	*Shear stress τ (N/mm²)*		*Equivalent stress σ_e (N/mm²)*
		Hull girder stresses	*Transverse bottom, side or deck girder stresses*	*Longitudinal bottom, side or deck girder stresses*	*Local stiffener bending stresses*		*One plate flange*	*Two plate flanges*	
Longitudinal girders	Seagoing	X 1)		X		190 f_1	90 f_1	100 f_1	
	Harbour	X 1)		X		190 f_1	100 f_1	110 f_1	
Transverse and vertical girders	Seagoing		X			160 f_1	90 f_1	100 f_1	180 f_1
	Harbour		X			180 f_1	100 f_1	110 f_1	200 f_1
Girder brackets	Seagoing		(X)	(X)		200 f_1 2)			
	Harbour		(X)	(X)		220 f_1 2)			
Longitudinal stiffeners	Seagoing and harbour				X	160 f_1			
	Seagoing and harbour			X	X	180 f_1	90 f_1		
	Seagoing and harbour	X 1)		X	X	245 f_1			
Transverse and vertical stiffeners	Seagoing and harbour		(X)	(X)	X	180 f_1			
Stiffener brackets	Seagoing and harbour		(X)	(X)	X	225 f_1			

X Stress component to be included
(X) Stress component to be included when relevant

1) Includes the hull girder stresses at a probability of exceedance of 10^{-4}, see 406.
2) Shows allowable stress in the middle of the bracket's free edge. For brackets of unproven design, additional stress analysis in way of stress concentration areas may be required. Reference is made to acceptance criteria for local structure analysis, F300.

C. Global analysis

C 100 General

101 A global analysis covers the whole ship.

102 A global analysis may be required if the structural response can otherwise not be sufficiently determined, e.g. for ships with large deck openings subjected to overall torsional deformation and stress response. A global analysis may also be required for ships without or with limited transverse bulkhead structures over the vessel length, e.g. Ro-Ro vessels and car carriers.

Guidance note:

For open type ships with large deck openings with total width of hatch openings in one transverse section exceeding 65% of ship's breadth, or length of hatch openings exceeding 75% of hold length, a torsional calculation covering the entire ship hull length may have to be carried out.

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103 Global analyses are generally to be based on loading conditions that are representative with respect to the responses and failure modes to be evaluated, e.g.: normal stress, shear stress and buckling.

104 If a global analysis is required for the evaluation of the fatigue life of critical members of the hull structure, design load conditions and criteria may be based on DNV Classification Note No. 30.7.

105 Design loading conditions and acceptance criteria may, subject to special consideration in each case, be taken in accordance with Sec.15.

C 200 Loading conditions

201 The selection of loading conditions and the application of loads will depend on the scope of the analysis. Directly calculated loads, torsion loads or racking loads may have to be applied.

C 300 Acceptance criteria

301 If the applied load condition is relevant for the longitudinal hull girder and main girder system, nominal and local stresses derived from a global analysis shall be checked according to the acceptance criteria given in B400.

Other acceptance criteria may be relevant depending on the type of analysis and applied loads.

D. Cargo hold or tank analysis

D 100 General

101 A cargo tank or hold analysis may be used to analyse deformations and nominal stresses of primary hull structural members. The model and the analysis shall be designed and performed in a suitable way for obtaining results as listed below. Acceptable methods are described in detail in DNV Classification Notes related to the considered type of vessel.

— stresses in transverse bulkheads
— stresses in longitudinal bottom, side, bulkhead and deck girders (see Guidance note)
— stresses in transverse bottom, side, bulkhead and deck girders (see Guidance note)
— stresses in girders and stringers on transverse bulkheads
— relative deflections of deep supporting members as floors, frames and girders.

Guidance note:

Shear stresses of plate flanges of the mentioned girders forming ships' sides or longitudinal bulkheads should not be taken from the model unless special boundary conditions are applied to represent the global shear forces correctly.

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

Hull girder normal stresses and hull girder shear stresses shall not be considered directly from the analysis unless special boundary conditions and loads are applied to represent the hull girder shear forces and hull girder bending moments correctly.

102 A cargo hold or tank analysis, carried out for the midship region, will normally be considered applicable also outside of the midship region. However, special direct calculations of girder structures outside of the midship region may be required if the structure or loads are substantially different from that of the midship region.

D 200 Loading conditions and load application

201 Selection of design loading conditions and application of local loads are given in B300.

D 300 Acceptance criteria

301 For the main girder system, nominal and local stresses derived from a cargo hold or tank analyses shall be checked according to the acceptance criteria given in B400.

E. Frame and girder analysis

E 100 General

101 A frame and girder analysis may be used to analyse stresses and deformations in the framing and girder systems within or outside of the midship region. The model and the analysis shall be designed and performed in a suitable way for obtaining results as listed below. Acceptable methods are described in detail in DNV Classification Notes related to the considered type of vessel.

— stresses in longitudinal bottom, side and deck girders (when relevant)
— stresses in transverse bottom, side and deck girders (when relevant)
— stresses in girders and stringers on transverse bulkheads (when relevant)
— stresses in brackets in connection with longitudinal, transverse or vertical girders located on bottom, side, deck or bulkhead structures.

However, shear stresses in plate flanges of the mentioned girders, forming ships' sides, inner sides or longitudinal bulkheads shall not be taken from the model unless special boundary conditions are applied to represent the global shear forces correctly.

102 The analysis may be included as a part of a larger 3-dimensional analysis, or run separately with prescribed boundary assumptions, deformations or forces. Prescribed boundary deformations may be taken from a cargo hold or tank analysis as described in sub-section D.

E 200 Loading conditions and load application

201 Selection of design loading conditions and application of local loads are given in B300.

E 300 Acceptance criteria

301 For the main girder system, nominal and local stresses derived from a frame and girder analysis shall be checked according to the acceptance criteria given in B400.

302 In way of local stress concentrations, and at local structural details where the finite element model does not represent the local response sufficiently, the structure may for proven design details be accepted based on the nominal stress response of the adjacent structures.

F. Local structure analysis

F 100 General

101 A local structure analysis may be used to analyse nominal stresses in laterally loaded local stiffeners and their connected brackets, subject to relative deformation between supports. The model and the analysis shall be designed and performed in a suitable way for obtaining results as listed below:

— nominal stresses in stiffeners
— stresses in brackets' free edge.

Acceptable methods are described in detail in DNV Classification Notes related to the considered type of vessel.

102 The analysis may be included as a part of a larger 3-dimensional analysis, or run separately with prescribed boundary assumptions, deformations or forces. Prescribed boundary deformations may be taken from a cargo hold or tank analysis as described in D.

F 200 Loading conditions and load application

201 Selection of design loading conditions and application of local loads are given in B300.

202 The most severe loading condition among those relevant for the cargo hold or tank analysis or the frame and girder analysis, shall be applied for the structure in question.

203 If the local structure analysis is run separately, prescribed boundary deformations or forces, taken from the cargo hold or tank analysis or the frame and girder analysis shall be applied. Local loads acting on the structure shall be applied to the model.

F 300 Acceptance criteria

301 Allowable nominal stresses are in general given in B400, Table B1.

302 The equivalent nominal allowable stress for brackets connected to longitudinal stiffeners may be taken as $\sigma_e = 245\ f_1$, when longitudinal stresses are included.

SECTION 13 BUCKLING CONTROL

A. General

A 100 Introduction

101 This section covers the requirements for buckling control of:

— plating subject to in-plane compressive and or shear stresses
— axially compressed stiffeners and pillars
— panel ultimate strength.

102 The buckling strength requirements are related to:

— longitudinal hull girder compression and shear stresses based on design values of still water and wave bending moments and shear forces
— axial forces in pillars, supporting bulkheads and panting beams based on the rule loads
— axial and shear forces in primary girders based on the rule loads.

A 200 Definitions

201 Symbols:

t = thickness in mm of plating
s = shortest side of plate panel in m
l = longest side of plate panel in m
= length in m of stiffener, pillar etc.
E = modulus of elasticity of the material
= $2.06 \cdot 10^5$ N/mm^2 for steel
σ_{el} = the ideal elastic (Euler) compressive buckling stress in N/mm^2
σ_f = minimum upper yield stress of material in N/mm^2, and shall not be taken less than the limit to the yield point given in Sec.2 B201.
τ_{el} = the ideal elastic (Euler) shear buckling stress in N/mm^2
σ_c = the critical compressive buckling stress in N/mm^2
τ_c = the critical shear stress in N/mm^2
σ_a = calculated actual compressive stress in N/mm^2
τ_a = calculated actual shear stress in N/mm^2

η = stability (usage) factor = $\dfrac{\sigma_a}{\sigma_c} = \dfrac{\tau_a}{\tau_c}$

z_n = vertical distance in m from the baseline or deckline to the neutral axis of the hull girder, whichever is relevant
z_a = vertical distance in m from the baseline or deckline to the point in question below or above the neutral axis, respectively
f_1 = material factor
= 1.0 for NV-NS steel [1)]
= 1.08 for NV-27 steel [1)]
= 1.28 for NV-32 steel [1)]
= 1.39 for NV-36 steel [1)]
= 1.47 for NV-40 steel. [1)]

1) For details see Sec.2 B and C.

B. Plating

B 100 General

101 Local plate panels between stiffeners may be subject to uni-axial or bi-axial compressive stresses, in some cases also combined with shear stresses. Methods for calculating the critical buckling stresses for the various load combinations are given below.

102 Formulae are given for calculating the ideal compressive buckling stress σ_{el}. From this stress the critical buckling stress σ_c may be determined as follows:

$$\sigma_c = \sigma_{el} \quad \text{when} \quad \sigma_{el} < \frac{\sigma_f}{2}$$

$$= \sigma_f\left(1 - \frac{\sigma_f}{4\sigma_{el}}\right) \quad \text{when} \quad \sigma_{el} > \frac{\sigma_f}{2}$$

103 Formulae are given for calculating the ideal shear buckling stress τ_{el}. From this stress the critical buckling stress τ_c may be determined as follows:

$$\tau_c = \tau_{el} \quad \text{when} \quad \tau_{el} < \frac{\tau_f}{2}$$

$$= \tau_f\left(1 - \frac{\tau_f}{4\tau_{el}}\right) \quad \text{when} \quad \tau_{el} > \frac{\tau_f}{2}$$

τ_f = yield stress in shear of material in N/mm^2

$= \frac{\sigma_f}{\sqrt{3}}$.

B 200 Plate panel in uni-axial compression

201 The ideal elastic buckling stress may be taken as:

$$\sigma_{el} = 0.9\,k\,E\left(\frac{t - t_k}{1000s}\right)^2 \qquad (\text{N/mm}^2)$$

For plating with longitudinal stiffeners (in direction of compression stress):

$$k = k_l = \frac{8.4}{\psi + 1.1} \qquad \text{for } (0 \le \psi \le 1)$$

For plating with transverse stiffeners (perpendicular to compression stress):

$$k = k_s = c\left[1 + \left(\frac{s}{l}\right)^2\right]^2 \frac{2.1}{\psi + 1.1} \qquad \text{for } (0 \le \psi \le 1)$$

c = 1.21 when stiffeners are angles or T-sections
= 1.10 when stiffeners are bulb flats
= 1.05 when stiffeners are flat bars

c = 1.3 when the plating is supported by floors or deep girders.

For longitudinal stiffened double bottom panels and longitudinal stiffened double side panels the c-values may be multiplied by 1.1.

ψ is the ratio between the smaller and the larger compressive stress assuming linear variation, see Fig.1.

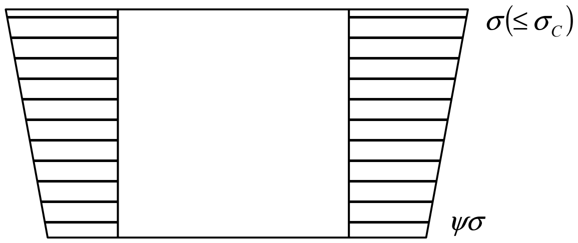

Fig. 1
Buckling stress correction factor

The above correction factors are not valid for negative ψ-values.

The critical buckling stress is found from 102.

202 For plate panels stiffened in direction of the compressive stress and with circular cut-outs, the ideal buckling stress σ_{el} shall be found by multiplying the factor k_l with a reduction factor r given as:

$$r = 1 - (0.5 + 0.25\,\psi)\,\frac{d}{s}$$

ψ = factor given in 201, Fig.1
d = diameter of cut-out, in m.

With edge reinforcement of thickness t at least equal to plate thickness t_o, factor r may be multiplied by:

$$0.8 + 0.1\,\frac{h}{t_0}\,,\quad \frac{h}{t} \leq 8$$

h = height of reinforcement, in mm.

203 For plate panels stiffened in direction of the compressive stress and with stadium formed cut-outs (see Fig.2) the ideal buckling stress σ_{el} shall be found by substituting the expression for factor k_l in 201 with the following:

$$k = \left[\frac{0.58}{0.35\,\psi + 1} + \left(\frac{s - b}{2a}\right)^2\right]\left[1 + 2.7\,\left(\frac{b}{a}\right)^2\right]$$

(see Fig.2)

ψ = as given in 201.

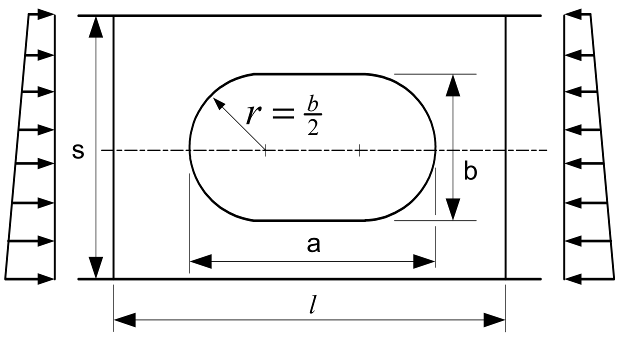

Fig. 2
Stiffening in direction of compressive stress

Guidance note:
The formula for k should not be applied when

a/b < 1.5 and b/s < 0.35

An approximation to a circular opening as given in 202 may then be applied.

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

204 For plate panels stiffened perpendicular to the compressive stress and with stadium formed cut-outs (see Fig.3) the ideal buckling stress σ_{el} may be found by multiplying the factor k_s with the reduction factor:

$$r = 1 - (0.5 + 0.25\psi)\,\frac{a}{l} \qquad \text{(see Fig.3)}$$

ψ = as given in 201.

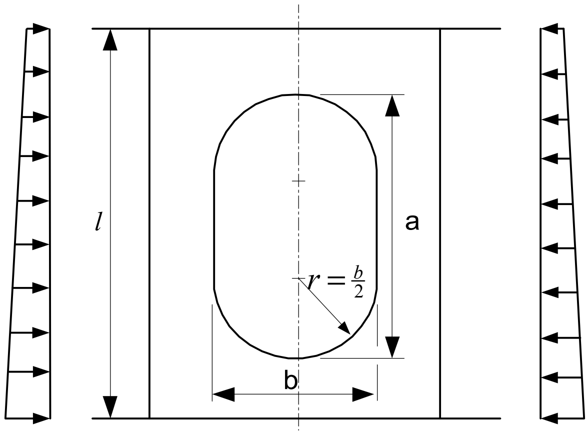

Fig. 3
Stiffening perpendicular to compressive stress

205 The critical buckling stress calculated in 201 shall be related to the actual compressive stresses as follows:

$$\sigma_c \geq \frac{\sigma_a}{\eta}$$

σ_a = σ_a calculated compressive stress in plate panels. With linearly varying stress across the plate panel, shall be taken as the largest stress.

In plate panels subject to longitudinal stresses, σ_a is given by:

$$\sigma_{al} = \frac{M_S + M_W}{I_N}(z_n - z_a)10^5 \quad (\text{N/mm}^2)$$

$$= \text{minimum } 30\ f_1\ \text{N/mm}^2 \text{ at side}$$

η = 1.0 for deck, single bottom and longitudinally stiffened side plating
= 0.9 for bottom, inner bottom and transversely stiffened side plating
= 1.0 for local plate panels where an extreme load level is applied (e.g. impact pressures)
= 0.8 for local plate panels where a normal load level is applied
M_S = stillwater bending moment as given in Sec.5
M_W = wave bending moment as given in Sec.5
I_N = moment of inertia in cm^4 of the hull girder.

For reduction of plate panels subject to elastic buckling, see 207.

M_S and M_W shall be taken as sagging or hogging values for members above or below the neutral axis respectively.

For local plate panels with cut-outs, subject to local compression loads only, σ_a shall be taken as the nominal stress in panel without cut-outs.

An increase of the critical buckling strength may be necessary in plate panels subject to combined in-plane stresses, see 400 and 500.

206 For ships with high speed and large flare in the forebody, the requirement for critical buckling stress σ_c of the strength deck as given in 205 shall be based on the following σ-value forward of 0.3 L from F.P.:

$$\sigma_{al} = \sigma_{l1} + \sigma_{l2}\left(1 - \frac{x}{0.3L}\right) \quad (\text{N/mm}^2)$$

σ_{l1} = σ_{al} as calculated in 205
σ_{l2} = 0 for $C_{AF} \leq 0.4$
= 50 f_1 N/mm^2 for $C_{AF} \geq 0.5$
x = distance in m from F.P. x need not be taken smaller than 0.1 L
C_{AF} = as defined in Sec.5 B200.

For intermediate values of C_{AF} the σ_{l2} - value shall be varied linearly.

207 Elastic buckling ($\sigma_{el} < \sigma_a/\eta$) in plate panels may be accepted after special consideration. An acceptable method for evaluating ultimate compressive stresses above the critical buckling stress in the elastic range (σ_{el} < 0.50 σ_f) is given in Appendix A.

For plate panels taking part in the longitudinal strength the effective width b_e shall be calculated according to Appendix A for those panels sustaining elastic buckling. The area of each panel shall be reduced by the ratio b_e/b when calculating the hull girder moment of inertia inserted in the formula for ΔM_U in App.A B500. The M_A-value to be applied is given by:

$$M_A = M_S + M_W$$

M_S and M_W as given in 205.

Appendix A shall not be applied for plate panels subject to the combined effect of compression and shear.

B 300 Plate panel in shear

301 The ideal elastic buckling stress may be taken as:

$$\tau_{el} = 0.9 k_t E \left(\frac{t - t_k}{1000 s}\right)^2 \quad (\text{N/mm}^2)$$

$k_t = 5.34 + 4 \left(\frac{s}{l}\right)^2$

The critical shear buckling stress is found from 103.

302 For plate panels with cut-outs the ideal buckling stress
σ_{el} shall be found by multiplying the factor k_t with a reduction factor r given as:

a) For circular cut-outs with diameter d:

$$r = 1 - \frac{d}{s}$$

With edge reinforcement of thickness t at least equal to the plate thickness t_0, factor r may be multiplied by:

$$0.94 + 0.023 \frac{h}{t_0}, \quad \frac{h}{t} \le 8$$

h = height of reinforcement.

Alternatively, with buckling stiffeners on both sides of opening, factor r may be multiplied by 1.3

b) For rectangular openings the reduction factor may be found from Fig.4. With edge reinforcement of thickness t at least twice the plate thickness and height at least equal to 8 t, the factor may be multiplied by 2.1.

Alternatively, with buckling stiffeners along the longer edges the factor may be multiplied by 1.4, with stiffeners along the shorter edges by 1.5, see Fig.5.

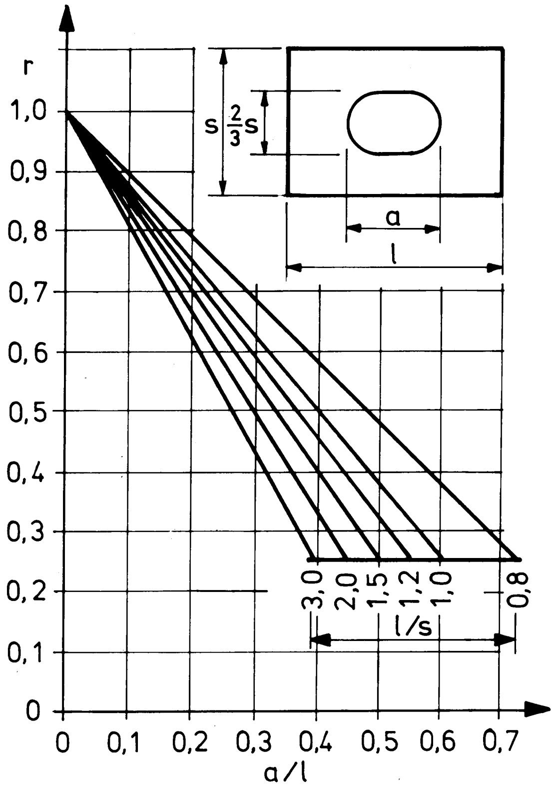

Fig. 4
Buckling stress reduction factor

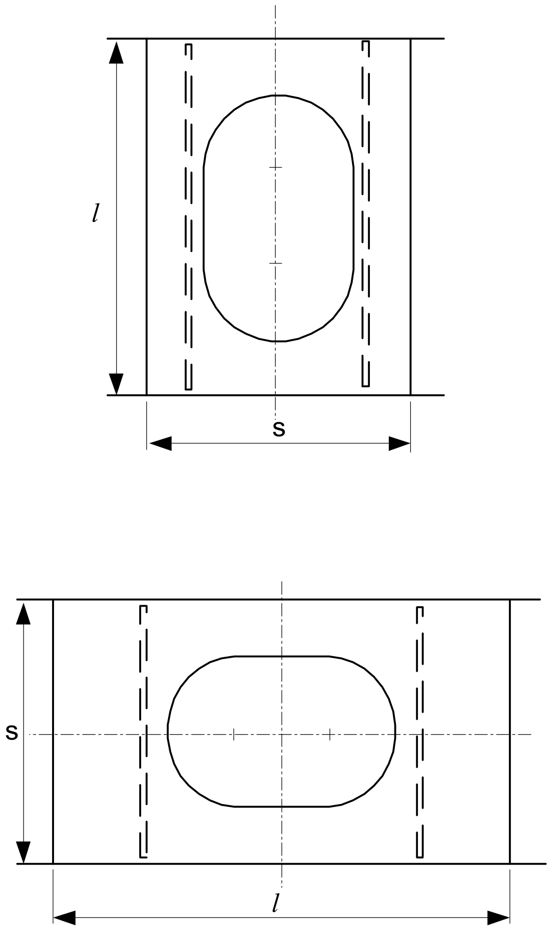

Fig. 5
Buckling stiffeners

303 The critical shear stress calculated in 301 and 302 shall be related to the actual shear stresses as follows:

$$\tau_c \geq \frac{\tau_a}{\eta}$$

τ_a = calculated shear stress. In plate panels in ship's side and longitudinal bulkheads the shear stresses are given in Sec.5 D.
For local panels in girder webs with cut-outs, τ_a shall be taken as the stress in web plate without cut-out
η = 0.90 for ship's side and longitudinal bulkhead subject to hull girder shear forces
= 0.85 for local panels in girder webs when nominal shear stresses are calculated (τ_a = Q/A)
= 0.90 for local panels in girder webs when shear stresses are determined by finite element calculations or similar.

An increase of the critical buckling strength may be necessary in plate panels subject to combined in-plane stresses, see 400 and 500.

B 400 Plate panel in bi-axial compression

401 For plate panels subject to bi-axial compression the interaction between the longitudinal and transverse buckling strength ratios is given by:

$$\frac{\sigma_{ax}}{\eta_x \sigma_{cx}} - K \frac{\sigma_{ax}\sigma_{ay}}{\eta_x \eta_y \sigma_{cx}\sigma_{cy}} + \left(\frac{\sigma_{ay}}{\eta_y \sigma_{cy}}\right)^n \leq 1$$

σ_{ax} = compressive stress in longitudinal direction (perpendicular to stiffener spacing s)
σ_{ay} = compressive stress in transverse direction (perpendicular to the longer side l of the plate panel)
σ_{cx} = critical buckling stress in longitudinal direction as calculated in 200
σ_{cy} = critical buckling stress in transverse direction as calculated in 200
η_x, η_y = 1.0 for plate panels where the longitudinal stress σ_{al} (as given in 205) is incorporated in σ_{ax} or σ_{ay}
= 0.85 in other cases
K = $c\,\beta^a$

c and a are factors given in Table B1.

$$\beta = 1000 \frac{s}{t - t_k}\sqrt{\frac{\sigma_f}{E}}$$

n = factor given in Table B1.

Table B1 Values for c, a, n			
	c	a	n
$1.0 < l/s < 1.5$	0.78	minus 0.12	1.0
$1.5 \leq l/s < 8$	0.80	0.04	1.2

For plate panels in structures subject to longitudinal stresses, such stresses shall be directly combined with local stresses to the extent they are acting simultaneously and for relevant load conditions. Otherwise combinations based on statistics may be applied.

In cases where the compressive stress σ_{ax} or σ_{ay} is based on an extreme loading condition (dynamic loads at probability level 10^{-8} or less) the corresponding critical buckling stress σ_{cx} or σ_{cy} may be substituted by σ_{ux} or σ_{uy} according to Appendix A. This is only relevant in the elastic range
(σ_c based on $\sigma_{el} < 0.65\ \sigma_f$).

B 500 Plate panel in bi-axial compression and shear

501 For plate panels subject to bi-axial compression and in addition to in-plane shear stresses the interaction is given by:

$$\frac{\sigma_{ax}}{\eta_x \sigma_{cx} q} - K \frac{\sigma_{ax}\sigma_{ay}}{\eta_x \eta_y \sigma_{cx}\sigma_{cy} q} + \left(\frac{\sigma_{ay}}{\eta_y \sigma_{cy} q}\right)^n \leq 1$$

σ_{ax}, σ_{ay}, σ_{cx}, σ_{cy}. η_x, η_y, K and n are as given in 401.

$$q = 1 - \left(\frac{\tau_a}{\tau_c}\right)^2$$

τ_a and τ_c are as given in 303.

Only stress components acting simultaneously shall be inserted in the formula, see also 401.

C. Stiffeners and pillars

C 100 General

101 Methods for calculating the critical buckling stress for the various buckling modes of axially compressed stiffeners and pillars are given below. Formulae for the ideal elastic buckling stress σ_{el} are given. From this stress the critical buckling stress σ_c may be determined as follows:

$$\sigma_c = \sigma_{el} \quad \text{when} \quad \sigma_{el} < \frac{\sigma_f}{2}$$

$$= \sigma_f \left(1 - \frac{\sigma_f}{4\sigma_{el}}\right) \quad \text{when} \quad \sigma_{el} > \frac{\sigma_f}{2}$$

C 200 Lateral buckling mode

201 For longitudinals subject to longitudinal hull girder compressive stresses, supporting bulkhead stiffeners, pillars, cross ties, panting beams etc., the ideal elastic lateral buckling stress may be taken as:

$$\sigma_{el} = 0.001 \text{ E } \frac{I_A}{A l^2} \quad (\text{N/mm}^2)$$

I_A = moment of inertia in cm^4 about the axis perpendicular to the expected direction of buckling
A = cross-sectional area in cm^2.

When calculating I_A and A, a plate flange equal to 0.8 times the spacing is included for stiffeners. For longitudinals supporting plate panels where elastic buckling is allowed, the plate flange shall not be taken greater than the effective width, see B207 and Appendix A.

Where relevant t_k shall be subtracted from flanges and web plates when calculating I_A and A.

The critical buckling stress is found from 101.

The formula given for σ_{el} is based on hinged ends and axial force only.

If, in special cases, it is verified that one end can be regarded as fixed, the value of σ_{el} may be multiplied by 2. If it is verified that both ends can be regarded as fixed, the value of σ_{el} may be multiplied by 4.

In case of eccentric force, additional end moments or additional lateral pressure, the strength member shall be reinforced to withstand bending stresses.

202 For longitudinals and other stiffeners the critical buckling stress calculated in 201 shall be related to the actual compressive stress as follows:

$$\sigma_c \geq \frac{\sigma_a}{\eta}$$

σ_a = calculated compressive stress.
For longitudinals $\sigma_a = \sigma_{al}$ as given in B205. For ships with high speed and large flare, see also B206
η = 0.85.

203 For pillars, cross ties and panting beams the critical buckling stress as calculated in 201 shall not be less than:

$$\sigma_c = \frac{10P}{A\eta} \quad (\text{N/mm}^2)$$

$$\eta = \frac{k}{\left(1 + \frac{l}{i}\right)}, \quad \text{minimum } 0.3$$

P = axial load in kN as given for various strength members in 204 and 205. Alternatively, P may be obtained from direct stress analysis, see Sec.12
l = length of member in m
i = radius of gyration in cm = $\sqrt{\frac{I_A}{A}}$
I_A and A as given in 201
k = 0.5 for pillars below exposed weather decks forward of 0.1 L from F.P.
= 0.6 for pillars below weather decks when sea loads are applied
= 0.7 in all other cases.

204 The nominal axial force in pillars is normally to be taken as:

$$P = n\,F$$

n = number of decks above pillar. In case of a large number of decks (n > 3) a reduction in P will be considered based upon a special evaluation of load redistribution

F = the force contribution in kN from each deck above and supported by the pillar in question given by:

$$F = p\,A_D \quad (kN)$$

p = design pressure on deck as given in Table B1 in Sec.8 B

A_D = deck area in m^2 supported by the pillar, normally taken as half the sum of span of girders supported, multiplied by their loading breadth.

For centre line pillars supporting hatch end beams (see Figs. 6 and 7):

$$A_D = 4(A_1 + A_2)\frac{b_1}{B} \quad \text{when transverse beams}$$

$$= 4(A_3 + A_4 + A_5)\frac{b_1}{B} \quad \text{when longitudinals}$$

b_1 = distance from hatch side to ship's side.

205 The nominal axial force in cross ties and panting beams is normally to be taken as:

$$P = e\,b\,p \quad (kN)$$

e = mean value of spans in m on both sides of the cross tie

b = load breadth in m

p = the larger of the pressures in kN/m^2 on either side of the cross tie (e.g. for a side tank cross tie, the pressure head on the ship's side may be different from that on the longitudinal bulkhead).

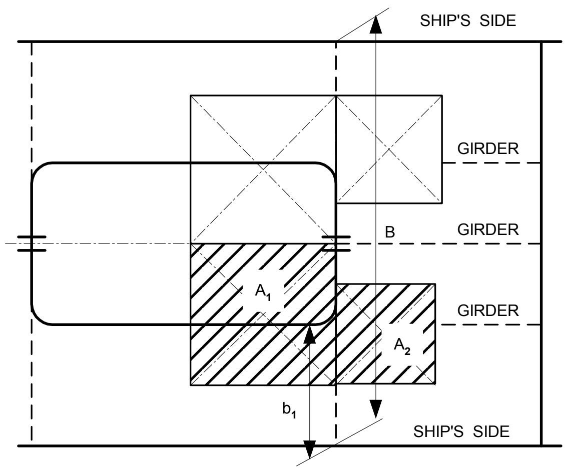

Fig. 6
Deck with transverse beams

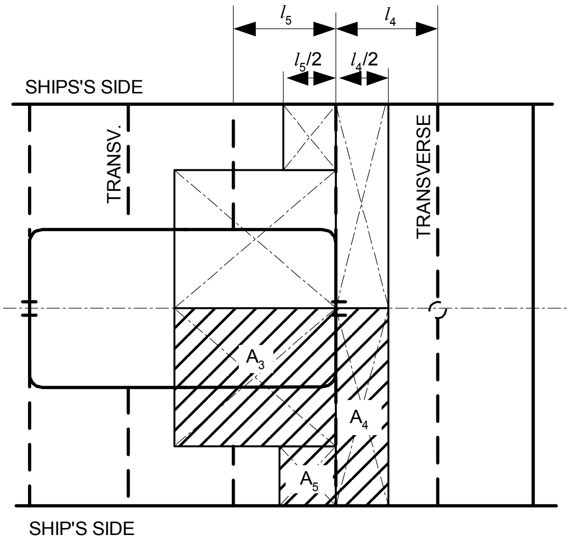

Fig. 7
Deck with longitudinals

C 300 Torsional buckling mode

301 For longitudinals and other stiffeners in the direction of compressive stresses, the ideal elastic buckling stress for the torsional mode may be taken as:

$$\sigma_{el} = \frac{\pi^2 E I_W}{10^4 I_p l^2}\left(m^2 + \frac{K}{m^2}\right) + 0.385 E \frac{I_T}{I_P} \quad (\text{N/mm}^2)$$

K = $\frac{C l^4}{\pi^4 E I_W} 10^6$

m = number of half waves, given by the following table:

	$0 < K \leq 4$	$4 < K \leq 36$	$36 < K \leq 144$	$K > 144$
m	1	2	3	4

I_T = St Venant's moment of inertia in cm^4 of profile (without plate flange)

= $\frac{h_w t_w^3}{3} 10^{-4}$ for flat bars (slabs)

= $\frac{1}{3}\left[h_w t_w^3 + b_f t_f^3 \left(1 - 0.63 \frac{t_f}{b_f}\right)\right] 10^{-4}$
for flanged profiles

I_P = polar moment of inertia in cm^4 of profile about connection of stiffener to plate

= $\frac{h_w^3 t_w}{3 \cdot 10^4}$ for flat bars

= $\left(\frac{h_w^3 t_w}{3} + h_w^2 b_f t_f\right) 10^{-4}$ for flanged profiles

I_W = sectorial moment of inertia in cm^6 of profile about connection of stiffener to plate

= $\frac{h_w^3 t_w^3}{36} 10^{-6}$ for flat bars

= $\frac{t_f b_f^3 h_w^2}{12} 10^{-6}$ for T-profiles

$= \dfrac{b_f^3 h_w^2}{12(b_f + h_w)^2}[t_f(b_f^2 + 2b_f h_w + 4h_w^2) + 3t_w b_f h_w]10^{-6}$

for angles and bulb profiles

h_w = web height in mm
t_w = web thickness in mm
b_f = flange width in mm
t_f = flange thickness in mm. For bulb profiles the mean thickness of the bulb may be used
t_p = thickness of supporting plate in mm
l = span of profile in m
s = spacing of profiles in m.

Where relevant t_k shall be substracted from all thicknesses (t_w, t_f and t_p).

C = spring stiffness exerted by supporting plate panel

$= \dfrac{kEt_p^3}{3s\left(1 + \dfrac{1.33\, k h_w t_p^3}{1000\, s t_w^3}\right)} 10^{-3}$

k = $1 - \eta_p{}^a$, not to be taken less than zero

$\eta_p = \dfrac{\sigma_a}{\sigma_{ep}}$

a = 2 in general
= 1 for flat bar profiles
σ_a = calculated compressive stress. For longitudinals, see B205 and 206
σ_{ep} = elastic buckling stress of supporting plate as calculated in B201.

For flanged profiles k need not be taken less than 0.2.

302 The critical buckling stress as found from 301 and 101 shall not be less than:

$$\sigma_c \geq \frac{\sigma_a}{\eta}$$

σ_a = calculated compressive stress. For longitudinals $\sigma_a = \sigma_{el}$ as given in B205. For ships with high speed and large flare, see also B206
η = 0.9 in general
= 0.85 when the adjacent plating is allowed to buckle in the elastic mode, according to B207.

303 For open thin-walled and short columns, such as cross ties, the torsional buckling mode is to be assessed. The ideal elastic torsional buckling stress is given by:

$$\sigma_{el} = \frac{G\, I_T}{I_P} + \frac{0.001\, f_{end}\; E\, C_W}{I_P\, l^2} \quad (\text{N/mm}^2)$$

Where relevant, t_k shall be subtracted from flanges and web when calculating I_T, I_P and C_W.

G = shear modulus
$= \dfrac{E}{2(1+\upsilon)}$
υ = Poisson's ratio
= 0.3
I_T = St. Venants moment of inertia in cm^4
I_P = polar moment of inertia in cm^4
f_{end} = end constraint factor
= 1.0 where both ends are pinned
= 2.0 where one end is pinned and the other end is fixed
= 4.0 where both ends are fixed
C_W = warping constant in cm^6

l = unsupported length of the pillar in m

304 The critical buckling stress as found from 303 and 101 shall not be less than:

$$\sigma_c \geq \frac{\sigma_a}{\eta}$$

σ_a = calculated compressive stress obtained from direct stress analysis, see Pt.3 Ch.1 Sec.12
η = 0.7

C 400 Web and flange buckling

401 The σ_{el} -value required for the web buckling mode for flanged profiles may be taken as:

$$\sigma_{el} = 3.8\,E\left(\frac{t_w - t_k}{h_w}\right)^2 \quad (N/mm^2)$$

The critical buckling stress σ_c found from 101 shall not be less than as given in 302.

402 For flanges on angles and T-sections of longitudinals an other highly compressed stiffeners the thickness shall not be less than:

$$t_f = 0.1\,b_f + t_k \quad (mm)$$

b_f = flange width in mm for angles, half the flange width for T-sections.

C 500 Transverse beams and girders

501 For beams and stiffeners supporting plating subject to compressive stresses perpendicular to the stiffener direction the moment of inertia of the stiffener section (including effective plate flange) shall not be less than:

$$I = \frac{0.09\,\sigma_a\,\sigma_{el}\,l^4\,s}{t} \quad (cm^4)$$

l = span in m of beams or stiffeners
s = spacing in m of beams or stiffeners
t = plate thickness in mm
σ_{el} = 1.18 σ_a when less than $\sigma_f/2$

$$= \frac{\sigma_f^2}{4(\sigma_f - 1.18\,\sigma_a)} \quad \text{otherwise}$$

σ_a = actual compressive stress.

502 For transverse girders supporting longitudinals or stiffeners subject to axial compression stresses the moment of inertia of the girder section (including effective plate flange) shall not be less than:

$$I = 0.3\,\frac{S^4}{l^3 s}\,I_S \quad (cm^4)$$

S = span in m of girder
l = distance in m between girders
s = spacing in m of stiffeners
I_S = moment of inertia in cm^4 of longitudinal or stiffener necessary to satisfy the lateral buckling mode requirement given in 201—202

$$= \frac{\sigma_{el}\,A\,l^2}{0.001\,E}$$

σ_{el} = as given in 501
A = as given in 201.

SECTION 14 STRUCTURES FOR HIGH TEMPERATURE CARGO

A. General

A 100 Introduction

101 The rules in this section apply to ships intended to carry liquid cargo at a temperature higher than 80°C at atmospheric pressure.

102 The liquid cargo may be transported in integral cargo tanks or independent cargo tanks, dependent of structure and strength.

A list of cargoes which may be covered by these rules is given in F.

103 Cargoes of different temperatures and natures shall not be carried simultaneously in adjacent tanks or in the cargo area unless especially investigated and accepted.

104 The temperature stresses in the cargo containment area with surroundings shall be determined and documented, valid both for part-cargo and full-cargo conditions, see D.

105 Heat balance calculations for part-cargo and full-cargo conditions are also to be available, see D.

106 For a specific gravity of cargo exceeding 1.025 t/m^3 reference is made to Sec.4 C300.

107 The definitions of integral tank or independent tank are given in Pt.5 Ch.4 Sec.1 D.

108 Ships complying with these rules may be assigned the class notation **Tanker for Asphalt** or **Tanker for C**, whichever is applicable. See also Pt.5 Ch.3 and Ch.4.

A 200 Special features notations

201 Ships built according to these rules may be given the additional notation **HOT** e.g. **HOT (...°C cargo tank no....)**.

202 Ships built for carrying cargoes with specific gravity heavier than sea water the additional notation **HL(ρ) (cargo tank no....)** may be given, see Sec.4 C300.

A 300 Survey and testing

301 See Pt.2 Ch.3 Sec.8 and Pt.5 Ch.3 Sec.1 D whichever is relevant.

A 400 Signboards

401 See Pt.5 Ch.3 Sec.1 E or Pt.5 Ch.4 Sec.1 F, whichever is relevant.

B. Materials and material protection

B 100 Hull and tank material

101 See Sec.2. For mild steel and high strength steel there will be a reduction in the yield strength at higher temperatures. This reduction is in the order of 20 N/mm^2 per 50°C increase in temperature above 80°C and shall be taken into account when calculating the strength.

102 The use of high strength steel in the cargo containment area may be advantageous or necessary to absorb the temperature stresses added.

103 When calculating the f_{2b} and f_{2d} factors, see Sec.6 A 201 and Sec.8 A 201, the elements in the hull structure intended to buckle shall be excluded. Such elements may, however, be included when they are in tension.

B 200 Insulation material

201 Insulation materials used on board to reduce the heat transfer in the cargo area must be approved with regard to the ability to withstand dynamic loads from the cargo, sticking, insulation etc.

B 300 Corrosion protection

301 Ballast tanks within the cargo area or adjacent to the cargo area shall be coated to prevent corrosion.

Guidance note:
The coating material must be compatible with expected environmental conditions e.g. resistive against heat, elastic against expansion.

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

Corrosion additions above table values given in Sec.2 D200 should be considered.

Particular attention shall be paid to the upper part of side tanks, hot sides of ballast tanks and upper deck subject to the salt atmosphere.

C. Ship arrangement

C 100 Location and separation of spaces

101 The cargo pump rooms shall be separated from the cargo area by cofferdam or insulation, preferably an open, ventilated cofferdam.

C 200 Equipment within the cargo area

201 Equipment fitted on cargo tank deck or inside the cargo tanks shall be fastened to the main structure with due consideration to the thermal expansion and stresses that will occur.

C 300 Surface metal temperature

301 See Pt.5 Ch.3 Sec.3 J100.

C 400 Cargo heating media

401 See Pt.5 Ch.3 Sec.4 D.

D. Load conditions

D 100 Full and partial cargo conditions

101 See Sec.5 or Pt.5 Ch.3 or Ch.4, whichever is relevant.

102 All partial cargo conditions where cargo temperature exceeds 80°C shall be arranged with symmetric loading in the transverse direction. During charging and discharging the maximum difference between two adjacent liquid levels should be limited to about 3 meters or 1/4 h whichever is the less, where h is the depth of the longitudinal bulkhead or the tank depth. Alternate tank filling in longitudinal direction should be basis for the thermal stresses.

D 200 Water ballast conditions

201 Water ballast is at no time to be carried adjacent to the tanks with hot cargo. A defined safe zone must be specified.

E. Scantlings of the cargo area

E 100 Construction considerations

101 Hot cargo directly on the outer side shell plating shall be avoided.

102 With a cargo temperature of up to about 140°C, an integral cargo stiffening system consisting of single bottom, deck and double boundary at sides, transverse/longitudinal girders and stiffeners may be feasible. Longitudinal and transverse cargo separation bulkheads may be of non-corrugated type, preferably without deep girders/stringers. The dimensions and details to be calculated and considered with due respect to the temperature stresses.

With a cargo temperature of up to about 200°C, an integral cargo system consisting of double skin may be feasible. The inner containment to be transverse stiffened while outer system should be longitudinal stiffened. Single deck may be accepted. Longitudinal and transverse cargo separation bulkheads to be of vertically corrugated type without girders/stringers. When longitudinal strength is calculated the transverse stiffened skin may be allowed to buckle and thus disregarded when subject to compressive longitudinal forces.

With a cargo containment temperature above about 200°C independent cargo system will normally be required.

103 The termination of structure at forward or aft end of the cargo area shall be designed to transfer axial forces (longitudinal forces) due to temperature decrease.

104 Where the temperatures as well as temperature gradients are high, all transitions in the main structures shall be carefully designed with respect to high shear forces.

105 Weld dimensions in structures where high shear forces are involved shall be specially calculated.

E 200 Thermal stress analysis

201 It will generally be accepted that the temperature stresses are established within the parallel midship portion of the cargo area and then used generally for the whole cargo area.

Guidance note:

For a ship with class notation **Tanker for Asphalt** the following coefficients may be used in the heat balance calculations.

	kcal/hour/m²/°C
Asphalt to inner bottom:	50
Asphalt to inner ship side:	50
Seawater to outer ship side:	7400 (with ship moving)
Air to outer ship side:	20
Air to deck (outside): in be-tween inner and outer shell	10
Air to outer ship side:	10
Air to inner ship side:	10
Air to web in the trans. webframe:	5

The air in the double bottom is assumed stationary layered with the same temperature as the structure. Hence no heat transfer from air to the structure will exist.

The air in side tanks is not stationary.

For the deck beams:

- asphalt to deck beam: 50

The following material data for mild steel may be used:

- density: 7860 kg/m^3
- specific heat: 0.114 kcal/kg/°C
- coefficient for heat conduction: 0.3 t + 59.l96 kcal/h m °C.

The effect from various scantlings is negligible.

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202 The calculated temperature loadings shall represent full load and partial load conditions, seagoing as well as harbour conditions.

203 The ambient temperature in the sea water and in the air shall be 0°C when heat flow is calculated.

204 The temperature stresses shall be combined with still water and wave bending stresses as well as static and dynamic stresses from cargo and seawater.

205 The total results shall be checked against allowable stresses, see below, and the global and local buckling strength.

Local elastic buckling is acceptable, see also Appendix A. Reduced stiffness of plating shall be used in the calculations. The final results shall include correct stiffnesses.

Guidance note:

The 3-dimensional finite element method model, or an equivalent means for establishing the temperature stresses, may extend from middle of one cargo hold to the middle of an adjacent hold. Symmetric condition may be assumed at the centre line.

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E 300 Acceptable stress level

301 The stress level shall not exceed the values given in this chapter, where actual loading conditions are calculated without taking temperature into account.

302 For independent cargo tank systems, reference is made to Pt.5 Ch.5 Sec.5.

303 When the temperature stresses are included the following stresses are acceptable (all values are given at 180°C):

a) Transverse and longitudinal girders

- nominal stress for NV-NS σ_{max} = 190 N/mm^2
- nominal stress for NV32 σ_{max} = 260 N/mm^2
- nominal stress for NV36 σ_{max} = 300 N/mm^2
- shear stress for NV-NS τ_{max} = 110 N/mm^2
- shear stress for NV32 τ_{max} = 155 N/mm^2

- *shear stress for NV36* τ_{max} = 175 N/mm^2
- *equivalent stress for NV-NS* $\sigma_{e\ max}$ = 205 N/mm^2
- *equivalent stress for NV32* $\sigma_{e\ max}$ = 280 N/mm^2
- *equivalent stress for NV36* $\sigma_{e\ max}$ = 315 N/mm^2

When the thermal stresses are the dominant part of the stress level, higher stresses than above may be accepted locally

$\left(\text{up to } \sigma_{max} = \sigma_F \text{ and } \tau_{max} = \frac{\sigma_F}{\sqrt{3}}\right)$.

b) Hull section modulus
Stresses from cargo conditions shall be as given by Sec.5 C303 when D102 is taken account of. The same effect applies to the minimum requirement.

c) Longitudinals
The stresses shall be as given in this chapter increased by 30 N/mm^2 for NV-NS or 80 N/mm^2 for NV36 steel when the temperature in elements is 180°C.

d) Beams, frames
The stresses shall be as given in this chapter increased by 30 N/mm^2 for NV-NS or 80 N/mm^2 for NV36 steel when the temperature in elements is 180°C.

e) Plating
Minimum thicknesses to be as for an ordinary ship without high temperatures.

E 400 Girders

401 The forces introduced to the girder system due to the temperature rise (i.e. the temperature gradients) make it important to control the girders with respect to axial-bending and shear stresses, tripping strength, welding (type and size), continuity, transfer of forces when flanges change direction, cut-outs (shape, situation, local strengthenings) etc.

F. Type of cargoes

F 100 List of cargoes

101 Examples of cargoes which may be covered by these rules:

Cargo	*Specific gravity* *t/m^3*	*Temperature* *°C*
Asphalt (bitumen)	1.025	130 to 250
Coal tar (solvents)	1.20	130 to 250
Creosote	1.10	90 to 105
Coal tar (pitch molten)	1.20	230 to 280 [1)]
Carbon Black feedstock	about 1.2	about 100
Sulphur (molten)	1.80	155 [1)]
1) Independent tanks required according to Pt.5 Ch.4.		

SECTION 15 SPECIAL REQUIREMENTS - ADDITIONAL CLASS

A. Introduction

A 100 Introduction

101 This section gives an overview of the different structural approval methods, their scope and applicability for different vessel types. These hull approval methods are identified by the following class notations:

— **NAUTICUS** (Newbuilding)
— **PLUS**
— **CSA**.

A 200 Scope

201 The scope of **NAUTICUS (Newbuilding)** or **CSR** covers the elements as specified in Table A1 and includes both ultimate strength and fatigue strength evaluations.

202 The class notations **PLUS** and **CSA** require additional assessments to those specified in **NAUTICUS (Newbuilding)** or **CSR**.

203 The **CSA** notation is given in four different alternatives represented by qualifiers. Qualifier **FLS1** represents the first level of the range of **CSA** notations, focusing on fatigue only. Also qualifier **FLS2** indicates a scope addressing fatigue limit state evaluations, but with a more comprehensive analysis scope. The **CSA-1** and **CSA-2** notations include a scope covering an ultimate limit state assessment in addition to the fatigue assessments.

204 For a detailed description of the scope of the notations, reference is made to Table A1.

Table A1 Additional structural class notations – overview of structure

Class notations	*Ultimate strength*	*Fatigue strength locations*	*Loads*
NAUTICUS (Newbuilding)	— Yield and buckling	— Stiffener end connections — Lower hopper knuckle	— Rule loads
CSR	— Yielding and buckling — Hull girder capacity	— Stiffener end connections — Knuckle connections as described in CSR Pt.1 Ch.9 Sec.2.	— Rule loads
PLUS	— NA	— Deck plating i.w.o openings and attachments — Bottom and side shell plating — Longitudinal stiffener-frame connections — Ship type specific details (see C402)	— Rule loads
CSA-FLS1	— NA	— Panel knuckles — Discontinuous plating structure — Ship type specific details (see D502)	— Direct wave load
CSA-FLS2	— NA	— Details as defined for **NAUTICUS** (**Newbuilding**) or **CSR** — Details as defined for **PLUS**, except longitudinal stiffener-frame connections. — Details as defined for **CSA-FLS1**	— Direct wave load
CSA-1	— Yield and buckling — Hull girder capacity	— As for **CSA-FLS1**	— Direct wave load
CSA-2	— Yield and buckling — Hull girder capacity	— As for **CSA-FLS2**	— Direct wave load

A 300 Objective

301 The general objective of the hull approval methods described in this section is to provide a framework for the evaluation of the structure against defined acceptance criteria based on an extended calculation procedure covering load and structural response analysis.

A 400 Application

401 **NAUTICUS (Newbuilding)** is mandatory for certain ship types and sizes. The notation is not applicable for vessels classified under the Common Structural Rules as described in CSR Pt.1 and CSR Pt.2.

402 **CSA** and **PLUS** are voluntary and applicable to all types of ships, provided that these vessels comply with **NAUTICUS(Newbuilding)** or **CSR**.

403 **CSA** applies both to conventional ships as special design configurations related to main dimensions, hull form, structural arrangement and or mass distribution (steel, equipment and cargo).

404 The class notations **PLUS** can be combined with **CSA**.

405 The class notations **CSA-FLS1**, **CSA-FLS2**, **CSA-1** and **CSA-2** can not be given independently of each other as the higher level class notation also includes the scope of the lower level class notation.

The scope of class notation **CSA-2** includes the scope of **CSA-FLS1**, **CSA-FLS2** and the scope of class notation **CSA-1** includes the scope of **CSA-FLS1.** The scope of class notation **CSA-FLS2** includes the scope of **CSA-FLS1**.

406 The calculations specified in the requirements shall be carried out by computer programs supplied by or recognised by the Society. As recognised computer programs are considered all programs applied by shipyards where reliable results have been demonstrated to the satisfaction of the Society.

Wave load analysis computer programs and their application shall be specially approved.

A 500 Structure

The different notations are discussed in the remaining of this section as follows:

— Sub-section B: **NAUTICUS (Newbuilding)**
— Sub-section C: **PLUS**
— Sub-section D: **CSA**.

B. Class notation NAUTICUS (Newbuilding)

B 100 General

101 The notation **NAUTICUS (Newbuilding)** describes an extended calculation procedure for the verification of hull structures. The procedure includes use of finite element analysis for determination of scantlings in the midship area, and extended requirements to fatigue calculations for end structures of longitudinals in bottom, inner bottom, side, inner side, longitudinal bulkheads and upper deck.

102 The notation is mandatory for certain vessels. When applicable, this is stated in Pt.5 for the type of vessel in question.

103 The direct strength calculation is in general to be based on the principles given in Sec.12, with scope of the analysis as defined in B200.

B 200 Finite element analysis

201 A finite element analysis shall be performed for the midship region to document results as listed below:

— relative deflections of supporting members as bulkheads, floors, web frames and girders
— stresses in transverse bulkheads
— stresses in longitudinal girders in bottom, side, bulkhead and deck
— stresses in transverse girders in bottom, side, bulkhead and deck
— stresses in girders and stringers on transverse bulkheads
— stresses in brackets of longitudinal, transverse or vertical girder structures located on bottom, side, deck or bulkhead
— stresses in selected stiffeners and associated brackets where the stiffeners' supports are subjected to relative deflections.

The stresses shall not exceed the acceptance criteria given in Sec.12 B400.

Hull girder normal stresses and hull girder shear stresses shall not be considered directly from the analysis unless special boundary conditions and loads are applied to represent the hull girder shear forces and hull girder bending moments correctly.

For ships where this class notation is mandatory, details regarding areas to be evaluated by finite element analysis are given in Pt.5.

The above mentioned results can be obtained by using a cargo hold or tank analysis and frame and girder analysis, together with local structure analyses for stiffeners, subject to relative deformations and other critical details, when relevant.

Further description of such calculations are given in Sec.12, sub-sections D, E and F. Acceptable procedures are given in DNV Classification Notes for the respective types of vessels.

B 300 Fatigue strength assessment

301 The fatigue strength assessment is in general to be carried out for end structures of longitudinals in the cargo area located in bottom, inner bottom, side, inner side, longitudinal bulkheads and strength deck. The assessment shall be carried out in accordance with Sec.16.

302 The fatigue strength assessment is in general to be carried out for:

— longitudinals in way of end supports in the cargo area, illustrated by hot spot (1) and (2) in Fig.1, located in bottom, inner bottom, side, inner side, longitudinal bulkheads and strength deck
— the lower hopper knuckle.

The assessment shall be carried out in accordance with Sec.16.

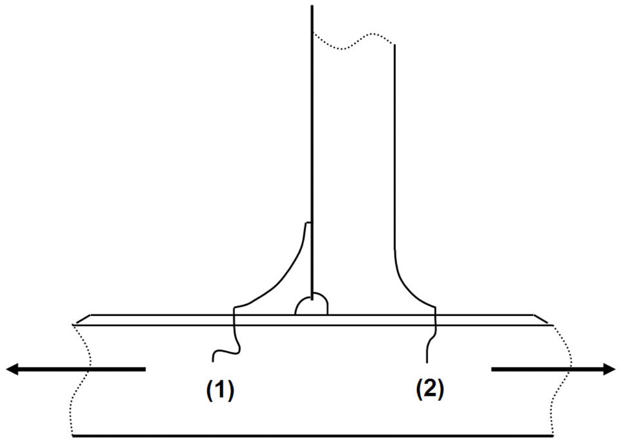

Fig. 1
Example of hotspots as checked in NAUTICUS (Newbuilding)

303 The effect of relative deformation shall be taken into account in the fatigue evaluation of longitudinals. The deformations shall be based on results from the finite element analysis required in 200, applying fatigue loads as described in Sec.16.

C. Class notation PLUS

C 100 Classification

101 The **PLUS** notation is intended for vessels operating in harsh areas and include extended scope of fatigue strength verification for hull structural details.

102 Net scantlings as defined by **NAUTICUS (Newbuilding)** or **CSR**, whichever is relevant, shall be used.

103 Calculations documenting compliance with requirements in this section shall be submitted for information. Guidance on documentation level is given in DNV Classification Note No. 34.2.

104 Hot spots covered by **NAUTICUS (Newbuilding)** or **CSR** need not be recalculated according to **PLUS** requirements.

C 200 Application

201 The **PLUS** notation is primarily intended for tankers and gas carriers and container carriers of conventional design, but can also be applied to other types of vessel. Generally the vessels shall comply with:

— Class notation **CSR** or **NAUTICUS (Newbuilding)**

C 300 Fatigue strength requirements

301 The fatigue strength evaluation shall be carried out based on the target fatigue life and service area specified by the **CSR** or **NAUTICUS (Newbuilding)** notation.

The effect of low cycle fatigue shall be included in the assessment for details subjected to large stress variations during loading and unloading operations.

Fatigue calculations shall be carried out according to the procedures specified by DNV Classification Note No. 34.2.

302 The following details in the cargo area shall be considered in the fatigue strength assessment in addition to those required for other class notations:

— longitudinal stiffener-frame connections located in the bottom, inner bottom, side and inner side including connected web stiffener, cut out and collar plate. (See illustration in Fig.2.)

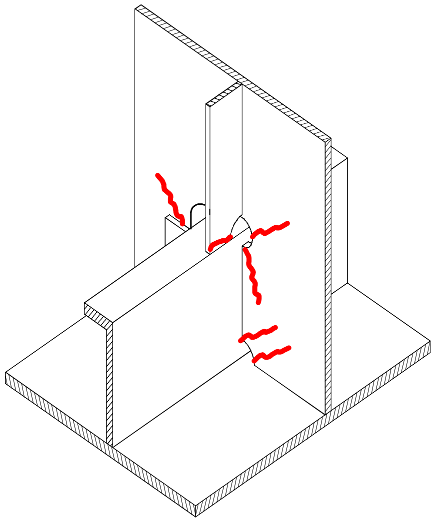

Fig. 2
Web stiffener, cut out and collar plate crack locations.

— deck plating in way of stress concentrations from openings, scallops, pipe penetrations and attachments
— bottom and side shell plating connection to frames and stiffeners
— stringer heels and toes where relevant

Guidance note:

The fatigue requirements for the deck plating, top coaming outside corner/transition areas (i.e. container vessels) will normally be satisfied provided that the target fatigue life is obtained with a stress concentration factor K_g of 1.7.

The control of the deck plating may have direct impact on the hull girder cross section, ref. Pt.3 Ch.1 Sec.5 C305.

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— and ship type specific details as specified below if applicable:

LNG membrane carrier:

— upper hopper knuckle
— lower and upper chamfer knuckles
— longitudinal girders and longitudinal stringers at transverse bulkhead
— dome opening and coaming.

LPG carrier:

— lower and upper side brackets
— dome opening and coaming.

D. Class notation CSA

D 100 General

101 The calculation procedure in this sub-section is an extension of the finite element method calculations described for the notations **NAUTICUS (Newbuilding)**, **CSR** and **PLUS**.

The hull structural scantlings are however not to be less than determined by the main class requirements.

102 The **CSA** notation requires the same scope for direct calculations of wave loads and spectral fatigue analysis. The qualifiers -1 and -2 require in addition direct calculated ultimate strength analysis.

The class notation **CSA** with qualifiers **-FLS1** and **-FLS2** may be assigned to ships complying with the requirements in D100 to D500. The qualifiers **-1** and **-2** may be assigned to ships complying with the requirements in D100 to D700.

103 If the vessel is assigned both the **PLUS** notation and a **CSA-** notation, all details required by the **CSA-** notation shall not be included in the PLUS analysis. Other details included in the **PLUS** notation shall be analysed based on Rule loads, e.g. longitudinal stiffener-frame connections. The scope for **NAUTICUS (Newbuilding)** or **CSR** is independent of the application of **CSA**.

104 The **CSA-1, 2** ultimate strength analysis is required for all structural members in the cargo hold area. Except for ships where transverse strength is of special importance (ro-ro, car carrier, catamaran, etc.), buckling evaluations need only be performed for longitudinal members (also transverse stresses need to be included in the buckling evaluation).

The analyses should be performed in accordance with the general principles stated in DNV Classification Note No. 34.1.

105 Net scantlings as defined by **NAUTICUS (Newbuilding)** or **CSR**, whichever is relevant, shall be used.

106 Calculations documenting compliance with requirements in this section shall be submitted for information. Guidance on documentation level is given in DNV Classification Note No. 34.1.

D 200 Selection of loading conditions

201 The design load conditions for fatigue shall normally be based on the vessels loading manual and shall normally include ballast and full load conditions for the specific ship.

The loading conditions for fatigue shall be selected to represent typical loading situations, which will be used during most of the operational lifetime of the vessel while at sea.

The design load conditions for ultimate strength shall be based on the vessels loading manual and shall in addition include part load conditions as relevant for the specific type of ship.

For selection of still water load conditions to be used as basis for extreme wave load determination, (return period of 25 years), the most demanding loading conditions defined in the loading manual shall be used.

The most demanding loading conditions are normally selected as those giving maximum stresses in longitudinal material in different parts of the vessel.

For vessels (ro-ro, catamaran, etc.) where transverse capacity is of major interest, load conditions giving maximum stresses in transverse material will also relevant.

More detailed information about selection of loading conditions is given in DNV Classification Note 34.1.

The loading conditions are in addition to be defined to cover the full range of still water bending moments and shear forces from maximum sagging to maximum hogging conditions.

D 300 Wave load analysis

301 Direct wave load calculations should be performed in accordance with the general principles stated in DNV Classification Note Nos. 34.1 and 30.7. The transfer functions shall be calculated based on a 3D hydrodynamic model. The effect of forward speed shall be included. Non-linear effects shall be accounted for in the determination of extreme vertical shear forces and bending moments.

302 Design loads shall be determined for loading conditions giving maximum vertical bending moment amidships, maximum horizontal and torsional moment (if relevant), vertical maximum acceleration in tank no.1, maximum external pressure in tank no.1, maximum vertical shear force in forward and aft holds, maximum transverse acceleration (if relevant).

Partial loading conditions resulting in large hull girder loads and local pressures shall be considered if relevant.

The stillwater bending moment and shear forces shall be combined with the corresponding extreme wave loads such that sets of simultaneously acting loads are obtained.

Guidance note:

The stresses in the hull from the selected still water loading conditions should be added to the dynamic parts. The dynamic stress combinations should be constructed taking due consideration of simultaneously acting loads with proper phasing or time lag as determined from the hydrodynamic calculations.

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303 Fatigue loads shall be based on 10^{-4} probability of exceedance.

Reference loads for extreme loads shall be calculated for a 25-year return period using wave scatter diagrams for the North Atlantic. This will serve as basis for the wave load analysis with respect to the calculation of hull girder and main girder system stress response (400 and 500) as well as hull girder capacity analysis (600).

D 400 Finite element analysis

401 The structural analysis shall be able to capture global and local stress variations. A global structural model of the entire ship shall be used to represent the overall stiffness of the ship. Finer meshed models shall be used to capture more local stress distributions for evaluation of yield and fatigue strength.

The finite element analysis of the hull structure should be carried out in accordance with the principles given in DNV Classification Note Nos. 34.1 and 30.7.

D 500 Fatigue strength assessment

501 The fatigue strength assessment shall be performed according to Sec.16. The dynamic stresses based on the global finite element calculations for wave loads derived from the direct load calculations shall be utilised.

The fatigue strength evaluation shall be carried out based on the target fatigue life and service area specified for the vessel, but minimum 20 years world wide for vessels with **NAUTICUS(Newbuilding)** notation. For vessels with **CSR** notation the minimum target fatigue life is 25 years North Atlantic.

Fatigue stress evaluation based on nominal calculated stresses and application of relevant stress concentration factors may normally be accepted. When stress concentration factors for the geometrical details are not available, a fine mesh finite element calculation shall be performed.

502 For vessel with **CSA-FLS1** notation fatigue calculations are also to be carried out for highly stressed structural details in the cargo hold region, such as:

— panel knuckles
— discontinuous plating structure.

For hatch corners and similar constructions it may also be relevant to carry out fatigue calculations for non-welded details at the radius edge.

Ship type specific details shall be determined for each project based on DNV Classification Note 34.1 and available experience.

Fatigue calculations shall in general cover the entire cargo hold area. More detailed information about areas and how fatigue assessment should be carried out for different ship types is given in DNV Classification Notes No. 34.1 and 30.7.

D 600 Yield and buckling capacity

601 For vessels with notation **CSA-1, 2**, longitudinal hull girder and main girder system nominal and local stresses derived from the direct strength calculations shall be checked according to the criteria specified in 502, 503 and 504. All stresses refer to 25 year North Atlantic conditions.

602 Allowable equivalent nominal stresses are:

$$\sigma_e = 0.95\sigma_f \ \ (\text{N/mm}^2)$$

σ_f = minimum upper yield stress of the material
σ_e = equivalent stress.

603 Local linear peak stresses in areas with pronounced geometrical changes, such as in hatch corners, frame corners etc., may need special consideration. Local peak stresses in this context are stresses calculated with *Stress concentration models* that have a finer finite element mesh representation than used for nominal stress determination.

For extreme 25 year North Atlantic loads, linear peak stress corresponding to an acceptable equivalent plastic strain is:

$$\sigma_e = 400\ f_1 \ \ (\text{N/mm}^2)$$

Local peak stresses as given above may be accepted provided plastic mechanisms are not approached (developed) in the associated structural parts.

Guidance note:

Areas above yield determined by a linear finite element method analysis may give an indication of the actual area of plastification. Otherwise, a non-linear finite element method analysis may need to be carried out in order to trace the full extent of the plastic zone.

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604 The Ultimate Capacity control of local stiffened panels shall be performed for all longitudinal material (bottom, inner bottom, side, inner side, longitudinal bulkheads and strength deck.) according to the DNV PULS code.

For vessels (ro-ro, catamaran, etc.) where transverse capacity is of major interest, buckling calculations should be performed also for transverse material.

PULS stands for Panel Ultimate Limit State and is a computerized non-linear buckling code recognized by the Society.

The PULS Ultimate Capacity usage factor shall not to exceed 0.90 for stiffened panels.

PULS Ultimate Capacity estimate of stiffened panels accepts local elastic buckling of plates between stiffeners.

Guidance note:
The ultimate strength control of stiffened panels, girders etc. may be assessed using recognised non-linear FE programs. The strength assessments should consider all relevant effects according to DNV's approval.

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605 The buckling and ultimate strength control of unstiffened and stiffened curved panels may be performed according to the method as given in DNV-RP-C202.

D 700 Hull girder capacity

701 For vessels with notation **CSA-1, 2**, the ultimate sagging and hogging bending capacity of the hull girder shall be determined, for both intact and damaged conditions.

The ultimate hull girder bending capacity check applies to tankers, gas carriers and bulk carriers. For application concerning other ship types a case by case evaluation will be given by the Society.

702 The following damage conditions shall be considered independently, using the worst possible position in each case:

1. Collision

with penetration of one ship side, single or double side within a breadth of B/16.

The damage extents are shown in Fig. 4 and given by:

Damage parameter	*Damage extent*	
	Single side	*Double side*
Height: *h/D*	0.75	0.60
Length: *l/L*	0.10	0.10
h = penetration height		
l = penetration length		

Guidance note:
Calculations utilising symmetrical characteristics, i.e. the capacities of the damaged parts of the cross section are reduced with 50% on both sides of the ship, will be accepted.

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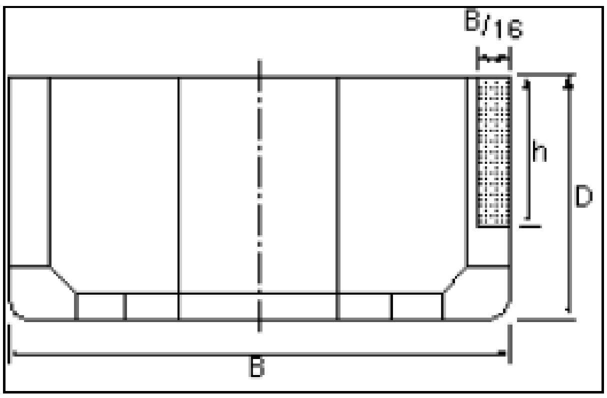
2. Grounding

with penetration of bottom, single or double bottom. The damage extents are shown in Fig. 3 and given by:

Damage parameter	*Damage extent*	
	Single bottom	*Double bottom*
Height: *b/B*	0.75	0.55
Length: *l/L*	0.50	0.30
b= penetration breadth		

The height of the damage should not be taken larger than 2 m (i.e. min.(B/20, 2).



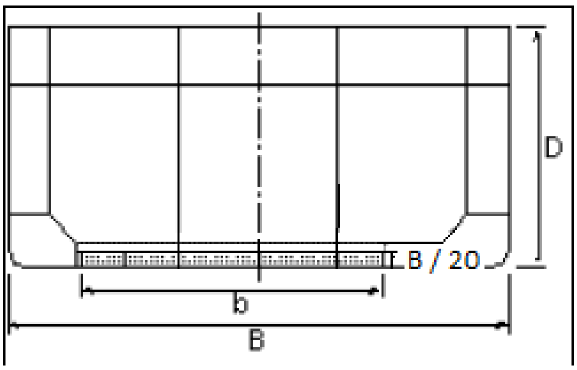


Fig. 3
Damage extent collision (left) and grounding (right)

703 The ultimate hull girder capacity is calculated according to the accept criteria and limit shown in Table E1.

Table E1 Hull girder strength check: accept criteria – required safety factors

Intact strength	*Damage strength*
$M_S + \gamma_{W1} M_W \leq M_{U1} / \gamma_M$	$\gamma_S M_S + \gamma_{W2} M_W \leq M_{UD} / \gamma_M$
where: M_S = maximum design sagging or hogging still water moment according to the loading conditions from the loading manual used in the wave load analysis M_W = design wave bending moment according to the wave load analysis in 300 M_{U1} = hull girder bending moment capacity in intact condition γ_{M1} = 1.1 (partial safety factor on M_W for environmental loads) γ_M = 1.15 (material factor) in general γ_M = 1.25 (material factor) to be considered for hogging checks of designs with bi-axial/shear stresses conditions in bottom area of such a magnitude that they will significantly reduce the hull girder capacity. For more details, see DNV Classification Notes No.34.1.	where: M_S = maximum design sagging or hogging still water moment according to the loading conditions from the loading manual used in the wave load analysis M_W = design wave bending moment according to the wave load analysis in 300 M_{UD} = hull girder bending moment capacity in damaged condition γ_S = 1.1 (factor on M_S allowing for moment increase with accidental flooding of holds) γ_{W2} = 0.67 (wave load reduction factor corresponding to 3 month exposure in world-wide climate). γ_M = 1.0 (material factor) in general γ_M = 1.10 (material factor) to be considered for hogging checks of designs with bi-axial/shear stresses conditions in bottom area of such a magnitude that they will significantly reduce the hull girder capacity. For more details, see DNV Classification Notes No.34.1.

Guidance note:

The ultimate sagging and hogging bending capacity of the hull girder may be assessed using recognised non-linear FE programs. The strength assessments should consider all relevant effects according to DNV's approval.

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704 The Ultimate Strength M_U shall be checked for the weakest interframe cross-section including all relevant local load and double bottom bending effects.

SECTION 16 FATIGUE CONTROL

A. General

A 100 Introduction

101 The background and assumptions for carrying out fatigue calculations in addition to or as a substitute to the specific rule requirements in Sec.5 to Sec.11 are given in this section. Load conditions, design criteria and applicable calculation methods are specified.

For some ship types, such direct fatigue calculations are specified in the rules for the class notation in question.

A 200 Application

201 The application of direct fatigue calculations is governed by the following cases:

1) The calculations are required as part of rule scantling determination when simplified formulations do not represent the dynamic stress distribution and a direct stress analysis has been required with a reference to this section.
2) Serving as an alternative basis for the scantlings, direct stress calculations may give reduced scantlings compared to the explicit fatigue requirements.

A 300 Loads

301 The vessel shall be evaluated for fatigue due to global and local dynamic loads. For the local loads, stresses due to internal and external pressures may be calculated separately and combined using a correlation factor between the sea pressure loads and internal pressure loads. Simplified formulas for dynamic loads are given in DNV Classification Note No. 30.7. The simplified loads may be substituted by directly computed dynamic loads.

Guidance note:
In case the values of roll radius K_r and the metacentric height GM have not been calculated for the relevant loading conditions, the following approximate values may be used:

	Tanker		*Bulk carrier*		*Container carrier*	
	K_r	*GM*	K_r	*GM*	K_r	*GM*
Loaded	0.35B	0.12B	0.39B	0.17B	0.39B	0.04B
Ballast	0.45B	0.33B	0.39B	0.25B	0.39B	0.04B

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302 The fatigue strength evaluation shall be based on the most frequently used design load conditions. The fraction of the lifetime operating under each considered loading condition shall reflect the intended operational trading pattern of the ship. If nothing else is specified, the values in Table A1 shall be used.

Table A1 Distribution of design load conditions

Vessel type	*Tankers*	*Gas carriers*	*Bulk carriers*	*Container carriers*
Loaded condition	0.425	0.45	0.5	0.65
Ballast condition	0.425	0.4	0.35	0.2

A 400 Design criteria

401 The fatigue analysis shall be based on a period equal to the planned life of the vessel. The period is, however, normally not to be taken less than 20 years. Unless otherwise specified the fatigue calculation shall be based on 80% of North Atlantic wave scatter diagram as described in DNV Classification Note No. 30.7 (equivalent to world wide scatter diagram).

402 The cumulative effect of the stress history may be expressed by linear cumulative damage usage factor (Miner-Palmgren), which shall not exceed the value $\eta = 1.0$ using S-N data for mean value minus 2 times the standard deviation.

A 500 Calculation methods

501 Acceptable calculation methods are given in DNV Classification Note No. 30.7.

502 For welded joints the S-N curves of which the effect of the weld is taken into account, shall be used. The effects of a corrosive environment on the fatigue life shall be taken into account through appropriate S-N curves.

For coated ballast water tanks, S-N curves in air may be used for the specified design life of the vessel minus five (5) years and S-N curves for corrosive environment shall be used for the last five (5) years of the specified design life.

For uncoated cargo oil tanks and coated cargo tanks, S-N curves in air may be used for the specified design life.

A 600 Basic requirements

601 Global stress components may be calculated based on gross scantlings, if not otherwise specified.

Local stress components should be calculated based on net scantlings, i.e. deducting a corrosion addition as defined by the actual notation.

The calculated stress may be reduced due to the mean stress effect. The correction shall be based on a calculated value of the mean stress. The stress concentration factors shall be included when calculating the mean stress.

602 For longitudinals the fatigue evaluation may be carried out based on direct calculation of the stresses. The stresses to be taken into account are:

1) Nominal hull girder longitudinal stresses.
2) Stresses due to bending of longitudinal girders due to lateral loading.
3) Local bending stresses of longitudinals for lateral loading.
4) Bending stresses due to support deflection of longitudinals.

B. Improvement of fatigue life by fabrication

B 100 Weld improvement method

101 Post-weld fatigue strength improvement methods are to be considered as a supplementary means of achieving the required design fatigue life, T_d, and are subjected to quality control procedures. The benefit of post-weld treatment to the calculated fatigue life can only be applied for corrosion free conditions. Where corrosion free conditions are ensured by the application of a protective coating applied after the post-weld treatment, the protective coating is to be maintained throughout the design life of the vessel.

102 For structural details where the benefit of post-weld treatment is applied to meet the fatigue life requirement, the calculated fatigue life at the design stage for the considered structural detail excluding the effect of post-weld treatment is not to be less than $T_d/1.47$.

For structural details in a cargo hold for dry bulk cargo where mechanical damage due to loading/unloading operations is likely to occur, the calculated fatigue life at design stage excluding post-weld treatment effects is not to be less than 20 years.

Where post weld treatment is applied, details of the grinding standard including the extent, smoothness particulars, final weld profile, and grinding workmanship and quality acceptance criteria are to be clearly shown on the applicable drawings and submitted for review together with supporting calculations indicating the proposed factor on the calculated fatigue life.

103 *Post-weld treatment methods at fabrication stage*

The basic post-weld treatment methods considered to improve fatigue strength at the fabrication stage related to weld geometry control and defect removal are weld profiling and toe grinding.

Guidance note:
Information concerning grinding method and particulars is given in DNV Classification Note 30.7 [11.2].

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104 The improvement methods are applied to the weld toe. Thus, they are intended to increase the fatigue life of the weld from the viewpoint of a potential fatigue failure arising at the weld toe. The possibility of failure initiation at hot spots other than the weld toe shall always be considered.

Guidance note:
If the failure is shifted from the weld toe to the root by applying post-weld treatment, there may be no significant improvement in the overall fatigue performance of the joint. Improvements of the weld root cannot be expected from treatment applied to weld toe.

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105 When weld improvement methods in accordance with 103 are applied, full penetration welds, or partial penetration welds with a minimum root face $r = t_0/3$ are to be used to mitigate or eliminate the possibility of cracking at the weld root.

APPENDIX A ELASTIC BUCKLING AND ULTIMATE STRENGTH

A. Introduction

A 100 Scope and description

101 Average in-plane compressive stresses above the elastic buckling stress σ_{el} may be allowed for plate elements subject to extreme loading conditions (probability level of 10^{-8} or less), as long as functional requirements do not prohibit large and off-plane elastic deflections.

An accepted procedure for evaluating the ultimate compressive strength is given in the following.

The ultimate stress limit and effective width of local plate panels are given in B100 and B200. The ultimate strength of stiffened panels, simple girders and ship hull girders is given in B300 to B500.

B. Calculation procedure

B 100 Estimation of ultimate stress

101 For each local panel where elastic buckling is expected ($\sigma_a > \eta\sigma_{el}$), the maximum allowable compressive stress σ_u is given by:

$$\sigma_u = \psi_u \, \sigma_{el}$$

σ_{el} = elastic buckling stress as calculated from Sec.13 B201
ψ_u = excess factor given as a function of σ_f / σ_{el}

For longitudinally stiffened plating:

$$\psi_u = 1 + 0.375 \left(\frac{\sigma_f}{\sigma_{el}} - 2 \right)$$

For transversely stiffened plating (compressive stress perpendicular to longest side *l* of plate panel):

$$\psi_u = 1 + c \left(\frac{\sigma_f}{\sigma_{el}} - 2 \right)$$

$$c = \frac{0.75}{\frac{l}{s} + 1}$$

B 200 Calculation of effective width

201 Due to the elastic buckling the effective width of plating taking part in the compression area will be reduced.

The effective width for stresses induced above the elastic buckling level is given by:

$$\frac{b_e}{b} = \frac{\sigma_u - \sigma_{el}}{\sigma_f - \sigma_{el}}$$

σ_u = ultimate stress given in 100
σ_f = minimum upper yield stress of material.

b and b_e is always to be taken perpendicular to the direction of the compressive stress.

B 300 Ultimate load of stiffened panels

301 The ultimate load capacity of a stiffened plate panel in compression is given by:

$$P_U = 0.1 \left[\sigma_{el} A + (\sigma_m - \sigma_{el}) A_R \right] \quad \text{(kN)}$$

A = total area (cm^2) of panel
= $10\, b\, (t - t_k) + \Sigma a_s$
A_R = reduced area of panel
= $10\, b_e\, (t - t_k) + \Sigma a_s$
b = total width (m) of panel
b_e = reduced width (m) as given in 201
t = thickness (mm) of plating
a_s = area (cm^2) of stiffener/girder in direction of compressive stress

σ_{el} = elastic buckling stress (N/mm^2) of plating
σ_m = $\sigma_{c\,l}$ or 0.9 σ_f, whichever is the smaller, when stiffeners in direction of stress
= 0.9 σ_f when stiffeners perpendicular to stress
$\sigma_{c\,l}$ = critical buckling stress of stiffeners in direction of compressive stresses, as calculated in Sec.13 C200 and C300.

The design condition is given by:

$$P_U \geq P_A / \eta_u$$

P_A = actual compressive load in panel, based on extreme dynamic load
= 0.1 σ_a A
η_u = 0.85.

B 400 Ultimate strength of simple girders with stiffened panel flange

401 The ultimate bending moment capacity of girders with a stiffened plate flange in compression is given by:

$$M_U = M_E + \Delta M_U \quad \text{(kNm)}$$

M_E = moment capacity corresponding to the elastic buckling limit

$$= \frac{\sigma_{el}\ I}{1000\ z_p} \quad \text{(kNm)}$$

σ_{el} = elastic buckling stress (N/mm^2) of plating in compression flange calculated with 100% effective plate
I = moment of inertia of girder (cm^4) with intact plate flange b (100% effective)
z_p = distance (cm) from neutral axis to compression flange, see Fig.1

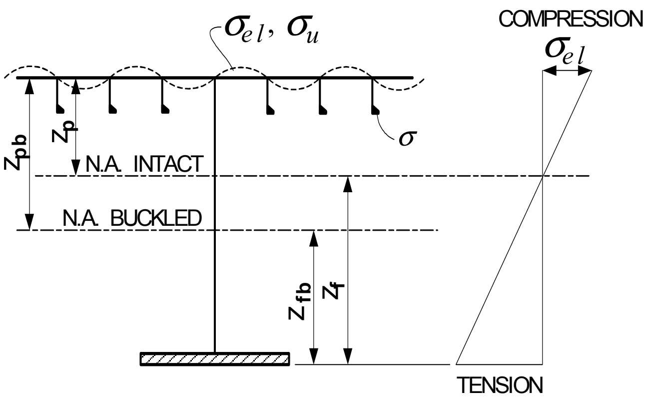

Fig. 1
Simple girder with panel flange

ΔM_U = additional moment due to increase in allowable stress above elastic buckling limit
= ΔM_{UP} or ΔM_{UF} whichever is the smaller:

$$\Delta M_{UP} = \frac{\sigma_m - \sigma_{el}}{1000\ z_{pb}}\ I_B \quad \text{(kNm)}$$

$$\Delta M_{UF} = \frac{0.9\,\sigma_f - \sigma_{el}\ z_f / z_p}{1000\ z_{fb}}\ I_B \quad \text{(kNm)}$$

z_f = distance (cm) from neutral axis to tension flange of intact section
z_{pb} = distance (cm) from neutral axis to compression flange of buckled section
z_{fb} = distance (cm) from neutral axis to tension flange of buckled section
I_B = moment of inertia (cm^4) of girder with buckled plate flange b_e.
σ_m as given in 300.
The area of the buckled plate flange (A_R) is estimated as outlined in 300. The design condition is given by:

$$M_U \geq M_A / \eta_u$$

M_A = actual moment in girder, based on extreme dynamic load
η_u = 0.85.

B 500 Ultimate strength of complex girders

501 The ultimate bending moment capacity of a ship hull girder with stiffened plate panels at various levels is given by:

$$M_U = M_E + \Delta M_U \quad \text{(kNm)}$$

M_E = moment capacity corresponding to the elastic buckling limit of the local plate panel subject to elastic buckling (see Guidance note)

$$= \frac{\sigma_{el}\ I}{1000\ z_e} \quad \text{(kNm)}$$

σ_{el} = elastic buckling stress (N/mm^2) of local plate panel
I = moment of inertia of hull girder (cm^4) with intact plating (100% effective plating)
z_e = vertical distance (cm) from neutral axis of intact section to middle of buckled plate panel, see Fig.2

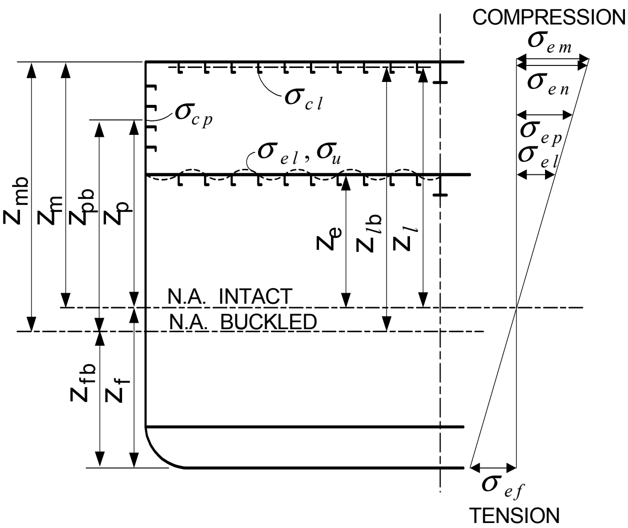

Fig. 2
Hull girder

ΔM_U = additional moment above elastic buckling limit, to be taken as the smaller of: ΔM_{UP1}, ΔM_{UP2}, ΔM_{UP3} and ΔM_{UF}

$$\Delta M_{UP1} = \frac{1.18\,\sigma_{cp} - \sigma_{ep}}{1000\ z_{pb}}\ I_B \quad \text{(kNm)}$$

σ_{cp} = critical buckling stress of the intact plate panel (on compression side) with the smallest buckling safety (σ_c / σ_a) as calculated in Sec.13 B200
σ_{ep} = $\sigma_{el}\ z_p / z_e$
z_p = vertical distance (cm) from neutral axis of intact section to middle of intact plate panel
z_{pb} = vertical distance (cm) from neutral axis of buckled section to middle of intact plate panel.
I_B = moment of inertia (cm^4) of hull section with buckled plate panel, which is inserted with effective width as given in 201

$$\Delta M_{UP2} = \frac{\sigma_{cl} - \sigma_{en}}{1000\ z_{lb}}\ I_B \quad \text{(kNm)}$$

σ_{cl} = critical buckling stress of the longitudinal (on the compression side) with the smallest buckling safety (σ_c / σ_a) as calculated in Sec.13 C200 or C300
$\sigma_{e\,n}$ = $\sigma_{el}\ z_l / z_e$
z_l = vertical distance (cm) from neutral axis of intact section to longitudinal in question
$z_{l\,b}$ = vertical distance (cm) from neutral axis of buckled section to longitudinal

$$\Delta M_{UP3} = \frac{0.9\,\sigma_f - \sigma_{em}}{1000\ z_{mb}}\ I_B \quad \text{(kNm)}$$

σ_{em} = $\sigma_{el}\, z_m / z_e$
z_m = vertical distance (cm) from neutral axis of intact section to deck or bottom, whichever is in compression
z_{mb} = vertical distance (cm) from neutral axis of buckled section to deck or bottom (in compression)

$$\Delta M_{UF} = \frac{0.9\,\sigma_f - \sigma_{ef}}{1000\, z_{fb}}\, I_B \quad \text{(kNm)}$$

σ_{ef} = $\sigma_{el}\, z_f / z_e$
z_f = vertical distance (cm) from neutral axis of intact section to deck or bottom, whichever is in tension
z_{fb} = vertical distance (cm) from neutral axis of buckled section to deck or bottom (in tension).

The design condition is given by:

$$M_U \geq M_A / \eta_u$$

M_A = actual moment in hull girder
η_u = 0.85.

Guidance note:

In cases where several plate panels with different values of elastic buckling stress are involved, a stepwise calculation of M_E has to be made according to the general formula:

$$M_E = \sum_{i=1}^{n} \Delta M_{EI}$$

$$\Delta M_{EI} = \frac{\sigma_{ei} - \sigma_{e(i-1)} \dfrac{z_{ei}}{z_{e(i-1)}}}{1000\, z_{ei}}\, I_{E(i-1)}$$

σ_{ei} = elastic buckling stress (N/mm^2) of local panel considered in step i
$\sigma_{E(i-1)}$ = elastic buckling stress of local panel considered in previous step
$I_{E(i-1)}$ = moment of inertia of hull girder with effective width of elastically buckled panels in earlier steps inserted
z_{ei} = vertical distance (cm) from neutral axis in above section to middle of the plate panel i
$z_{E(i-1)}$ = vertical distance from neutral axis in above section to the plate panel i – 1.

In the first step $I_E(i-1) = I$ (intact moment of inertia). σ_{E1} will be the lowest elastic buckling stress in relation to the actual stress in the considered plate, and $\sigma_E(i-1) = 0$.

When last step in the elastic buckling calculation ($\Delta M_{EN} M_E$) has been performed and the total found, the highest elastic buckling stress σ_{en} shall be used as σ_e in the further calculation of ΔM_U.

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CHANGES – HISTORIC

Note that historic changes older than the editions shown below have not been included. Older historic changes (if any) may be retrieved through http://www.dnvgl.com.

January 2015 edition

Main changes January 2015, entering into force 1 July 2015

- **Sec.1 General requirement**

— A101: Rule reference for CSR-notation has been updated.

- **Sec.2 Materials**

— General: B: Text have been updated in accordance with IACS UR S6 Rev. 7.
— A new Table B4 *Minimum material grades for membrane type liquefied gas carriers with length exceeding 150 m* has been inserted. The subsequent tables have been renumbered.
— A new Figure 1 *Typical deck arrangement for membrane type liquefied natural gas carriers* has been inserted.

July 2014 edition

Amendments July 2014

- **Sec.1 General requirements**

— Table C1: H081 - Global strength analysis has been substituted by H082 - Longitudinal strength analysis.

Main changes January 2014, entering into force 1 July 2014

- **Sec.1 General Requirements**

— In A101, references to coming IACS Harmonized Common Structural Rules (CSR-H), which will be implemented later in line with ongoing IACS processes, have been updated.

July 2013 edition

Main changes coming into force 1 January 2014

- **Sec.3 Design Principles**

— The third bullet point in A701 has been amended for human consumption.

- **Sec.16 Fatigue Control**

— A new sub-section B100 *Weld improvement methods* has been added, giving criteria for the application of weld improvement methods, e.g. grinding. The added requirements are in line with the current CSR Rules for Bulk Carriers.

January 2013 edition

Main changes coming into force 1 July 2013

- **Sec.1 General Requirements**

— Items C105 to C108 deleted due to deletion of Class Notation **COAT-1** and **COAT-2**.

- **Sec.3 Design Principles**

— Figure references updated.

- **Sec.15 Special Requirements - Additional Class**

— E702: a new Figure 4 has been inserted.

— E703: accept criteria for ultimate hull girder capacity has been amended.
— Sub-section D: Deletion of Class Notation **COAT-1** and **COAT-2**, which is made historic.
— As a consequence, Class Notation **CSA** is moved from sub-section E to D.
— Sub-section F Class Notation **COAT-PSPC(X)** has been deleted and moved to Pt.6 Ch.31.