



INTLREG
INTERNATIONAL REGISTER OF SHIPPING

RULES AND REGULATIONS FOR CLASSIFICATION OF STEEL VESSELS 2021

Part 3 Hull Structures

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CHANGES HISTORY

Refer Changes history in Part 1

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CHAPTER 1 GENERAL

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SECTION 1 APPLICATION

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1.1. Application**1.1.1. Scope of application**

1.1.1.1. These rules are applicable to the hull structures of welded steel ships of conventional form for assigning main class, except for oil tankers and bulk carriers of 150 m in length and above. These rules are not applicable to Inland vessels. Rules for inland vessels and rules for oil tankers and bulk carriers of 150 m in length and above are provided in separate parts.

1.1.1.2. Aluminum structures and wooden decks are also covered by these rules to the extent that these materials are acceptable as alternative materials.

1.1.2. Rule Application

Additional requirements as determined by the Society may be applicable for particular ship types based on the vessel type assigned in the Class Notation.

SECTION 2 DEFINITIONS

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2.1 Symbols

2.1.1. The following symbols are used:

- i. L = length of the ship in meters (m) declared 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 it is not needed 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.
- ii. 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.
- iii. A.P. = the after perpendicular is the perpendicular at the after end of the length L .
- iv. L_F = length of the ship as defined in the International Convention of Load Lines:
 The length is defined as 96 per cent of the total length on a waterline at 85 per cent of the least molded 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. For ships designed with a rake of keel, the waterline on which this length is measured shall be parallel to the designed waterline.
- v. B = greatest molded breadth in meters (m), measured at the summer waterline.
- vi. D = molded depth as defined in ICLL as the vertical distance in m from baseline to molded deck line at the uppermost continuous deck measured amidships.
- vii. D_F = least moulded depth taken as the vertical distance in meters (m) from the top of the keel to the top of the freeboard deck beam at side. In ships having rounded gunwales, the molded depth shall be measured to the point of intersection of the molded lines of the deck and side shell plating, the lines extending as though the gunwale was of angular design.
 The molded 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 in cases 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.
- viii. T_{ms} = mean moulded summer draught in meters (m).
- ix. Δ = moulded displacement in tonnes (t) in salt water (density 1.025 t/m³) on draught T_{ms} .
- x. C_B = block coefficient

$$= \frac{\Delta}{1.025 L B T_{ms}}$$

For barge rigidly connected to a push-tug, C_B shall be calculated for the combination barge/ push-tug.

- xi. C_{BF} = block coefficient as defined in the International Convention of Load Lines:

$$= \frac{\nabla}{L_F B T_F}$$
- xii. ∇ = volume of the moulded displacement, excluding bossings, taken at the molded draught T_F .
- xiii. T_F = 85% of the least moulded depth.
- xiv. 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.
- xv. g_0 = standard acceleration of gravity= 9.81 m/s².
- xvi. k_m = material factor depending on material strength group. Refer Ch.2.
- xvii. t_c = corrosion addition as given in Ch. 2 Sec. 4 [4.2] and [4.3], as relevant.
- xviii. x = axis in the ship's longitudinal direction.
- xix. y = axis in the ship's athwartships direction.
- xx. z = axis in the ship's vertical direction.
- xxi. E = modulus of elasticity of the material

- $= 2.06 \times 10^5 \text{ N/mm}^2$ for steel
 $= 0.69 \times 10^5 \text{ N/mm}^2$ for aluminum alloy.
- xxii. C_{WV} = wave load coefficient given in Ch 4 Sec 2 [2.2].
- xxiii. Amidships = the middle of the length L as shown in Fig. 1.2.1

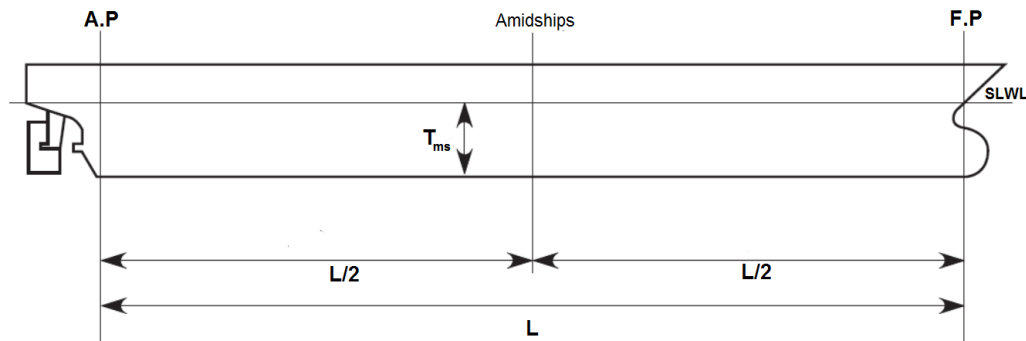


Fig. 1.2.1 Definition of amidships

2.2 Terms

2.2.1. Linear and angular motions of the ship are defined as mentioned below:

- a) *Surge* is the linear motion along the x-axis
- b) *Sway* is the linear motion along the y-axis
- c) *Heave* is the linear motion along the z-axis
- d) *Roll* is the angular motion about the x-axis
- e) *Pitch* is the angular motion about the y-axis
- f) *Yaw* is the angular motion about the z-axis.

2.2.2. *Molded deck line, rounded sheer strake, Sheer strake, and Stringer plate* are as defined in Fig.1.2.2

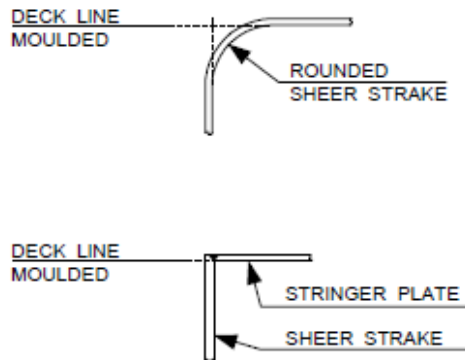


Fig. 1.2.2 Deck corners

2.2.3. 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.

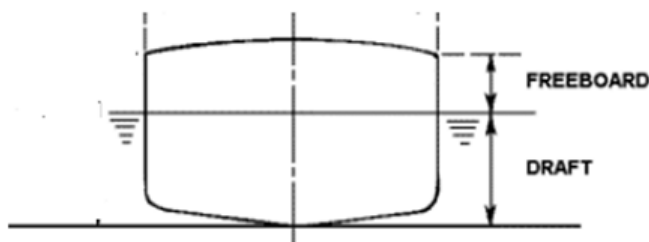


Fig. 1.2.3 Freeboard

- 2.2.4. The *freeboard deck* is generally 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 vessel are fitted with permanent means of watertight closing.

For vessel 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 choice of the owner and subject to the approval of the Administration, a lower deck may be designated as the freeboard deck provided that 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.

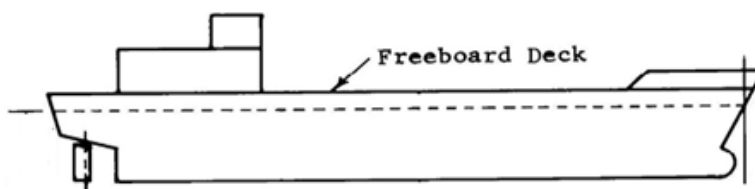


Fig 1.2.4 Freeboard deck

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

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

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

H = height in meters (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.

- 2.2.6. *Double bottom structure* is defined as shell plating with stiffeners below the top of the inner bottom, refer fig 1.2.5, and other elements below and inclusive of the inner bottom plating. However, sloping hopper tank top side shall be regarded as longitudinal bulkhead.

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

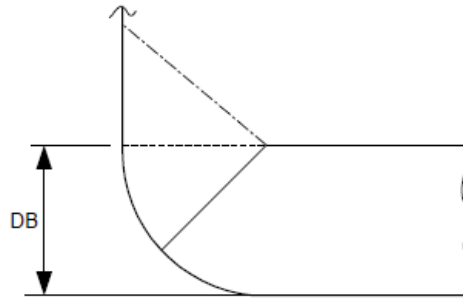


Fig 1.2.5 Double Bottom

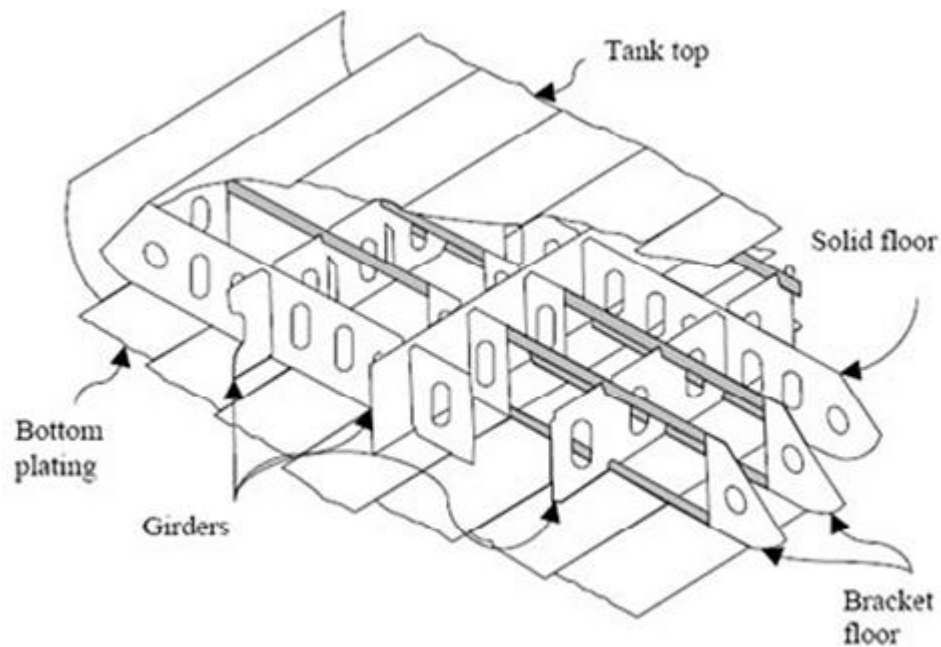


Fig 1.2.6 Bottom structure

- 2.2.8. *Side structure* is defined as shell plating with stiffeners and girders and other elements between the bottom structure and the uppermost deck at side.
- 2.2.9. *Deck structure* is defined as deck plating with stiffeners, girders and supporting pillars.
- 2.2.10. *Bulkhead structure* is defined as transverse or longitudinal bulkhead plating with stiffeners and girders and other elements.

Watertight bulkhead is a collective term for transverse bulkheads required according to Ch 3 Sec 1 and longitudinal bulkheads, if required, to meet the required level of subdivision and watertight integrity of the hull structure.

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.

2.2.11. *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 Ch 3 Sec 1.

2.2.12. *Superstructure*

- i. 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 percent of the breadth (B). A raised quarter deck is regarded as a superstructure.
- ii. An enclosed superstructure is a superstructure with:
 - a) Enclosing bulkheads of efficient construction,
 - b) Access openings, if any, in these bulkheads fitted with doors fulfilling the requirements of relevant sections of Pt 4
 - c) All other openings in sides or ends of the superstructure fitted with efficient weather tight means of closing.

A bridge or poop shall not be considered as enclosed unless access is provided for the crew to reach machinery and other working spaces inside these superstructures by alternate means which are available at all times when bulkhead openings are closed.

- iii. 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.
- iv. The length of a superstructure (L_{ss}) is the mean length of the part of the superstructure which lies within the length (L).
- v. A *long forward superstructure* is defined as an enclosed forward superstructure with length L_{ss} equal to or greater than 0.25 L.

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

2.2.14. *Girder* is a collective term for primary supporting members. Tank girders with special names are shown in Fig.1.2.7. Other terms used are:

- a) Floor (a bottom transverse girder)
- b) Stringer (a horizontal girder).

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

- a) Frame
- b) Reversed frame (inner bottom transverse stiffener)
- c) Deck longitudinal
- d) Side longitudinal
- e) Bottom longitudinal
- f) Inner bottom longitudinal
- g) Bulkhead longitudinal
- h) Beam

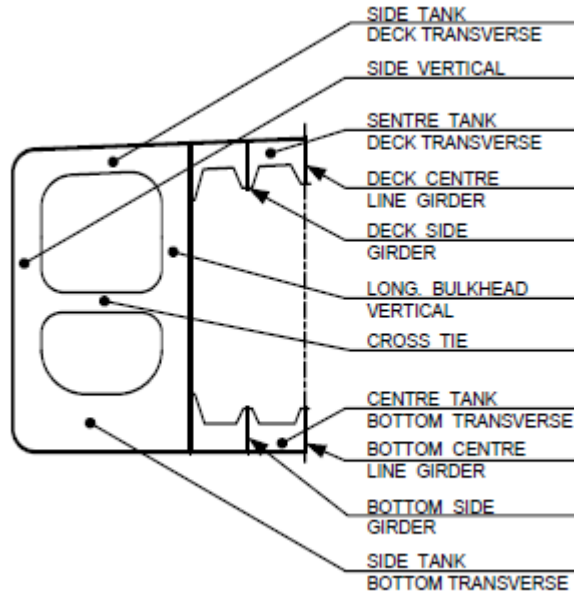


Fig. 1.2.7 Tank girders

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

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

2.2.18. *Probability density function $f(x)$* - The probability that a realization 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 $F(x)$.

2.2.19. *Cumulative probability $F(x)$* is defined as:

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

2.2.20. *Exceedance probability $Q(x)$* is defined as:

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

2.2.21. *Probability of exceedance* or *exceedance probability* may be explained 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 .

2.2.22. *Quantile* - The p quantile may be defined as the value, x_p , of a random variable x , which corresponds 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 .

2.3 Ship types definitions

- 2.3.1. A ship which carries more than 12 passengers is defined as a *passenger ship*.
- 2.3.2. Any ship which is not a passenger ship is defined as a *cargo ship*.
- 2.3.3. A cargo ship constructed for the carriage of liquid cargoes in bulk is defined as a *tanker*.

SECTION 3 VERIFICATION OF COMPLIANCE

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3.1. General

- 3.1.1. Relevant criteria such as additional features and classification notations assigned or applicable to the ship based on ship length, type, size, operational features etc. is to be considered, and, are to comply with the rules prescribed in this part and applicable requirements outlined in other parts, when plans and documents are submitted for approval, (as detailed in 3.2 below); in case of New Buildings.
- 3.1.2. When a ship is surveyed by the Society during construction, the Society:
- Approves the plans and documentation submitted as required by the rules.
 - Proceeds, if needed, with the assessment and appraisal of the design of materials and equipment used in the construction of the ship and their inspection at works
 - Undertake surveys or obtains appropriate evidence to satisfy itself that the scantlings and construction meet the rule requirements in relation to the approved drawings, either through surveys or by obtaining appropriate evidence.
 - Attends tests and trials provided for in the rules.
 - Assigns the classifications character of the society's notation.
- 3.1.3. As a general rule, all materials, machinery, boilers, auxiliary installations, equipment, items etc. which are covered by the class and used or fitted on board ships surveyed by the Society during construction are to be new and, where intended for essential services are to be tested by the Society. Second hand materials, machinery, appliances and items may be used subject to the specific agreement of the Society and the Owner.
- 3.1.4. As part of Surveyor's interventions during construction:
- The surveyor shall examine all the parts of the ship covered by INTLREG Rules.
 - Examine the construction methods and procedures, when required by the rules.
 - Check selected items covered by the rule requirements.
 - Attend tests and trials, where applicable and deemed necessary.
- 3.1.5. It is the Builder's responsibility to inform the Society immediately, of the modifications or deviations from approved arrangements and to deal with them as necessary, during and throughout the ship construction. It shall be the responsibility of the Builder to ensure that the diversions from the requirements of the rules or approved plans, except minor ones which do not affect the structural strength of the vessel, are accepted and approved by the Society.

3.2. Plans and particulars

- 3.2.1 Plans and documents that are required to be submitted to Society to facilitate the verification of compliance of hull structural requirements outlined in this part are presented in Table 1.3.1.

Table 1.3.1 – Required Plans and Documents		
<i>Plan / Document Type</i>	<i>Additional Description</i>	<i>Submission Type</i>
General Arrangement Plan	Nil	For Information
Tank and Capacity Plan	Nil	For Information
Lines Plan with Offsets Table	Nil	For Information
Docking Arrangement Plan	Nil	For Information
Midship Section Drawing	Refer Remark 2	For Approval
Shell Expansion Drawing	Refer Remark 3	For Approval
Structural Drawing ⁽¹⁾	Decks, Bottom and Inner Bottom	For Approval

Structural Drawing ⁽¹⁾	Fore End Ship Structure	For Approval
Structural Drawing ⁽¹⁾	Aft End Ship Structure	For Approval
Structural Drawing ⁽¹⁾	Engine Room Area	For Approval
Structural Drawing ⁽¹⁾	Transverse Bulkheads	For Approval
Structural Drawing ⁽¹⁾	Longitudinal Bulkheads	For Approval
Framing Plan	Refer Remark 4	For Approval
Longitudinal Sections Drawing	Refer Remark 5	For Approval
Preliminary Loading Manual	Refer Remark 7	For Information
Loading Manual	Refer Remark 6	For Approval
Longitudinal Strength Analysis	Refer Remark 8	For Information
Structural Drawing ⁽¹⁾	Superstructure	For Approval
Structural Drawing ⁽¹⁾	Deckhouse Structures	For Approval
Structural Drawing ⁽¹⁾	Supporting Structures of heavy or loaded objects. Refer Remark 9	For Approval
Welding Tables	Refer Remark 10	For Approval

Remarks:

1. Structural drawing should contain dimensional details, scantling details, material specifications, details of scallops, cutouts, end connection details, corner radii etc., as relevant, for the depicted hull structural part.
2. Drawing of the midship transverse section providing information of geometric dimensions, scantlings, material specifications, main dimensions / particulars of the vessel including summer draught, block coefficient, design speed and classification notations of the vessel.
3. Drawing showing the shell expansion containing information on dimensional and scantling details of shell strakes, representation of shell framing system, location and details of major seam and butt welds.
4. Drawing of transverse sections at each ordinary and web frame showing the positions and type of stiffeners and primary support members. The drawing shall include geometric dimensions, scantlings and material specifications, wherever relevant.
5. Drawing of typical longitudinal sections showing the structural arrangement of primary support members and stiffeners parallel to the vessel's centreline. The drawing shall include geometric dimensions, scantlings and material specifications.
6. Loading Manual is to be submitted for applicable vessels based on criteria outlined in Ch. 5 Sec 6 [6.1]. For description and data / information to be contained in the Loading Manual, refer to Ch. 5 Sec 1 [1.2.2] and Ch. 5 Sec 6 [6.2].
7. Preliminary Loading Manual is to be submitted for information upon request by INTLREG based on assessment on vessel type, size, category, preliminary loading pattern information etc. The preliminary loading manual shall contain the required data and information as for Loading Manual but is based on preliminary ship data and shall be used to determine design loads to be used in strength approval of the vessel.
8. Longitudinal Strength Analysis is to be submitted for information upon request by Society based on assessment on vessel type, size, category, preliminary loading pattern information etc. The data and information to be contained in the longitudinal strength analysis calculations is detailed in Ch. 1 Sec 3 [3.3.1].
9. Structural drawing for supporting structures of heavy or loaded objects to be submitted in cases where the static force is greater than 50 kN or bending moment at deck is greater than 100 kN m.
10. Welding tables should contain the various weld types along with information on weld dimensions such as throat thickness, leg size etc. employed to weld structural members of hull structure.
11. Identical or similar structures in various positions should preferably be covered by the same plan.

- 3.2.2 All relevant information / documentation affecting hull structures or ship safety shall be submitted in the cases of installations for which no notation is requested / available.

- 3.2.3 Loading guidance information (loading manual and loading computer system) shall be approved and certified in accordance with Ch 5 Sec 6.

3.3. Specifications and calculations

- 3.3.1 In cases where longitudinal strength analysis calculations are requested, the same shall be provided to Society with below mentioned relevant information:
- a) Maximum still water bending moments and shear forces as defined in Ch 5, Sec 2
 - b) Limiting Values of still water bending moments and shear forces
 - c) Buoyancy data
 - d) Mass of light ship and its longitudinal distribution
 - e) Cargo capacity in tonnes (t)
 - f) Cargo, ballast and bunker distribution, including maximum mass of cargo in tonnes (t) in each compartment.
- 3.3.2 In support for local strength calculations, the following may have to be submitted upon request by Society:
- a) Minimum and maximum ballast draught and corresponding trim
 - b) Load on deck, hatch covers and inner bottom
 - c) Stowage rate and angle of repose of dry bulk cargo
 - d) Maximum density of intended tank contents
 - e) Height of air pipes
 - f) Mass of heavy machinery components
 - g) Design forces for securing devices on hatch covers and external doors
 - h) Design forces for cargo securing and container supports
 - i) Any other local loads or forces which will affect the hull structure.

3.4. Specific purpose documentation

- 3.4.1 Plans and particulars that are to be submitted to Society for hull appendages (rudder, stern frame, propeller nozzles, propeller shaft brackets etc.), hull equipments (anchoring equipment, mooring and towing equipment, deck machinery etc.), closing appliances (doors, hatches, windows etc.), corrosion prevention system etc. are specified in relevant chapters and sections of Pt 4.
- 3.4.2 Additional plans and particulars related to hull structure that are to be submitted to Society based on vessel type and various required class notations are specified in relevant chapters and sections of Pt 3 and Pt 4.

3.5. International and national regulations

- 3.5.1 The designer shall take responsibility to ensure that the design of the ship is in compliance with relevant and applicable National and International regulations. The Society will not be responsible for the failure to comply with National and International regulations, as a part of general classification process. Upon request, the review of design for compliance with applicable National or International rules and regulations may be done in cases where an agreement exists between Society and the Flag administration.

3.6. Workmanship

- 3.6.1. Requirements to be complied with by the manufacturer.
Suitable equipment and facilities to enable the proper handling of materials, manufacturing processes, structural components etc. shall be provided at the manufacturing plant. In addition, the manufacturing plant shall have at its disposal sufficiently qualified personnel.

- 3.6.2. Quality control
During manufacture and on completion, the manufacturer's personnel has to examine all structural components to the extent required, so as to ensure that they are complete, that the dimensions are correct and that the workmanship is satisfactory and meets the standards of good shipbuilding practice.

3.7. Details in manufacturing documents

- 3.7.1. All significant details concerning quality and functional ability of the component concerned shall be entered in the manufacturing documents (e.g. workshop drawing etc.). In addition to scantlings, wherever relevant such details include but not limited to:

- Surface conditions (e.g. finishing of flame cut edges and weld seams)
- Special methods of manufacture
- Inspection and acceptance requirements
- Permissible tolerances, wherever applicable.

If due to any reason INTLREG finds the quality or functional ability of the component doubtful, the manufacturer is liable to submit relevant improvements to INTLREG. This may require the manufacturer to submit a reinforcement which may previously (at the time of plan approval) was not necessary.

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

3.8.1 General

- 3.8.1.1. Ships built in accordance with the following requirements may be given the notation **IWS**

- 3.8.1.2. The **IWS** notation indicates that the ship is prepared for in-water survey.

Remarks:

1. The conditions under which in-water survey is allowed are given in relevant sections of Pt 1
2. Means should be delivered to enable the diver to confirm that the sea suction openings are clear. Hinged sea suction grids will enable this operation, preferably with revolving weight balance or with a counter weight, and secured with bolts practical for dismantling and fitting when the ship is afloat.

3.8.2 Documentation required onboard

The below mentioned plans shall be submitted for information or approval and shall be available onboard.

- a) Arrangement plan of markings for identification of tanks on sides and bottom - for approval
- b) Arrangement plan of openings in sides and bottom below the deepest load waterline, bottom plugs, echo sounders and any other underwater equipment - for information
- c) Procedure describing measurement of bearing clearances of rudder arrangements - for information
- d) Arrangement of any impressed current system - for information.

3.8.3 Markings of ship's sides and bottom

The underwater body shall be marked in such a way that the surveyor can identify the location of any observations undertaken. 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 color.

Marking shall normally be placed as follows:

- a) At flat bottom in way of intersections of tank bulkheads or watertight floors and girders
- b) 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)
- c) The intersection between tank top and watertight floors in way of ship's sides
- d) All openings for sea suctions and discharge
- e) Letter and number codes shall be applied on the shell for identification of tanks, sea suctions and discharges.

3.8.4 Rudder

3.8.4.1. Bearing materials shall be made of stainless steel, bronze or an approved type of synthetic material and shall fulfill the requirements specified in relevant sections of Pt 4.

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

3.8.5 Tailshaft

The tailshaft shall be designed to minimum 5 years survey interval. Refer to relevant sections of Pt 1

3.8.6 Thrusters

Thrusters shall have 5 year survey interval or alternatively the reduced scope survey, as required in relevant sections of Pt 1, shall be possible while the ship is afloat.

CHAPTER 2 MATERIALS

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SECTION 1 GENERAL

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1.1. General

- 1.1.1. The requirements regarding the application of various structural materials as well as protection methods and materials are specified in this section.
- 1.1.2. Rolled steel and aluminum used for hull structures are normally to be supplied with INTLREG's material certificates in compliance with the requirements given in Pt.2.
- 1.1.3. In connection with the rule requirements for each individual part, requirements for material certificates for forgings, castings and other materials for special parts and equipment are specified.

SECTION 2 HULL STRUCTURE MATERIALS

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2.1. General

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

Remarks:

When the hull plating is being measured at periodical surveys and the wastage considered in relation to reductions allowed by the rules, it should be noted that such allowed reductions are based on the nominal thicknesses required by the rules.

The under thickness tolerances acceptable for classification should be Refer 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 relevant section of Pt 2. In such cases, the material will reach earlier, the minimum thickness allowable at the hull gaugings.

It is upon the shipyard and owner, taking into account above such scenarios, to decide whether, for commercial reasons, stricter under thickness tolerances should be specified in the individual cases.

2.2. Material Classes and Designations

- 2.2.1. Hull materials of various strength groups will be mentioned as follows:

- a) MS denotes normal strength structural steel with yield point not less than 235 N/mm²
- b) HT-32 denotes high strength structural steel with yield point not less than 315 N/mm²
- c) HT-36 denotes high strength structural steel with yield point not less than 355 N/mm²
- d) HT-40 denotes high strength structural steel with yield point not less than 390 N/mm².

- 2.2.2. Hull material of various grades will be mentioned as follows:

- a) A, B, D and E denotes MS-steel grades
- b) AH, DH, EH and FH denotes HT-steel grades. HT-steel may also be referred to by a combination of grade and strength group. For eg; HT-steel of grade AH with yield point not less than 355 N/mm² may be referred as AH 36 in line with the designations provided in Pt 2 Ch. 1 Sec 3.

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

Table 2.2.1 Material Factor for Strength Groups

Strength Group	k_m
MS	1.00
HT-32	0.78
HT-36	0.72
HT-40	0.68

- 2.2.4. Material factor k_m for high strength structural steel, that are not explicitly indicated in Table 2.2.1, with yield point not less than 265 N/mm² and with yield point not less than 335 N/mm² may be taken as 0.93 and 0.74 respectively.

2.3. Steel Grades and Classes for Various Hull Members

- 2.3.1. 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 2.2.2 to Table 2.2.8. General requirements are given in Table 2.2.2, while additional minimum requirements are given in the following:
- a) Table 2.2.3 – for ships, excluding liquefied gas carriers covered in Table 2.2.4, with length exceeding 150 m and single strength deck
 - b) Table 2.2.4 – for membrane type liquefied gas carriers with length exceeding 150 m
 - c) Table 2.2.5 – for ships with length exceeding 250 m
 - d) Table 2.2.6 – for single side bulk carriers subjected to SOLAS regulation XII/6.5.3
 - e) Table 2.2.7 – for ships with ice strengthening
 - f) Table 2.2.8 – the material grade requirements for hull members of each class depending on the thickness.
- 2.3.2. For strength members not mentioned in Tables 2.2.2 to 2.2.7, Class IV may be applied.
- 2.3.3. The steel grade is to correspond to the as-built plate thickness and material class.
- 2.3.4. Plating materials for stern frames supporting the rudder and propeller boss, rudders, rudder horns and shaft brackets are in general not to be of lower grades than corresponding to Class II.
- 2.3.5. For rudder and rudder body plates subjected to stress concentrations (e.g. in way of lower support of semi-spade rudders or at upper part of spade rudders) Class III is to be applied.
- 2.3.6. Materials in local strength members shall not be of lower grades than those corresponding to the material class IV. However, for heavy foundation plates in engine room, grade A may also be accepted for MS-steel with thickness above 40 mm.
- 2.3.7. For materials in:
- a) Hull equipment and appendages (stern frames and rudders, anchoring and mooring equipment, masts and rigging, crane pedestals etc.), Refer Pt 4
 - b) Hull structures related to installations for which no notation is available or requested, these will be considered and notation requirements usually maintained.

2.4. Requirements for low air temperatures

- 2.4.1. For 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.

2.5. Material at cross-joints

- 2.5.1. 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.

Table 2.2.2 – 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	- Class I within 0.4L amidships - Grade A/AH outside 0.4L amidships
A2. Deck plating exposed to weather, other than that belonging to the Primary or Special category	
A3. Side plating	
PRIMARY:	
B1. Bottom plating, including keel plate	- Class II within 0.4L amidships - Grade A/AH outside 0.4L amidships
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	
SPECIAL:	
C1. Sheer strake at strength deck ⁽¹⁾	- Class III within 0.4L amidships - Class II outside 0.4L amidships - Class I outside 0.6L amidships
C2. Stringer plate in strength deck ⁽¹⁾	
C3. Deck strake at longitudinal bulkhead, excluding deck plating in way of inner-skin bulkhead of double-hull ships ⁽¹⁾	
C4. Strength deck plating at outboard corners of cargo hatch openings in container carriers and other ships with similar hatch opening configurations	- Class III within 0.4L amidships - Class II outside 0.4L amidships - Class I outside 0.6L amidships - Min. Class III within cargo region
C5. Strength deck plating at corners of cargo hatch openings in bulk carriers, ore carriers combination carriers and other ships with similar hatch opening configurations	- Class III within 0.6L amidships - Class II within rest of cargo region
C5.1 Trunk deck and inner deck plating at corners of openings for liquid and gas domes in membrane type liquefied gas carriers	
C6. Bilge strake in ships with double bottom over the full breadth and length less than 150 m	- Class II within 0.6L amidships - Class I outside 0.6L amidships
C7. Bilge strake in other ships ⁽¹⁾	- Class III within 0.4L amidships - Class II outside 0.4L amidships - Class I outside 0.6L amidships
C8. Longitudinal hatch coamings of length greater than 0.15L including coaming top plate and flange	- Class III within 0.4L amidships - Class II outside 0.4L amidships - Class I outside 0.6L amidships - Not to be less than Grade D/DH
C9. End brackets and deck house transition of longitudinal cargo hatch coamings	
Remarks:	
1. Single strakes required to be of Class III 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 2.2.3 – Minimum Material Grades for ships, excluding liquefied gas carriers covered in Table 2.2.4, with length exceeding 150 m and single strength deck⁽¹⁾

<i>Structural member category</i>	<i>Material grade</i>
<ul style="list-style-type: none"> – 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
<p><i>Remarks:</i></p> <p>1. The requirements of Table 2.2.3 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.</p>	

Table 2.2.4 – Minimum Material Grades for membrane type liquefied gas carrier with length exceeding 150 m⁽¹⁾

<i>Structural member category</i>	<i>Material grade</i>
Longitudinal plating of strength deck where contributing to the longitudinal strength	Grade B/AH within 0.4L amidships
Trunk deck plating	Class II within 0.4L amidships
Continuous longitudinal plating of strength members above the strength deck <ul style="list-style-type: none"> – Inner deck plating – Longitudinal strength member plating between the trunk deck and inner deck 	Grade B/AH within 0.4L amidships
<p><i>Remarks:</i></p> <p>1. Table 2.2.4 is applicable to membrane type liquefied gas carriers with deck arrangements as shown in Fig. 2.2.1. Table 2.2.4 may apply to similar ship types with a "double deck" arrangement above the strength deck.</p>	

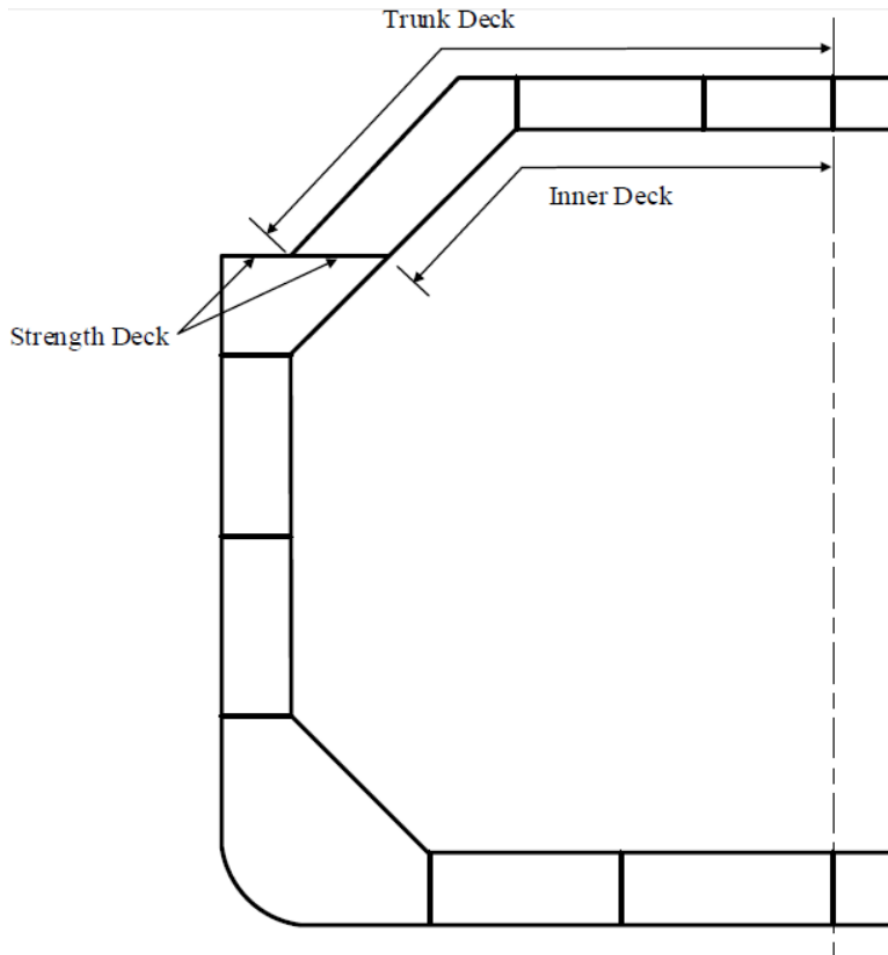


Fig. 2.2.1 Typical deck arrangement for membrane type Liquefied Natural Gas Carriers

Table 2.2.5 – Minimum Material Grades for ships with length exceeding 250 m	
<i>Structural member category</i>	<i>Material grade</i>
Shear strake at strength deck ⁽¹⁾	Grade E/EH within 0.4L amidships
Stringer plate in strength deck ⁽¹⁾	Grade E/EH within 0.4L amidships
Bilge strake ⁽¹⁾	Grade D/DH within 0.4L amidships
Remarks: 1. 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 2.2.6 – Minimum Material Grades for single-side skin bulk carriers subjected to SOLAS regulation XII/6.5.3

<i>Structural member category</i>	<i>Material grade</i>
Lower bracket of ordinary side frame ^{(1), (2)}	Grade D/DH
Side shell strakes included totally or partially between the two points located to 0.125 <i>l</i> above and below the intersection of side shell and bilge hopper sloping plate or inner bottom plate ⁽²⁾	Grade D/DH
<p><i>Remarks:</i></p> <p>1. The term "lower bracket" means webs of lower brackets and webs of the lower part of side frames up to the point of 0.125 <i>l</i> above the intersection of side shell and bilge hopper sloping plate or inner bottom plate.</p> <p>2. The span of the side frame, <i>l</i>, is defined as the distance between the supporting structures.</p>	

Table 2.2.7 – Minimum Material Grades for ships with ice strengthening

<i>Structural member category</i>	<i>Material grade</i>
Shell strakes in way of ice strengthening area for plates	Grade B/AH

Table 2.2.8 – Material Grade Requirements for Classes I, II, III and IV

<i>Class</i>	<i>I</i>		<i>II</i>		<i>III</i>		<i>IV</i>	
<i>Thickness, in mm</i>	<i>MS</i>	<i>HT</i>	<i>MS</i>	<i>HT</i>	<i>MS</i>	<i>HT</i>	<i>MS</i>	<i>HT</i>
$t \leq 15$	A	AH	A	AH	A	AH	A	AH
$15 < t \leq 20$	A	AH	A	AH	B	AH	A	AH
$20 < t \leq 25$	A	AH	B	AH	D	DH	A	AH
$25 < t \leq 30$	A	AH	D	DH	D	DH	A	AH
$30 < t \leq 35$	B	AH	D	DH	E	EH	A	AH
$35 < t \leq 40$	B	AH	D	DH	E	EH	A	AH
$40 < t \leq 100$	D	DH	E	EH	E	EH	B	AH

SECTION 3 OTHER MATERIALS

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3.1. Aluminum

- 3.1.1. Aluminum alloy for marine use may be used in the construction of superstructures, deckhouses, hatch covers, hatch beams and sundry items, provided that the strength of the aluminum structure is equivalent to that required for a steel structure.
- 3.1.2. Alloys marked A shall be used for rolled products taking part in the longitudinal strength. The alloy shall be chosen considering the stress level concerned.
- 3.1.3. 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 IR-A1MgSil the most unfavorable properties corresponding to -T4 condition shall be used.
- 3.1.4. The joining material or deposit weld metal shall not have mechanical properties inferior to that of the parent material.
- 3.1.5. The various formulae and expressions involving the factor k_m may normally also be applied for aluminum alloys where:

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

σ_f = yield stress in N/mm² 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 k_m the equivalent minimum value for aluminum alloys may normally be obtained when the requirement is divided by $\sqrt{(1/k_m)}$

3.2. Stainless steel

- 3.2.1. Due attention shall be given to the reduction of strength of stainless steel with increasing temperature for clad steel and solid stainless steel.
- 3.2.2. The material factor k included in the various formulae for scantlings and in expressions giving allowable stresses is given in [3.2.3] and [3.2.4] for austenitic stainless steel and steel with clad layer of austenitic stainless steel respectively.
- 3.2.3. For austenitic stainless steel the material factor k can be taken as:

$$1/k_m = \left[\left(3.9 + \frac{t-20}{650} \right) \sigma_f - 4.15(t-20) + 220 \right] 10^{-3}$$

σ_f = yield stress in N/mm² 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:

$$1/k_m = 1.21 - 3.2(t-20)10^{-3}$$

- 3.2.4. For clad steel the material factor k can be taken as:

$$1/k_m = \frac{1.67\sigma_f - 1.37t}{1000} - 41.5 \sigma_{fb}^{-0.7} + 1.6$$

- σ_f = yield stress in N/mm² at 0.2% offset of material in clad layer and temperature +20°C ($\sigma_{0.2}$).
 σ_{fb} = yield stress in N/mm² of base material.
 t = cargo temperature in °C.

k shall not be taken greater than that given for the base material in Table 2.2.1
The calculated factor may be used for the total plate thickness.

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

Remarks:

For ferritic-austenitic stainless steels with yield stress 450 N/mm², the following material factor will normally be accepted:

$$\begin{array}{lll} 1/k_m & = 1.6 & \text{at } +20^\circ\text{C} \\ & = 1.36 & \text{at } +85^\circ\text{C} \end{array}$$

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

$$\begin{array}{lll} 1/k_m & = 1.39 & \text{at } +20^\circ\text{C} \\ & = 1.18 & \text{at } +85^\circ\text{C} \end{array}$$

For intermediate temperatures linear interpolation may be applied.

SECTION 4 CORROSION ADDITIONS FOR STEEL SHIPS

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4.1. General

- 4.1.1. Corrosion additions as given in [4.2] shall be added to the scantlings of steel structures in tanks for cargo oil and /or water ballast. In the following the term “cargo oil” will be used as a collective term for liquid cargoes which may be carried by oil carriers.

4.2. Corrosion additions

- 4.2.1. Corrosion addition t_c , as specified in Table 2.4.1, shall be given for plates, stiffeners and girders in tanks for water ballast and /or cargo oil and of holds in dry bulk cargo carriers.
- 4.2.2. 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 4.2.1, i.e. weather deck plate over void space and external stiffeners, should be given a corrosion addition $t_c = 1.5$ mm.
- 4.2.3. It is assumed that tanks for ballast water only are protected by an effective coating or an equivalent protection system. The magnitude of corrosion addition t_c is subject to special consideration for members within or being part of the boundary of tanks for ballast water only, for which a corrosion prevention system is not fitted.

4.3. Requirements for optional notation ECA (Enhanced Corrosion Addition)

- 4.3.1. For assigning optional notation **ECA**, a further corrosion addition t_{c1} in mm, as specified in Table 2.4.2, will need to be added to the scantlings of structural members in ballast tanks, cargo oil tanks and cargo holds in bulk cargo carriers in addition to the corrosion addition t_c in mm, as specified in Table 2.4.1, required for the assignment of main class. The following class notations may be chosen:

ECA(WB), ECA(WBu), ECA(WBs)	for ballast tanks
ECA(CO), ECA(COu), ECA(COs)	for cargo oil tanks
ECA (HC), ECA(HCu), ECA(HCs)	for cargo holds in bulk carriers

Where:

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

Combination of the above notations may also be chosen. For example, **ECA (WB/COu)** may be assigned if all ballast tanks and upper part (above D/2) of all cargo oil tanks meets the requirements of **ECA** notation.

The procedure in applying t_{c1} in the rule scantling formula is outlined in the following sections.

- 4.3.2. 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:

$$t = t_{\text{actual}} - t_{c1} \quad (\text{mm})$$

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

$$t'_c = t_c + t_{c1} \quad (\text{mm})$$

4.3.4. For stiffeners where formulae are given in the rules with the w_c increase in section modulus for compensation of the corrosion addition (t_c), the w_c need not be additionally adjusted for the corrosion addition (t_{c1}).

4.3.5. 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:

$$t_{reduced} = t_{actual} - (t_c + t_{c1}) \quad (\text{mm})$$

4.3.6. The throat thickness of continuous and intermittent fillet welding is given in Ch 11 with an addition of $0.5 t_c$ mm. The total corrosion addition shall be taken as:

$$(0.5t'_c) = 0.5 (t_c + t_{c1}) \quad (\text{mm})$$

4.3.7. The additional corrosion thickness t_{c1} shall be given in the design drawings in the form of a general note.

Remarks:

Example of general note to be provided in the design drawing:

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

Table 2.4.1 Corrosion addition t_c in mm		
Internal structural 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 spaces ³⁾	2.0	1.0

Cargo oil tank only/ Other spaces ³⁾	1.0	0.5 (0) ²⁾
Hold of dry bulk cargo carrier ⁴⁾ /Other spaces ³⁾	0.5	0.5
<p><i>Remarks:</i></p> <p>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.</p> <p>2) The figure in brackets refers to non-horizontal surfaces.</p> <p>3) Other spaces denotes the hull exterior and all spaces other than water ballast and cargo oil tanks and holds of dry bulk cargo carriers.</p> <p>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.</p> <p>5) The figure in brackets refers to webs and bracket plates in lower part of main frames in bulk carrier holds.</p>		

Table 2.4.2 Corrosion addition t_{c1} in mm (applicable for optional ECA notation)		
Internal structural 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 spaces ²⁾	2.0	1.0

Cargo oil tank only/ Other spaces ²⁾	1.0	0.5
Hold of dry bulk cargo carrier ³⁾ /Other spaces ²⁾	0.5	0.5
<p><i>Remarks:</i></p> <p>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.</p> <p>2) Other spaces denotes the hull exterior and all spaces other than water ballast and cargo oil tanks and holds of dry bulk cargo carriers.</p> <p>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.</p> <p>4) For vessels with notation ECA(WB), ECA(WBu) or ECA(WBs), cargo oil tanks and holds of dry bulk cargo carriers may be treated as "Other spaces"</p>		

CHAPTER 3 DESIGN FUNDAMENTALS

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SECTION 1 GENERAL ARRANGEMENT DESIGN

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1.1. General

- 1.1.1. The requirements for arrangement as given in section 1.3 to section 1.5 and section 1.14 assume damage cases as defined by SOLAS and are not mandatory to non-convention vessels.
- 1.1.2. Risks and consequences of flooding due to leakages or damages to side and bottom shall be taken into consideration in the design of non-convention vessels. INTLREG may require design damage cases to be defined and described in the ship documentation.
- 1.1.3. Notwithstanding the above provisions, non-convention vessels shall be designed to meet all relevant requirements for arrangement specified in the maritime regulations for non-convention vessels enforced by vessel's Flag Administration or Port Authorities or Coastal Authorities, as applicable.
- 1.1.4. In cases where no specific maritime regulations are established by vessel's Flag Administration or Port Authorities or Coastal Authorities for non-convention vessels, the requirements for arrangement provided in this section shall be met as far as reasonable and practicable. Refer above section 1.1.1 and 1.1.2 also in this regard. Alternatively the requirements for arrangement specified in any internationally recognized standards or regulations for non-convention vessels may be adopted.
- 1.1.5. Additional requirements for arrangement applicable based on vessel type is to be provided as advised by the Surveyor.

1.2. Definitions

1.2.1. Symbols

L_F = length in m as defined in Ch 1 Sec 2 [2.1.1]
 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 protruding the waterline, the position of P_F will be specially considered.

D_F = least molded depth to the freeboard deck in m as defined in Ch 1 Sec 2.[2.1.1]

1.3. Watertight bulkhead arrangement

- 1.3.1. At least the following transverse watertight bulkheads shall be provided in all ships:
 - a) One collision bulkhead
 - b) One aft peak bulkhead
 - c) One bulkhead at each end of the engine room.
- 1.3.2. For ships with an electric propulsion plant, both the generator room and the engine room shall be enclosed by watertight bulkheads.
- 1.3.3. In addition to the requirements of 1.3.1 and 1.3.2, the number and disposition of bulkheads shall be arranged to suit the requirements for transverse strength, subdivision, floodability and damage stability, and shall be in accordance with the requirements of national regulations, where applicable.

- 1.3.4. For vessels where no damage stability calculations have been carried out, the total number of watertight transverse bulkheads shall not be less than given in Table 3.1.1.
- 1.3.5. After special consideration of arrangement and strength, the number of watertight bulkheads, as required by Table 3.1.1, may be reduced. Refer above section 1.3.3 in this regard.
- 1.3.6. Barges shall have a collision bulkhead and an aft end bulkhead. However, 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.
- 1.3.7. The watertight bulkheads shall extend to the bulkhead deck.
- 1.3.8. 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 bulkhead deck shall be arranged as a watertight structure, and the second deck shall be watertight outside the casing above the engine room.
- 1.3.9. In ships with a raised quarter deck, the watertight bulkheads within the quarter deck region shall extend to this deck.
- 1.3.10. The number of openings in watertight bulkheads shall be kept at a minimum. Where penetrations of watertight bulkheads and internal decks are necessary for access, piping, ventilation, electrical cables, arrangements shall be made to maintain the watertight integrity.
- 1.3.11. Openings situated below the bulkhead deck and which are intended for use when the ship is at sea, shall have watertight doors, which shall be closable from the bulkhead deck or place above the deck. The operating device shall be well protected and accessible.
- 1.3.12. Watertight doors are accepted in the engine room 'tween deck bulkheads, on condition that a signboard is fixed at each door to indicate that the door be kept closed while the ship is at sea.
- 1.3.13. 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, as outlined in Ch. II-1/Reg.7-2 of SOLAS 1974 (as amended).

Table 3.1.1 Number of transverse bulkheads		
Ship length in m	Engine room	
	Aft	Elsewhere
$L \leq 65$	3	4
$65 < L \leq 85$	4	4
$85 < L \leq 105$	4	5
$105 < L \leq 125$	5	6
$125 < L \leq 145$	6	7
$145 < L \leq 165$	7	8
$165 < L \leq 190$	8	9
$190 < L \leq 225$	9	10
$L > 225$	specially considered	

1.4. Collision bulkhead

- 1.4.1. A collision bulkhead shall be fitted on all ships and shall extend to the bulkhead deck. The distance x_c in metres (m), from the perpendicular P_F to the collision bulkhead shall be taken between the following limits:

$$\begin{aligned} x_c \text{ (minimum)} &= 0.05L_F - x_r \quad \text{for } L_F < 200 \text{ m} \\ &= 10 - x_r \quad \text{for } L_F \geq 200 \text{ m} \end{aligned}$$

$$\begin{aligned} x_c \text{ (maximum)} &= 0.05L_F + 3.0 - x_r \quad \text{for } L_F < 100 \text{ m} \\ &= 0.08L_F - x_r \quad \text{for } L_F \geq 100 \text{ m} \end{aligned}$$

Where x_r = adjustment of reference point due to bulbous bow in metres as given in [1.4.2].

A greater value of x_c (maximum) may be permitted by the Flag Administration. Refer section [1.4.3]

- 1.4.2. For ships without bulbous bows the reference point shall be taken where the forward end of L_F coincides with the forward side of stem, on the waterline on which L_F is measured::

$$x_r = 0$$

For ships having any part of the underwater body extending forward of P_F , such as a bulbous bow, x_r in metres (m), shall be taken as:

$$x_r = \min(0.5 x_b ; 0.015L_F ; 3.0)$$

Where x_b = distance in metres (m) from P_F to the extreme forward end of the bulb extension, Refer Fig.3.1.1.

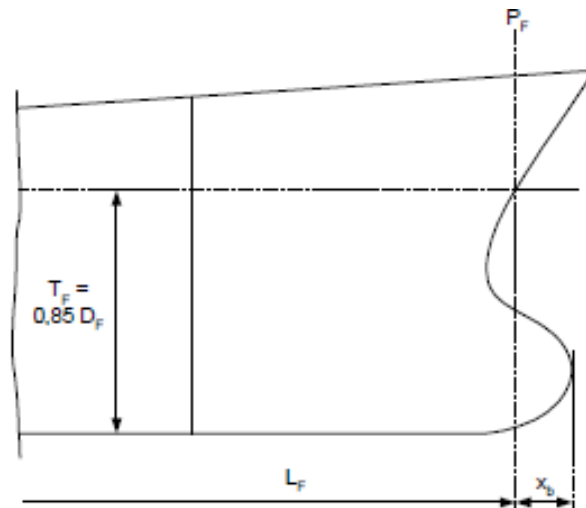


Fig. 3.1.1 Bulbous bow shape

- 1.4.3. If 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, then an increase of the maximum distance given by [1.4.1] may be acceptable.

- 1.4.4. 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 [1.4.1], Refer Fig.3.1.2. The ramp shall be arranged for weathertight closing over its complete length. The distance x_k in Fig.3.1.2 shall not be less than the minimum value of x_c as given in [1.4.1].

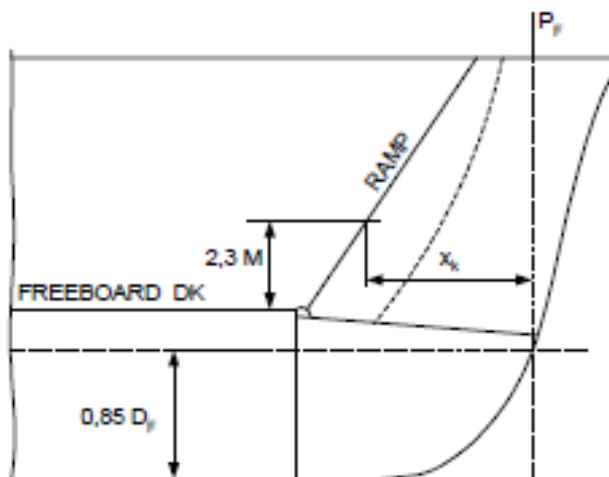


Fig. 3.1.2 Bow visor or door

- 1.4.5. The position of the collision bulkhead shall satisfy the minimum requirement to x_c as given in [1.4.1] for barges.
- 1.4.6. In general, the collision bulkhead shall be in one plane; however, the bulkhead may have steps or recesses provided that they are within the limits prescribed in [1.4.1].
- 1.4.7. Doors, manholes, permanent access openings, ventilation ducts or any other openings shall not be cut in the collision bulkhead below the freeboard deck. Where the collision bulkhead is extended above the freeboard deck, the number of openings in the extension shall be kept to a minimum compatible with the design and proper working of the ship.
- 1.4.8. The collision bulkhead may be pierced below the bulkhead deck by not more than one pipe for dealing with fluid in the forepeak tank. Requirements for arrangements of such piping are provided in relevant sections of Pt 5A.
- 1.4.9. For ships having complete or long forward superstructures, the collision bulkhead shall extend weather tight to the next deck above the bulkhead 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 bulkhead deck forming the step is made weather tight. 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, are to be made weather tight.

1.5. Aft peak bulkhead

- 1.5.1. An aft peak bulkhead, enclosing the stern tube and rudder trunk in a watertight compartment, is to be provided. Where the shafting arrangements make enclosure of the stern tube in a watertight compartment impractical, alternative arrangements are specially considered.
- 1.5.2. The aft peak bulkhead maybe stepped below the bulkhead deck, provided that the degree of safety of the ships as regards subdivision is not thereby diminished.

- 1.5.3. The aft peak bulkhead location on ships powered and / or controlled by equipment that do not require the fitting of a stern tube and /or rudder trunk are also subject to special consideration.
- 1.5.4. The aft peak bulkhead may terminate at the first deck above the deepest draught at the aft perpendicular, provided that this deck is made watertight to the stern or to the transom.
- 1.5.5. Aft peak or machinery space bulkhead may terminate as specified in [1.5.4] when the aft space is not utilized for cargo or passengers.

1.6. Cofferdams

- 1.6.1. A cofferdam means an empty space arranged so that compartments on each side have no common boundary; a cofferdam maybe located vertically or horizontally. As a rule, a cofferdam shall be kept gas-tight and shall be properly ventilated and of sufficient size to allow proper inspection, maintenance and safe evacuation.
- 1.6.2. Cofferdams shall be provided to separate from each other the following dedicated tank types:
 - a) Tanks for mineral oil
 - b) Tanks for vegetable oil
 - c) Tanks for fresh water for human consumption.
- 1.6.3. Cofferdams shall also be provided between compartments intended for liquid hydrocarbons (fuel oil, lubricating oil) and those intended for fresh water (drinking water, water for propelling machinery and boilers) as well as tanks intended for the carriage of liquid foam for fire extinguishing.
- 1.6.4. Additionally, cofferdams shall be arranged separating tanks carrying fresh water for human consumption from other tanks containing substances hazardous to human health. Normally, tanks for fresh water and water ballast are considered non-hazardous.

1.7. Fore end compartments

- 1.7.1 The fore peak and other compartments located forward of the collision bulkhead shall not be arranged for the carriage of fuel oil, lubrication oil or other flammable products.

1.8. Aft end compartments

- 1.8.1 Stern tubes shall be enclosed in a watertight space (or spaces) of moderate volume. In case the stern tube terminates at an aft peak bulkhead also being a machinery space bulkhead, a pressurized stern tube sealing system may be accepted as an alternative to the watertight enclosure. Other measures to minimise the danger of water penetrating into the ship in case of damage to stern tube arrangement may be taken at the discretion of the Society.
- 1.8.2 Propulsion thruster compartment is regarded as steering gear room and shall be arranged as per requirements specified in Section [1.11]

1.9. Minimum bow height

- 1.9.1. For vessels to which International Convention on Loadlines is applicable, the minimum bow height requirements are to be complied in accordance with the requirements specified in Regulation 39 of ICLL 1966 (as amended). Furthermore, additional reserve buoyancy in the fore end for all ships assigned with type "B" freeboard other than oil tankers, chemical tankers

and gas carriers shall be in accordance with the relevant requirements specified in Regulation 39 of ICLL 1966 (as amended).

- 1.9.2. For vessels to which International Convention on Loadlines is not applicable, the minimum bow height and additional reserve buoyance requirements are to be complied in accordance with relevant requirements, if any, specified in the maritime regulations enforced by vessel's Flag Administration or Port Authorities or Coastal Authorities, as applicable.

1.10. Access arrangements

- 1.10.1. All vessels shall be provided with means of access giving safe and practical access to the internal structure during operational phase. All tanks shall be accessible for easy inspection and close-up survey, as defined in Pt 1 Ch 3.
- 1.10.2. Ship structures on oil tankers, bulk carriers, ore carriers and combination carriers subject to overall and close-up inspection and thickness measurements shall be provided with means of access which shall be described in a ship structure access manual. Reference is made to Ch II-1/Reg 3.6 of SOLAS 1974 (as amended).
- 1.10.3. 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 manholes shall be smooth. Manholes in the inner bottom plating shall have reinforcement rings. Manhole covers in the inner bottom plating in cargo holds shall be effectively protected.
- 1.10.4. The access opening to pipe tunnel shall be fitted with a 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 a watertight bulkhead.
- 1.10.5. All closed spaces shall be accessible for easy inspection. Special measures for the inspection and maintenance shall be put in place for small closed spaces for which the design causes impracticality for access. Closing of spaces of limited size, that are not possible to enter for inspection and maintenance, may be accepted after special consideration.
- 1.10.6. For vessels, except those exclusively intended for the carriage of containers, permanent means for access are to be provided for narrow ballast tanks (such as double skin construction). The aforementioned permanent means of access could be fixed platforms, climbing/foothold rails, ladders etc., accompanied 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 1 Ch 3.

1.11. Steering gear compartment

- 1.11.1. The steering gear compartment shall be readily accessible and separated from machinery spaces. Refer also Ch. II-1/Reg. 29.13 of SOLAS 1974 (as amended).

1.12. Shaft tunnels

- 1.12.1. 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.

- 1.12.2. The shaft tunnel may be omitted in ships with service restriction notation **R2, R3, R4** and **RC** provided the shafting is otherwise effectively protected. Bearings and stuffing boxes shall be accessible.

1.13. Fuel oil tanks

- 1.13.1. The arrangement of fuel oil tanks shall be in accordance with the requirements specified in Ch II-2/Reg. 4.2 of SOLAS 1974 (as amended) and Annex I/Ch. 3/Reg. 12A of MARPOL (as amended).

1.14. Double Bottom

- 1.14.1. The arrangement of double bottom shall be in accordance with the requirements specified in Ch II-1/Reg. 9 of SOLAS 1974 (as amended).
- 1.14.2. In addition to the above, requirements for double bottom and/or double skin for specific vessel types such as oil tankers, chemical carriers, liquefied gas carriers etc. shall also comply with the relevant requirements outlined in various codes and conventions such as MARPOL, IBC Code, IGC Code etc, as applicable.
- 1.14.3. Bottom arrangements regulated under the SOLAS Convention that are not in compliance with Ch II-1/Reg. 9 of SOLAS 1974 (as amended) are subject to acceptance by the vessel's Flag Administration.

SECTION 2 STRUCTURAL DESIGN PRINCIPLES

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2.1. Design procedure

- 2.1.1. Generally hull scantlings are based on the two design aspects, namely load (demand) and strength (capability).

The probability distribution for the load and the strength of a given structure may be as showed in Fig.3.2.1

The rules have established design loads which may be divided into two categories, internal and external loads. External loads are the loads imposed by the sea whereas internal loads are due to cargo, ballast and bunkers. The design loads are used in strength formulae and calculation methods where a satisfactory strength level is represented by allowable stresses and /or usage factors.

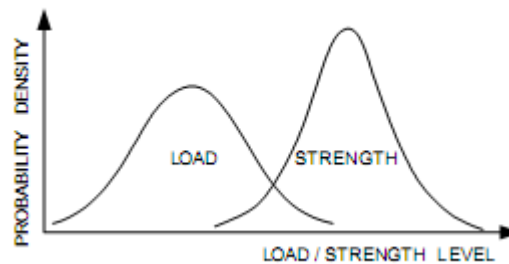
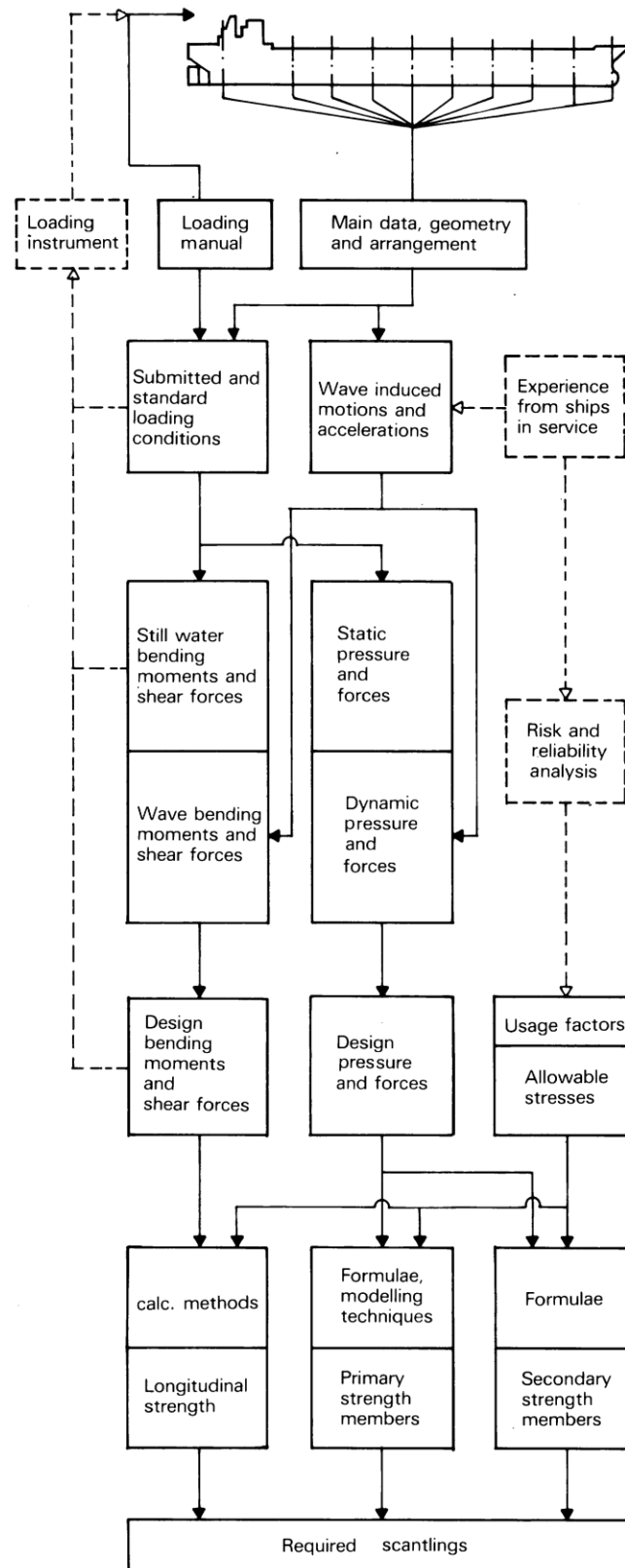


Fig. 3.2.1 Probability distribution

- 2.1.2. The elements of the rule design procedure are shown in Fig.3.2.2 and further elaborated in the following.

2.2. Loading conditions

- 2.2.1. Static loads are derived from the loading conditions submitted by the builder or standard conditions specified in the rules. The standard conditions are supposed to give suitable flexibility with respect to the loading of ordinary ship types.
- 2.2.2. Dry cargoes are assumed to be general cargo or bulk cargo (coal, grain) stowing at 0.7 t/m³, unless specifically stated. Liquid cargoes are expected to have density equal to or less than that of seawater.



- 2.2.3. 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 centerline. For ships for which unsymmetrical cargo or ballast condition(s) are intended, the effect of this is to be considered in the design.
- 2.2.4. Dynamic loads are derived 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 due to the motions of ship in irregular seas in rotational and translational degrees of freedom 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.
- 2.2.5. Wave-induced loads determined according to accepted theories, model tests or full scale measurements may be accepted as equivalent basis for classification.

2.3. Hull girder strength

- 2.3.1. A minimum longitudinal strength standard estimated by the section modulus at bottom and deck is required for the hull girder cross-section.

2.4. Plate strength

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

$$t = \frac{3.16 C k_a s \sqrt{h}}{\sqrt{\sigma / k_m}} + t_c \quad (\text{mm})$$

$$t_{\min} = t_0 + k L \sqrt{k_m} + t_c \quad (\text{mm})$$

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 metres (m)

l = stiffener span in metres (m)

σ = nominal allowable bending stress in N/mm^2 for mild steel

h = maximum design lateral pressure head in metres (m)

t_0, k = as given in relevant chapters and sections

k_m = material factor given in Ch 2 Sec 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

2.5. Stiffeners, local bending and shear strength

- 2.5.1. The section modulus requirement is given as function of boundary conditions, bending moments and nominal allowable bending stress, for stiffeners exposed to lateral pressure. The boundary conditions are included in a bending moment factor. The bending moment factor corresponds to m in the following expression:

$$M = \frac{ql^2}{m} \quad (\text{kN m})$$

M is the expected bending moment.

q = 10.055 $h b$

h = as specified in [2.4.1]

b = effective load breadth of stiffener in meters (m), for uniform pressure equal to stiffener spacing s .

l = the length or span of the member under consideration in meters (m).

Based on the above, the section modulus requirement for stiffeners exposed to lateral pressure can be expressed as follows:

$$Z = \frac{10000 s l^2 h w_c k_m}{m \sigma} \quad (\text{cm}^3)$$

h = as specified in [2.4.1]

s = spacing of member in meters (m)

l = the length or span of the member under consideration in meters (m).

m = bending moment factor

w_c = section modulus corrosion factor in tanks as specified in Ch 3 Sec 3 [3.10.5]

σ = nominal allowable bending stress in N/mm² for mild steel.

k_m = material factor given in Ch 2 Sec 2

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

- 2.5.2. The general elastic bending theory is used to derive the m - value for elastic deflections. In Table 3.2.1, m - values are given for some defined load and boundary conditions.

- 2.5.3. 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.

A built-in safety is accounted for in the above mentioned procedure as the bending moment at a yielding support is not increased beyond the value corresponding to first yield.

- 2.5.4. Maximum normal stress is maintained within the specified limits corresponding to the design pressure by combining the normal allowable bending stresses with possible axial stresses.

- 2.5.5. 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 in kN

P is the total load force on the member in kN

k_s is shear force factor.

Based on the above, the effective shear area requirements given as a function of boundary conditions and nominal allowable shear stress can be expressed as follows:

$$A_s = \frac{10 Q k_m}{\tau} + A_k \quad (\text{cm}^2)$$

k_m = material factor given in Ch 2 Sec 2





τ = 90 N/mm² in general



A_k = corrosion addition area for the effective shear area.

A_k may be obtained by adding the corrosion addition t_c to the net web thickness or increasing the web height correspondingly.

- 2.5.6. k_s -values normally to be applied are given separately for each of the local structures. In Table 3.2.1, k_s -values are given for some defined load and boundary conditions.
- 2.5.7. Direct strength formulae for girders are limited to simple girders. The boundary conditions and the nominal allowable stresses are given in a similar manner as for stiffeners. For girder systems, direct calculations are assumed to be used for deriving the stress patterns.

Allowable stresses corresponding to specified pressure combinations and indicated model fineness are given for the most common structural arrangements. Acceptable shear stresses, in general is 90/ k_m N/mm².

Table 3.2.1 Value 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 k _{s1}	2 m ₂ -	3 m ₃ k _{s3}
			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

2.6. Buckling strength

- 2.6.1. To prevent buckling or tripping of structural elements when subjected to compressive stresses and shear stresses, structural stability requirements are provided. The critical buckling stress shall be checked for the various strength members based on general elastic buckling formulae, corrected in the plastic range. Compressive stresses beyond the elastic buckling strength may be permitted for plate elements which are subjected to extreme loading conditions. For calculation of elastic and ultimate compressive strength, refer Ch 14.

2.7. Impact strength

- 2.7.1. Strengthening against slamming may be required for ships designed for a small draught at F.P. In Ch 6 Sec 8, the requirements for bottom structures forward are given in a general form taking various structural arrangements into consideration. Remarks may be made in the classification certificate to indicate the draught upon which the slamming strength compliance is checked and verified. If the bottom scantlings are based on full ballast tanks in the forebody, this will also be stated.

The impact loads from the sea on flat areas in after bodies of special design may also have to be considered, wherever deemed necessary. Reference is made to relevant requirements specified in Ch 7 Sec 5 in this regard.

- 2.7.2. Strengthening may be required in the bow region above the summer load waterline in ships with large bow flare and / or large bow radius. Ch 7 Sec 5 specifies the requirements for structural arrangement and scantlings.
- 2.7.3. Special requirements for strengthening against sloshing impact loads will have to be considered in large tanks for liquid cargo and / or ballast. Refer Ch 4 Sec 3 in this regard.

2.8. Fatigue

- 2.8.1. In general the susceptibility of hull structures to fatigue cracking has been taken care of by special requirements to detail design. However, a special calculation evaluating dynamic stresses, stress concentration factors and environment may have to be performed in some cases, such as, when high tensile steel is applied in stiffening members subjected to high frequency fluctuating loads. For calculation of fatigue strength, Refer Ch 15.

2.9. Local vibrations

- 2.9.1. As for the requirements for scantlings given in the rules, vibrations in the hull structural elements are not considered. 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.

2.10. Transverse strength

- 2.10.1. The overall or local transverse strength need occasionally to be specially considered. In such cases the ship is assumed to have an angle of heel not less than 30°. No additional dynamic loads need to be added.

Acceptable stress levels will normally be:

$$\begin{aligned}\sigma &= 160 / k_m \text{ N/mm}^2 \text{ for structural members without longitudinal bending stresses} \\ &= \text{as given in relevant chapters for longitudinal members} \\ \tau &= 90 / k_m \text{ N/mm}^2 \\ k_m &= \text{material factor given in Ch 2 Sec 2}\end{aligned}$$

2.11. Miscellaneous strength requirements

- 2.11.1. Scantlings requirements of foundations, minimum thickness of plates 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.

2.12. Reliability based analysis of hull structures

- 2.12.1. Alternatives to detailed requirements in the rules may be accepted when the overall safety and reliability level is found to be equivalent or better than that of the rules. Approval may be revoked if subsequent information indicates that the chosen alternative is not satisfactory.
- 2.12.2. The method and procedures for evaluation of reliability are subject to the acceptance by the Society in each individual case. Reliability analysis procedures specified in internationally recognized codes and standards shall be considered as acceptable procedures.
- 2.12.3. 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.
- 2.12.4. Level III reliability methods are mainly considered applicable to:
- a) Unique design solutions
 - b) Novel designs where limited (or no) experience exists
 - c) Special case design problems
 - d) 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
- 2.12.5. 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.
- 2.12.6. 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 below mentioned considerations:

- a) Transferable target reliabilities from “similar”, existing design solutions
- b) Decision analysis
- c) Internationally recognised codes and standards.

2.13. Service restrictions

2.13.1. Reductions in the strength requirements may be given for ships with service restrictions.

2.13.2. The requirement to longitudinal strength may be reduced as given in Ch 5 Sec 2 [2.2.4] and Ch 5 Sec 3 [3.3.6] or Ch 5 Sec 3 [3.3.12], as applicable.

2.13.3. The dynamic terms in the requirements for local strength may generally be reduced as given in Table 3.2.2. The reductions should be applied to the parameters referred to in the relevant tables for design loads. For local pressures given with a factor k in the formula for design loads, only the part of k exceeding 1.0 is to be reduced. Refer below mentioned remark. Also refer to the remarks in the design loads tables provided in various chapters.

Remark:

In the formulae given for design loads, the load factor k may be reduced as follows:

$$\bar{k} = 1 + \left[(k - 1) \left(\frac{100 - x}{100} \right) \right]$$

x = reduction factor given in Table 3.2.2

Where factor C_{WV} is included as the dynamic factor a direct reduction of C_{WV} may be applied.

Table 3.2.2 Reduction of dynamic terms	
Service Notation	Reduction (x%)
R0	No reduction
R1	10%
R2	20%
R3	30%
R4	40%
RC	50%

SECTION 3 LOCAL DESIGN

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3.1. Span for stiffeners and girders

- 3.1.1. The design of the end connections in relation to adjacent structures decides the effective span of a stiffener (I) or girder (S). Generally, the span points at each end of the member, between which the span is measured, is to be determined as shown in Fig.3.3.1 and Fig.3.3.2, unless stated otherwise. The span point shall be defined by the intersection of the line defined by the stiffener face plate and the end support structure, in cases where 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.

3.2. End connections of stiffeners

- 3.2.1. Normally all types of stiffeners (longitudinals, beams, frames, bulkhead stiffeners) shall be connected at their ends. Sniped ends may be allowed, in special cases, refer Sec [3.2.4]. Following sub-sections specifies the general requirements for the various types of end connections (with and without brackets, and with sniped ends).
Special requirements for the specific structures may be given in other chapters. Requirements for weld connections are given in Ch 11.
- 3.2.2. The scantlings of brackets for stiffeners not taking part in longitudinal strength may normally be taken as follows:

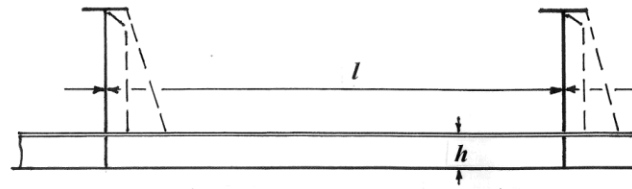
a) Thickness:

$$t_b = \frac{3 + k \sqrt{Z / w_c}}{\sqrt{k'_m / k_m}} + t_c \quad (\text{mm})$$

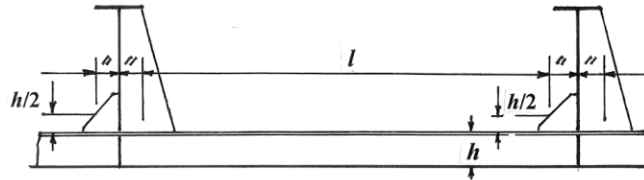
t_b = thickness of bracket in mm
 Z = required section modulus in cm^3 for the stiffener (smallest of connected stiffeners)
 k = 0.2 for brackets with flange or edge stiffener
 = 0.3 for brackets without flange or edge stiffener.

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

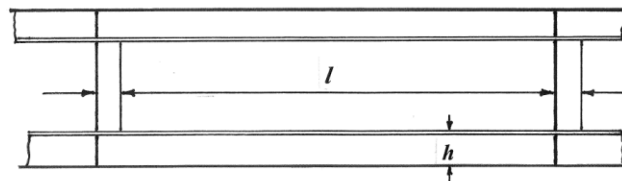
w_c = corrosion factor as given in Ch 3 Sec 3 [3.10.5]
 t_c = corrosion addition as given in Ch 2 Sec 4, need not be taken greater than 1.5 mm
 k_m = material factor for bracket
 k'_m = material factor k_m for stiffener.



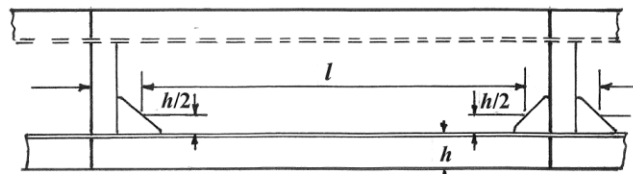
Continuous stiffener supported by single skin girders (1)



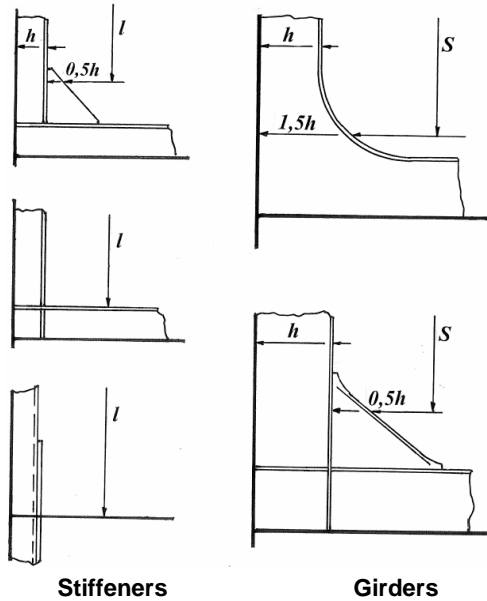
Continuous stiffener supported by single skin girders (2)



Continuous stiffener supported by double skin girders (1)



Continuous stiffener supported by double skin girders (2)



Stiffeners

Girders

Fig 3.3.1 Span points

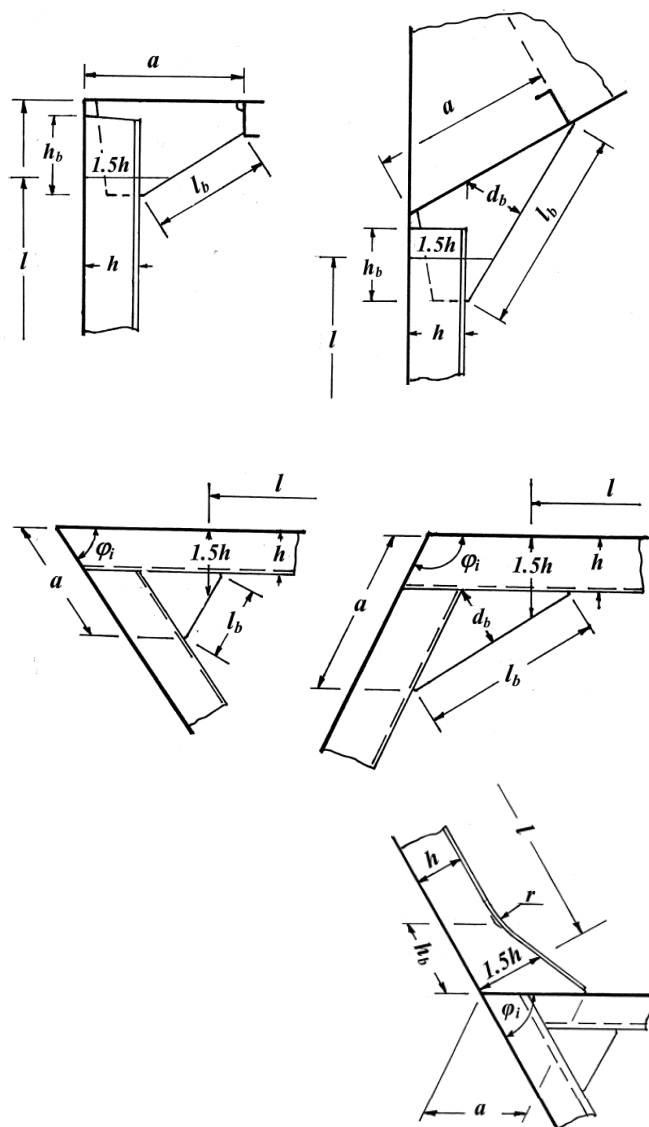


Fig 3.3.2 Stiffener end brackets

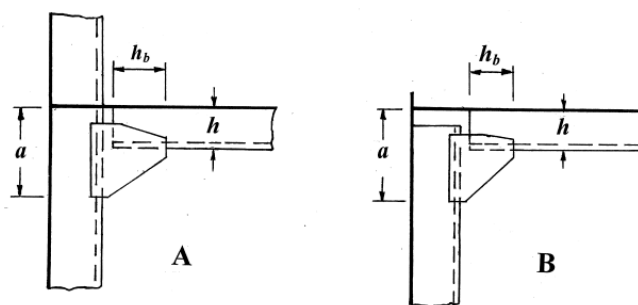


Fig. 3.3.3 Overlap end brackets

b) Arm length:

The arm length of brackets for stiffeners, refer Fig.3.3.2 and 3.3.3, not taking part in longitudinal strength may normally be taken as:

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

Z = required section modulus in cm^3 for the stiffener (smallest of connected stiffeners)
 t_b = thickness of bracket in mm
 c = 70 for brackets with flange or edge stiffener
= 75 for brackets without flange or edge stiffener.
 w_c = corrosion factor as given in Ch 3 Sec 3 [3.10.5]
 t_c = corrosion addition as given in Ch 2 Sec 4, need not be taken greater than 1.5 mm

The arm length, a , shall in no case to be taken less than $(1 + 1/\sin\phi_i) h$, where ϕ_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 , Refer Fig.3.3.2 and 3.3.3, is not to be less than h .

Brackets shall be arranged with flange or edge stiffener if the edge length, l_b , Refer Fig 3.3.2, exceeds $50 (t_b - t_c)$, except when the depth of the bracket defined as the distance from the root to the edge, d_b , Refer Fig 3.3.2, is less than $22 (t_b - t_c)$. The flange width should not to be less than:

$$W = 45 (1 + Z/2000) \quad (\text{mm}), \text{ minimum } 50 \text{ mm}$$

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.

The flange shall be effectively supported in way of the knuckle, in cases where the flange transition between the stiffener and an integral bracket is knuckled. 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 Refer Fig.3.3.2.

Remarks:

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 mentioned in Sect [3.2.2]
2. The end brackets for stiffeners may, as indicated in Fig.3.3.3, 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.

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

For longitudinals, Refer special requirements in Ch 6, Ch 7, Ch 8 and Ch 9, as applicable.

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

$$t = 3.95 \sqrt{(l - 0.5 s) s h k_m} + t_c \quad (\text{mm})$$

l = stiffener span in m
 s = stiffener spacing in m
 h = pressure head on stiffener in m

t_c = corrosion addition as given in Ch 2 Sec 4
 k_m = material factor given in Ch 2 Sec 2

3.3. End connections of girders

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

If adequate support of the adjoining face plates is provided, then bracket less connections may be applied.

- 3.3.2. 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.

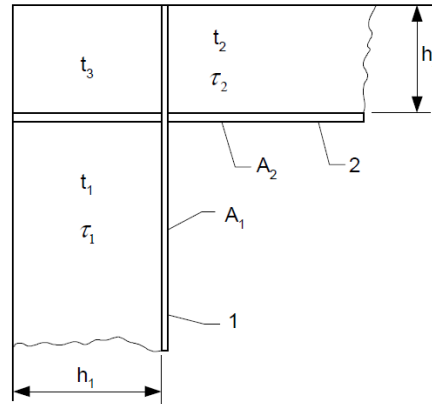
There shall be a smooth taper between bracket flange and girder face plate where flanges are continuous. If the flange is discontinuous, the face plate of the girder shall extend well beyond the toe of the bracket.

- 3.3.3. The arm length including depth of girder web may normally be taken as:

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

Z = rule section modulus in cm^3 of the strength member to which bracket is connected
 t_b = thickness of bracket in mm
 c = 63 for brackets on bottom and deck girders
= 88 for brackets on girders other than bottom and deck girders. This requirement may be modified after special consideration.
 w_c = corrosion factor as given in Ch 3 Sec 3 [3.10.5]
 t_c = corrosion addition as given in Ch 2 Sec 4, need not be taken greater than 1.5 mm

- 3.3.4. The required flange area of free flanges may be gradually tapered beyond the crossing flange, at cross joints of bracketless connections. 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 Refer Fig. 3.3.4):

$$t_3 = \left(\frac{\sigma_1 A_1}{h_2} + t_2 \frac{\tau_2}{100} \right) k_{m(3)} \quad (\text{mm})$$

or

$$t_3 = \left(\frac{\sigma_2 A_2}{h_1} + t_1 \frac{\tau_1}{100} \right) k_{m(3)} \quad (\text{mm})$$

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
 $k_{m(3)}$ = material factor for corner web plate t_3

3.4.1. The particulars given in below sub-sections shall be taken into account when the section modulus of the girder is calculated. The same particulars are to be applied during structural modeling in connection with direct stress analysis. 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. Accordingly, special attention shall be taken for the local effective flange that may require to be considered in stress analysis.

$$\mathbf{b}_e = \mathbf{C} \mathbf{b} \quad (\text{m})$$

C = as given in Table 3.3.1 for various numbers of evenly spaced stiffeners (r) along girder span

b = sum of plate flange width on each side of girder in m, normally taken to half the distance from nearest girder or bulkhead, refer Fig 3.3.5

- a = distance between points of zero bending moments, refer Fig 3.3.5
 = S for simply supported girders
 = 0.6 S for girders fixed at both ends
 S = span of girder
 r = number of stiffeners along girder span.

Table 3.3.1 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

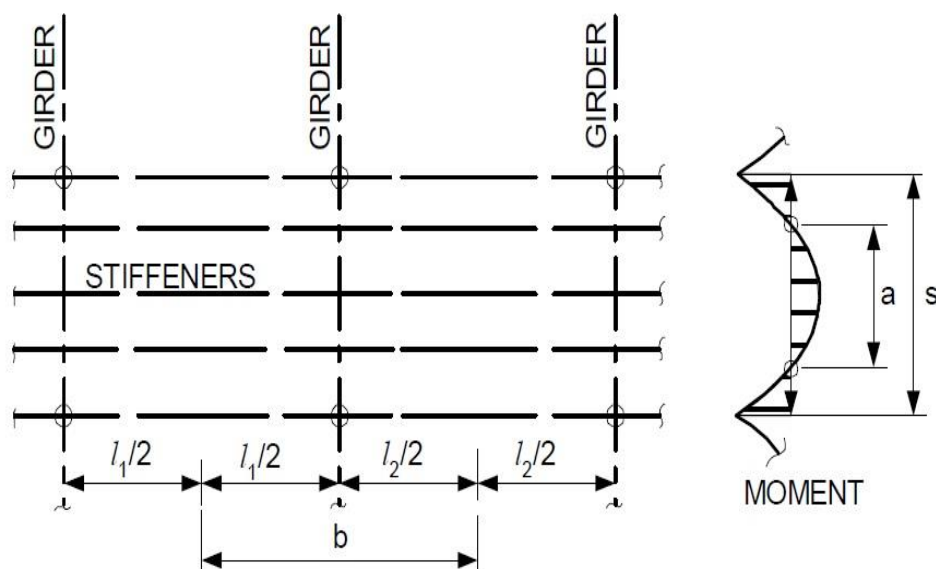


Fig.3.3.5. Effective Flange

- 3.4.3. The effective width for plate flanges having corrugations parallel to the girder is as given in 3.4.2. 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 Sec [3.4.2].
- 3.4.4. For effective width of plate flanges subject to elastic buckling, Refer Ch 14 and Appendix A.
- 3.4.5. 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.

3.4.6. The effective area of curved face plates is given by:

$$A_e = k' t_f b_{fp} \quad (\text{mm}^2)$$

b_{fp} = total face plate breadth in mm
 k' = flange efficiency coefficient, Refer also Fig.3.3.6

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

= 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

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

b = $0.5 (b_{fp} - t_w)$ for symmetrical free flanges
 = b_{fp} 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).

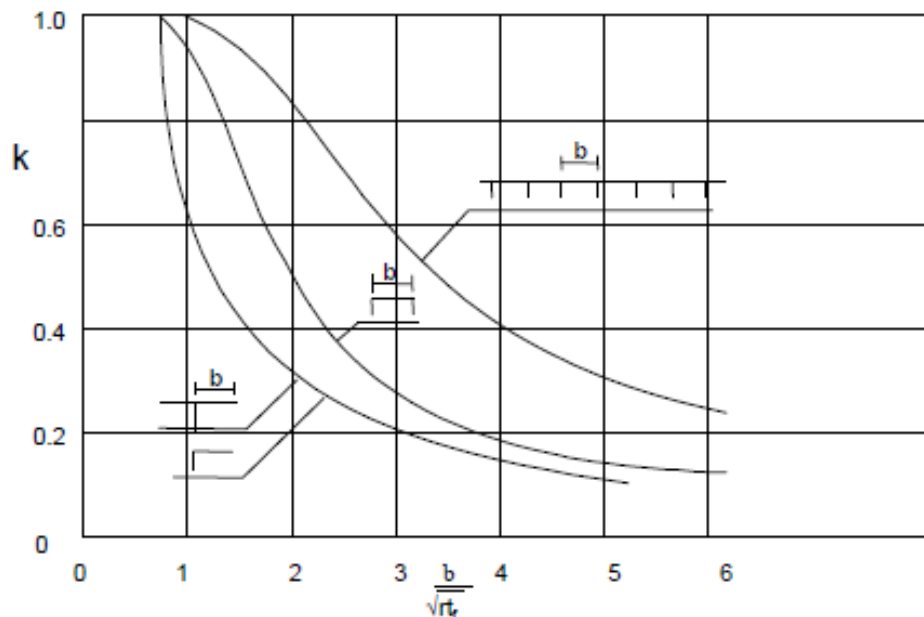


Fig. 3.3.6 Effective width of curved face plates for alternative boundary conditions

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

$$A_e = \frac{3 r t_f + k' s_r^2}{3 r t_f + s_r^2} t_f b_{fp} \quad (\text{mm}^2)$$

k', b_{fp}, r, t_f is as given in [3.4.6], Refer also in Fig 3.3.7

s_r = spacing of radial ribs or stiffeners in mm

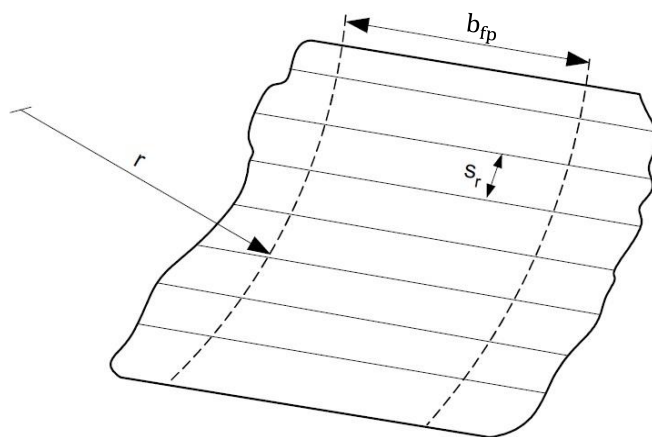


Fig. 3.3.7 Curved shell panel

3.5. Effective web of girders

- 3.5.1. The below sub-sections shall be used to determine the required web area of girder. The same particulars shall be used for structural modeling in connection with direct stress analysis, when applicable.
- 3.5.2. If the buckling strength is sufficient and shear stress level are acceptable, then holes in girders will generally be accepted. Holes shall be kept well clear of end of brackets, pillars, crossties and locations where shear stresses are high. For buckling control, refer Ch 14 Sec 3.
- 3.5.3. For ordinary girder cross-sections the effective web area shall be taken as:

$$A_w = 0.01h_n t_w \quad (\text{cm}^2)$$

h_n = net girder height in mm after deduction of cut-outs in the cross-section considered
 $= h_{n1} + h_{n2}$
 t_w = web thickness in mm, t_c not included.

h_n shall be taken as the smaller of the net height and the net distance through the opening in cases where the opening is located at a distance less than $h_w/3$ from the cross-section considered. Refer Fig.3.3.8

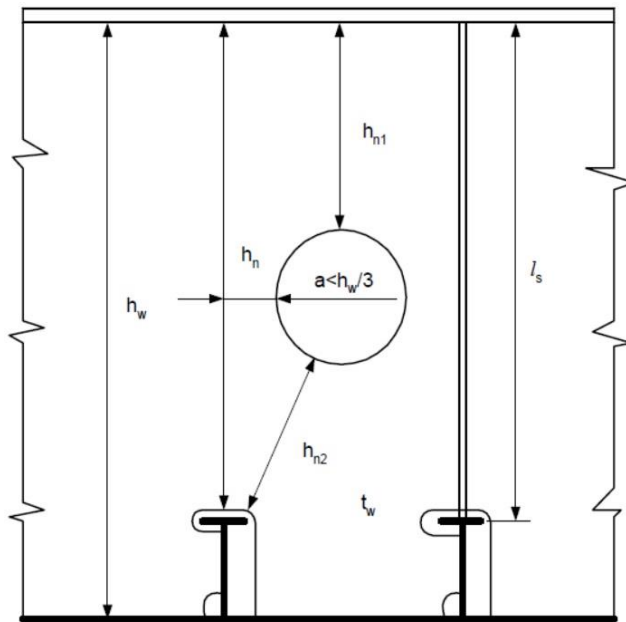


Fig. 3.3.8 Effective web area in way of openings

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

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

h_n = as given in Sec 3.5.3
 A_{Fl} = flange area in cm^2
 θ = angle of slope of continuous flange
 t_w = web thickness in mm, t_c not included. Refer also Fig.3.3.9.

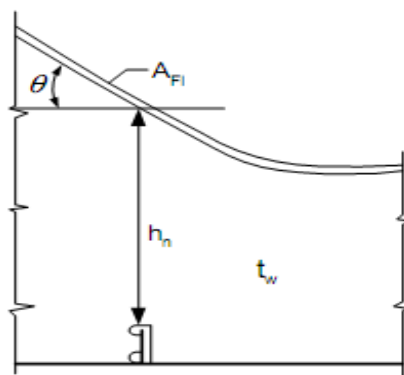


Fig. 3.3.9 Effective web area in way of brackets

3.6. Stiffening of girders

3.6.1. In order to obtain adequate lateral and web panel stability, girders, in general, shall be provided with tripping brackets and web stiffeners. The requirements given below lay down an acceptable standard. The stiffening system may, however, be modified based on direct stress analysis and stability calculations according to accepted methods. The sub-sections [3.6.2] to [3.6.3] are typically applicable for vessels less than 100 m in length while sub-sections 3.6.4] to [3.6.9] and [3.6.14] to [3.6.15] are typically applicable for vessels greater than 100 m in length. Other sub-sections, not mentioned above, are applicable to all vessels irrespective of length.

3.6.2. For vessels less than 100m in length, the web plate of girders are to be stiffened where:

$$h_w > 75 t_w \quad (\text{mm})$$

t_w = web thickness in mm, t_c not included.

with stiffeners of maximum spacing:

$$s = 60 t_w \quad (\text{mm})$$

Elsewhere stiffeners are required where:

$$h_w > 90 t_w \quad (\text{mm})$$

with stiffeners of maximum spacing:

$$s = 90 t_w \quad (\text{mm})$$

3.6.3. The spacing S_T of tripping brackets is normally not to exceed the values given in Table 3.3.2 valid for girders with symmetrical face plates. For others the spacing will be specially considered.

3.6.4. For vessels greater than 100 m in length, the spacing of stiffeners on the web plate is normally not to exceed:

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

or

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

- 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 = $90/k_m$ N/mm² in general within 20% of the span from each end of the girder
 = $60/k_m$ N/mm² elsewhere.

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

Table 3.3.2 Spacing between tripping brackets (for vessels with L<100m)	
Girder type	S_T (m)
Transverse girders Vertical girders Longitudinal girders outside 0.5 L amidships	0.02 b_f ¹⁾ maximum 6
Longitudinal girders within 0.5 L amidships	0.014 b_f ²⁾ maximum 4
Remarks: b_f = flange breadth in mm 1) For girders in tanks and machinery spaces S_T is not to exceed 0.014 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 is not to exceed 0.007 b_f .	

3.6.5. Longitudinal stiffening are to be normally given for deep longitudinal bottom and deck girders. The following requirements shall be complied with ,unless special buckling analysis has been carried out,:

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

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

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

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

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

or

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

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

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

3.6.7. 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.

- 3.6.8. The spacing S_T of tripping brackets is normally not to exceed the values given in Table 3.3.3 valid for girders with symmetrical face plates. Spacing will be specially considered for girders with unsymmetrical plates.

Table 3.3.3 Spacing between tripping brackets (for vessels with $L > 100\text{m}$)	
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
<p>Remarks:</p> <p>b_f = flange breadth in mm S = distance between transverse girders in m.</p> <p>1) For girders in tanks in the after body 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.</p>	

- 3.6.9. Tripping brackets on the center girder between the bottom transverses shall at the bottom to extend to the second bottom longitudinal from the center line. On one side, the bracket shall have the same depth as the center girder and on the other side half this depth.
- 3.6.10. If the mean shear stress exceeds 60 N/mm^2 , then the web plate shall be specially stiffened at openings. 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, Refer Fig.3.3.10. Scallops for longitudinals, frames or stiffeners deeper than 500 mm shall be stiffened along their free edge.

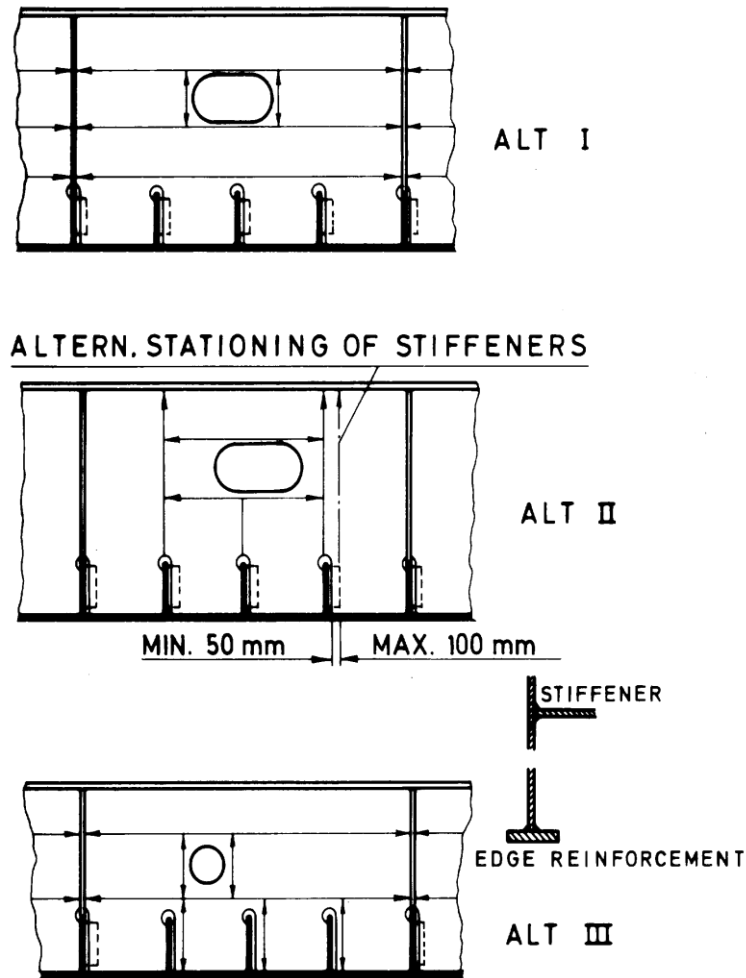


Fig. 3.3.10 Web plates with large openings

3.6.11. 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, t_c not included.

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.

3.6.12. Tripping brackets shall be fitted as required in Sec [3.6.3] or Sec [3.6.8], as applicable, 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.

3.6.13. Hatch end beams supporting hatch side coamings are at least to have tripping brackets located in the center line and between the hatch side coaming and the ship's side.

3.6.14. For vessels with length greater than 100 m, 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 3.3.4

s_v = as given in Sec 3.6.4

t_w = as defined in Sec 3.6.4.

Corrosion allowance (t_c) shall be applied in tanks.

Table 3.3.4 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

l_s = length, in m, of stiffener.

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

3.6.15. For vessels with length greater than 100 m, 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.

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

3.7. Reinforcement at knuckles

3.7.1. Sufficient stiffening shall be provided for the support of the knuckle whenever a knuckle is arranged in a main member (shell, longitudinal bulkhead etc.). As illustrated in Fig.3.3.11, 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. Where stiffeners intersect the knuckle as shown in Fig.3.3.11, effective support shall be provided for the stiffeners in way of the knuckle, e.g. as indicated in Fig.3.3.11.

3.7.2. It may be accepted to interrupt the stiffener at the knuckle, provided that proper end supports in terms of carling, bracket or equivalent is fitted, in cases where the stiffeners of the shell, inner shell or bulkhead intersect a knuckle at a narrow angle. 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.

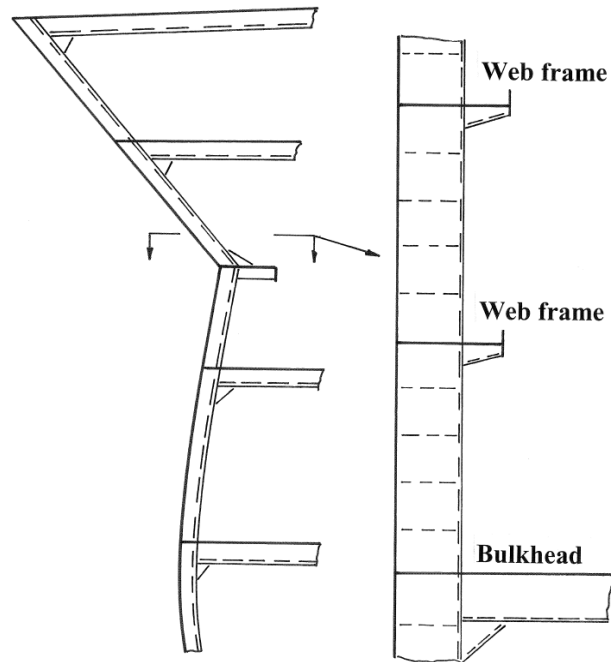


Fig. 3.3.11 Reinforcement at knuckle

- 3.7.3. 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 in cases where a stiffener or primary support member is knuckled within the length of the span, refer Fig.3.3.12.

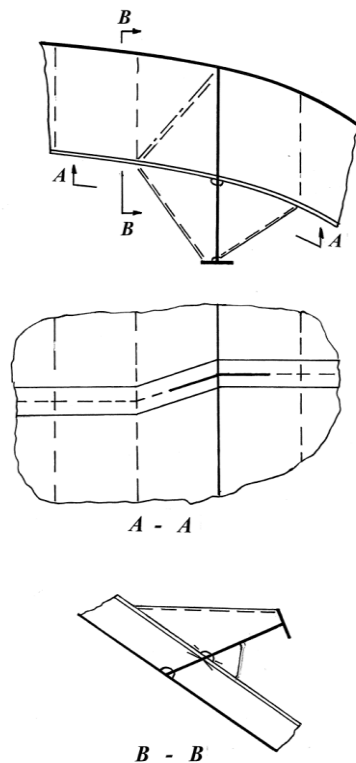


Fig. 3.3.12 Support arrangement for knuckled stringer

3.8. Continuity of local strength members

- 3.8.1. Structural continuity is of prime importance and adequate attention is to be paid in the design.
- 3.8.2. 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.
- 3.8.3. Where practicable, deck pillars shall be located in line with pillars above or below.
- 3.8.4. Below decks and platforms, strong transverses shall be fitted between verticals and pillars, so that rigid continuous frame structures are formed.

3.9. Welding of outfitting items to hull

- 3.9.1. Connections of outfitting details to the hull, in general, shall be such that stress-concentrations are minimized 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.
- 3.9.2. Equipment details such 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 top flange of girders and stiffeners shall be avoided if not well smoothed. Preferably supporting of out fittings shall be welded to the stiffener web.
- 3.9.3. 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.
- 3.9.4. Gutterway bars on strength deck shall be arranged with expansion joints unless the height/thickness ratio complies with the below formula:

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

- σ_f = minimum upper yield stress of material in N/mm², may be taken as 235 N/mm² for normal strength steel
- E = as given in Ch1 Sec 2, [2.1.1].

- 3.9.5. For welding of deck fittings to a rounded sheer strake, Refer also Ch 7 Sec 3 [3.2.6].

3.10. Properties and selection of sections

- 3.10.1. The moment of inertia I and section modulus Z of stiffeners, stringers and web frames may be calculated directly using basic engineering principles from the given dimensions and 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 Sec [3.4], or plate obtained from published tables and curves. For stiffeners, the plate effective flange width may normally be taken equal to the stiffener spacing.
- 3.10.2. 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 Sec [3.7.3]. 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 , refer Fig.3.3.13 shall be determined as given in Sec [3.10.6].

- 3.10.3. The requirements for standard section modulus and shear area are valid about an axis parallel to the plate flange. The requirement for standard section modulus and shear area may be determined by multiplying the rule requirement by $1 / \sin \varphi_W$, if the angle φ_W , refer Fig.3.3.13, between the stiffener web and the plate flange is less than 75° .
- 3.10.4. The section modulus may be taken as the average of each individual requirement in the group, where several members in a group with some variation are selected as equal. However, the requirement for the group shall not be taken less than 90% of the largest individual requirement.
- 3.10.5. Corrosion additions corresponding to the requirements given in Ch 2 Sec 4 shall be applied for stiffeners and primary support members, such as girders, stringers and web frames in tanks and in cargo holds of dry bulk cargo carriers. For built up sections the appropriate t_c -value may be added to the web and flange thickness after fulfillment of the net modulus requirement.

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

$$\begin{aligned} w_c &= 1 + 0.05 (t_{cw} + t_{cf}) && \text{for flanged sections} \\ &= 1 + 0.06 t_{cw} && \text{for bulbs} \end{aligned}$$

t_{cw} = corrosion addition t_c as given in Ch 2 Sec 4 [4.2] with respect to the profile web
 t_{cf} = corrosion addition t_c as given in Ch 2 Sec 4 [4.2] with respect to the profile flange.

For flat bars the corrosion allowance t_c may be added directly to the reduced thickness.

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

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

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:

$$z_{pa} = \frac{h_w(h_w + t_p)(t_w - t_c) \sin \varphi_W}{2000} + \frac{A_{fn}((h_{fc} + t_p/2) \sin \varphi_W - b_w \cos \varphi_W)}{1000}$$

φ_W = angle between the stiffener web and the attached plate flange. For angles of φ_W in excess of 75° , the values of $\sin \varphi_W$ and $\cos \varphi_W$ may be taken equal to 1.0 and 0.0 respectively.

A_{fn} = net effective area of flange in mm^2

$$= (2\gamma - 1)(A_f - b_f t_c)$$

A_f = cross sectional area of flange in mm^2

$$= b_f \times t_f \text{ in general}$$

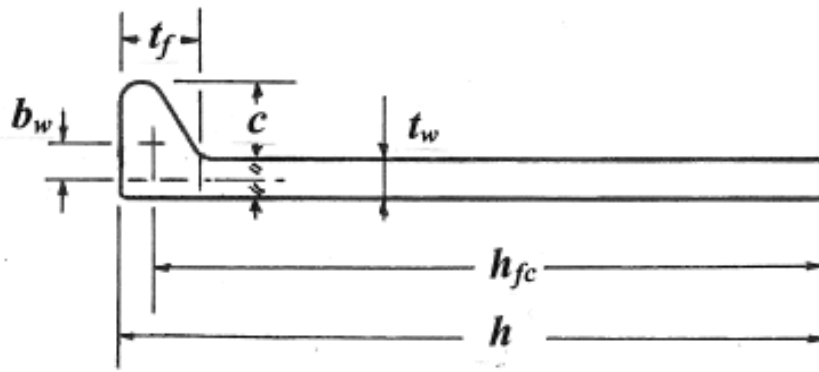
= maybe taken as obtained from Table 3.3.5 for bulb profiles

= 0.0 for flat bar stiffeners

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

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

	= 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 3.3.5 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 center of the flange area, Refer also Fig.3.3.13 = 0.0 for symmetrical flanges = $(b_f - t_w)/2$ in rolled angle profiles = may be taken as given in Table 3.3.5 for bulb profiles.
h_{fc}	= distance in mm, measured in the plane of and from lower edge of the web to the level of the center of the flange area, Refer also Fig. 3.3.13 = $h - \frac{t_f}{2}$ in general = may be taken as given in Table 3.3.5 for bulb profiles
h_w	= height of stiffener web in mm, Refer also Fig 3.3.13.
l	= span length of stiffener in m
t_f	= thickness of flange in mm in general = may be taken as given in Table 3.3.5 for bulb profiles = 0.0 for flat bar stiffeners
t_c	= as given in Ch 2 Sec 4,[4.2]
t_p	= thickness of attached plate in mm
t_w	= web thickness of stiffener in mm
b_e	= as given in Fig.3.3.13





h (mm)	C (mm)	t_f (mm)	b_f^* (mm)	$A_f - t_f \times t_w$ (mm ²)	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 3.3.5b Characteristic flange data for JIS bulb profiles (refer also Fig.3.3.13)						
h (mm)	C (mm)	t_f (mm)	b_f^* (mm)	A_f (mm ²)	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. 3.3.14 Bulb profiles (DIN and JIS Standard)

3.11. Cold formed plating

- 3.11.1. 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.
- 3.11.2. 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:
- i) The steel is killed and fine grain treated, i.e. grade D/DH or higher.
 - ii) 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.
 - iii) 100% visual inspection of the deformed area shall be carried out. In addition, random check by magnetic particle testing shall be carried out.
 - iv) The bending radius is in no case to be less than 2 times the plate thickness.

CHAPTER 4 DESIGN LOADS

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SECTION 1 GENERAL

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1.1. Introduction

- 1.1.1. In this section, formulae for wave induced ship motions and accelerations as well as lateral pressures expressed in terms of corresponding design pressure heads are given. The given design wave coefficient is also a basic parameter for the longitudinal strength calculations.
- 1.1.2. The ship motions and accelerations in Section 2 are given as extreme values (i.e. probability level = 10^{-8}).
- 1.1.3. Design pressures expressed in terms of corresponding design pressure heads caused by sea, liquid cargoes, dry cargoes, ballast and bunkers as given in Section 3 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 Section 2 to a 10^{-4} probability level.
- 1.1.4. Impact pressures expressed in terms of corresponding design pressure heads caused by the sea (slamming, bow impact) are not covered by this section. Design values are given in the sections dealing with specific structures.
- 1.1.5. Design pressure head, h , in m, is defined as the water pressure head corresponding to the design pressure, p in kN/m^2 , deduced using the formula $h = p/(\rho_w g_0)$ where ρ_w is the density of seawater in 1.025 t/m^3 , g_0 as defined in Ch 1 Sec 2 [2.1.1] and $(\rho_w g_0) \approx 10$.

1.2. Definitions

- 1.2.1. Symbols:
- | | |
|----------|--|
| p | = design pressure in kN/m^2 |
| h | = design pressure head in m |
| ρ_w | = density of sea water, i.e. 1.025 t/m^3 |
| g_0 | = as defined in Ch 1 Sec 2 [2.1.1]. |
- 1.2.2. The load point for which the design pressure head 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 head shall be taken as the greater of:
- $$h_m \text{ and } (h_a + h_b)/2$$
- h_m , h_a and h_b are calculated pressure heads at the midpoint and at each end respectively.
- c) For girders:
- Midpoint of load area

SECTION 2 SHIP MOTIONS AND ACCELERATIONS

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2.1. General

- 2.1.1 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.

- 2.1.2 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.

2.2. Basic parameters

- 2.2.1 The acceleration, sea pressures and hull girder loads have been related to a wave coefficient as given in Table 4.2.1.

- 2.2.2 For ships with restricted service, C_{wv} 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: **RC** 50%.

- 2.2.3 A common acceleration parameter is given by:

$$a_{ca} = \frac{3 C_{wv}}{L} + C_v C_{v1}$$

$$C_v = \sqrt{L}/50, \text{ maximum } 0.2$$

$$C_{v1} = V/\sqrt{L}, \text{ minimum } 0.8$$

Table 4.2.1 Wave coefficient C_{wv}	
L	C_{wv}
$L \leq 100$	$0.0792 L$
$100 < L < 300$	$10.75 - [(300 - L)/100]^{3/2}$
$300 \leq L \leq 350$	10.75
$L > 350$	$10.75 - [(L - 350)/150]^{3/2}$

2.3. Roll motion and acceleration

2.3.1. The roll angle (single amplitude) is given by:

$$\phi = \frac{50 c}{B + 75} \quad (\text{radians})$$

Where,

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	=	roll period as defined below, not to be taken less than 30 seconds

2.3.2. The roll period, in general, is given by:

$$T_{ROLL} = \frac{2 k_{roll}}{\sqrt{GM_T}} \quad (\text{seconds})$$

k _{roll}	=	roll radius of gyration in m
GM _T	=	metacentric height in m

The values of k_{roll} and GM_T to be used shall give the minimum realistic value of T_R for the load considered. In case k_{roll} and GM_T have not been calculated for such condition, the following approximate design values may be used:

k _{roll}	=	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 _T	=	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.

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

$$a_{roll} = \phi \left(\frac{2\pi}{T_{ROLL}} \right)^2 R_{ROLL} \quad (\text{m/s}^2)$$

Where,

R_{ROLL} = distance, in m, from the center of mass to the axis of rotation

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

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

2.3.4. The radial roll acceleration may normally be neglected.

2.4. Pitch motion and acceleration

2.4.1. The pitch angle is given by:

$$\theta = 0.25 \frac{a_{ca}}{C_B} \quad (\text{radians})$$

2.4.2. The period of pitch may be normally taken as:

$$T_{PITCH} = 1.8 \sqrt{\frac{L}{g_0}} \quad (\text{seconds})$$

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

$$a_{pitch} = \theta \left(\frac{2\pi}{T_{PITCH}} \right)^2 R_{PITCH} \quad (\text{m/s}^2)$$

Where,

T_{PITCH} = pitch period

R_{PITCH} = distance from the center of mass to the axis of rotation, in m

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

z = as given in Sec [2.3.3]

With T_P as given in Sec 2.4.2, the pitch acceleration is given by:

$$a_{pitch} = 120 \theta \frac{R_{PITCH}}{L} \quad (\text{m/s}^2)$$

2.4.4. The radial pitch acceleration may normally be neglected.

2.5. Surge, sway / yaw and heave accelerations

2.5.1. The surge acceleration is given by:

$$a_{surge} = 0.2 g_0 a_{ca} \sqrt{C_B} \quad (\text{m/s}^2)$$

2.5.2. The combined sway/yaw acceleration is given by:

$$a_{sway} = 0.3 g_0 a_{ca} \quad (\text{m/s}^2)$$

2.5.3. The heave acceleration is given by:

$$a_{heave} = 0.7 g_0 \frac{a_{ca}}{\sqrt{C_B}} \quad (\text{m/s}^2)$$

2.6. Combined vertical acceleration

2.6.1. The combined vertical acceleration (acceleration of gravity not included) may normally be approximated by:

$$a_{vert} = \frac{k_v g_0 a_{ca}}{C_B} \quad (\text{m/s}^2)$$

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, refer Fig.4.2.1.

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

- 2.6.2. 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 Sec [2.1].

$$a_{\text{vert}} = \max \left\{ \left(\sqrt{a_{\text{roll-z}}^2 + a_{\text{heave}}^2} \right) \text{ or } \left(\sqrt{a_{\text{pitch-z}}^2 + a_{\text{heave}}^2} \right) \right\} \quad (\text{m/s}^2)$$

a_{heave} = as given in Sec 2.5.3
 $a_{\text{roll-z}}$ = vertical component of the roll acceleration given in Sec [2.3.3]
 $a_{\text{pitch-z}}$ = vertical component of the pitch acceleration given in Sec [2.4.3]

Note that $a_{\text{roll-z}}$ and $a_{\text{pitch-z}}$ are equal to a_{roll} and a_{pitch} using the horizontal projection of R_{ROLL} and R_{PITCH} respectively.

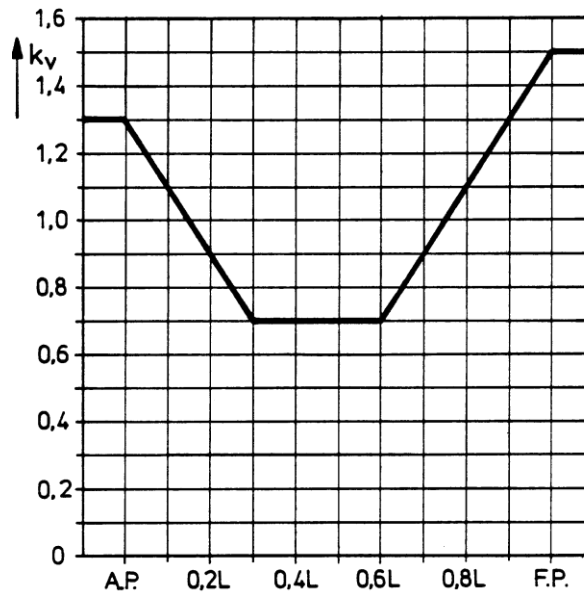


Fig. 4.2.1 Acceleration distribution factor

2.7. Combined transverse acceleration

- 2.7.1. Acceleration along ship's transverse axis is given as the combined effects of sway/yaw and roll calculated as indicated in Sec [2.1], i.e.,

$$a_{\text{trans}} = \sqrt{a_{\text{sway}}^2 + (g_0 \sin \phi + a_{\text{roll-y}})^2} \quad (\text{m/s}^2)$$

Where,

$a_{\text{roll-y}}$ = transverse component of the roll acceleration given in Sec [2.3.3]

Note that $a_{\text{roll-y}}$ is equal to a_{roll} using the vertical projection of R_{ROLL} , i.e. $z_{\text{vc}} - z$. z_{vc} is the vertical coordinate of the center of mass. z is given in Sec [2.3.3]

2.8. Combined longitudinal acceleration

- 2.8.1. Acceleration along ship's longitudinal axis is given as the combined effects of surge and pitch calculated as indicated in Sec 2.1, i.e.,

$$a_{\text{long}} = \sqrt{a_{\text{surge}}^2 + (g_0 \sin \theta + a_{\text{pitch-x}})^2} \quad (\text{m/s}^2)$$

Where,

$a_{\text{pitch-x}}$ = longitudinal component of the pitch acceleration given in Sec [2.4.3]

Note that $a_{\text{pitch-x}}$ is equal to a_{pitch} using the vertical projection of R_{PITCH} , i.e. $z_{\text{vc}} - z$. z_{vc} is the vertical coordinate of the center of mass. z is given in Sec [2.3.3]

SECTION 3 DESIGN PRESSURE HEADS AND FORCES

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3.1. General

- 3.1.1 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.
- 3.1.2 The design sea pressures are assumed to be acting on the ship's outer panels at full draught.
- 3.1.3 The internal pressures are given for the panel in question irrespective of possible simultaneous pressure from the opposite side. For outer panels sea pressure at ballast draught may be deducted.
- 3.1.4 The gravity and acceleration forces from heavy units of cargo and equipment may influence the scantlings of primary strength members.

3.2. Design pressure heads for external sea pressures

- 3.2.1. The design pressure head acting on the ship's side, bottom and weather deck shall be taken as the sum of the static and the dynamic pressure heads as:

- for load point below summer load waterline:

$$h_1 = h_0 + h_{dp}^{1)} \quad (m)$$

- for load point above summer load waterline:

$$\begin{aligned} h_2 &= a (h_{dp} - \{(0.4 + 0.02 k_s)h_0\})^{1)} \quad (m) \\ &= \text{minimum } 0.625 + 0.0025L_1 \text{ for sides} \\ &= \text{minimum } 0.5 \text{ for weather decks.} \end{aligned}$$

The dynamic pressure head h_{dp} shall be taken as:

$$h_{dp} = h_1 + 13.5 \frac{y}{B + 75} - 0.12 (T_{ms} - z) \quad (m)$$

Where,

$$\begin{aligned} h_1 &= \frac{k_s C_{WV} + k_f}{10} \\ &= (k_s C_{WV} + k_f) \left(0.08 + 0.015 \frac{V}{\sqrt{L}} \right) \quad \text{if } \frac{V}{\sqrt{L}} > 1.5 \end{aligned}$$

$$\begin{aligned} k_s &= 3 C_B + \frac{2.5}{\sqrt{C_B}} && \text{at AP and aft} \\ &= 2 && \text{between } 0.2L \text{ and } 0.7L \text{ from AP} \\ &= 3 C_B + \frac{4.0}{C_B} && \text{at FP and forward} \end{aligned}$$

Between specified areas k_s may be varied linearly.

The definition of parameters used in the above formulations is as follows:

- 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

C_{WV}	= as given in Ch 4 Sec 2 [2.2]
k_f	= the smallest of T_{ms} and f
f	= vertical distance, in m, from the waterline to the top of the ship's side at transverse section considered, maximum $0.8 C_{WV}$
L_1	= ship length, in m, need not be taken greater than 300 m.
h_0	= vertical distance, in m, from the waterline at draught T_{ms} to the load point
y	= horizontal distance, in m, from the centre line to the load point, minimum $B/4$
z	= vertical distance, in m, from the baseline to the load point, maximum T_{ms}

Remarks:

1) h_2 and the last term in h_1 may be reduced by the percentages given in Ch 4 Sec 2 [2.2.2] for ships with service restrictions. C_{WV} shall not be reduced.

- 3.2.2. The sea pressure head at minimum design draught which may be deducted from internal design pressure heads shall be taken as:

$$h = T_M - z \quad (\text{m})$$

$$= \text{minimum } 0$$

T_M	= minimum design draught, in m, normally taken as $0.35 T_{ms}$ for dry cargo vessels and $2 + 0.02 L$ for tankers
z	= vertical distance, in m, from the baseline to the load point.

- 3.2.3. The design pressure head on watertight bulkheads (compartment flooded) shall be taken as:

$$h = h_b \quad (\text{m})$$

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

- 3.2.4. The design pressure head on inner bottom (double bottom flooded) shall not be less than:

$$h = T_{ms} \quad (\text{m})$$

3.3. Design pressure heads for internal pressures due to liquid in tanks

- 3.3.1. Tanks for crude oil or bunkers are normally to be designed for liquids of density equal to that of sea water, taken as $\rho = 1.025 \text{ t/m}^3$. 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 **HLC(ρ)**, indicating the highest cargo density applied as basis for approval.

- 3.3.2. The pressure head in full tanks shall be taken as the greater of:

$$h = \frac{\rho}{\rho_w} \left(1 + \frac{0.5 a_{\text{vert}}}{g_0} \right) h_s \quad (\text{m}) \quad (1)$$

$$h = \frac{\rho}{\rho_w} \left[0.67 (h_s + \phi b) - 0.12 \sqrt{H b_{\text{top}} \phi} \right] \quad (\text{m}) \quad (2)$$

$$h = \frac{\rho}{\rho_w} \left[0.67 (h_s + \theta l) - 0.12 \sqrt{H l_{\text{top}} \theta} \right] \quad (\text{m}) \quad (3)$$

$$h = 0.67 \left(\frac{\rho}{\rho_w} h_p + \Delta h_{\text{dyn}} \right) \quad (\text{m}) \quad (4)$$

$$h = \frac{\rho}{\rho_w} h_s + h_{\text{gen}} \quad (\text{m}) \quad (5)$$

The definition of parameters used in the above formulations is as follows:

a_{vert}	= vertical acceleration as given in Ch 4 Sec 2 [2.6], taken in the centre of gravity of the tank
ϕ	= as given in Ch 4 Sec 2 [2.3]
θ	= as given in Ch 4 Sec 2 [2.4]
ρ_w	= as given in Ch 4 Sec 1 [1.2]
ρ	= density of ballast, bunkers or liquid cargo in t/m^3 , normally not to be taken less than 1.025 t/m^3
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
H	= height, in m, of the tank
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
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
b_{top}	= breadth, in m, of top of tank
l_{top}	= length, in m, of top of tank
h_{gen}	= 2.5 m in general = 1.5 m in ballast holds in dry cargo vessels. = pressure head corresponding to tank pressure valve opening pressure when exceeding the general value.
Δh_{dyn}	= pressure head corresponding to calculated pressure drop for air pipes or overflow pipes, if applicable, according to relevant sections regarding the same in Pt 5

For calculation of girder structures, the pressure head as calculated by formulae (4) above shall be increased by a factor of 1.15.

The formulae normally giving the greatest pressure heads are indicated in Fig. 4.3.1 to Fig. 4.3.3 for various types.

For sea pressure head at minimum design draught which may be deducted from above formulae, refer to Sec [3.2.2].

Formulae (2) and (3) are based on a 2% ullage in large tanks.

Remarks:

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 .

2) If the pressure drop for air pipes or overflow pipes, if applicable, according to Pt 5A is not available, Δh_{dyn} may normally be taken as 2.5 m for ballast tanks and 0 m for other tanks. If arrangements for the prevention of over pumping of ballast tanks in accordance with Pt 5 are fitted, Δh_{dyn} may be taken as zero.

3) When a ship is designed with 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.

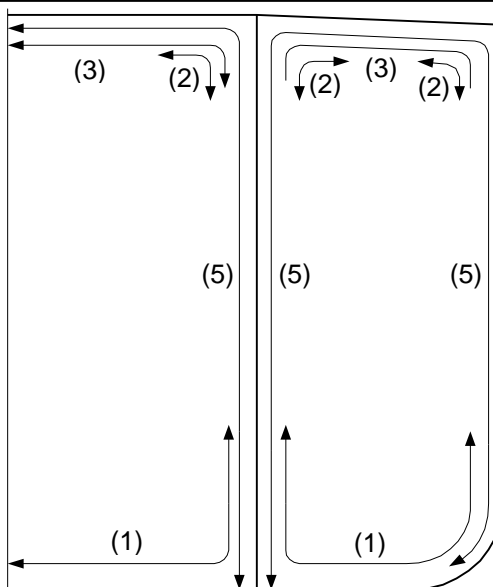


Fig. 4.3.1 Section in cargo tanks

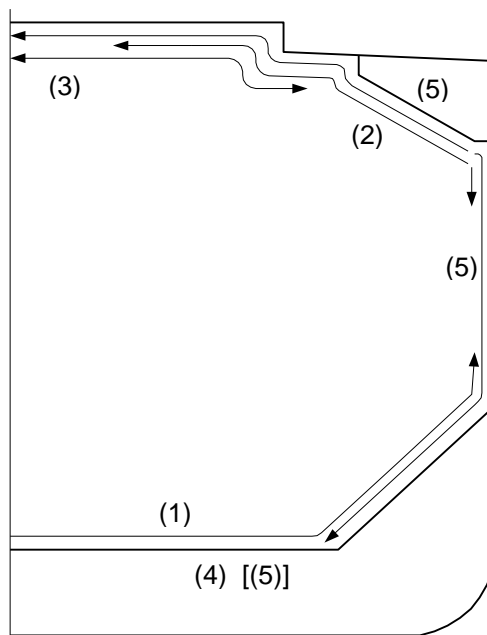


Fig. 4.3.2 Section in bulk cargo hold

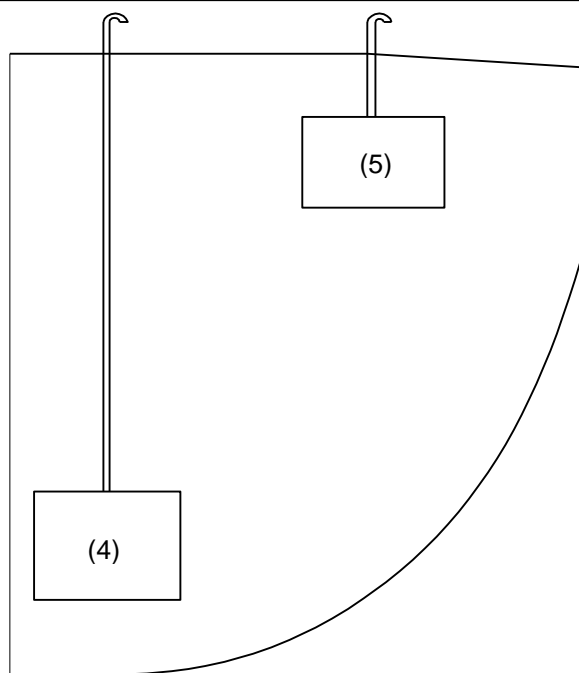


Fig. 4.3.3 Section in engine room

- 3.3.3. The pressure head in full tanks shall be taken as the greater of: Tanks with $l_b < 0.13L$ and $b_b < 0.56B$ shall have scantlings for unrestricted filling height.

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

$$h = \frac{\rho}{\rho_w} \left(0.408 - \frac{L}{1962} \right) l_b \quad (\text{m})$$

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

$$h = \frac{\rho}{\rho_w} \left(0.306 - \frac{B}{981} \right) b_b \quad (\text{m})$$

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 ($\alpha_t < 0.2$).

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

If the wash bulkheads are not fully effective ($\alpha_t > 0.2$; $\alpha_l > 0.2$), l_b and b_b may be substituted by l_s and b_s as given in Sec 3.3.6. α_t and α_l are also defined in Sec [3.3.6].

- 3.3.4. The minimum sloshing pressure head on web frames and girder panels in cargo and ballast tanks, except ballast tanks in double side and double bottom, shall be taken as 2 m. In double side and double bottom ballast tanks the minimum sloshing pressure head shall be taken as 1.2 m.

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

$$h = h_{bhd} \left(1 - \frac{s}{l_s}\right)^2 \quad (\text{m}) \quad \text{for webframes}$$

$$h = h_{bhd} \left(1 - \frac{s}{b_s}\right)^2 \quad (\text{m}) \quad \text{for longitudinal girders}$$

h_{bhd} = sloshing pressure on wash or end bulkheads as given in Sec 3.3.6.

s = distance, in m, from bulkhead to webframe or girder considered.

l_s and b_s are as given in Sec 3.3.6.

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

The sloshing pressure heads (h_s) given in Sec 3.3.6 and Sec 3.3.9 shall be considered together with the normal strength formulae given in Ch 7, Ch 8 and Ch 9.

The impact pressure heads (h_i) given in Sec 3.3.7, Sec 3.3.8, Sec 3.3.9, and Sec 3.3.10 shall be used together with impact strength formulae given in Ch 9 Sec 5 [5.4].

l_s and b_s are as given in Sec 3.3.6.

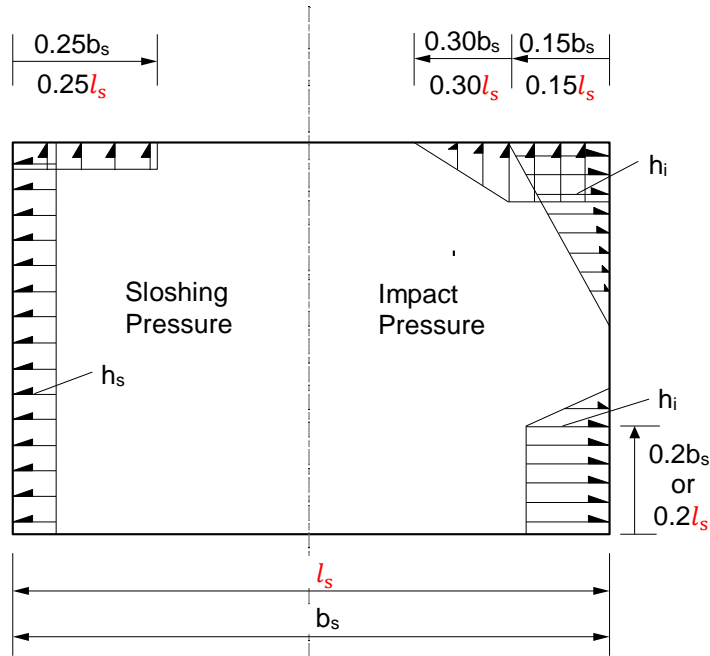


Fig. 4.3.4 Sloshing and impact pressure distribution

- 3.3.6. Sloshing pressure head

For strength members located less than $0.25l_s$ away from transverse wash and end bulkheads the pressure head shall not be taken less than Refer Fig. 4.3.4):

$$h = \frac{\rho}{\rho_w} l_s k_f \left[0.4 - \left(0.39 - \frac{1.7 l_s}{L} \right) \frac{L}{350} \right] \quad (\text{m})$$

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

$$h = 7 \frac{\rho}{\rho_w} k_f \left(\frac{b_s}{B} - 0.3 \right) GM^{0.75} \quad (\text{m})$$

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

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

h_{fh} = filling height, in m.

H = tank height, in m, within $0.15 l_s$ or $0.15 b_s$

GM = maximum GM, in m, including correction for free surface effect.

$$GM_{\min} = 0.12 B$$

l_s = effective sloshing length in m given as:

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

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

b_s = effective sloshing breadth in m given as:

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

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

l = tank length, in m

b = tank breadth, in m

n_t = number of transverse wash bulkheads in the tank with $\alpha_t < 5$

α_t = ratio between openings in transverse wash bulkhead and total transverse area in the tank below considered filling height, Refer Fig.4.3.5.

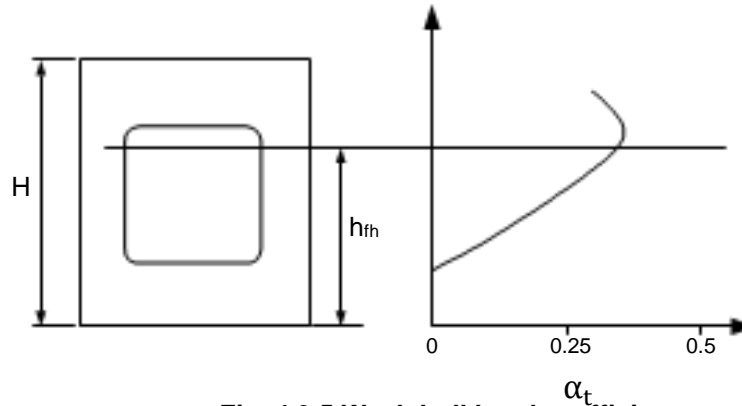


Fig. 4.3.5 Wash bulkhead coefficient

If no restriction to filling height, h_{fh} is taken as $0.7H$

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, Refer Fig.4.3.6

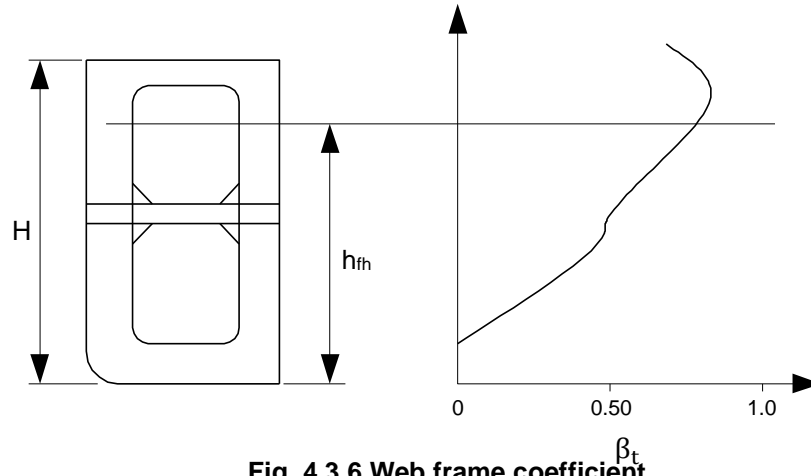


Fig. 4.3.6 Web frame coefficient

If no restriction to filling height, h_{fh} is taken as $0.7H$

n_l = number of longitudinal wash bulkheads in the tank with $\alpha_l < 5$
 α_l = similar to α_t but taken for the 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 but taken for longitudinal ring-girders

3.3.7. Impact pressure head in upper parts of tanks

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

Within $0.15 l_s$ from transverse wash or end bulkheads:

$$h_i = \frac{\rho}{\rho_w} k_f \left(\frac{220 l_s}{L} - 7.5 \right) \sin^2 \gamma \quad (\text{m}) \quad \text{for} \quad \frac{l_s}{L} < \frac{350 + L}{3550}$$

$$h_i = \frac{\rho}{\rho_w} k_f \left(25 + \frac{L}{13} \right) \left(0.5 + \frac{l_s}{L} \right) \sin^2 \gamma \quad (\text{m}) \quad \text{for} \quad \frac{l_s}{L} > \frac{350 + L}{3550}$$

Within $0.15 b_s$ from longitudinal wash bulkheads and tank sides:

$$h_i = 240 \frac{\rho}{\rho_w} \frac{k_f}{B} \left(\frac{b_s}{B} - 0.3 \right) GM^{1.5} \sin^2 \gamma \quad (\text{m})$$

Outside $0.15 l_s$ and $0.15 b_s$ the pressure head may be reduced to zero at $0.3 l_s$ and $0.3 b_s$, respectively, Refer Fig. 4.3.4. In tank corners within $0.15 l_s$ and $0.15 b_s$ the impact pressure head shall not be taken smaller than h_i (transversely) or $[h_i$ (longitudinally) + $0.4 h_i$ (transversely)]. The reflected impact pressure on vertical surfaces adjacent to

horizontal or inclined surfaces above will have an impact pressure head linearly reduced to 50% of the pressure head above, $0.1 l_s$ or $0.1 b_s$ metres below.

l_s , b_s and GM are as given in Sec [3.3.6]

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

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

h_{fh} = maximum allowable filling height, in m.

H = tank height, in m, within $0.15 l_s$ or $0.15 b_s$

γ = angle between considered panel and the vertical.

3.3.8. Impact pressure head in lower part of smooth tanks

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

$$h_i = 1.42 \frac{\rho}{\rho_w} k l_s \sin^2 \delta \quad (\text{m}) \quad \text{on transverse bulkheads upto a height of } 0.2 l_s$$

$$h_i = 1.50 \frac{\rho}{\rho_w} b_s \sin^2 \delta \quad (\text{m}) \quad \text{on longitudinal bulkheads upto a height of } 0.2 b_s$$

The impact pressure head may be reduced to zero 1 meter above the heights given, Refer Fig.4.3.4.

The impact pressure head within $0.15 b_s$ in tank corners at outermost side of transverse bulkheads shall not be taken less than [h_i (longitudinally) + $0.4 h_i$ (transversely)]

If the tank is arranged with a horizontal stringer within the height $h_{fh} < 0.2 l_s$ or $h_{fh} < 0.2 b_s$, a reflected impact pressure head of the same magnitude as on adjacent transverse or longitudinal bulkhead shall be used on the underside of the stringer panel.

l_s and b_s are free sloshing length and breadth, in m, at height considered, as given in Sec 3.3.6.

$$k = 1 \quad \text{for } L < 200$$

$$= 1.4 - 0.002L \quad \text{for } L > 200$$

δ = angle between the lower boundary panel and the horizontal.

3.3.9. The sloshing and impact pressure heads given in Sec [3.3.6] and Sec [3.3.7] shall be multiplied by the below mentioned magnification factors for tanks with upper panels higher than $L/20$ m above lowest seagoing waterline:

$$\left(1 + 6 \frac{z_e}{L} \right) \quad \text{for longitudinal sloshing}$$

$$\left(1 + 7.5 \frac{z_e GM}{B^2} \right) \quad \text{for transverse sloshing}$$

$$\left(1 + 18 \frac{z_e}{L} \right) \quad \text{for longitudinal impact}$$

$$\left(1 + 17.5 \frac{z_e GM}{B^2} \right) \quad \text{for transverse impact}$$

$$z_e = \left(z_t - T_s - \frac{L}{20} \right) \quad (\text{m})$$

z_t = distance from baseline to panel considered, in m.

T_s = lowest seagoing draught, in m; $0.50 T_{ms}$ may normally be used.

- 3.3.10. The low filling impact pressure head as given in Sec [3.3.8] shall be multiplied by the below magnification factor for tanks with smooth boundaries (no internal structural members) with tank bottom higher than the D/2:

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

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

z_i = distance from panel considered to D/2, in m.

θ and Φ = pitch and roll angle as given in Ch 4 Sec 2 [2.4] and Ch 4 Sec 2 [2.3].

3.4. Design pressure heads for dry cargoes, stores, equipment and accommodation

- 3.4.1. The pressure head on inner bottom, decks or hatch covers shall be taken as:

$$h = \frac{\rho_c}{\rho_w} \left(1 + 0.5 \frac{a_{\text{vert}}}{g_0}\right) H_{\text{st}} \quad (\text{m})$$

a_{vert} = as given in Ch 4 Sec 2 [2.6]

H_{st} = stowage height, in m.

ρ_c = stowage rate of dry cargo, in t/m³

Standard values of ρ_c and H_{st} are given in Table 4.3.1.

If decks (excluding inner bottom) or hatch covers are designed for cargo loads heavier than the standard loads given in Table 4.3.1 the notation **DK (+)** or **HA (+)** respectively, will be assigned.

- 3.4.2. When the weather deck or weather deck hatch covers are designed to carry deck cargo the pressure head, in general, to be taken as the greater of h as specified in Sec [3.2.1] and Sec [3.4.1]. 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 4.3.1 Standard load parameters		
Decks	Parameters	
Sheltered deck, sheltered hatch covers and inner bottom for cargo or stores	ρ_c	H_{st}
	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_{st} shall be measured to the top of coaming.
	$\rho_c H_{\text{st}}$	
Weather deck and weather deck hatch covers intended for cargo	1.0 t/m ² for $L \leq 100$ 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 $100 \text{ m} < L < 150 \text{ m}$, the standard value of $\rho_c H_{\text{st}}$ 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
<p><i>Remarks:</i></p> <p>1) If $\sum \rho_c H_{st}$ for cargo spaces exceed the total cargo capacity of the vessel, ρ_c 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 $\rho_c H_{st}$ shall not be taken less than the combined load of deck mass and maximum allowable deck load.</p>	

- 3.4.3. The pressure head from bulk cargoes on sloping and vertical sides and bulkheads shall be taken as:

$$h = \frac{\rho_c}{\rho_w} \left(1 + 0.5 \frac{a_{vert}}{g_0} \right) K h_c \quad (m)$$

- 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_{vert} = as given in Ch 4 Sec 2 [2.6]
 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

3.5. Forces due to deck cargo units and deck equipment

- 3.5.1. 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:

$$P_V = (g_0 + 0.5 a_{vert}) M \quad (KN)$$
- vertical force in combination with transverse force:

$$P_{VC} = g_0 M \quad (KN)$$
- transverse force in combination with vertical force:

$$P_{TC} = 0.67 a_{trans} M \quad (KN)$$
- vertical force in combination with longitudinal force:

$$P_{VC} = (g_0 + 0.5 a_{vert}) M \quad (KN)$$

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:

$$P_{LC} = 0.67 a_{long} M \quad (KN)$$

- M = mass of unit in tonnes (t)
 a_{vert} = as given in Ch 4 Sec 2 [2.6]
 a_{trans} = as given in Ch 4 Sec 2 [2.7]
 a_{long} = as given in Ch 4 Sec 2 [2.8]

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

CHAPTER 5 LONGITUDINAL STRENGTH

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SECTION 1 GENERAL

Contents

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1.1. Introduction

- 1.1.1. The requirements regarding the longitudinal hull girder scantlings with respect to bending and shear are given in this chapter. Scantlings of hull members contributing to longitudinal strength are also to comply with the buckling requirements given in Ch 14 and of local strength given in relevant chapters in Part 3.
- 1.1.2. The wave bending moments and shear forces are given as the design values with a probability of exceedance of 10^{-8} . When determining the section modulus and the shear area of the hull girder and in connection with control of buckling and ultimate strength, these values are applied. When considering combined local and longitudinal stresses in local elements, reduced values will have to be used, Refer Ch 5 Sec 2 [2.2.5].
- 1.1.3. This section does not cover the buckling strength of longitudinal members. For such control, requirements are given in Ch 14.
- 1.1.4. For ships with small block coefficient, high speed and large flare, the hull girder buckling strength and section modulus in the forebody may have to be specially considered based on the distribution of still water and vertical wave bending moments indicated in Ch 5 Sec 2 [2.1] and Ch 5 Sec 2 [2.2] respectively. In particular, this applies to ships with length $L > 120$ m and speed $V > 17$ knots.
- 1.1.5. The combined effects of vertical and horizontal bending of the hull girder may have to be specially considered as indicated in Ch 5 Sec 3 [3.3] for narrow beam ships and for ships with openings in shipside / deck.
- 1.1.6. 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. 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.
- 1.1.7. In addition to the limitations given in Sec 1[1.1.4] to Sec [1.1.6], special considerations will be given to vessels with the following proportions:

$$\begin{aligned} L/B &\leq 5 \\ B/D &\geq 2.5 \end{aligned}$$

1.2. Definitions

1.2.1. Symbols:

For L , B , D , T_{ms} , C_B , Refer Ch 1 Sec 2 [2.1]

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_{WV} = wave coefficient as given in Ch 4 Sec 2

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 deck line to the neutral axis of the hull girder, whichever is relevant

z_a = vertical distance, in m, from the baseline or deck line to the point in question below or above the neutral axis, respectively

M_{ST} = design still water bending moment, in kN m, as given in Ch 5 Sec 2 [2.1]

Q_{ST} = design still water shear force, in kN, as given in Ch 5 Sec 2 [2.1]

M_{WV} = rule wave bending moment, in kN m, as given Ch 5 Sec 2 [2.2]

Q_{WV} = rule wave shear force, in kN, as given in Ch 5 Sec 2 [2.2]

M_{WH} = rule wave bending moment about the vertical axis as given in Ch 5 Sec 2 [2.2.6]

M_{WT} = rule wave torsional moment as given in Ch 5 Sec 2 [2.2.7].

1.2.2. Terms:

a) *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.

b) *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 center line
- the allowable local loadings for the structure (hatch covers, decks, double bottom, etc.)
- the relevant operational limitations

Remarks:

1) Permissible torsional still water moment limits are generally applicable for ships with large deck openings as given in Sec 1.1.6 and class notation **CONTAINER** or **Container Carrier**.

c) 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.

Remarks:

1) The term "Loading computer system" also covers the term "Loading instrument".

The loading instrument is ship specific onboard equipment and the results of the calculations are only applicable to the ship for which it has been approved.

An approved loading instrument cannot replace an approved loading manual.

Single point loading instruments are not acceptable.

For the loading instrument, an operation manual is always to be provided. The operation manual and the instrument output shall be prepared in a language understood by the users. If this language is not English, a translation into English shall be included.

The operation of the loading instrument shall be verified upon installation. It shall be documented that the agreed test conditions and the operation manual for the instrument is available onboard.

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.

SECTION 2 HULL GIRDER BENDING MOMENTS AND SHEAR FORCES

Contents

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2.1. Still water conditions

- 2.1.1. Design still water bending moments, M_{ST} , and still water shear force, Q_{ST} , shall be calculated along the ship length for design cargo and ballast loading conditions as mentioned in Sec [2.1.2].

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. Fig. 5.2.1 shows the sign conventions of M_{ST} and Q_{ST} .

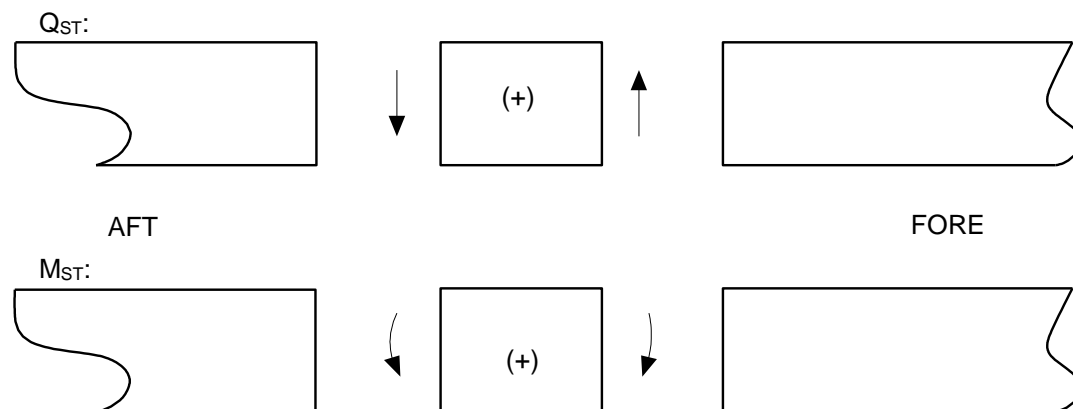


Figure 5.2.1 Sign conventions of M_{ST} and Q_{ST}

- 2.1.2. In general, the following design cargo and ballast loading conditions, based on the amounts of bunker, fresh water, stores etc. at departure and arrival, shall be considered for the calculations of M_{ST} and Q_{ST} . 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, the same shall be 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 shall be as specified in relevant chapters and sections.

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 relevant chapters and sections, 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
- harbor condition for which an increased vapor pressure has been approved
- docking condition afloat.

Combination carriers:

- conditions as specified for oil tankers and cargo ships
- in addition to the above, any other loading condition likely to result in high bending moments or shear forces may require to be investigated.

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 harbor conditions including loading and unloading transitory conditions shall be checked where applicable.

Remarks:

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.

- 2.1.3. The design conditions shall not include ballast loading conditions involving partially filled peak and /or other ballast tanks at departure, arrival or during intermediate conditions; unless:

- design stress limits are satisfied for all filling levels between empty and full and

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 Sec [2.1.2] 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, and full or partially filled at intended level for those tanks are to 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 centerline to the waterline
 D = propeller diameter.

Refer Fig.5.2.2.

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

2.1.4. In cargo loading conditions, the requirements given in Sec [2.1.3] applies to peak tanks only.

2.1.5. Requirements given in Sec [2.1.3] and Sec [2.1.4] are not applicable to ballast water exchange using the sequential method. However, the loading manual or ballast water management plan of any vessel that intends to employ the sequential ballast water exchange method shall contain bending moment and shear force calculations for each de-ballasting or ballasting stage in the ballast water exchange sequence.

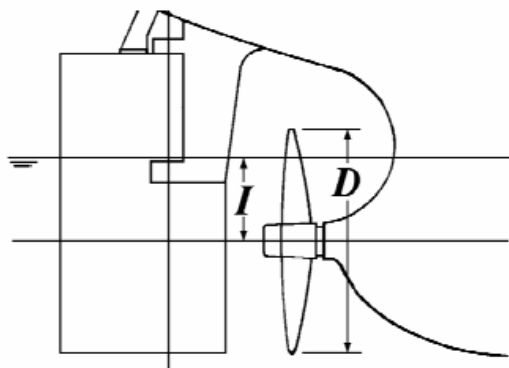


Figure 5.2.2 Definitions of I and D

2.1.6. Normally, the design still water bending moments within 0.4 L amidships (sagging and hogging) are not to be taken less than:

$$M_{ST} = M_{SO} \quad (\text{kN m})$$

$$M_{SO} = -0.065 C_{WU} L^2 B (C_B + 0.7) \quad (\text{kN m}) \text{ in sagging}$$

$$M_{SO} = C_{WU} L^2 B (0.1225 - 0.015 C_B) \quad (\text{kN m}) \text{ in hogging}$$

$C_{WU} = C_{WV}$ for unrestricted service

Outside 0.4 L amidships M_{SO} may be gradually decreased to zero at F.P. and A.P as specified in Sec [2.1.7]

The still water bending moments are normally taken as the design still water bending moments as mentioned above. They may, however, have to be calculated for ballast and particular non-homogeneous load conditions after special considerations. For each condition the calculations are to be based on relevant and realistic amounts of bunker, fresh water and stores at departure and arrival. Larger values of M_{SO} based on cargo and ballast conditions shall be applied when relevant, refer Sec [2.1.2].

If the calculated still water bending moment exceeds the design still water bending moment M_{SO} value as mentioned above, the calculated value is to be used in Sec 3.3.5 of this chapter.

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

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

$$M_{ST} = k_{sm} M_{SO} \quad (\text{kN m})$$

M_{SO} = still water bending moment amidships as given in Sec [2.1.6]
 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.

Values of k_{sm} shall be varied linearly between specified positions. k_{sm} may also be obtained from Figure 5.2.3.

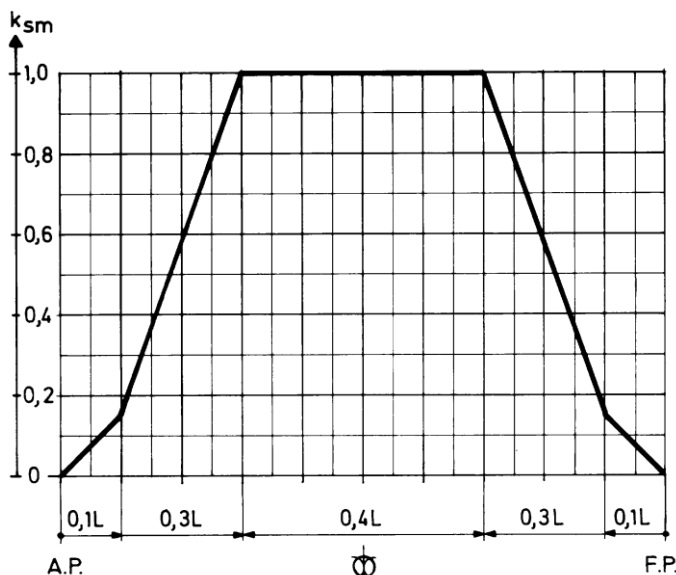


Figure 5.2.3 Still water bending moment

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

- 2.1.8. Design values of stillwater shear forces along the length of the ship are normally not to be taken less than:

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

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

M_{SO} = design still water bending moments (sagging or hogging) as given in Sec [2.1.6].

Larger values of Q_{ST} based on load conditions ($Q_{ST} = Q_{SL}$) shall be applied when relevant, refer Sec [2.1.2]. Q_{SO} may be dispensed with as design basis for ships with arrangement giving small possibilities for variation in the distribution of cargo and ballast.

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 as mentioned below:

- when sagging condition; positive in fore body, negative in after body
- when hogging condition; negative in fore body, positive in after body

2.2. Wave load conditions

2.2.1. The rule vertical wave bending moments amidships are given by:

$$M_{WV} = M_{WO} \quad (\text{kN m})$$

$$M_{WO} = -0.11 \alpha C_{WV} L^2 B (C_B + 0.7) \quad (\text{kN m}) \text{ in sagging}$$

$$M_{WO} = 0.19 \alpha C_{WV} L^2 B C_B \quad (\text{kN m}) \text{ in hogging}$$

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

C_B is not to be taken less than 0.6.

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

$$M_{WV} = k_{wm} M_{WO} \quad (\text{kN m})$$

M_{WO} = as given in Sec 2.2.1
 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 fore body the adjustments to k_{wm} as given in Table 5.2.1, limited to the control for buckling as given in Ch 14, apply.

Table 5.2.1 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 Adjustment	1.2 between 0.48L and 0.65L from A.P. 0.0 at FP and A.P	No adjustment	1.2 between 0.48L and 0.65L from A.P. 0.0 at FP and A.P
<i>Remarks:</i> 1) Adjustment for C_{AV} not to be applied when $C_{AF} \geq 0.50$				

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

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

$$c_v = \frac{\sqrt{L}}{50}, \text{ maximum } 0.2$$

A_{WP} = area of water plane forward of 0.2 L from F.P. at draught T_{ms}

A_{DK} = projected area in horizontal plane of deck (including forecastle deck) forward of 0.2L from FP

z_f = vertical distance from summer load waterline to deck line 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.5.2.4.

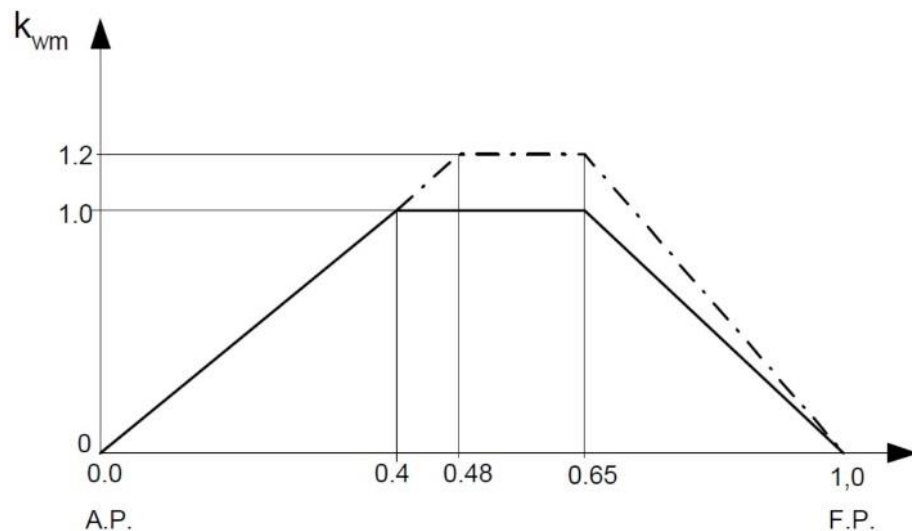


Figure 5.2.4 Wave bending moment distribution

2.2.3. 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:

$$Q_{WVP} = 0.3 \beta k_{wqp} C_{WV} L B (C_B + 0.7) \quad (\text{kN})$$

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

$$Q_{WVN} = -0.3 \beta k_{wqn} C_{WV} L B (C_B + 0.7) \quad (\text{kN})$$

Positive shear force when there is a surplus of buoyancy forward of section considered, Refer also Fig.5.2.1.

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

- β = 1.0 for seagoing conditions
= 0.5 for harbor 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 AP
- 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_{WV} = wave coefficient as mentioned in Ch 5 Sec 1 [1.2.1]

The adjustments given in Table 5.2.2 shall be applied for ships with high speed and or large flare in the fore body.

Table 5.2.1 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.
Remarks: 1) Adjustment for C_{AV} not to be applied when $C_{AF} \geq 0.50$				

C_{AV} as defined in Sec [2.2.2]

C_{AF} as defined in Sec [2.2.2]

Between specified positions k_{wq} can be varied linearly. Values of k_{wq} may also be obtained from Fig. 5.2.5

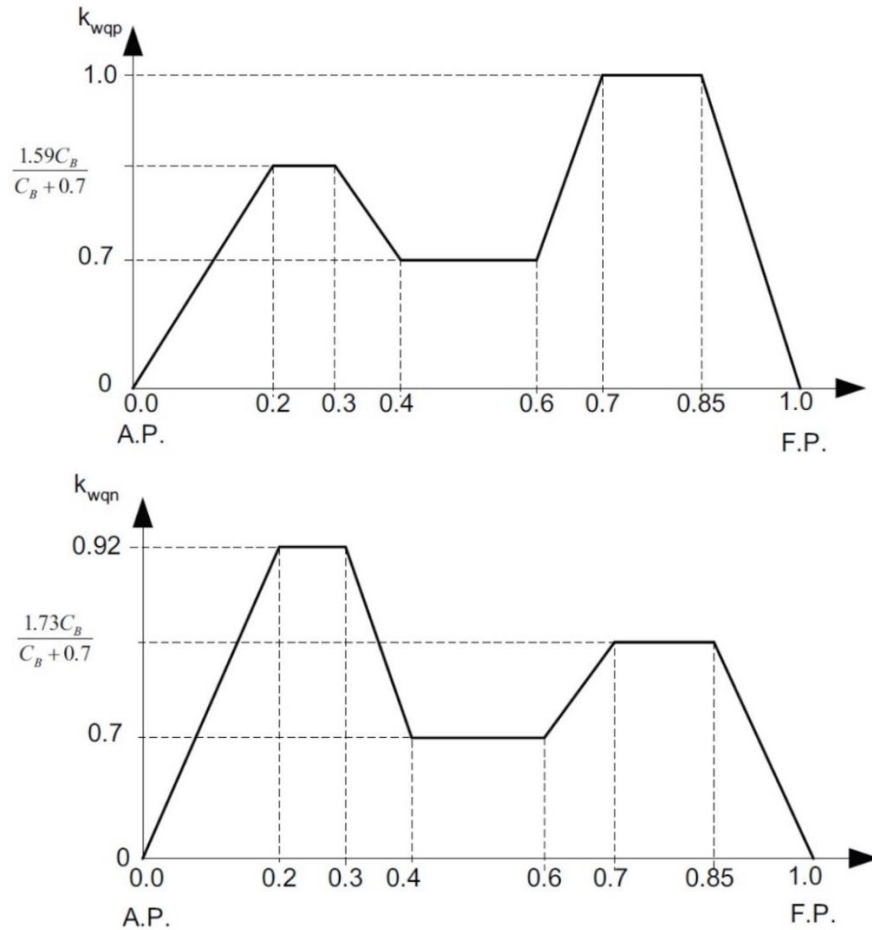


Figure 5.2.5 Wave shear force distribution

- 2.2.4. For ships with service restrictions, refer Ch 4 Sec 2 [2.2.2] for the applicable reductions to C_{WV} used in the formulations for determining rule vertical wave bending moments and wave shear forces as specified in Sec [2.2.1] and Sec [2.2.3] respectively.
- 2.2.5. When hull girder stresses due to wave loads are combined with local stresses in girder systems, stiffeners and plating, in accordance with Ch 13, reduction in the wave bending moments and shear forces may be done as follows:

$$M_{WVR} = 0.59 M_{WV}$$

$$Q_{WVR} = 0.59 Q_{WV}$$

- 2.2.6. The rule horizontal wave bending moments along the length of the ship are given by:

$$M_{WH} = 0.22 L^{\frac{9}{4}} (T_{ms} + 0.3 B) C_B \left(1 - \cos\left(\frac{360 x}{L}\right) \right) \quad (\text{kN m})$$

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

- 2.2.7. 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:

$$M_{WT} = 1.40 L^{\frac{5}{4}} (T_{ms} + 0.3 B) C_B z_e \sin\left(\frac{360 x}{L}\right) \pm 0.13 L^{\frac{4}{3}} B^2 \frac{A_{WP}}{L B} \left(1 - \cos\left(\frac{360 x}{L}\right)\right) \text{ (kN m)}$$

A_{WP} = water plane area of vessel, in m^2 , at draught T_{ms}
 z_e = distance, in m, from the shear center of the midship section to a level 0.7 T_{ms} above the base line
 x = distance, in m, from A.P. to section considered.

SECTION 3 HULL GIRDER BENDING STRENGTH AND STIFFNESS**Contents**

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3.1. Midship section particulars

- 3.1.1. When calculating the moment of inertia and section moduli, the effective sectional area of continuous longitudinal strength members is in general the net area after deduction for openings as given in Sec 5.

Superstructures which do not form a strength deck, deckhouses, bulwarks and non-continuous longitudinal hatch coamings are not to be included in the net sectional area.

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

- 3.1.2. Generally, the rule section modulus refers to the baseline and the deck line.

- 3.1.3. 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. Calculation of the deck modulus is then done by dividing the moment of inertia by the following distance, provided this is greater than the distance to the deck line at side:

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

y_a = horizontal distance, in m, from the top of the continuous strength member to the ship's center line.

z_a = vertical distance, in m, from the neutral axis to the top of the continuous strength member

z_n = vertical distance, in m, from the neutral axis to the moulded deck line at side.

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

- 3.1.4. 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.
- 3.1.5. Longitudinal bulkheads shall terminate at an effective transverse bulkhead, and large transition brackets shall be fitted in line with the longitudinal bulkheads.
- 3.1.6. If openings are arranged in the ship sides, the shearing area of the remaining side plating is to be specially considered.
- 3.1.7. At ends of effective continuous longitudinal strength members in deck and bottom region large transition brackets are to be fitted.

3.2. Extent of high strength steel (HT-steel)

- 3.2.1. The vertical extent of HT-steel in m, if used, in deck or bottom shall not be less than:

$$z_{hs} = z_n \frac{f_2 - \left(\frac{1}{f_3} \right)}{f_2}$$

f_2 = stress factor, for the bottom structure given in Ch 6 and for the deck in Ch 8

f_3 = material factor (general symbol k_m) for the members located more than z_{hs} from deck or bottom, Refer Fig.5.3.1.

z_n = as defined in Sec [3.1.3]

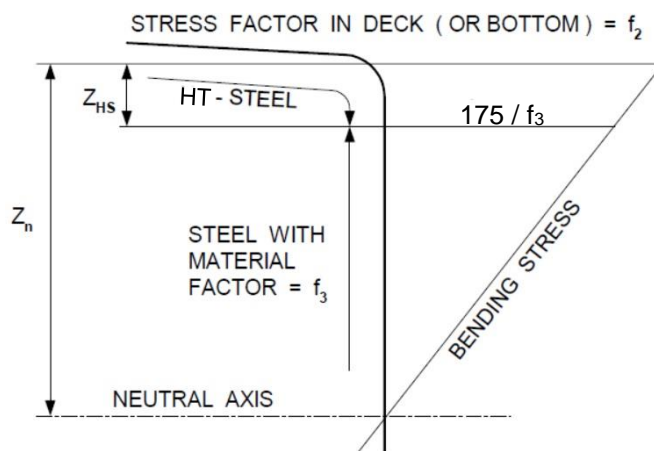


Figure 5.3.1 Vertical extent of HT-steel

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

- 3.2.2. The longitudinal extent of HT-steel, if used, in deck or bottom shall not be less than x_{hs} as indicated in Figure 5.3.2.

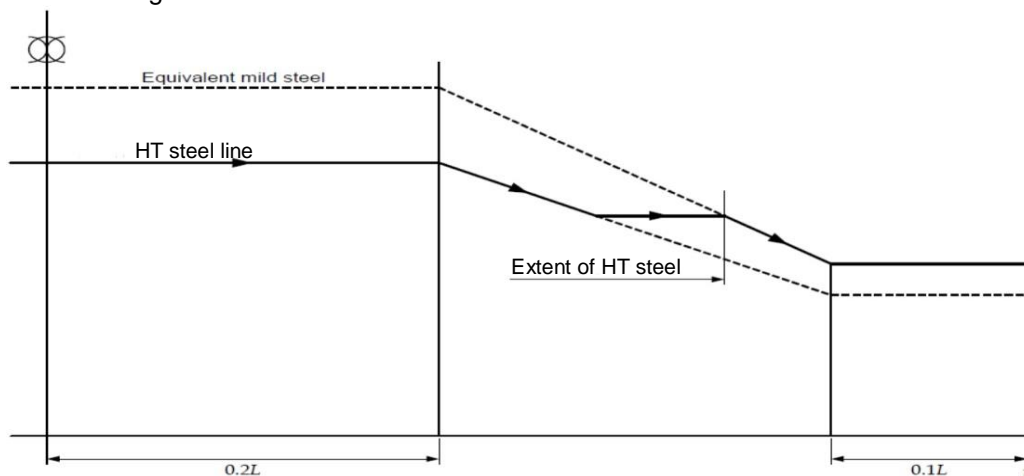


Figure 5.3.2 Longitudinal extent of HT-steel

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 HT-steel was used over the full length. Where material strength group changes, however, continuity in scantlings shall be maintained.

3.3. Section modulus

- 3.3.1. The requirements specified in Sec [3.3.2] are applicable to all ships irrespective of length. Requirements specified in Sec [3.3.3] to Sec [3.3.8] are typically applicable for ships with length greater than 100 m. For ships with length less than 100 m, the requirements specified in Sec [3.3.9] to Sec [3.3.13] are to be normally used. The requirements specified in Sec [3.3.3] to Sec [3.3.4] and Sec [3.3.7] to Sec [3.3.8] may be applied to ships with length less than 100 m where deemed necessary based on vessel's structural arrangement, operational profile and loading conditions.

- 3.3.2. The requirements given in Sec [3.3.3] and Sec [3.3.6] 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, Refer Ch 5 Sec 1[1.1.6]. In particular this applies to ships of length $L > 120$ m and speed $V > 17$ knots.

- 3.3.3. 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.
-

- 3.3.4. Buckling strength of members contributing to the longitudinal strength and subjected to compressive and shear stresses is to be checked in accordance with Ch 14. Buckling strength

evaluation of members shall also be performed, in particular, in regions where changes in the framing system or significant changes in the hull cross-section occur.

Maintenance of the continuity of structure throughout the length of the ship is required. Adequate transitional structure is to be provided where significant changes in structural arrangement occur.

For ships with large deck openings such as container ships, 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.

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

$$Z_O = \frac{|M_{ST} + M_{WV}|}{\sigma_L} 10^3 \quad (\text{cm}^3)$$

$$\begin{aligned} \sigma_L &= 175 / k_m \text{ N/mm}^2 \text{ within } 0.4 L \text{ amidship} \\ &= 125 / k_m \text{ N/mm}^2 \text{ within } 0.1 L \text{ from A.P. or F.P.} \end{aligned}$$

Between specified positions σ_L shall be varied linearly.

- 3.3.6. In addition to the section modulus requirements specified in Sec [3.3.5], the midship section modulus about the transverse neutral axis shall not be less than:

$$Z_O = k_m C_{WVO} L^2 B (C_B + 0.7) \quad (\text{cm}^3)$$

C_B , in this case is not to be taken less than 0.6

$$\begin{aligned}
 C_{WVO} &= 10.75 - \left[\frac{(300 - L)}{100} \right]^{\frac{3}{2}} && \text{for } 100 \leq L < 300 \\
 &= 10.75 && \text{for } 300 \leq L \leq 350 \\
 &= 10.75 - \left[\frac{(L - 350)}{150} \right]^{\frac{3}{2}} && \text{for } L > 350
 \end{aligned}$$

For ships with restricted service, C_{WVO} 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 **RC**: 25%

- 3.3.7. The midship section modulus about the vertical neutral axis (center line) is normally not to be less than:

$$Z_{OH} = 5 k_m L^{\frac{9}{4}} (T_{ms} + 0.3B) C_B \quad (\text{cm}^3)$$

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 $195/k_m \text{ N/mm}^2$.

The combined effect may be taken as:

$$\sigma_{ms} + \sqrt{\sigma_{mw}^2 + \sigma_{wh}^2}$$

σ_{ms} = stress due to M_{ST}

σ_{mw} = stress due to M_{WV}

σ_{wh} = stress due to M_{WH} , the horizontal wave bending moment as given in Ch 5 Sec 2 [2.2.6]

- 3.3.8. 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

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

- For scallops in bottom

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

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

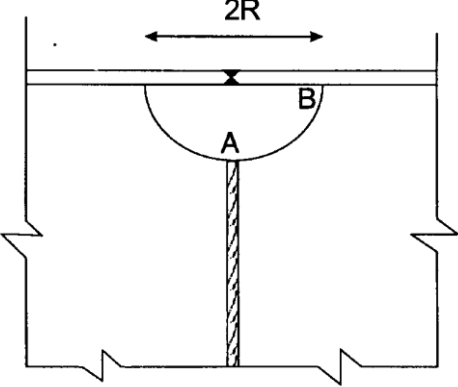
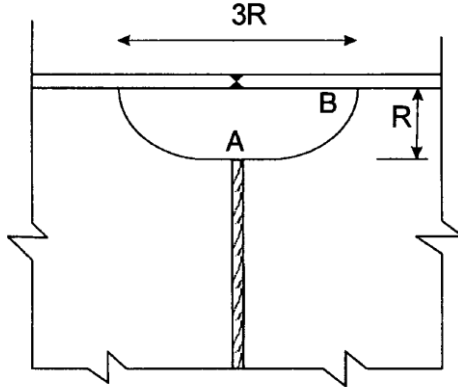
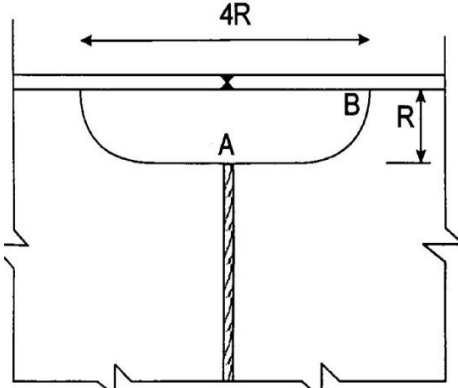
Z_{deck} = midship section modulus in cm^3 at deck as built

Z_{bottom} = midship section modulus in cm^3 at bottom as built

$M_{WV,hog}$ = the rule vertical wave hogging bending moment amidships, as defined in Ch 5 Sec 2 [2.2.1]

$M_{WV,sag}$ = the rule vertical wave sagging bending moment amidships, as in defined in Ch 5 Sec 2 [2.2.1]

Stress concentration factors for scallops are given in Table 5.3.1.

Table 5.3.1 Stress concentration factors K_{ga} for scallops		
Structure	Point A	Point B
	1.67	1.2
	1.13	1.2
	1.07	1.2
<p><i>Remarks:</i> For scallops without transverse welds, the K- factor at B will be governing for the design</p>		

- 3.3.9. The section modulus requirements within 0.4 L amidships about the transverse neutral axis based on cargo and ballast conditions for ships with length less than 100 m are given by:

$$Z_0 = \frac{k_m |M_{ST} + M_{WV}|}{175} 10^3 \quad (\text{cm}^3)$$

- 3.3.10. When still water bending moments calculated for harbor and sheltered water conditions (enclosed fjords, lakes, rivers) are inserted in the formula in Sec 3.3.9, the unrestricted service wave bending moments (calculated using $\alpha = 1$ as per Ch 5 Sec 2 [2.2.1]) may be reduced by 30%.

- 3.3.11. The buckling strength of longitudinally compressed structures is to be checked according to Ch 14.

- 3.3.12. In addition to the section modulus requirements specified in Sec [3.3.9], the midship section modulus about the transverse neutral axis for ships with length less than 100 m is not to be less than:

$$Z_0 = k_m C_{WVO} L^2 B (C_B + 0.7) \quad (\text{cm}^3)$$

C_B , in this case is not to be taken less than 0.5

$$C_{WVO} = 5.7 + 0.022 L, \quad \text{minimum } 7.0$$

For ships with restricted service, C_{WVO} may be reduced as specified in Sec [3.3.6]

- 3.3.13. As a basis for the section modulus calculation, the following sectional area of the deck may give an approximate section modulus:

$$A = \frac{0.11 L^2 B}{D} \quad (\text{cm}^2)$$

A = total sectional area of deck plating including deck longitudinals outside line of hatches, and the sheer strake plating, the width of which being limited to the Rule value.

3.4. Moment of inertia

- 3.4.1. The midship section moment of inertia about the transverse neutral axis shall not be less than:

$$I = 3 C_{WV} L^3 B (C_B + 0.7) \quad (\text{cm}^4)$$

Minimum values of C_B are to be taken as specified in Sec [3.3.6] and Sec [3.3.12], as applicable.

SECTION 4 SHEAR STRENGTH

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4.1. General

- 4.1.1. This section is to be normally applied to ships with length equal to or greater than 100 m. However, the procedures and requirements specified in this section may be applied to ships with length less than 100 m also if the shear strength verification is deemed necessary based on the ship's structural arrangement and provided scantlings, operational profile and cargo and ballast loading patterns and conditions etc.
- 4.1.2. The shear stress in ship's sides and longitudinal bulkheads shall not exceed $110 / k_m$ N/mm². Additionally, the plate panels shall be checked for adequate shear and combined buckling strength as stated in Ch 14 Sec 2 [2.3] and Ch 14 Sec 2 [2.5].
- 4.1.3. 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.
- 4.1.4. The thickness requirements for side shell (or combined thickness of inner and outer shell, for ships with double skin construction) and possible longitudinal bulkhead are given by:

$$t = \frac{|\Phi (Q_{ST} + Q_{WV} \pm 0.5 \Delta Q_S)|}{\tau} \frac{S_N}{I_N} 10^2 \quad (\text{mm})$$

Φ = shear force distribution factor as given in Table 5.4.1

For the arrangements shown in Table 5.4.1 and for other arrangements Φ may be taken from a direct shear flow calculation.

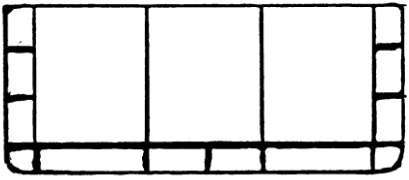
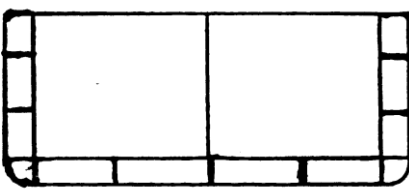
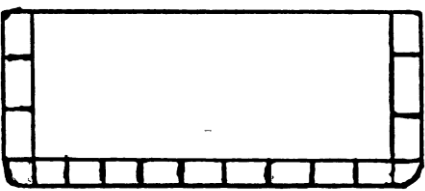
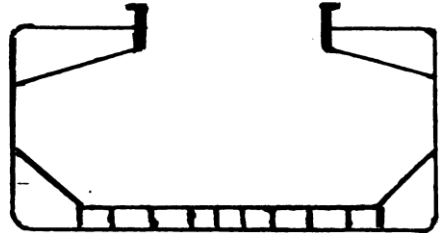
ΔQ_S = shear force correction due to shear carrying longitudinal bottom members (girders or stiffeners) and uneven transverse load distribution
 = 0 when $Q_{ST} = k_{sq} Q_{SO}$ as given in Ch 5 Sec 2 [2.1.8]
 = ΔQ_{SL} when $Q_{ST} = Q_{SL}$, i.e. based on cargo and ballast conditions

ΔQ_{SL} is given in 4.3 for ships with two longitudinal bulkheads
 ΔQ_{SL} is given in 4.4 for ships with center line longitudinal bulkhead.
 ΔQ_{SL} is given in 4.4 for ships without longitudinal bulkhead
 ΔQ_{SL} is given in 4.2 for bulk and ore-bulk-ore (OBO) carriers

For other arrangements ΔQ_S will be specially considered.

τ = $110 / k_m$ N/mm², provided the buckling strength Refer Sec [4.1.2] above does not require smaller allowable stress.

I_N / S_N may normally be taken as 90 D at the neutral axis.

Table 5.4.1 Shear force distribution factor.	
	$\Phi_S = 0.109 + 0.0911 \frac{A_S}{A_L}$ $\Phi_L = 0.391 - 0.0911 \frac{A_S}{A_L}$
	$\Phi_S = 0.338 + 0.0167 \frac{A_S}{A_C}$ $\Phi_C = 0.324 - 0.0334 \frac{A_S}{A_C}$
	$\Phi_S = 0.50$
	$\Phi_S = 0.50$

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 center 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. Projected length and expanded length of the corrugations are to be related to the reduction of area of the corrugated bulkhead.

- 4.1.5. 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.

The shear force determining scantlings will be specially considered for ships where fore peak and any deep tank is not intended to carry ballast when the ship is in light ballast condition.

4.2. Ships with single or double skin and without other effective longitudinal bulkheads

- 4.2.1. The thickness of side shell shall not be less than given by the formula in Sec [4.1.4]. When $Q_{ST} = Q_{SL}$, 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 tonnes (t), for the hold in question
 P_N = bunker or ballast, in tonnes (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
 $K_N = \frac{V_H A_N'}{H_h A_N A_B'}$ to be calculated for each filled tank
 H_h = height of hold, in m
 V_H = volume of hold, in m³
 A_N = horizontal cross-sectional area (m²) (port and starboard) at level of inner bottom tank no. N
 A_N' = horizontal cross-sectional area (m²) (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 ΔQ -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 Figure 5.4.1. 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:

$$C_P = \frac{9.81 C B_{DB} L_H H_h}{V_H} \quad (\text{kN/t})$$

$$C_D = 10 C B_{DB} L_H \quad (\text{kN/m})$$

$$C = \frac{B}{2.2 (B + L_H)} \quad (\text{for conventional designs})$$

- B_{DB} = breadth of the flat part of the double bottom, in m
 L_H = length of hold, in m.

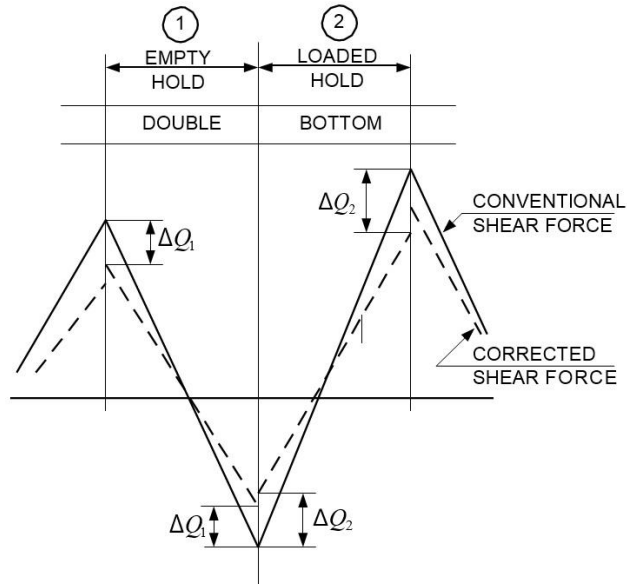


Figure 5.4.1 Shear force correction

- 4.2.2. For shell plates completely within a top wing tank or a hopper tank, the thickness requirements calculated from the formula in Sec [4.1.4] may be divided by 1.2.

4.3. Ships with two effective longitudinal bulkheads

- 4.3.1. 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:

$$\sum t = 2.7 k_m (L B)^{\frac{1}{3}} + \sum t_c \quad (\text{mm})$$

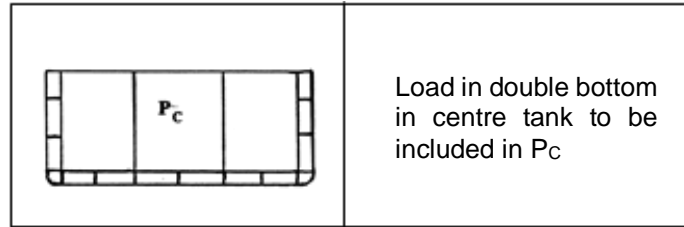
of which the thickness of each longitudinal bulkhead at 0.5 D shall not be less than:

$$t = 0.6 k_m (L B)^{\frac{1}{3}} + t_c \quad (\text{mm})$$

The thickness of the longitudinal bulkhead plating may be linearly reduced to 90% at deck, above 0.5 D.

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 Sec [4.1.5] at fore end of machinery spaces and after end of fore peak or adjacent deep tank.

- 4.3.2. The thickness of the double side and the longitudinal bulkhead shall not be less than given by the formula in Sec [4.1.4]. Above 0.5 D the thickness of the plating may be linearly reduced to 90% at deck.



When $Q_{ST} = Q_{SL}$ the shear force correction due to load distribution is given by:

- For the double side

$$\Delta Q_{SL} = 0.5 P_c \left[\left(1 - \frac{s_{ft}}{l_c} \right) (1 - C_T) \left(\frac{r}{r+1} \right) - 2 \Phi_S \right] \quad (\text{kN})$$

- For the longitudinal bulkhead

$$\Delta Q_{SL} = 0.5 P_c \left[\left(1 - \frac{s_{ft}}{l_c} \right) \frac{(1 - C_T)}{r+1} - 2 \Phi_L \right] \quad (\text{kN})$$

C_T = fraction of the center 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 center 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 oil-tight transverse bulkheads in the center tank

l = distance, in m, between oil-tight transverse bulkheads in the side tank

s_{ft} = distance, in m, between floors in the center tank

NL = number of longitudinal girders in center tank

NB = number of transverse floors in center tank

Φ_S = as given in Sec [4.1.4]

Φ_L = as given in Sec [4.1.4]

r is defined as 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:

$$r = \frac{1}{\frac{A_L}{A_S} + \frac{2 (N_S + 1) b_m A_L}{l (N_S A_T + R)}}$$

b_m = 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 .

A_L = as given in Sec 4.1.4

A_S = as given in Sec 4.1.4

The total efficiency of the girder frames in the side tank is denoted by R , which is given by the formula:

$$R = \left(\frac{n_{grf}}{2} - 1 \right) \frac{A_R}{\gamma} \quad (\text{cm}^2)$$

- n_{grf} = 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
 $\gamma = 1 + \frac{300 b^2 A_R}{I_R}$
 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 center tank. For the longitudinal bulkheads, this relation is indicated in Table 5.4.2.

Table 5.4.2 Shear force correction for longitudinal bulkhead		
<i>The ship has over the length:</i>	<i>The center tank has over the length:</i>	<i>Inclination of the shear force curve:</i>
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

The change in inclination for the side shell is contrary to that given in Table 5.4.2.

The shear force curve is supposed to remain unchanged at the middle point of l .

Plus sign shall be used if the turning of the shear force curve leads to an increased shear force, otherwise minus sign. Shown in Figure 5.4.2 is an example, where the slope increases for the longitudinal bulkhead and decreases for the side shell.

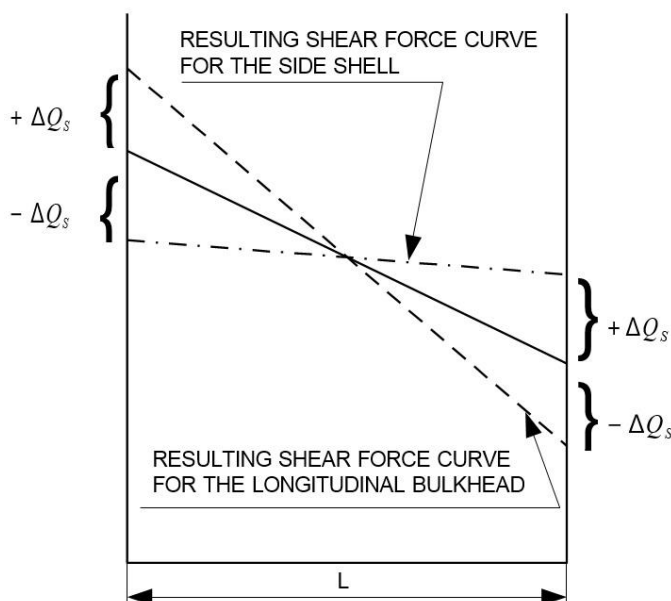


Figure 5.4.2 Shear force correction

4.4. Ships with number of effective longitudinal bulkheads different from two

- 4.4.1. The sum of thicknesses at 0.5 D of ship's sides and longitudinal bulkhead(s) shall not be less than:

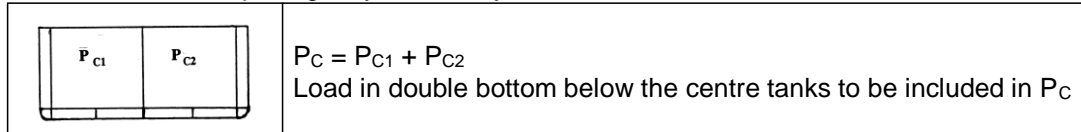
$$\sum t = 2.6 k_m (L B)^{\frac{1}{3}} + (0.8 + 0.1n_{bhl}) + \sum t_c \quad (\text{mm})$$

n_{bhl} = 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 Sec [4.1.4] at fore end of machinery spaces and after end of fore peak or adjacent deep tank.

- 4.4.2. For ships with double sides and a center line bulkhead, the thickness of center line bulkhead and the double side shall not be less than given by the formula in Sec [4.1.4]. Above 0.5 D the thickness of the plating may be linearly reduced to 90% at deck.



When $Q_{ST} = Q_{SL}$, the shear force correction due to load distribution is given by:

- For the double side:

$$\Delta Q_{SL} = P_C \left(0.3 \left(1 - \frac{s_{ft}}{l_c} \right) (1 - C_T) - \Phi_S \right) \quad (\text{kN})$$

- For the center line bulkhead

$$\Delta Q_{SL} = P_C \left(0.4 \left(1 - \frac{s_{ft}}{l_c} \right) (1 - C_T) - \Phi_C \right) \quad (\text{kN})$$

P_C = resulting force, in kN, due to difference between tank contents and buoyancy along the center tank length l_c . P_C is always to be taken positive. Calculation of the term P_C shall be done specially for each part loading when the loading P_C is variable along the length.

C_T = fraction of the center 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 oil-tight transverse bulkheads in the center tank

s_{ft} = distance, in m, between floors in the center tank

NL = number of longitudinal girders in one center tank

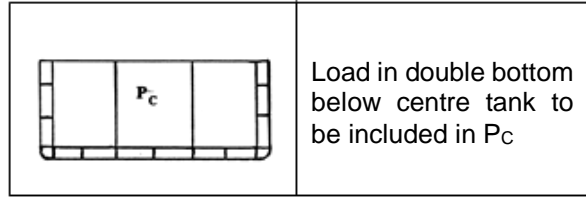
NB = number of transverse floors in the center tank

Φ_S = as given in Sec [4.1.4]

Φ_C = as given in Sec [4.1.4]

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 positive value or a negative value. A positive 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.

- 4.4.3. 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 Sec [4.1.4]. Above 0.5 D the thickness of the double side plating may be linearly reduced to 90% at deck.



When $Q_{ST} = Q_{SL}$, 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 center tank length l_c . P_C is always to be taken positive. Calculation of the term P_C shall be done specially for each part loading, when the loading P_C is variable along the length.
- C_T = fraction of the center 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 oil-tight transverse bulkheads in the center tank
- s_{ft} = distance, in m, between floors in the center tank.

The shear force correction ΔQ_S for the ship side may be taken according to the principles outlined in Fig.5.4.1, always giving a decreased inclination of the shear force curve.

4.5. Strengthening in way of transverse stringers

- 4.5.1. The local thickness of ship's sides and longitudinal bulkheads supporting stringers on transverse bulkheads shall not be less than:

$$t = \frac{k_m P_{STR}}{240 b_{str}} + 0.75 t_r \quad (\text{mm})$$

- P_{STR} = stringer supporting force, in kN, based on design loads in accordance with Ch 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 Sec [4.1.4], with full value of Q_{WV}

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.

SECTION 5 OPENINGS IN LONGITUDINAL STRENGTH MEMBERS**Contents**

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5.1. Positions

- 5.1.1. Normally the keel plate is not to have openings. Openings shall be avoided in the bilge plate, as far as practicable, within 0.6 L amidships. Any necessary openings in the bilge plate shall be kept clear of the bilge keel.
- 5.1.2. 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.
- 5.1.3. Openings in side shell, longitudinal bulkheads and longitudinal girders are not to be located than twice the opening breadth below strength deck or termination of rounded deck corner.
- 5.1.4. Generally, small openings are 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.

5.2. Deduction-free openings

- 5.2.1. 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 when calculating the midship section modulus.
- 5.2.2. Deduction of the smaller openings (manholes, lightening holes, single scallops in way of seams etc.) need not be done 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.
- 5.2.3. A deduction-free sum of smaller openings breadths in one transverse section in the bottom or deck area equal to

$$0.06 \left(B - \sum b \right)$$

may be considered equivalent to the above reduction in section modulus.

B = breadth of ship
 $\sum b$ = sum of breadths of large openings.

- 5.2.4. When calculating deduction-free openings, the openings are assumed to have longitudinal extensions as shown by the shaded areas in Fig.5.5.1, i.e. inside tangents at an angle of 30° to each other.

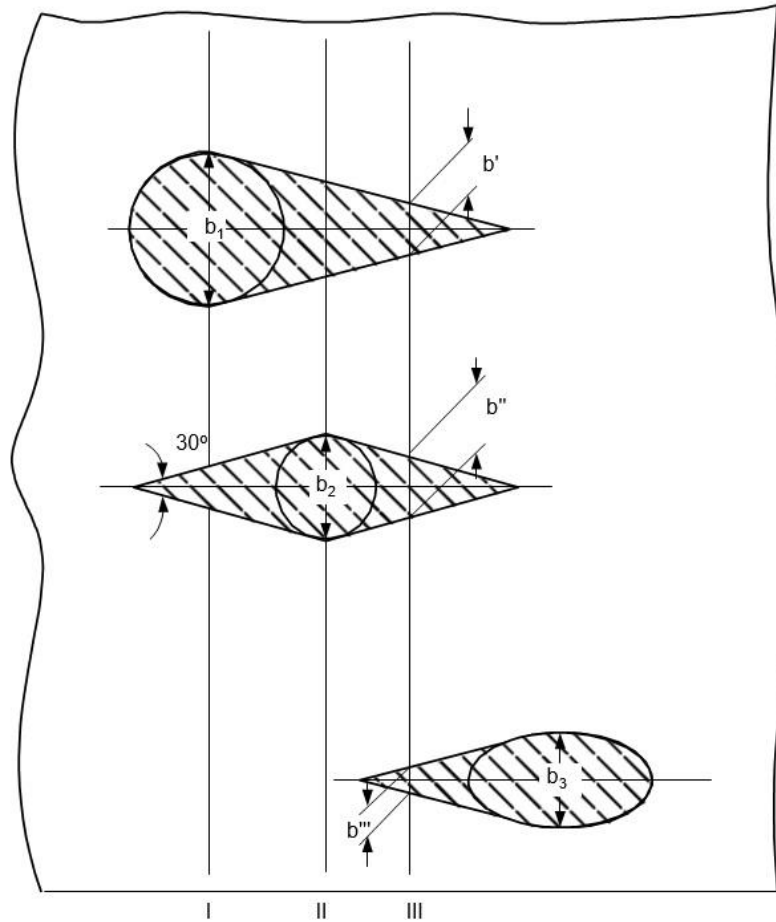


Figure 5.5.1 Deduction-free openings

Example for transverse section III:

$$\sum b_{III} = b^I + b^{II} + b^{III}$$

- 5.2.5. It is assumed that the deduction-free openings are arranged approximately symmetric about the ship's center line, and that the openings do not cut any longitudinal or girder included in the midship section area. Normally, openings in longitudinals are 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.

5.3. Compensations

- 5.3.1. Compensation for not considering 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 Sec 5.4 shall not be included in the sectional area of the compensation.

5.4. Reinforcement and shape of smaller openings

- 5.4.1. Circular openings with diameter equal to or greater than 0.325 m shall have edge reinforcement in strength deck and outer bottom within 0.6 L amidships (for «open» ships within the total cargo hold region). The cross-sectional area of edge reinforcements shall not be less than:

$$2.5 d_{op} t_{pl} \quad (\text{cm}^2)$$

d_{op} = diameter of opening, in m

t_{pl} = plating thickness, in mm.

- 5.4.2. Normally the reinforcement is to be a vertical ring welded to the plate edge. Acceptance of the alternative arrangements may be done but the distance from plating edge to reinforcement is in no case to exceed $0.05 d_{op}$.
- 5.4.3. In areas specified in Sec [5.4.1], 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 Sec 5.4.1 for circular openings, taking d_{op} as the breadth of the opening.
- 5.4.4. In areas specified in Sec [5.4.1], 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:

$$R = 0.2 b_{op}$$

b_{op} = breadth of opening.

The edges of such rectangular openings shall be reinforced as required in Sec [5.4.1].

For corners of streamlined shape, as given by Fig.5.5.2 and Table 5.5.1, the transverse extension of the curvature shall not be less than:

$$a = 0.15 b_{op} \quad (\text{m})$$

Edge reinforcement will then generally not be required. For large hatch openings, Refer Sec 5.5.

- 5.4.5. Openings in side shell in areas subjected to large shear stresses shall be of circular shape and shall have edge reinforcement as given in Sec [5.4.1] irrespective of size of opening.

5.5. Hatchway corners

- 5.5.1. For corners with rounded shape, the radius is within 0.6 L amidships generally not to be less than:

$$r = 0.03 \left(1.5 + \frac{l}{b_{hw}} \right) (B - b_{hw}) \quad (\text{m})$$

b_{hw} = breadth of hatchway, in m

l / b_{hw} = longitudinal distance, in m, between adjacent hatchways.

l / b_{hw} need not be taken greater than 1.0.

$(B - b_{hw})$ 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, refer Ch 8 Sec 1 [1.4.5].

Further reduction in radius will be considered when a corner with double curvature is adopted.

For corners of streamlined shape, as given by Fig.5.5.2 and Table 5.5.1, the transverse extension of the curvature shall not be less than:

$$a = 0.025 \left(1.5 + \frac{l}{b_{hw}} \right) (B - b_{hw}) \quad (m)$$

- 5.5.2. Alternative hatch corner designs (e.g. key hole) may be accepted subject to special consideration in each case.
- 5.5.3. For ships with length less than 100 m, openings in strength deck are to have corners with rounded or stream lined shape. For corners with rounded shape the radius is not to be less than:

$$r = 0.025 B \quad (m)$$

r need not be taken greater than 0.1 b (m) where b = breadth of opening in m. For local reinforcement of deck plating at circular corners, refer Ch 8 Sec 1 [1.4.5].

- 5.5.4. For ships with length less than 100 m, If the corners are given a streamlined shape according to Fig.5.5.2 and Table 5.5.1 with the ordinate a equal to r given in Sec 5.5.3, the deck plating need not be reinforced.
- 5.5.5. For ships with length less than 100 m, for very long hatches or if large cut-outs are taken at deck / shipside, corners of streamlined shape may be required. Reinforcement of the deck plating may also be considered.
- 5.5.6. For ships with length less than 100 m, alternative hatch corner designs (e.g. key hole) may be accepted subject to special consideration in each case.

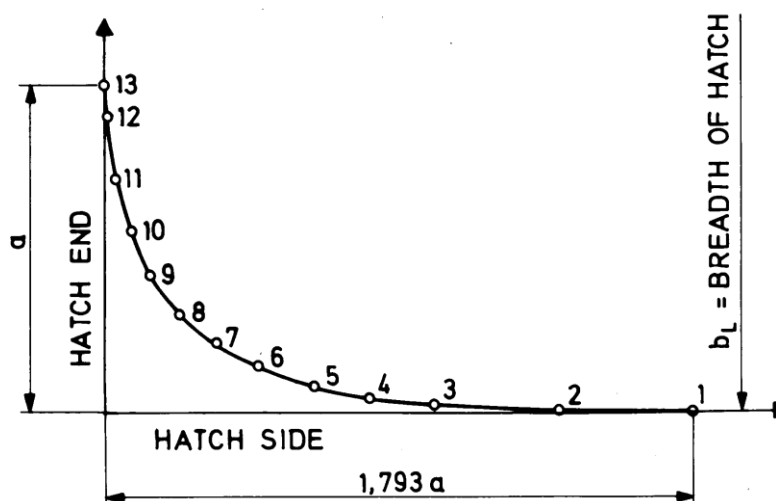


Fig 5.5.2 Streamlined deck corner

Table 5.5.1 Ordinates of streamlined corner		
<i>Point</i>	<i>Abscissa x</i>	<i>Ordinate Y</i>
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

5.6. Miscellaneous

- 5.6.1. 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.
- 5.6.2. Studs for securing small hatch covers are to 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.
- 5.6.3. Special considerations shall be given for the design of the hatch corners 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.

SECTION 6 LOADING GUIDANCE INFORMATION**Contents**

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6.1. General

- 6.1.1. 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 section 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 (Refer Ch 5 Sec 1 [1.2.2] for definition of category II ship) with length less than 90 m where the maximum deadweight does not exceed 30% of the maximum displacement.

- 6.1.2. If a loading computer system is installed onboard a ship, the system shall be approved in accordance with the relevant requirements stipulated by IACS UR L5, IACS UR S1 or S1A and IACS Recommendation No.48.
- 6.1.3. All ships of category I (Refer Ch 5 Sec 1 [1.2.2] for definition of category I ship) 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 relevant requirements given in IACS UR L5, IACS UR S1 or S1A and IACS Recommendation No.48.

6.2. Conditions of approval of loading manuals

- 6.2.1. The approved loading manual shall be based on the final data of the ship.
- 6.2.2. Modifications resulting in changes to the main data of the ship (e.g. lightship weight, buoyancy distribution, tank volumes or usage, etc.), require the loading manual to be updated and re-approved, and subsequently the loading computer system to be updated and re-approved. However, new loading guidance and an updated loading manual is not required to be resubmitted, provided that the resulting draughts, still water bending moments and shear forces do not differ from the originally approved data by more than 2%.
- 6.2.3. 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.
- 6.2.4. 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, Refer Ch 5 Sec 2 [2.1].
- 6.2.5. The loading manual shall describe relevant operational limitations, as applicable, as mentioned below:
- scantling draught
 - load specifications for cargo decks
 - design minimum ballast draught at midships
 - minimum slamming draught forward with forward double bottom ballast tanks filled
 - minimum slamming draught forward with any of the forward double bottom ballast tanks empty
 - maximum allowable cargo density
 - maximum cargo density and filling heights in any loading condition in loading manual
 - restrictions in cargo mass- and angle of repose
 - maximum service speed
 - envelope results and permissible limits of still water bending moments and shear forces, and still water torsional moments, if applicable
 - restrictions to GM-value
 - restrictions to filling of tanks in seagoing conditions
 - restrictions to ballast holds which may not be partially filled in seagoing conditions

- restrictions to double bottom ballast tanks which may be filled in alternate loaded seagoing conditions.

6.3. Condition of approval of loading computer systems

- 6.3.1. With respect to the approval of the loading computer system, the approval shall be in accordance with the relevant requirements stipulated by IACS UR L5, IACS UR S1 or S1A and IACS Recommendation No.48.

CHAPTER 6 BOTTOM STRUCTURE

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SECTION 1 GENERAL

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1.1. Introduction

1.1.1. The requirements in this chapter are applicable to bottom structures.

1.1.2. The formulae given for plating, stiffeners and girders are based on the structural design principles outlined in Ch 3 Sec 2. 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

The actual values for these parameters may be chosen and inserted in the formulae, wherever relevant.

Direct stress calculations based on said structural design principles and as outlined in Ch 13 will be considered as alternative basis for the scantlings.

1.2. Definitions

1.2.1. Symbols:

L	= rule length, in m ¹⁾
L_F	= length, in m as defined in Ch 1 Sec 2 [2.1.1]
B	= rule breadth, in m ¹⁾
D	= rule depth, in m ¹⁾
T_{ms}	= rule draught, in m ¹⁾
C_B	= rule block coefficient ¹⁾
V	= maximum service speed, in knots, on draught T_{ms}
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
	$= \left(1.1 - 0.25 \frac{s}{l}\right)^2$
	= 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, Refer Ch 3 Sec 3 [3.1]. For curved stiffeners l may be taken as the cord length
w_c	= section modulus corrosion factor in tanks, Refer Ch 3 Sec 3 [3.10.5]
	= 1.0 in other compartments
σ	= nominal allowable bending stress in N/mm ² due to lateral pressure
h	= design pressure head, in m, as given in Sec 2.
k_m	= material factor. Refer Ch 2 Sec 2 and Ch 2 Sec 3
f_{2b}	= stress factor below the neutral axis of the hull girder depending on surplus in mid-ship section modulus and maximum value of the actual still water bending moments:

$$f_{2b} = \frac{5.7 (M_{ST} + M_{WV})}{Z_B}$$

Z_B	= mid-ship section modulus, in cm ³ , at bottom as built
M_{ST}	= normally to be taken as the largest design still water bending moment, in kN m. M_{ST} shall not be taken less than 0.5 M_{SO} . When actual design moment is not known, M_{ST} may be taken equal to M_{SO}

- M_{SO} = design still water bending moment, in kN m, given in Ch 5 Sec 2
 M_{WV} = rule wave bending moment, in kN m, given in Ch 5 Sec 2. Hogging or sagging moment to be chosen in relation to the applied still water moment.
 Z_R = rule mid-ship section modulus, in cm^3 , as given in Ch 5 Sec 3 [3.3.9]

Remarks:

1) For details Refer Ch 1 Sec 2 [2.1.1]

2) In special cases, a more detailed evaluation of the actual still water moment M_{ST} to be used may be allowed. In order to estimate f_{2b} , the simultaneous occurring of a certain local load on a structure and the largest possible negative value in the same area of the hull girder may be used.

Example: Inner bottom longitudinal in a loaded hold of a bulk carrier with **BC-A**-notation. Local load from Table 5.2.1: h4. M_{ST} 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_{ST} / M_{SO} in no case to be taken less than 0.5.

1.3. Documentation

- 1.3.1. Plans and particulars to be submitted for approval or information are specified in Ch1Sec 3.

1.4. Structural arrangement and details

- 1.4.1. The engine room is normally to have a double bottom.
- 1.4.2. Double bottoms within the cargo region are normally to be longitudinally stiffened in ships with length $L > 150$ m
- 1.4.3. Single bottoms within the cargo region are normally to be longitudinally stiffened.
- 1.4.4. 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. Refer Fig. 6.1.1 - a
 - The longitudinals may be cut at transverse members within 0.5 L amidships in ships with length $50 \text{ m} < L < 150$ m. In that case continuous brackets connecting the ends of the longitudinals shall be fitted. Refer Fig. 6.1.1 - b
 - The longitudinals may be welded against the floors in ships with length $L < 50$ m, and in larger ships outside 0.5 L amidships. Brackets are to be fitted. Refer Fig. 6.1.1 - c
- 1.4.5. To provide access to all parts of the double bottom, manholes shall be cut in the inner bottom, floors and longitudinal girders. 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.

Normally manholes are 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.

- 1.4.6. In order 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 practically possible. The drain holes shall be placed

as near to the bottom as practically possible. The total area of the air holes shall be greater than the area of the filling pipes.

- 1.4.7. 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. Access opening shall be regarded as an opening in watertight bulkhead.
- 1.4.8. 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 Ch 2 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.
- 1.4.9. Weld connections shall satisfy the general requirements given in Ch 11.
- 1.4.10. For end connections of stiffeners and girders, Refer Ch 3 Sec 3.
- 1.4.11. Bilge wells shall not have common boundary with the bottom and/or side plating. Maximum vertical distance a bilge well is allowed to protrude into the double bottom is defined in Sec 1.5.3.

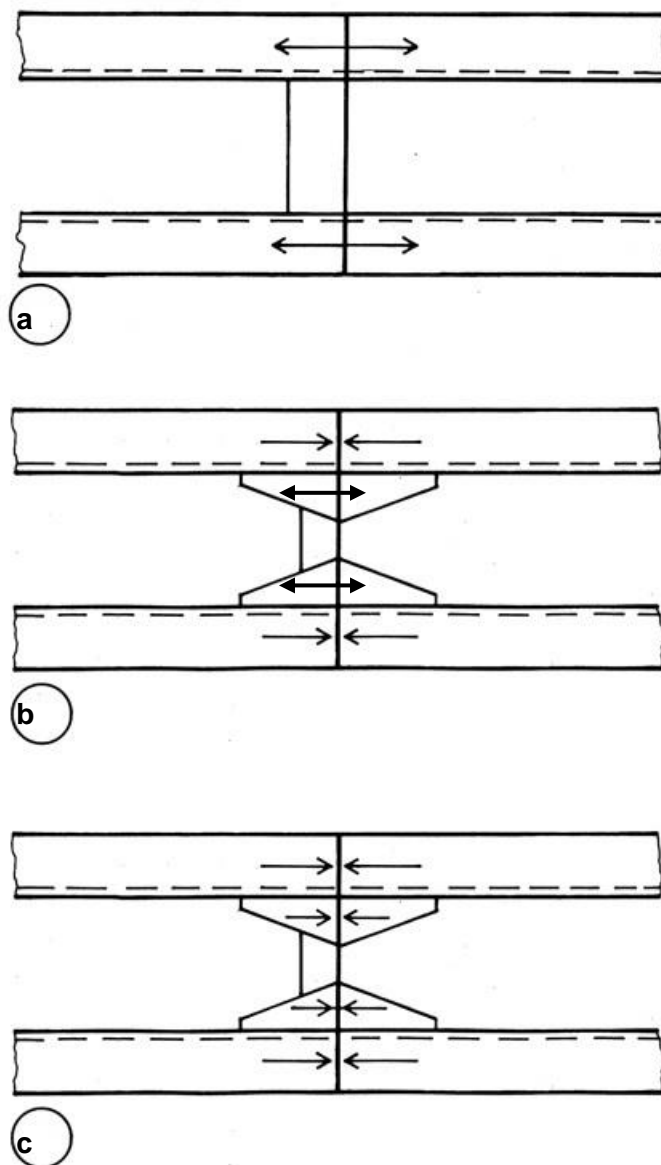


Figure 6.1.1: Longitudinal Connections

1.5. Bottom arrangement

- 1.5.1. A double bottom shall be fitted for passenger vessels and cargo ships other than tankers, 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.
- 1.5.2. The depth of the double bottom is given in Ch 6 Sec 4 [4.1]. 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.
- 1.5.3. 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 the relevant requirements of this chapter. Reference is also made to the relevant requirements contained in Ch II-1 / Regulation 9 of SOLAS 1974 (as amended) regarding wells constructed in the double bottom.

- 1.5.4. Referring to Ch II-1 / Regulation 9 of SOLAS 1974 (as amended), a double bottom need not be fitted in way of watertight tanks used exclusively for the carriage of liquids, and also including dry tanks of moderate size, provided the safety of the ship is not impaired in the event of bottom or side damage.
- 1.5.5. Any part of the ship that is not fitted with a double bottom in accordance with Sec [1.5.1] to Sec [1.5.4] shall be capable of withstanding bottom damages. Refer Ch II-1 / Regulation 9.8 of SOLAS 1974 (as amended).
- 1.5.6. Provided that the Flag Administration of the ship grants their approval of the double bottom arrangement, the requirements in Sec [1.5.1] to Sec [1.5.5] may be specially considered for cargo vessels with L_F less than 80 m and that are regulated under the SOLAS Convention.

Remark:

Bottom arrangements regulated under SOLAS Convention that are not in compliance with Ch II-1 / Regulation 9 of SOLAS 1974 (as amended) are subject to acceptance by the Flag Administration of the ship.

- 1.5.7. Subject to agreement with the Society, the requirements in Sec [1.5.1] to Sec [1.5.5] may be specially considered for vessels not regulated under the SOLAS convention.

SECTION 2 DESIGN LOADS

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2.1. Local loads on bottom structures

- 2.1.1. All generally applicable local loads, expressed in terms of corresponding design pressure heads, on bottom structures are given in Table 6.2.1 for ships with L less than 100 m and Table 6.2.2 for ships with L equal to or greater than 100 m, based upon the general loads given in Ch 4. In connection with the various local structures, reference is made to these tables, indicating the relevant loads in each case.

2.2. Total loads on double bottom

- 2.2.1. In connection with direct stress calculations on double bottom structures, total loads shall be taken as differences between internal and external pressures derived from corresponding internal and external design pressure heads using the methodology outlined in Ch 4 Sec 1 [1.1.5]. These loads are specified in Ch 13.

Table 6.2.1. Design loads for bottom structures for ships with L < 100 m		
Structure	Load Type	Design pressure head h (m)
Outer bottom:	Sea pressure	$h_1 = h_0 + h_{dp}^{(1)}$
	Liquid cargo in tank above	$h_2 = \frac{\rho}{\rho_w} h_s$
Inner bottom:	Dry cargo in cargo holds	$h_3 = k \frac{\rho_c}{\rho_w} H_{st}$
	Liquids in tank above ²⁾	$h_4 = k \frac{\rho}{\rho_w} h_s$
		$h_5 = 0.67 \left(\frac{\rho}{\rho_w} h_p + \Delta h_{dyn} \right)$
		$h_6 = \frac{\rho}{\rho_w} h_s + h_{gen}$
		$h_7 = \frac{\rho}{\rho_w} (h_s + 0.3 b)$
Inner bottom, floors and girders:	Pressure on tank boundaries in double bottom	$h_9 = 0.67 \left(\frac{\rho}{\rho_w} h_p + \Delta h_{dyn} \right)$
		$h_{10} = \frac{\rho}{\rho_w} h_s + h_{gen}$
	Flooded condition	$h_{11} = h_b$
Remarks: 1) For ships with service restrictions, h_3 , h_4 and the last term in h_1 may be reduced as given in Ch 3 Sec 2 Table 3.2.2. C_{wv} shall not be reduced for the calculation of last term in h_1 . 2) h_7 and h_8 refer to tank sides and ends, respectively. Adjacent structures to be reinforced accordingly.		

Table 6.2.2. Design loads for bottom structures for ships with $L \geq 100$ m

Structure	Load Type	Design pressure head h (m)
Outer bottom	Sea pressure	$h_1 = h_0 + h_{dp}^{(1)}$
	Net pressure in way of cargo tank or deep tank	$h_2 = \frac{\rho}{\rho_w} \left(1 + \frac{0.5 a_{vert}}{g_0} \right) h_s - T_M$ $h_3 = \frac{\rho}{\rho_w} h_s + h_{gen} - T_M$
Inner bottom	Dry cargo in cargo holds	$h_4 = \frac{\rho_c}{\rho_w} \left(1 + 0.5 \frac{a_{vert}}{g_0} \right) H_{st}$
	Ballast in cargo holds	$h_5 = (1 + 0.05 a_{vert}) h_s$ $h_6 = \left[0.67 (h_s + \phi b) - 0.12 \sqrt{H b_{top} \phi} \right]$ $h_7 = 0.67 (h_p + \Delta h_{dyn})$ $h_8 = h_s + h_{gen}$
	Liquid cargo in tank above	$h_9 = \frac{\rho}{\rho_w} \left(1 + \frac{0.5 a_{vert}}{g_0} \right) h_s$ $h_{10} = \frac{\rho}{\rho_w} \left[0.67 (h_s + \phi b) - 0.12 \sqrt{H b_{top} \phi} \right]$ $h_{11} = 0.67 \left(\frac{\rho}{\rho_w} h_p + \Delta h_{dyn} \right)$ $h_{12} = \frac{\rho}{\rho_w} h_s + h_{gen}$
Inner bottom, floors and girders	Pressure on tank boundaries in double bottom	$h_{13} = 0.67 \left(\frac{\rho}{\rho_w} h_p + \Delta h_{dyn} \right)$ $h_{14} = \frac{\rho}{\rho_w} h_s + h_{gen}$
	Flooded condition	$h_{15} = h_b$
Remarks: 1) For ships with service restrictions, the last term in h_1 may be reduced as given in Ch 3 Sec 2 Table 3.2.2. C_{WV} shall not be reduced for the calculation of last term in h_1 . 2) h_6 and h_{10} to be used in tanks / holds with largest breadth $> 0.4 B$.		

The definition of parameters used in the above formulations contained in Table 6.2.1 and Table 6.2.2 is as follows:

a_{vert}	= for use in Table 6.2.2; vertical acceleration as given in Ch 4 Sec 2 [2.6], taken in the center of gravity of the tank
ϕ	= for use in Table 6.2.2; roll angle in radians as given in Ch 4 Sec 2 [2.3]
ρ_w	= as given in Ch 4 Sec 1 [1.2]
ρ	= density of liquid cargo in t/m^3 , normally not to be taken less than 1.025 t/m^3
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
H	= for use in Table 6.2.2; height, in m, of the tank
b	= for use in Table 6.2.1; breadth of the tank, in m = for use in Table 6.2.2; 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
l	= for use in Table 6.2.1; total length of tanks, in m
b_{top}	= for use in Table 6.2.2; breadth, in m, of top of tank
h_{gen}	= $(0.03 L - 0.5) \text{ m}$, minimum 1 m, in general (for use in Table 6.2.1) = 2.5 m, in general (for use in Table 6.2.2) = 2.5 m, in cargo tanks (for use in Table 6.2.1) = 1.5 m, in ballast holds of dry cargo vessels (for use in Table 6.2.2)
	= pressure head corresponding to tank pressure valve opening pressure when exceeding the general value (for use in Table 6.2.1 and Table 6.2.2)
Δh_{dyn}	= as given in Ch 4 Sec 3 [3.3.2]
h_{dp}	= as given in Ch 4 Sec 3 [3.2.1]
h_0	= vertical distance, in m, from the waterline at draught T_{ms} to the load point
T_M	= for use in Table 6.2.2; minimum design draught amidships, in m, normally taken as $0.35 T_{\text{ms}}$ for dry cargo vessels and $2 + 0.02 L$ for tankers
h_b	= vertical distance, in m, 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_{st}	= 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 ρ_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
k	= for use in Table 6.2.1; 1.3 aft of $0.2 L$ from F.P. = 1.5 within $0.2 L$ from F.P.

SECTION 3 PLATING AND STIFFENERS

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3.1. General

- 3.1.1. Requirements for laterally loaded plating and stiffeners and additionally the scantlings and stiffening requirements for double bottom floors and girders are given in this section. For single bottom and peak tank girders, Refer Sec 6 and Sec 7.

3.2. Keel plate

- 3.2.1. The keel plate or garboard strake shall extend over the complete length of the ship. The breadth shall not be less than:

$$b = 800 + 5 L \quad (\text{mm})$$

- 3.2.2. The thickness shall not be less than:

$$t = 7.0 + 0.05 L_1 \sqrt{k_m} + t_c \quad (\text{mm})$$

In no case, the thickness is to be less than that of the adjacent bottom plate.

3.3. Bottom and bilge plating

- 3.3.1. For vessels with $L \geq 100$ m, 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 2 Sec 2, shall not be less than:

$$b = 800 + 5 L \quad (\text{mm})$$

- 3.3.2. The thickness requirement corresponding to lateral pressure is given by:

$$t = \frac{49.96 k_a s \sqrt{h}}{\sqrt{\sigma}} + t_c \quad (\text{mm})$$

h = h_1 or h_2 in Table 6.2.1 for vessels with $L < 100$ m
= h_1 to h_3 (when relevant) in Table 6.2.2 for vessels with $L \geq 100$ m
 σ = as given in Table 6.3.1 for vessels with $L < 100$ m
= as given in Table 6.3.2 for vessels with $L \geq 100$ m

The definition of the parameters used in the above equation is given in Sec [1.2] of this chapter.

- 3.3.3. The longitudinal and combined buckling strength of the platings shall be checked according to Ch 14.

- 3.3.4. The thickness shall not be less than:

$$t = 5.0 + 0.04 L_1 \sqrt{k_m} + t_c \quad (\text{mm})$$

Table 6.3.1. Values of σ for vessels with $L < 100$ m	
Stiffening type	Allowable stress σ ⁽¹⁾
Transverse stiffening	$60 \frac{Z_B}{Z_R}$, maximum $\frac{120}{k_m}$; within 0.4 L $\frac{160}{k_m}$; within 0.1 L from the perpendiculars
Longitudinal stiffening	$\frac{120}{k_m}$; within 0.4 L $\frac{160}{k_m}$; within 0.1 L from the perpendiculars
Remarks: 1) Between specified regions, the σ -value may be varied linearly.	

Table 6.3.2. Values of σ for vessels with $L \geq 100$ m	
Stiffening type	Allowable stress σ ⁽¹⁾
Transverse stiffening	$\frac{175}{k_m} - 120 f_{2b}$, maximum $\frac{120}{k_m}$; within 0.4 L $\frac{160}{k_m}$; within 0.1 L from the perpendiculars
Longitudinal stiffening	$\frac{120}{k_m}$; within 0.4 L $\frac{160}{k_m}$; within 0.1 L from the perpendiculars
Remarks: 1) Between specified regions, the σ -value may be varied linearly. 2) f_{2b} = stress factor as given in Sec [1.2] of this chapter.	

- 3.3.5. There shall be a gradual transition in plate thickness between the midship region and the end regions.
- 3.3.6. The thickness of the bilge plate shall not be less than that of the adjacent bottom and side plates, whichever is the greater.
- 3.3.7. If the bilge plate is not stiffened, or has only one stiffener inside the curved part, the thickness shall not be less than:

$$t = \frac{\sqrt[3]{R^2 l h}}{417.7} + t_c \quad (\text{mm})$$

- R = radius of curvature (mm)
l = distance between circumferential stiffeners, i.e. bilge brackets (mm)
h = $\left(h_0 + B \frac{\phi}{2} + 0.088 C_B \left(\frac{B}{2} + 0.8 C_{WV} \right) \right)$ (m) ; for vessels with $L \geq 100$ m
= $2 h_1 - h_0$ (m) minimum ; for vessels with $L \geq 100$ m
= $2 h_1 - h_0$ (m) ; for vessels with $L < 100$ m
 ϕ = roll angle in radians as given in Ch 4 Sec 2 [2.3].
 C_{WV} = wave coefficient as given in Ch 4 Sec 2 [2.2].

In case of longitudinal stiffening positioned outside the curvature, R is substituted by:

$$R_1 = R + 0.5 (a + b)$$

Refer Fig.6.3.1. The lengths a and b are normally not to be greater than s/3.

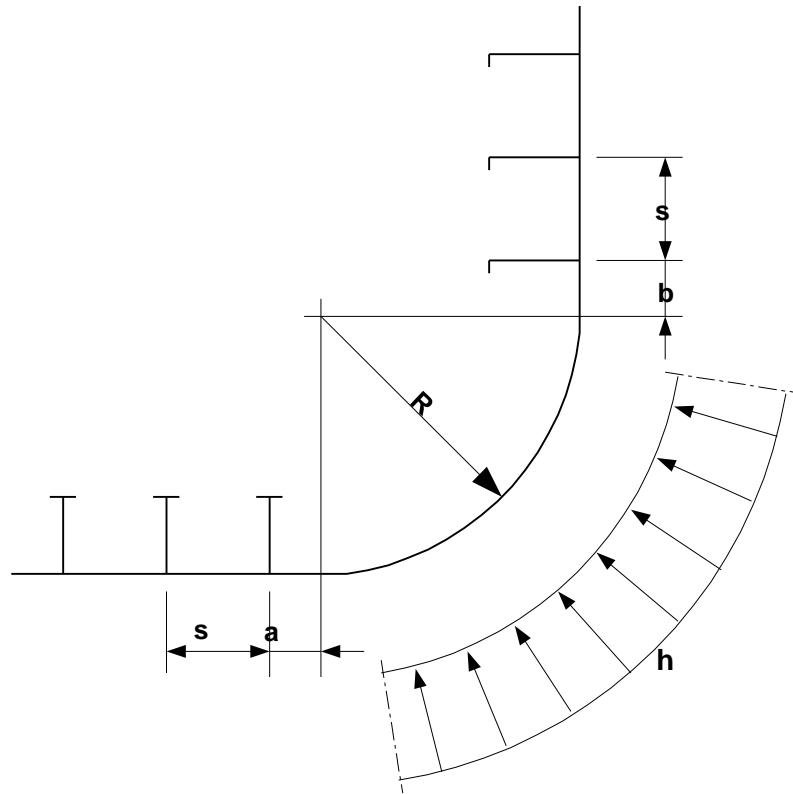


Figure 6.3.1: Bilge without longitudinal stiffening

3.4. Inner bottom plating

3.4.1. The thickness requirement corresponding to lateral pressure is given by:

$$t = \frac{49.96 k_a s \sqrt{h}}{\sqrt{\sigma}} + t_c \quad (\text{mm})$$

h = h_3 to h_{11} whichever is relevant as given in Table 6.2.1 for vessels with $L < 100$ m

- σ = h_4 to h_{15} whichever is relevant as given in Table 6.2.2 for vessels with $L \geq 100$ m
 = as given in Table 6.3.3 for vessels with $L < 100$ m
 = as given in Table 6.3.4 for vessels with $L \geq 100$ m

The definition of the parameters used in the above equation is given in Sec [1.2] of this chapter.

- 3.4.2. The thickness shall not be less than:

$$t = t_0 + 0.03 L_1 \sqrt{k_m} + t_c \quad (\text{mm})$$

- 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 holds if ceiling is fitted.
 = 5.0 in void spaces, machinery spaces and tanks.

- 3.4.3. The longitudinal and combined buckling strength of the plating shall be checked according to Ch 14.

Table 6.3.3. Values of σ for vessels with $L < 100$ m	
Stiffening type	Allowable stress σ ⁽¹⁾
Transverse stiffening	$\frac{140}{k_m}$; within 0.4 L $\frac{160}{k_m}$; within 0.1 L from the perpendiculars $\frac{220}{k_m}$; for flooded condition
Longitudinal stiffening	$\frac{140}{k_m}$; within 0.4 L $\frac{160}{k_m}$; within 0.1 L from the perpendiculars $\frac{220}{k_m}$; for flooded condition
Remarks:	
1) Between specified regions, the σ -value may be varied linearly.	

Table 6.3.4. Values of σ for vessels with $L \geq 100$ m

Stiffening type	Allowable stress σ ⁽¹⁾
Transverse stiffening	$\frac{200}{k_m} - 110 f_{2b}$, maximum $\frac{140}{k_m}$; within 0.4 L $\frac{160}{k_m}$; within 0.1 L from the perpendiculars $\frac{220}{k_m}$; for flooded condition
Longitudinal stiffening	$\frac{140}{k_m}$; within 0.4 L $\frac{160}{k_m}$; within 0.1 L from the perpendiculars $\frac{220}{k_m}$; for flooded condition
Remarks: 1) Between specified regions, the σ -value may be varied linearly. 2) f_{2b} = stress factor as given in Sec [1.2] of this chapter.	

3.5. Plating in double bottom floors and longitudinal girders

3.5.1. The thickness requirement of floors and longitudinal girders forming boundaries of double bottom tanks is given by:

$$t = \frac{49.96 k_a s \sqrt{h}}{\sqrt{\sigma}} + t_c \quad (\text{mm})$$

- h = h_9 to h_{11} whichever is relevant as given in Table 6.2.1 for vessels with $L < 100$ m
= h_{13} to h_{15} whichever is relevant as given in Table 6.2.2 for vessels with $L \geq 100$ m
= h_1 for sea chest boundaries (including top and partial bulkheads) as given in Table 6.2.1 and Table 6.2.2 for vessels with $L < 100$ m and $L \geq 100$ m respectively
 σ = as given in Table 6.3.5 for vessels with $L < 100$ m
= as given in Table 6.3.6 for vessels with $L \geq 100$ m

3.5.2. The thickness of longitudinal girders, floors, supporting plates and brackets shall not be less than:

$$t = 6.0 + k L_1 \sqrt{k_m} + t_c \quad (\text{mm})$$

- k = 0.04 for center girder in vessels with $L < 100$ m
= 0.04 for center girder up to 2 m above keel plate in vessels with $L \geq 100$ m
= 0.02 for other girders in vessels with $L < 100$ m
= 0.02 for other girders and remaining part of center girder in vessels with $L \geq 100$ m

= 0.05 for sea chest boundaries (including top and partial bulkheads) for all vessels irrespective of length.

The definition of the parameters used in the above equations is given in Sec [1.2] of this chapter.

3.5.3. The buckling strength of girders shall be checked according to Ch 14.

Table 6.3.5. Values of σ for vessels with $L < 100$ m	
Member type	Allowable stress σ ⁽¹⁾
Longitudinal girders	$\frac{130}{k_m}$; within 0.4 L $\frac{160}{k_m}$; within 0.1 L from the perpendiculars $\frac{220}{k_m}$; for flooded condition
Floors	$\frac{160}{k_m}$; in general $\frac{220}{k_m}$; for flooded condition
Sea chest boundaries (including top and partial bulkheads)	$\frac{120}{k_m}$; in general $\frac{220}{k_m}$; for flooded condition
Remarks:	
1) Between specified regions, the σ -value may be varied linearly.	

Table 6.3.6. Values of σ for vessels with $L \geq 100$ m

Member type	Allowable stress σ ⁽¹⁾
Longitudinal girders	<p>Transversely stiffened: $\frac{190}{k_m} - 120 f_{2b}$, maximum $\frac{130}{k_m}$; within 0.4 L</p> <p>Longitudinally stiffened: $\frac{130}{k_m}$; within 0.4 L $\frac{160}{k_m}$; within 0.1 L from the perpendiculars $\frac{220}{k_m}$; for flooded condition</p>
Floors	<p>$\frac{160}{k_m}$; in general $\frac{220}{k_m}$; for flooded condition</p>
Sea chest boundaries (including top and partial bulkheads)	<p>$\frac{120}{k_m}$; in general $\frac{220}{k_m}$; for flooded condition</p>
<p>Remarks:</p> <p>1) Between specified regions, the σ-value may be varied linearly. 2) f_{2b} = stress factor as given in Sec 1.2 of this chapter.</p>	

3.6. Transverse frames

3.6.1. The section modulus requirement of bottom and inner bottom frames is given by:

$$Z = 6.3 s h l^2 w_c k_m \quad (\text{cm}^3)$$

h = h_1 to h_{11} whichever is relevant as given in Table 6.2.1 for vessels with $L < 100$ m
= h_1 to h_{15} whichever is relevant as given in Table 6.2.2 for vessels with $L \geq 100$ m

The definition of the parameters used in the above equation is given in Sec [1.2] of this chapter.

3.6.2. In general, struts fitted between bottom and inner bottom frames are not to be considered as effective supports for the frames. The requirements given in Sec [3.6.1], however, may be reduced after special consideration. When bottom and inner bottom frames have the

same scantlings, a reduction on section modulus as required by Sec [3.6.1] of 35% will be accepted if strut is provided at middle length of span.

3.6.3. The thickness of web and flange shall not be less than the larger of:

$$t = 4.5 + k' + t_c \quad (\text{mm})$$

$$= 1.5 + \frac{h_w}{g \sqrt{k_m}} + t_c \quad (\text{mm})$$

- k' = 0.015 L_1
 = 5.0 maximum for vessels with $L \geq 100$ m
 h_w = web height, in mm
 g = 75 for flanged profile webs
 = 41 for bulb profiles
 = 22 for flat bar profiles.

3.7. Bottom longitudinals

3.7.1. The section modulus requirement is given by:

$$Z = \frac{830 s h l^2 w_c}{\sigma} \quad (\text{cm}^3)$$

- h = h_1 or h_2 in Table 6.2.1 for vessels with $L < 100$ m
 = h_1 to h_3 (when relevant) in Table 6.2.2 for vessels with $L \geq 100$ m
 σ = as given in Table 6.3.8 for vessels with $L < 100$ m
 = as given in Table 6.3.7 for vessels with $L \geq 100$ m

The definition of the parameters used in the above equation is given in Sec [1.2] of this chapter.

For vessels with $L \geq 100$ m, longitudinals connected to vertical girders on transverse bulkheads shall be checked by a direct stress analysis, Refer Ch 13.

3.7.2. The buckling strength of longitudinals shall be checked according to Ch 14.

3.7.3. The thickness of web and flange shall not be less than the larger of:

$$t = 4.5 + k' + t_c \quad (\text{mm})$$

$$= 1.5 + \frac{h_w}{g \sqrt{k_m}} + t_c \quad (\text{mm})$$

- k' = 0.015 L_1
 = 5.0 maximum for vessels with $L \geq 100$ m
 h_w = web height, in mm
 g = 75 for flanged profile webs
 = 41 for bulb profiles
 = 22 for flat bar profiles.

3.7.4. In general, struts fitted between bottom and inner bottom longitudinals are not to be considered as effective supports for the longitudinals. The requirements given in Sec [3.7.1], however, may be reduced after special consideration. When bottom and inner

bottom longitudinals have the same scantlings, a reduction on section modulus (as required by Sec [3.7.1] of 35% will be accepted if strut is provided at middle length of span.

3.7.5. A longitudinal shall be fitted at the bottom where the curvature of the bilge plate starts.

Table 6.3.7. Values of σ for vessels with $L \geq 100$ m

<i>Member type</i>	<i>Allowable stress σ ⁽¹⁾</i>
Bottom & bilge longitudinals	Single bottom:
	$\frac{225}{k_m} - 130 f_{2b}$, maximum $\frac{160}{k_m}$; within 0.4 L
	Double bottom:
	$\frac{225}{k_m} - 130 f_{2b} - 0.7 \sigma_{db}$, maximum $\frac{160}{k_m}$; within 0.4 L
	Bilge longitudinals:
	$\frac{225}{k_m} - 130 f_{2b} \left(\frac{z_n - z_a}{z_n} \right)$, maximum $\frac{160}{k_m}$; within 0.4 L
	$\frac{160}{k_m}$; within 0.1 L from the perpendiculars
<p>Remarks:</p> <p>1) Between specified regions, the σ-value may be varied linearly.</p> <p>2) f_{2b} = stress factor as given in Sec 1.2 of this chapter.</p> <p>3) σ_{db} = mean double bottom stress at plate flanges, normally not to be taken less than: = 20 / k_m for cargo holds in general cargo vessels = 50 / k_m for holds for ballast = (50 / k_m) (b/B) for tanks for liquid cargo b = breadth of tank at double bottom</p> <p>4) z_n and z_a are taken as defined in Ch 7 Sec 1 [1.2.1]</p>	

Table 6.3.8. Values of σ for vessels with $L < 100$ m	
Member type	Allowable stress σ ⁽¹⁾
Bottom & bilge longitudinals	$\frac{95}{k_m}$; within 0.4 L when $Z_B = Z_R$
	$\frac{160}{k_m}$; within 0.4 L when $Z_B \geq 2 Z_R$
	$\frac{160}{k_m}$; within 0.1 L from the perpendiculars
Remarks:	
1) Between specified regions, the σ -value may be varied linearly.	
2) Z_B and Z_R are defined in Sec [1.2] of this chapter.	

3.8. Inner bottom longitudinals

3.8.1. The section modulus requirement is given by:

$$Z = \frac{830 s h l^2 w_c}{\sigma} \quad (\text{cm}^3)$$

- h = h_3 to h_{11} whichever is relevant as given in Table 6.2.1 for vessels with $L < 100$ m
= h_4 to h_{15} whichever is relevant as given in Table 6.2.2 for vessels with $L \geq 100$ m
 σ = as given in Table 6.3.9 for vessels with $L < 100$ m
= as given in Table 6.3.10 for vessels with $L \geq 100$ m

The definition of the parameters used in the above equation is given in Sec [1.2] of this chapter.

3.8.2. The thickness of web and flange shall not be less than the larger of:

$$t = 4.5 + k' + t_c \quad (\text{mm})$$

$$= 1.5 + \frac{h_w}{g \sqrt{k_m}} + t_c \quad (\text{mm})$$

- k' = $0.015 L_1$
= 5.0 maximum for vessels with $L \geq 100$ m
 h_w = web height, in mm
g = 75 for flanged profile webs
= 41 for bulb profiles
= 22 for flat bar profiles.

3.8.3. In general, struts fitted between bottom and inner bottom longitudinals are not to be considered as effective supports for the longitudinals. The requirements given in Sec [3.8.1], however, may be reduced after special consideration. When bottom and inner

bottom longitudinals have the same scantlings, a reduction on section modulus (as required by Sec 3.8.1) of 35% will be accepted if strut is provided at middle length of span.

3.8.4. The buckling strength shall be checked according to Ch 14.

Table 6.3.9. Values of σ for vessels with $L < 100$ m

Member type	Allowable stress σ ⁽¹⁾
Inner bottom longitudinals	$\frac{110}{k_m}$; within 0.4 L when $Z_B = Z_R$
	$\frac{160}{k_m}$; within 0.4 L when $Z_B \geq 2 Z_R$
	$\frac{160}{k_m}$; within 0.1 L from the perpendiculars
	$\frac{220}{k_m}$; for flooded condition
Remarks: 1) Between specified regions, the σ -value may be varied linearly. 2) Z_B and Z_R are defined in Sec [1.2] of this chapter.	

Table 6.3.10. Values of σ for vessels with $L \geq 100$ m

Member type	Allowable stress σ ⁽¹⁾
Inner bottom longitudinals	$\frac{225}{k_m} - 100 f_{2b} - 0.7 \sigma_{db}$, maximum $\frac{160}{k_m}$; within 0.4 L
	$\frac{160}{k_m}$; within 0.1 L from the perpendiculars
	$\frac{220}{k_m}$; for flooded condition
Remarks: 1) Between specified regions, the σ -value may be varied linearly. 2) f_{2b} = stress factor as given in Sec 1.2 of this chapter. 3) σ_{db} = mean double bottom stress at plate flanges, normally not to be taken less than: = $20 / k_m$ for cargo holds in general cargo vessels = $50 / k_m$ for holds for ballast = $(50 / k_m) (b/B)$ for tanks for liquid cargo b = breadth of tank at double bottom	

3.9. Stiffening of double bottom floors and girders

3.9.1. The section modulus requirement of stiffeners on floors and longitudinal girders forming boundary of double bottom tanks is given by:

$$Z = \frac{1000 s h l^2 w_c}{\sigma} \quad (\text{cm}^3); \quad \text{in general}$$

$$Z = \frac{830 s h l^2 w_c}{\sigma} \quad (\text{cm}^3); \quad \text{when longitudinally stiffened}$$

- h = h₉ to h₁₁ whichever is relevant as given in Table 6.2.1 for vessels with L < 100 m
 = h₁₃ to h₁₅ whichever is relevant as given in Table 6.2.2 for vessels with L ≥ 100 m
 = h₁ for sea chest boundaries (including top and partial bulkheads) as given in Table 6.2.1 and Table 6.2.2 for vessels with L < 100 m and L ≥ 100 m respectively
 σ = as given in Table 6.3.11 for vessels with L < 100 m
 = as given in Table 6.3.12 for vessels with L ≥ 100 m

- 3.9.2. Stiffeners in accordance with the requirement in Sec 3.9.1 are assumed to have end connections. When section modulus (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:

$$t = 3.95 \sqrt{\frac{(l - 0.5 s) s h}{1/k_m}} + t_c \quad (\text{mm})$$

- 3.9.3. The thickness of web and flange shall not be less than as given in Sec [3.6.3]
 3.9.4. The longitudinal girders shall be stiffened at every transverse frame, in double bottoms with transverse stiffening.
 3.9.5. The longitudinal girders shall be satisfactorily stiffened against buckling.
 3.9.6. In double bottoms with longitudinal stiffening the floors shall be stiffened at every longitudinal.

Table 6.3.11. Values of σ for vessels with L < 100 m	
Member type	Allowable stress σ ⁽¹⁾
Double bottom floors and girders	$\frac{140}{k_m}$; within 0.4 L for longitudinal stiffeners $\frac{160}{k_m}$; within 0.1 L from the perpendiculars $\frac{160}{k_m}$; for other stiffeners $\frac{220}{k_m}$; for flooded condition
Sea chest boundaries (including top and partial bulkheads)	$\frac{120}{k_m}$; in general $\frac{220}{k_m}$; for flooded condition
Remarks: 1) Between specified regions, the σ-value may be varied linearly.	

Table 6.3.12. Values of σ for vessels with $L \geq 100$ m	
Member type	Allowable stress σ ⁽¹⁾
Double bottom floors and girders	<p>Longitudinal stiffeners:</p> $\frac{225}{k_m} - 110 f_{2b}, \text{ maximum } \frac{160}{k_m}; \text{ within } 0.4 L$ $\frac{160}{k_m}; \text{ within } 0.1 L \text{ from the perpendiculars}$ <p>Transverse and vertical stiffeners:</p> $\frac{160}{k_m}; \text{ within } 0.1 L \text{ from the perpendiculars}$ $\frac{220}{k_m}; \text{ for flooded condition}$
Sea chest boundaries (including top and partial bulkheads)	$\frac{120}{k_m}; \text{ in general}$ $\frac{220}{k_m}; \text{ for flooded condition}$
<p>Remarks:</p> <p>1) Between specified regions, the σ-value may be varied linearly.</p> <p>2) f_{2b} = stress factor as given in Sec [1.2] of this chapter.</p>	

SECTION 4 ARRANGEMENT OF DOUBLE BOTTOM

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4.1. General

- 4.1.1. 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 which is 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;

$$h = \frac{1000 B}{20} \quad (\text{mm}) ; \text{ minimum } 760 \text{ mm}$$

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. The minimum height may have to be increased after special consideration, for ships with a great rise of floors.

- 4.1.2. Girders extending from the bottom to the top plate of the engine seating shall be fitted under the main engine. The height of the girders shall not be less than that of the floors. The thickness of the plating in way of the engine shall be at least twice the rule thickness of inner bottom plating, if the engine is bolted directly to the inner bottom. Engine holding-down bolts shall be arranged as near as practicable to floors and longitudinal girders.

The thickness of the top plate of seatings for main engine and reduction gear should preferably be not less than:

$P_s \text{ (kW)} ^1$	$t \text{ (mm)}$
$P_s \leq 1000$	25
$1000 < P_s \leq 1750$	30
$1750 < P_s \leq 2500$	35
$2500 < P_s \leq 3500$	40
$P_s > 3500$	45
Remarks: 1) P_s = maximum continuous output of propulsion machinery. 2) The thickness of the engine girders should preferably not be less than 40% of the recommended top plate thickness	

4.2. Double bottom with transverse framing

- 4.2.1. Side girders shall be fitted so that the distance between the side girders and the center girder or the margin plate or between the side girders themselves does not exceed 4 meters. In the engine room, side girders are in all cases to be fitted outside the engine seating girders.
- 4.2.2. Normally, the floor spacing is to be not greater than that given in Table 6.4.1. In the engine room floors shall be fitted at every frame. Additional strengthening shall be provided in way of thrust bearing and below pillars.

Table 6.4.1 Plate floors		
<i>Draught (m)</i>	<i>Under deep tanks ¹⁾</i>	<i>Clear of deep tanks and machinery space ²⁾</i>
$T_{ms} \leq 2$	Every 4 th frame	Every 6 th frame
$2 < T_{ms} \leq 5.4$	Every 3 rd frame	Every 5 th frame
$5.4 < T_{ms} \leq 8.1$	Every 3 rd frame	Every 4 th frame
$T_{ms} > 8.1$	Every 2 nd frame	Every 3 rd frame
Remarks: 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 meters.		

- 4.2.3. Supporting plates for the transverse bottom frames shall be fitted at the center 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.

4.3. Double bottom with longitudinals

- 4.3.1. Side girders shall normally be fitted in such a manner that the distance between the side girders and the center girder or the margin plate or between the side girders themselves does not exceed 5 meters. In all cases in the engine room, one side girder is required to be fitted outside the engine seating girders. For double bottom girder systems below cargo holds and tanks, Refer Ch 6 Sec 5 [5.1].
- 4.3.2. The floor spacing is normally to be not 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.

Floors shall be fitted at every second side frame in the engine room.

Bracket floors shall be fitted at intermediate frames, extending to the first ordinary side girder outside the engine seating. Additional strengthening shall be provided in way of thrust bearing and below pillars.

- 4.3.3. Supporting plates shall be fitted at the center girder. Flange shall be provided to the free edge of the supporting plates. The breadth of the supporting plate shall be at least one longitudinal spacing. The spacing is normally not to exceed two frame spacings. Docking brackets shall be fitted between supporting plates on the center girder.

Alternative arrangements of supporting plates and docking brackets require special consideration of local buckling strength of center girder/duct keel and local strength of docking longitudinal subject to the forces from docking blocks.

SECTION 5 DOUBLE BOTTOM GIRDER SYSTEM BELOW CARGO HOLDS AND TANKS

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5.1. Main scantlings

- 5.1.1. In addition to fulfilling the minimum and local requirements given in Sec 3 and Sec 4, 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 Ch 13. The distance between floors and side girders as given in Sec 4 [4.2] and Sec 4 [4.3] may then be modified.

The relative deflection between the transverse bulkhead and the nearest floor shall be given special attention.

In dry Cargo ships with homogeneous loading only, the scantlings may be based on the local and minimum requirements in Sec 3 and Sec 4.

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6.1. Main scantlings

6.1.1. The main scantlings of single bottom girder system in tanks for liquid cargo and ballast shall be based on a direct stress calculations as outlined in Ch 13. For such calculations, the loads given in Ch 6 Sec 2 shall be used for vessels with $L \geq 100$ m. For vessels with $L < 100$ m, Refer Sec [6.1.2] to Sec [6.1.3].

6.1.2. For vessels with $L < 100$ m, the calculation should be based on a 2 or 3 dimensional frame analysis with the following loadings:

In ships with possibility for uneven loading of cargo it should be assumed that the bottom will be subject to external water pressure equal to $10 T_{ms} + 0.12 L$ (kN/m²) with empty hold. In ships with even loading, the net external load (i.e. sea pressure – part load in hold) on the bottom should not be taken less than $5 T_{ms} + 0.12 L$ (kN/m²).

The load on bottom in cargo holds intended for liquids with specific gravity greater than 1 t/m³ will be specially considered.

6.1.3. Acceptable stress levels for the calculation will be:

$$\begin{aligned}\sigma &= 160 \text{ N/mm}^2 \text{ for transverse structural members} \\ &= \text{as given for bottom longitudinals in Ch 6 Sec 3 Table 6.3.8} \\ \tau &= 90 \text{ N/mm}^2\end{aligned}$$

6.1.4. The strength of single bottom girders outside holds for liquid cargo may also be based on the requirements given in Sec [6.2].

6.2. Arrangement of single bottom girders outside holds for liquid cargo

6.2.1. If direct stress calculations of the single bottom girders are not carried out the following requirements may be applied.

6.2.2. The height (h) of centre girder and floors at centre line is not to be less than:

$$h = 250 + 20 B + 50 T_{ms} \quad (\text{mm})$$

6.2.3. Floors are to be fitted at every frame.

6.2.4. A center line girder is to be fitted.

6.2.5. Side girders are normally to have spacing not exceeding 2.5 m. Forward of 0.25 L from F.P, the spacing should not exceed 1.25 m.

6.3. Local scantlings

6.3.1. The flange area of floors and side girders with minimum height in accordance with Sec [6.2.2] is normally not to be less than:

$$\begin{aligned}3.5 T_{ms} \text{ (cm}^2\text{) in way of cargo holds and} \\ 5.0 T_{ms} \text{ (cm}^2\text{) in way of engine room.}\end{aligned}$$

When cement is filled to top of floors, the flange may be omitted in cargo holds.

6.3.2. Within 0.5 L amidships, the center girder flange area is not to be less than:

$$A = 0.6 L \text{ (cm}^2\text{)}$$

6.3.3 The flange area of side girders and center girder outside 0.5 L may be 80% of the value given in Sec [6.3.1] and Sec [6.3.2].

6.3.4 The minimum height of floors anywhere between the engine or gear girders is not to be less than 50% of the height given in Sec [6.2.2]. For this reduction the requirement for flange area given in Sec [6.3.1] is to be increased by 100% and the web thickness by 50%. For intermediate reduced heights the increase of flange area should be done correspondingly.

6.3.5 The thickness of web plates, flanges, brackets and stiffeners is generally not to be less than:

$$t = 6.0 + k L_1 \sqrt{k_m} + t_c \quad (\text{mm})$$

k

- = 0.04 for center girder in vessels with $L < 100$ m
- = 0.04 for center girder plating up to 2 m above keel plate in vessels with $L \geq 100$ m
- = 0.02 elsewhere in vessels with $L < 100$ m
- = 0.02 for other girders and remaining part of center girder plating in vessels with $L \geq 100$ m
- = 0.01 for stiffeners on girders on all vessels irrespective of length.

The thickness of girders is in addition not to be less than:

$$t = 15 s + t_c \quad (\text{mm})$$

s = web stiffener spacing, in m.

For thickness of top plate of seatings for main engine and reduction gear, Refer Ch 6 Sec 3 [3.3.4].

6.3.6 The thickness of the web plates is in addition to be checked for buckling according to Ch 14, with respect to in-plane compressive and shear stresses.

6.3.7 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. The width is not to be less than 1/20 of the distance between tripping brackets.

6.3.8 The end connections and stiffening of single bottom girder systems shall be as given in Ch 3 Sec 3.

SECTION 7 GIRDERS IN PEAKS

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7.1. General

- 7.1.1 The requirements outlined in this section are typically applicable for ships with $L \geq 100$ m except Sec [7.3.3]. For ships with $L < 100$ m, compliance with requirements outlined in Sec [7.2.2] and Sec [7.3.3] are normally required.

7.2. Arrangement

- 7.2.1 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.
- 7.2.2 In the after peak of single screw ships, the floors shall be of such a height that their upper edge is well above the stern tube.

7.3. Scantlings

- 7.3.1 The thickness of web plates, brackets and stiffeners is generally not to be less than:

$$t = 5.0 + k L_1 \sqrt{k_m} + t_c \quad (\text{mm})$$

- 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:

$$t = 12 s + t_c \quad (\text{mm})$$

s = stiffener spacing, in m.

- 7.3.2 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. The width is not to be less than $1/20$ of the distance between tripping brackets.

- 7.3.3 For vessels with $L < 100$ m, the thickness floors is in addition not to be less than:

$$t = 6.0 + 0.02 L + t_c \quad (\text{mm})$$

7.4. Details

- 7.4.1 Refer Ch 3 Sec 3 for end connections and stiffening of girders in general.
- 7.4.2 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 = as shown in Fig.6.7.1, in m, need not be taken greater than 5 m.
- 7.4.3 End brackets are to be provided to stiffeners on the floors and girders above the propeller (between the forward edge of the rudder and after end of propeller boss and within the diameter of propeller in transverse direction) in after peak tanks (not void spaces) as follows:

- When l_{s-t} exceeds 4 m, brackets shall be fitted at the both ends,
- When l_{s-t} exceeds 2.5 m. brackets shall be fitted at one end
- l_{s-t} = total length of stiffener as shown in Fig. 6.7.1, in m.

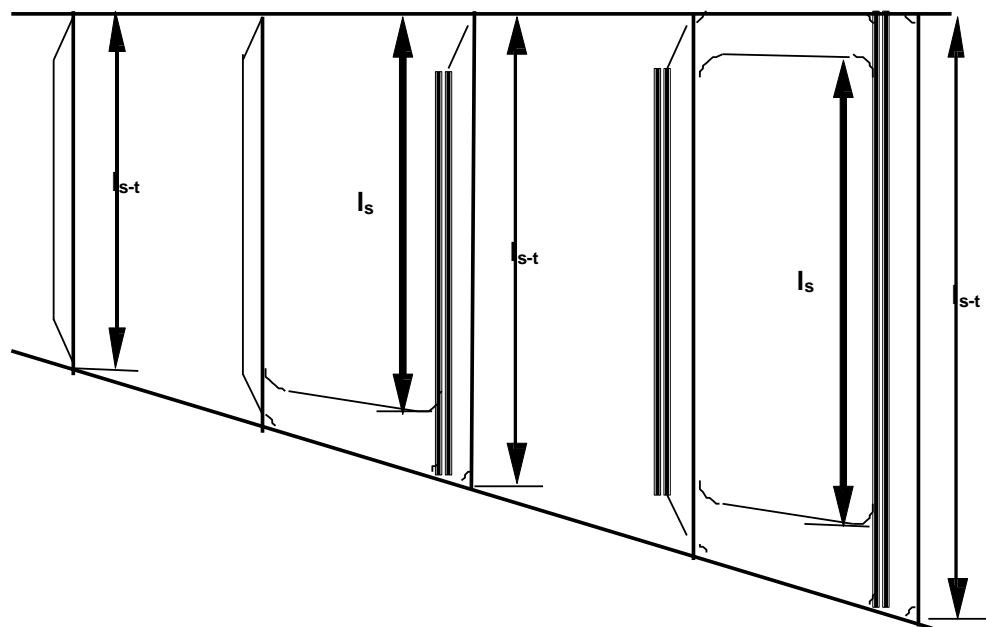


Figure 6.7.1: Stiffening of floors and girders in after peak tank

SECTION 8 SPECIAL REQUIREMENTS

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8.1. Bar keel

8.1.1. Where bar keels are fitted, the scantlings of the bar keel shall not be less than:

- Depth: $100 + 1.5 L$ (mm)
- Thickness: $10 + 0.6 L$ (mm)

8.2. Vertical struts

8.2.1. For vertical struts supporting the bottom and inner bottom longitudinals or frames, the sectional-area of the strut shall not be less than:

$$A = k l s T_{ms} k_m \quad (\text{cm}^2)$$

- k = 0.7 in way of ballast tanks
 = 0.6 elsewhere
 l = stiffener span, in m, disregarding the strut.

Refer Sec [1.2.1] of this chapter for the definitions of s , k_m and T_{ms}

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.

8.3. Strengthening against slamming for ships with $L < 100$ m

8.3.1. 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.

8.3.2. The flat part of the bottom forward may have to be strengthened against slamming. The slamming pressure head forward of $0.25 L$ from F.P. may be taken as:

$$h_{sl} = 24 \sqrt{L} \left(1 - \frac{20 d_b}{L} \right) \quad (\text{m})$$

d_b = design ballast draught in m at F.P.

Aft of $0.25 L$, the slamming pressure may be reduced linearly to zero at $0.45 L$ from F.P.

For ships with service restriction notations the strengthening will be specially considered.

8.3.3. If the bottom has a rise of floor greater than 15° , strengthening against slamming may be omitted.

8.3.4. The thickness of the bottom plating is not to be less than:

$$t = 2.85 s \sqrt{(h_{sl} k_m)} + t_c \quad (\text{mm})$$

8.3.5. Above the strengthened area, the thickness is to 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.

8.3.6. The section modulus of longitudinals or transverse stiffeners supporting the bottom plating defined in Sec [8.3.2] is not to be less than:

$$Z = 2.0 s h_{sl} l^2 w_c k_m \quad (\text{cm}^3)$$

- 8.3.7. If the ballast draught is less than 0.025 L, the following additional floors and longitudinal girders will be required in the slamming area:

Alternative 1: Floors at every frame. Additional side girders.

Alternative 2: Floors at every second frame, side girders at maximum spacing 1.5 m.

If the ballast draught is greater than 0.05 L, the floor and longitudinal girder arrangement should comply with the general rule requirements.

For intermediate draughts the floor and girder arrangement will need to be specially considered, especially with respect to shear areas of the webs.

The design ballast draught forward will be stated in the appendix to the classification certificate, wherever deemed necessary.

8.4. Strengthening against slamming for ships with $L \geq 100$ m

- 8.4.1. The bottom forward shall be strengthened according to the requirements provided in the below sub-sections. The strengthening will be specially considered for ships with service restriction notations.

- 8.4.2. 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.

- 8.4.3. The design slamming pressure head shall be taken as:

$$h_{sl} = \frac{c_1 c_2}{10 T_{BF}} B_B \left(0.56 - \frac{L}{1250} - \frac{x}{L} \right) \quad (\text{m})$$

$$c_1 = L^{\frac{1}{3}} \quad \text{for } 100 \text{ m} \leq L \leq 150 \text{ m}$$

$$c_1 = \left(225 - \frac{L}{2} \right)^{\frac{1}{3}} \quad \text{for } L > 150 \text{ m}$$

$$c_2 = 1675 \left(1 - \frac{20 T_{BF}}{L} \right)$$

T_{BF} = design ballast draught, in m, at F.P.

B_B = the breadth of the bottom in m at the height $0.15 T_{BF}$ 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

$$x_1 = \left[1.2 - (C_B)^{\frac{1}{3}} - \frac{L}{2500} \right] L$$

The assumed variation in design slamming pressure is shown in Fig.6.8.1.

8.4.4. The slamming pressure head (h_{sl}) may be reduced by $1.4 h$ (m) (where h is the height, in m, of the ballast tank), 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.

8.4.5. The thickness of the bottom plating below $0.05 T_{BF}$ from keel shall not be less than:

$$t = 2.85 k_a k_r s \sqrt{(h_{sl} k_m)} + t_c \quad (\text{mm})$$

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

h_{sl} = as given in Sec [8.4.3] or Sec [8.4.4].

Refer Sec [1.2.1] of this chapter for the definitions of s , k_m and k_a

8.4.6. The thickness may be gradually reduced to the ordinary requirement at side, above the area as specified in Sec [8.4.5]. For vessels with rise of floor, however, reduction will not be accepted below the bilge curvature.

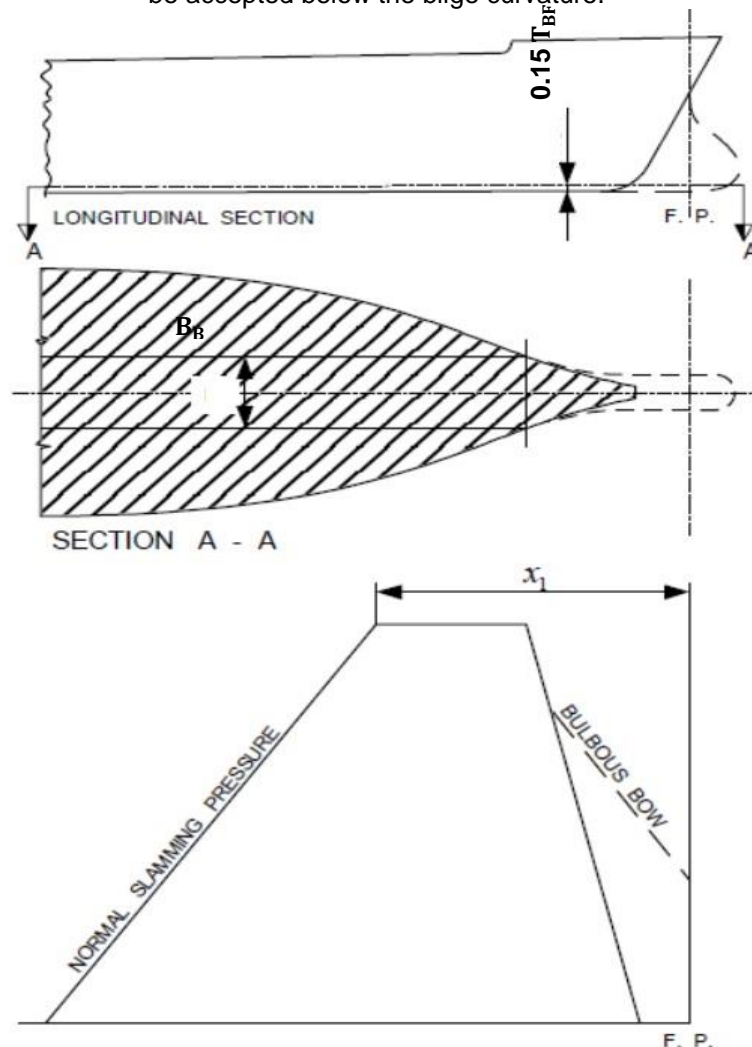


Figure 6.8.1: Design slamming pressure

- 8.4.7. The section modulus of longitudinals or transverse stiffeners supporting the bottom plating defined in Sec [8.4.5] and [Sec 8.4.6] shall not be less than:

$$Z = 1.5 s h_{sl} l^2 w_c k_m \quad (\text{cm}^3)$$

The shear area shall not be less than:

$$A_S = 0.3 (l - 0.5 s) s h_{sl} k_m + 10 h t_c \quad (\text{cm}^2)$$

h_{sl} = as given in Sec [8.4.3] or Sec [8.4.4].
 h = stiffener height, in m.

- 8.4.8. The net connection area of continuous stiffeners at girders shall satisfy the following expression:

$$\frac{1.7 A_F}{k_{mF}} + \frac{A_W}{k_{mW}} \geq \frac{2}{k_{mS}} (A_S - 10 h t_c)$$

A_F = connection area at flange, in cm^2
 A_W = connection area at web, in cm^2
 A_S = as given in [8.4.7] above
 k_{mF} = material factor k_m for top stiffener welded to flange
 k_{mW} = material factor k_m for shear connection
 k_{mS} = material factor k_m for the bottom stiffener.

- 8.4.9. In the bottom below $0.05 T_{BF}$, the spacing of stiffeners on web plates or bulkheads near the shell plating is not to exceed:

$$s_w = 0.09 t \quad (\text{m})$$

t = thickness of web or bulkhead plating, in mm.

- 8.4.10. The criteria in Sec 8.4.7 shall be also satisfied for the flanged primary members supporting stiffeners in part of the bottom, e.g. typical primary members in duct keel.

- 8.4.11. The sum of the products of shear area and the corresponding material factor k_m 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:

$$\sum_n \frac{A_{si}}{k_{m1i}} = c_3 l b h_{sl} \quad (\text{cm}^2)$$

A_{si} = shear area of end support member # i
 k_{m1i} = material factor k_m for end support member # i
 n = number of girders.

$$c_3 = 0.5 \left(1 - \frac{10 l b}{L B} \right); \text{ minimum } 0.25$$

h_{sl} = as given in Sec [8.4.3] or Sec [8.4.4].

l and b is the length and the breadth, in m, respectively of the loaded area supported by the girder or girder system. h_{sl} is taken at the middle of the girder system considered.

- 8.4.12. The design ballast draught forward will be stated in the appendix to the classification certificate, wherever deemed necessary.

**8.5. Strengthening for grab loading and discharging -
Optional class - special features notation IB (X)**

8.5.1. 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 Sec 8.5.3 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.

8.5.2. Application of the requirement given in [8.5.1] does not apply to vessels that are required to comply with rules conforming to Goal Based Standard (GBS).

8.5.3. The plate thickness shall not be less than:

$$t = 9.0 + 12 s \sqrt{k_m} + t_c \quad (\text{mm})$$

Refer Sec [1.2.1] of this chapter for the definitions of *s*.

8.6. Docking

8.6.1. The bottom scantlings required in this sub-section are considered to give ample strength for the safe docking of ships with length less than 120 meters and of normal design.

8.6.2. 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.

Remark:

Size and number of docking blocks should be estimated on the basis of a design pressure in blocks normally not exceeding 2 N/mm². With center 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.

CHAPTER 7 SIDE STRUCTURES

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SECTION 1 GENERAL

Contents

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1.1. Introduction

- 1.1.1. The requirements in this chapter are applicable to the side structures of a ship.
- 1.1.2. The formulae given for plating, stiffeners and girders are on the basis of structural design principles as specified in Ch 3 Sec 2. However, in most cases, 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.

The actual values of these parameters need to be chosen and inserted in the formulae, wherever relevant.

Direct stress calculations based on said structural principles and as specified in Ch 13 will be considered as an alternative basis for the scantlings.

1.2. Definitions

1.2.1. Symbols:

L	= rule length, in m ¹⁾
B	= rule breadth, in m ¹⁾
D	= rule depth, in m ¹⁾
T_{ms}	= rule draught, in m ¹⁾
C_B	= rule block coefficient ¹⁾
V	= maximum service speed, in knots, on draught T_{ms}
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
	$= \left(1.1 - 0.25 \frac{s}{l}\right)^2$
	= 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, Refer Ch 3 Sec 3 [3.1]. For curved stiffeners l may be taken as the cord length
S	= girder span, in m. For definition of span point, Refer Ch 3 Sec 3 [3.1].
w_c	= section modulus corrosion factor in tanks, Refer Ch 3 Sec 3 [3.10.5]
	= 1.0 in other compartments
σ	= nominal allowable bending stress in N/mm ² due to lateral pressure
h	= design pressure head, in m, as given in Sec 2.
k_m	= material factor. Refer Ch 2 Sec 2 and Ch 2 Sec 3
f_{2b}	= stress factor below the neutral axis of the hull girder as defined in Ch 6 Sec 1 [1.2.1]
f_{2d}	= stress factor below the neutral axis of the hull girder as defined in Ch 8 Sec 1 [1.2.1]
Z_A	= mid-ship section modulus, in cm ³ , as built, at deck or bottom respectively
Z_o	= rule mid-ship section modulus, in cm ³ , as given in Ch 5 Sec 3 [3.3.9]
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

Remarks:

1) For details -Refer Ch 1 Sec 2 [2.1.1]

1.2.2. The load point where the design pressure head acts shall be calculated for various strength members is defined as mentioned below:

- 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 head shall be taken as the greater of:

$$h_m \text{ and } \frac{h_a + h_b}{2}$$

h_m , h_a and h_b are the calculated pressure heads at midpoint and at each end respectively. Refer Fig. 7.1.1

- c) For girders: midpoint of load area.

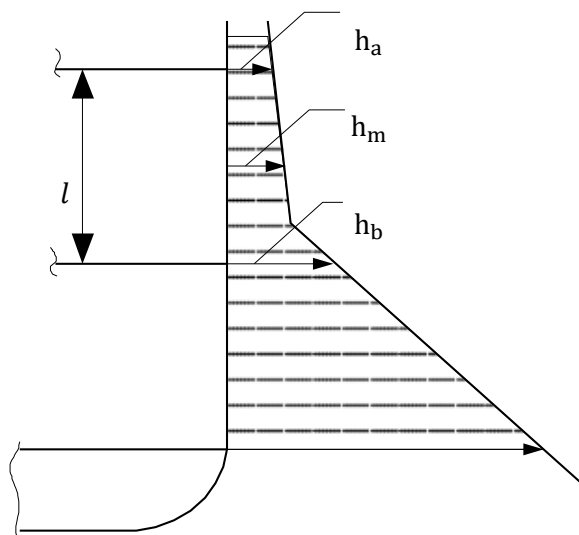


Fig. 7.1.1 Design pressure heads

1.2.3. The lower span of the side frame in way of longitudinally stiffened single bottom is defined as follows (Refer Fig.7.1.2):

$$l = l_2 - 0.3 r - 1.5 (h - a) \quad (\text{m})$$

- 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.

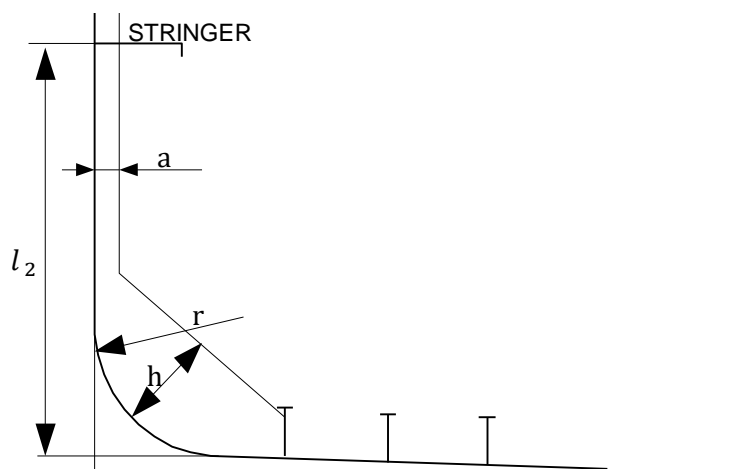


Fig. 7.1.2 Lower span of side frame

1.3. Documentation

- 1.3.1. Plans and particulars which have to be submitted for approval or information are specified in Ch 1 Sec 3.

1.4. Structural arrangement and details

- 1.4.1. The ship's side may be stiffened longitudinally or vertically.

Remark:

1) It is recommended that longitudinal stiffeners are used near bottom and strength deck in ships with length $L > 150$ m.

- 1.4.2. 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 side longitudinals shall be as required for bottom and deck longitudinals as outlined in Ch 6 and Ch 8 respectively.
- 1.4.3. Weld connections shall satisfy the general requirements given in Ch 11.
- 1.4.4. For end connections of stiffeners and girders, Refer Ch 3 Sec 3.

SECTION 2 DESIGN LOADS

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2.1. Local loads on side structures

- 2.1.1. All applicable general local loads on side structures, expressed in terms of corresponding design pressure heads, are given in Table 7.2.1 for ships with L less than 100 m and Table 7.2.2 for ships with L equal to or greater than 100 m, based upon the general loads given in Ch 4. In connection with the various local structures, reference is made to these tables, indicating the relevant loads in each case.

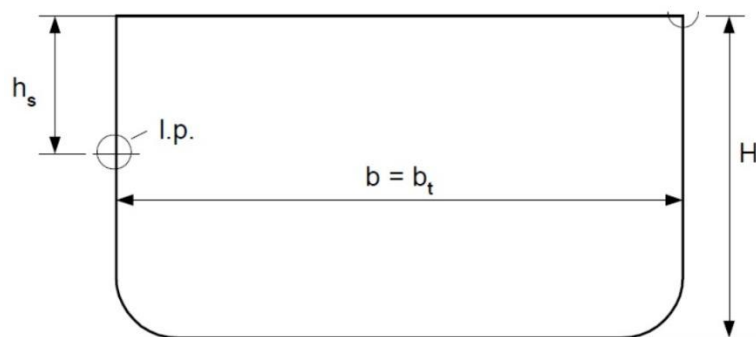
Table 7.2.1. Design loads for side structures for ships with L < 100 m	
Load type	Design pressure head h (m)
Sea pressure below summer load waterline	$h_1 = h_0 + h_{dp}^{(1)}$
Sea pressure above summer load waterline	$h_2 = (h_{dp} - \{(0.4 + 0.02 k_s)h_0\})^{(1)}$ minimum $0.625 + 0.0025 L$
Ballast, bunker or liquid cargo in side tanks, in general ^{(2) (3)}	$h_3 = k \frac{\rho}{\rho_w} h_s$ $h_4 = \frac{\rho}{\rho_w} h_s + h_{gen}$ $h_5 = 0.67 \left(\frac{\rho}{\rho_w} h_p + \Delta h_{dyn} \right)$ $h_6 = \frac{\rho}{\rho_w} (h_s + 0.3 b)$ $h_7 = \frac{\rho}{\rho_w} (h_s + 0.1 l)$
Remarks: 1) For ships with service restrictions, h_2 and the last term in h_1 may be reduced as given in Ch 3 Sec 2 Table 3.2.2. C_{wv} shall not be reduced for the calculation of last term in h_1 . 2) h_7 is to be applied for 25% of length of tank measured from the tank ends. 3) For partially filled tanks, Refer also Ch 9 Table 9.2.1	

Table 7.2.2. Design loads for side structures for ships with $L \geq 100$ m

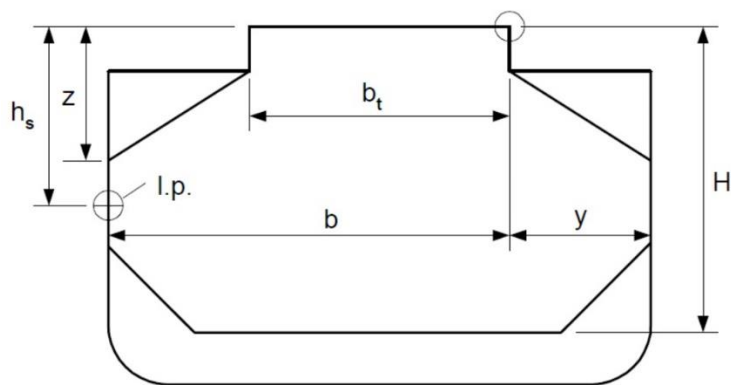
Load Type		Design pressure head h (m)
External	Sea pressure below summer load waterline	$h_1 = h_0 + h_{dp}^{(1)}$
	Sea pressure above summer load waterline	$h_2 = (h_{dp} - \{(0.4 + 0.02 k_s)h_0\})^{(1)}$ minimum $0.625 + 0.0025 L_1$
Internal	Ballast, bunker or liquid cargo in side tanks, in general	$h_3 = \frac{\rho}{\rho_w} \left(1 + \frac{0.5 a_{vert}}{g_0}\right) h_s - h_b$ $h_4 = \frac{\rho}{\rho_w} h_s + h_{gen} - h_b$ $h_5 = 0.67 \left(\frac{\rho}{\rho_w} h_p + \Delta h_{dyn}\right) - h_b$
	Above the ballast waterline at ballast, bunker or liquid cargo tanks with a breadth $> 0.4 B$	$h_6 = \frac{\rho}{\rho_w} \left[0.67 (h_s + \phi b) - 0.12 \sqrt{H b_{top} \phi}\right]$
	Above the ballast waterline and towards ends of tanks for ballast, bunker or liquid cargo with length $> 0.15 L$	$h_7 = \frac{\rho}{\rho_w} \left[0.67 (h_s + \theta l) - 0.12 \sqrt{H l_{top} \theta}\right]$
	In tanks with no restriction on their filling height ⁽²⁾	$h_8 = \frac{\rho}{\rho_w} \left(0.306 - \frac{B}{981}\right) b_b$
Remarks: 1) For ships with service restrictions, h_2 and the last term in h_1 may be reduced as given in Ch 3 Sec 2 Table 3.2.2. C_{wv} shall not be reduced for the calculation of last term in h_1 . 2) For tanks with free breadth $b_s > 0.56 B$, the design pressure heads will be specially considered according to Ch 4 Sec 3 [3.3.5]		

The definition of parameters used in the above formulations contained in Table 7.2.1 and Table 7.2.2 is as follows:

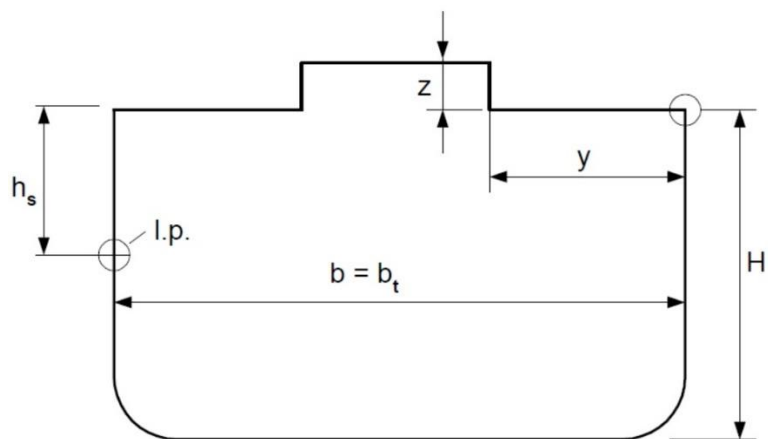
a_{vert}	= for use in Table 7.2.2; vertical acceleration as given in Ch 4 Sec 2 [2.6], taken in the centre of gravity of the tank
ϕ	= for use in Table 7.2.2; roll angle in radians as given in Ch 4 Sec 2 [2.3]
θ	= for use in Table 7.2.2; pitch angle in radians as given in Ch 4 Sec 2 [2.4]
ρ_w	= as given in Ch 4 Sec 1 [1.2]
ρ	= density of ballast, bunker or liquid cargo in t/m^3 , normally not to be taken less than 1.025 t/m^3
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
H	= for use in Table 7.2.2; height, in m, of the tank
b	= for use in Table 7.2.1; breadth of the tank, in m = for use in Table 7.2.2; the largest athwartship distance, in m, from the load point to the tank corner at top of the tank / hold most distant from the load point. Refer Fig. 7.2.1
l	= for use in Table 7.2.1; total length of tanks, in m = for use in Table 7.2.2; the largest longitudinal distance, in m, from the load point to the tank corner at top of the tank most distant from the load point.
b_{top}	= for use in Table 7.2.2; breadth, in m, of top of tank / hold
l_{top}	= for use in Table 7.2.2; length, in m, of top of tank
b_b	= for use in Table 7.2.2; distance, in m, between tank sides or effective longitudinal wash bulkhead at the height at which the strength member is located.
L_1	= ship length, need not be taken greater than 300 m
h_{gen}	= $(0.03 L - 0.5) \text{ m}$, minimum 1 m, in general (for use in Table 7.2.1) = 2.5 m, in general (for use in Table 7.2.2) = 2.5 m, in cargo tanks (for use in Table 7.2.1) = 1.5 m, in ballast holds of dry cargo vessels (for use in Table 7.2.2) = pressure head corresponding to tank pressure valve opening pressure when exceeding the general value (for use in Table 7.2.1 and Table 7.2.2)
Δh_{dyn}	= as given in Ch 4 Sec 3 [3.3.2]
h_{dp}, k_s	= as given in Ch 4 Sec 3 [3.2.1]
h_0	= vertical distance, in m, from the waterline at draught T_{ms} to the load point
T_{ms}	= rule draught, in m
h_b	= for use in Table 7.2.2; vertical distance, in m, from the load point to the minimum design draught, which may normally be taken as $0.35 T_{\text{ms}}$ for dry cargo vessels and $2 + 0.02 L$ for tankers. For load points above the ballast waterline $h_b = 0$
k	= for use in Table 7.2.1; 1.3 aft of $0.2 L$ from F.P. = 1.5 within $0.2 L$ from F.P.



RECTANGULAR TANK SHAPE



STEPPED CONTOUR
($z/y < \varphi$)



STEPPED CONTOUR
($z/y < \varphi$)

Fig. 7.2.1 Tank shapes

SECTION 3 PLATING AND STIFFENERS

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3.1. Side plating, general

3.1.1. The thickness requirement corresponding to lateral pressure is given by the formula:

$$t = \frac{49.96 k_a s \sqrt{h}}{\sqrt{\sigma}} + t_c \quad (\text{mm})$$

- h = h₁ to h₇, whichever is relevant, in Table 7.2.1 for vessels with L < 100 m
 = h₁ to h₈, whichever is relevant, in Table 7.2.2 for vessels with L ≥ 100 m
 σ = as given in Table 7.3.1 for vessels with L < 100 m
 = as given in Table 7.3.2 for vessels with L ≥ 100 m

The definition of the parameters used in the above equation is given in Sec [1.2] of this chapter.

3.1.2. The thickness in any region of the ship is not to be less than:

$$t = 5.0 + k L_1 \sqrt{k_m} + t_c \quad (\text{mm})$$

- 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 for vessels with L ≥ 100 m and k (minimum) = 0 for vessels with L < 100 m]
 = 0.06 for plating connected to the stern frame for all vessels irrespective of length

The definition of the parameters used in the above equations is given in Sec [1.2] of this chapter.

3.1.3. The thickness of the side plating between a section aft of amidships where the breadth at the load waterline exceeds 0.9 B and a section forward of amidships where the load waterline breadth exceeds 0.6 B, and taken from the lowest ballast waterline to 0.25 T_{ms} (minimum 2.2 m) above the summer load line, shall not be less than:

$$t = 31 (s + 0.7) \left(\frac{B T_{ms}}{\sigma_f^2} \right)^{\frac{1}{4}} + t_c \quad (\text{mm})$$

- σ_f = minimum yield stress in N/mm² as given in Ch 2 Sec 2 [2.2.1].

3.1.4. The side plating thickness is also to satisfy the buckling strength requirements given in Ch 14, taking into account also the combination of shear and compressive in-plane stresses, where relevant.

3.1.5. In cases where the end bulkhead of a superstructure is located within 0.5L amidships, the side plating shall be given a smooth transition to the sheer strake below.

Table 7.3.1. Values of σ for vessels with $L < 100$ m

<i>Stiffening type</i>	<i>Allowable stress σ ⁽¹⁾</i>
Transverse stiffening	$\frac{120}{k_m}$; within 0.4 L at neutral axis $60 \frac{Z_A}{Z_R}$; maximum $\frac{120}{k_m}$; within 0.4 L at deck or bottom $\frac{160}{k_m}$; within 0.1 L from the perpendiculars
Longitudinal stiffening	$\frac{140}{k_m}$; within 0.4 L at neutral axis $\frac{120}{k_m}$; within 0.4 L at deck or bottom $\frac{160}{k_m}$; within 0.1 L from the perpendiculars
Remarks: 1) Between specified regions, the σ -value may be varied linearly.	

Table 7.3.2. Values of σ for vessels with $L \geq 100$ m

<i>Stiffening type</i>	<i>Allowable stress σ ^{(1) (2)}</i>
Transverse stiffening	$\frac{120}{k_m}$; within 0.4 L at neutral axis $\frac{160}{k_m}$; within 0.05 L from F. P and 0.1 L from A. P
Longitudinal stiffening	$\frac{140}{k_m}$; within 0.4 L at neutral axis $\frac{160}{k_m}$; within 0.05 L from F. P and 0.1 L from A. P
Remarks: 1) Between specified regions, the σ -value may be varied linearly. 2) 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 k_m as for the plating considered.	

3.2. Sheer strake at strength deck

3.2.1. The breadth shall not be less than:

$$b = 800 + 5 L \quad (\text{mm}), \text{maximum } 1800 \text{ mm}$$

3.2.2. 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 .

3.2.3. 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.

3.2.4. When radius of curvature is less than 15 t, cold rolling and bending of rounded sheer strakes are not acceptable.

3.2.5. When it is intended to use hot forming for rounding of the sheer strake, all the 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.

3.2.6. The welding of deck fittings to rounded sheer strakes shall be kept to a minimum within 0.6 L amidships. However, subject to surveyor's consent, such welding may be carried out provided:

- When cold formed, the material is of grade D or a grade with higher impact toughness.
- The material is hot formed in accordance with Sec [3.2.5].

The weld joints shall be subjected to magnetic particle inspection.

The design of the fittings shall be such as to minimize stress concentrations, with a smooth transition towards deck level.

3.2.7. In cases where the sheer strake extending 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.

3.2.8. In general, bulwarks are 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.

3.3. Longitudinals

3.3.1. The section modulus requirement is given by:

$$Z = \frac{830 s h l^2 w_c}{\sigma} \quad (\text{cm}^3), \quad \text{minimum } 15 \text{ cm}^3$$

- h = h₁ to h₇, whichever is relevant, in Table 7.2.1 for vessels with L < 100 m
 = h₁ to h₈, whichever is relevant, in Table 7.2.2 for vessels with L ≥ 100 m
 σ = as given in Table 7.3.3 for vessels with L < 100 m
 = as given in Table 7.3.4 for vessels with L ≥ 100 m

The definition of the parameters used in the above equation is given in Sec [1.2] of this chapter.

- 3.3.2. The thickness of web and flange shall not be less than the larger of:

$$t = 4.5 + k' + t_c \quad (\text{mm})$$

$$= 1.5 + \frac{h_w}{g \sqrt{k_m}} + t_c \quad (\text{mm})$$

- k' = 0.01 L₁ in general
 = 0.015 L₁ 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.

- 3.3.3. Longitudinals supported by side verticals subject to relatively large deflections shall be checked by a direct strength calculation, Refer Ch 13 Sec 3. Increased bending stresses at transverse bulkheads shall be evaluated and may be absorbed by increased end brackets.

- 3.3.4. The buckling strength of longitudinals shall be checked according to Ch 14.

Table 7.3.3. Values of σ for vessels with L < 100 m	
Member type	Allowable stress σ ⁽¹⁾
Side longitudinals	$\frac{95}{k_m}$; within 0.4 L at deck or bottom when Z _A = Z _R
	$\frac{160}{k_m}$; within 0.4 L at deck or bottom when Z _A ≥ 2 Z _R
	$\frac{160}{k_m}$; within 0.25 D above and below the neutral axis
	$\frac{160}{k_m}$; within 0.1 L from the perpendiculars
Remarks:	
1) Between specified regions, the σ-value may be varied linearly.	
2) Z _A and Z _R are defined in Sec [1.2] of this chapter.	

Table 7.3.4. Values of σ for vessels with $L \geq 100$ m

Member type	Allowable stress σ ^{(1) (3)}
Side longitudinals	$\frac{225}{k_m} - 130 f_2 \left(\frac{z_n - z_a}{z_n} \right), \text{ maximum } \frac{160}{k_m}; \text{ within } 0.4 L \text{ amidships}$ $\frac{160}{k_m}; \text{ within } 0.1 L \text{ from the perpendiculars}$
Remarks: 1) Between specified regions, the σ -value may be varied linearly. 2) f_2 = stress factor f_{2b} below the neutral axis, as specified in Sec [1.2] of this chapter. = stress factor f_{2d} above the neutral axis, as specified in Sec [1.2] of this chapter. 3) For longitudinals $\sigma = 160 / k_m$ may be used in any case in combination with heeled condition pressure heads h_6 and h_8 as specified in Table 7.2.2 4) z_n and z_a are taken as defined in Sec [1.2] of this chapter.	

3.4. Main frames

3.4.1. Main frames are frames which are 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.

3.4.2. For vessels with $L \geq 100$ m, the section modulus requirement is given by:

$$Z = C s h l^2 w_c k_m \quad (\text{cm}^3)$$

- h = h_1 to h_8 , whichever is relevant, in Table 7.2.2 for vessels with $L \geq 100$ m
 C = 3.7 when external pressure head (h_1 to h_2) is used
 = 4.3 when internal pressure head (h_3 to h_8) is used
 l = corresponding to full length or span of frame including brackets.

3.4.3. For vessels with $L < 100$ m, the section modulus requirement is given by the greater of:

$$Z = 5.0 s h l^2 w_c k_m \quad (\text{cm}^3) \text{ and}$$

$$Z = 6.5 \sqrt{L} k_m \quad (\text{cm}^3)$$

- h = h_1 to h_7 , whichever is relevant, in Table 7.2.1 for vessels with $L < 100$ m
 l = full length or span of frame including brackets.

3.4.4. The thickness of web and flange shall meet the requirements specified in Sec [3.3.2].

3.4.5. The requirement given in Sec [3.4.2] and Sec [3.4.3] 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.

For vessels with $L \geq 100$ m, the section modulus of frame, including bracket, at frame ends shall not be less than the requirements given in Sec [3.4.2] with l equal to total span of frame including brackets and applying C -factors as mentioned below.

Upper end:

$C = 5.6$ when external pressure head (h_1 to h_2) is used

$C = 6.4$ when internal pressure head (h_3 to h_8) is used

Lower end:

$C = 7.4$ when external pressure head (h_1 to h_2) is used

$C = 8.6$ when internal pressure head (h_3 to h_8) is used

In single deck vessels, for 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.

For vessels with $L < 100$ m, the section modulus of frame, including bracket is not to be less than:

- 2 Z at lower end
- 1.7 Z at upper end

$Z =$ as specified in Sec [3.4.3]

For all vessels irrespective of length, 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.

- 3.4.6. Brackets may be omitted provided the frame is carried through a supporting member and the section modulus as given in Sec [3.4.2] or Sec [3.4.3], as applicable, is increased by 50% and inserting total span in the formula.
- 3.4.7. The section modulus for a main frame shall not be less than that for the 'tween deck frame above.
- 3.4.8. Frames at hatch end beams shall be reinforced for ships without top wing tank to withstand the additional bending moment from the deck structure.
- 3.4.9. For vessels with $L \geq 100$ m, main frames made of angles or bulb profiles having a span of l more than 5 m shall be supported by tripping brackets at the middle of the span. For areas forward of 0.15 L from F.P, Refer also Sec 5 [5.1] of this chapter.

3.5. Tween deck frames and vertical peak frames

- 3.5.1. 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.
- 3.5.2. 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, Refer also Ch 3 Sec 3 [3.2].

3.5.3. The section modulus shall not be less than the greater of:

$$Z = 5.5 s h l^2 w_c k_m \quad (\text{cm}^3) \quad \text{and}$$

$$Z = k \sqrt{L k_m} \quad (\text{cm}^3)$$

k = 6.5 for peak frames

= 4.0 for 'tween deck frames

h = h_1 to h_7 , whichever is relevant, in Table 7.2.1 for vessels with $L < 100$ m

= h_1 to h_8 , whichever is relevant, in Table 7.2.2 for vessels with $L \geq 100$ m

3.5.4. The thickness of web and flange shall meet the requirements specified in Sec [3.3.2].

3.5.5. For vessels with $L < 100$ m, the requirement for section modulus given in Sec [3.5.3] may be modified as for main frames specified in Sec [3.4.3] provided effective brackets as given in Sec [3.4.5] are fitted at both ends.

SECTION 4 GIRDERS

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4.1. General

- 4.1.1. The thickness of web plates, flanges, brackets and stiffeners of girders shall not be less than:

$$t = 5.0 + k \sqrt{k_m} + t_c \quad (\text{mm})$$

- k = 0.01 L₁ in general
 = 0.02 L₁ for girder webs, flanges and brackets in cargo oil tanks and ballast tanks in cargo area
 = 0.03 L₁ (= 6.0 maximum) for girder webs, flanges and brackets in peaks.

The thickness of girder web plates in single skin construction, in addition, is not to be lesser than:

$$t = 12 s + t_c \quad (\text{mm})$$

s = web stiffener spacing, in m.

- 4.1.2. The buckling strength of web plates which are subjected to in- plane compressive and shear stresses shall be checked according to Ch 14.
- 4.1.3. In the aft peak, engine and boiler room, side verticals are normally to be fitted at every 5th frame.
- 4.1.4. Verticals in the engine room and verticals less than 0.1 L from the perpendiculars shall have a depth not less than:

$$h = 2 L S \quad (\text{mm}) ; \text{ maximum } 200 S$$

L and S are defined in Sec 1.2 of this chapter.

Verticals with moment of inertia equivalent to a girder with height h and flange breadth in accordance with Sec [4.1.5] are also acceptable. If the side verticals are fitted closer than required by Sec [4.1.3], the required moment of inertia may be reduced correspondingly.

- 4.1.5. 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).

- 4.1.6. The transverse bulkheads or the side verticals with deck transverses shall be fitted in the 'tween deck spaces to ensure adequate transverse rigidity.
- 4.1.7. Vertical peak frames shall be supported by stringers or perforated platforms at a vertical distance not exceeding $[2.25 + L/400]$ (m).
- 4.1.8. The arrangements of end connections and stiffening of girders shall be as given in Ch 3 Sec 3. Stiffeners on girders in the after peak shall have end connections.

4.2. Simple girders

- 4.2.1 The required section modulus is given by :

$$Z = \frac{1000 b h S^2 w_c}{\sigma} \quad (\text{cm}^3)$$

- h = h_1 to h_4 as given in Table 7.2.1 and Table 7.2.2 for vessels with $L < 100$ m and $L \geq 100$ m respectively.
= $1.15 h_5$ as given in Table 7.2.1 and Table 7.2.2 for vessels with $L < 100$ m and $L \geq 100$ m respectively.
= h_6 to h_7 whichever is relevant as given in Table 7.2.1 for vessels with $L < 100$ m
= h_6 to h_8 whichever is relevant as given in Table 7.2.2 for vessels with $L \geq 100$ m
b = loading breadth, in m
 σ = as given in Table 7.4.1 for vessels with $L < 100$ m
= as given in Table 7.4.2 for vessels with $L \geq 100$ m

The above requirement applies about any axis parallel to that of ship's side.

4.2.2 The web area requirement (after deduction of cut-outs) at the girder ends is given by:

$$A = k S b h k_m + 10 h_g t_c \quad (\text{cm}^2)$$

- k = 0.6 for continuous horizontal girders and upper end of vertical girders
= 0.8 for lower end of vertical girders
b = as given in Sec 4.2.1
 h_g = girder height, in m
h = h_1 to h_7 whichever is relevant as given in Table 7.2.1 and Table 7.2.2 for vessels with $L < 100$ m and $L \geq 100$ m respectively.

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.

The requirement shall be increased for oblique angles by the factor $1 / \cos \theta$, where θ is the angle between the web plate of the girder and the perpendicular to the ship's side.

Table 7.4.1. Values of σ for vessels with $L < 100$ m

Member type	Allowable stress σ
Simple girders	For continuous longitudinal girders ⁽¹⁾ :
	$\frac{95}{k_m}$; within 0.4 L at deck or bottom when $Z_A = Z_R$
	$\frac{160}{k_m}$; within 0.4 L at deck or bottom when $Z_A \geq 2 Z_R$
	$\frac{160}{k_m}$; within 0.25 D above and below the neutral axis
	$\frac{160}{k_m}$; within 0.1 L from the perpendiculars
	For other girders:
	$\frac{160}{k_m}$
Remarks:	
1) Between specified regions, the σ -value may be varied linearly.	
2) Z_A and Z_R are defined in Sec 1.2 of this chapter.	

Table 7.4.2. Values of σ for vessels with $L \geq 100$ m	
Member type	Allowable stress σ ^{(1) (3)}
Simple girders	<p>For continuous longitudinal girders:</p> $\frac{190}{k_m} - 130 f_2 \left(\frac{z_n - z_a}{z_n} \right), \text{ maximum } \frac{160}{k_m}; \text{ within } 0.4 L \text{ amidships}$ $\frac{160}{k_m}; \text{ within } 0.1 L \text{ from the perpendiculars}$
	<p>For other girders:</p> $\frac{160}{k_m}$
<p>Remarks:</p> <p>1) Between specified regions, the σ-value may be varied linearly.</p> <p>2) f_{2b} = stress factor f_{2b} below the neutral axis, as specified in Sec [1.2] of this chapter. = stress factor f_{2d} above the neutral axis, as specified in Sec [1.2] of this chapter.</p> <p>3) For longitudinal girders $\sigma = 160 / k_m$ may be used in any case in combination with heeled condition pressure heads h_6 and h_8 as specified in Table 7.2.2</p> <p>4) z_n and z_a are taken as defined in Sec [1.2] of this chapter.</p>	

4.3. Complex girder systems

4.3.1 In addition to fulfilling the general local requirements given in Sec [4.1], the main scantlings of girders being parts of a complex system may have to be based on a direct stress analysis as outlined in Ch 13.

4.4. Cross ties

4.4.1 The buckling strength shall satisfy the requirements given in Ch 14.

4.4.2 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.

4.4.3 Side verticals may be regarded as individual simple girders between cross ties, provided effective cross ties, as defined in Sec [4.4.2], are positioned as follows:

- Side verticals with 1 cross tie:
 The cross tie is located $0.36 l$ to $0.5 l$ from the lower end.

- Side verticals with 2 cross ties:

The lower cross tie is located $0.21\ l$ to $0.30\ l$ from the lower end.

The upper cross tie is located $0.53\ l$ to $0.58\ l$ 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.

SECTION 5 SPECIAL REQUIREMENTS

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5.1. Strengthening against bow impact

5.1.1. The bow region referred in this section is normally to be taken as the region forward of a position 0.1L abaft F.P. and above the summer load waterline.

5.1.2. The effect of bow impact loads is in general to be evaluated for all ships. Normally strengthening is required only for ships with well-rounded bow lines and / or flare.

The impact pressure given in Sec [5.1.3] 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.

5.1.3. The design bow impact pressure head be taken as:

$$h_{sl} = C (2.2 + C_f) (0.4 V \sin \beta + 0.6 \sqrt{L})^2 \quad (\text{m})$$

- C = $0.018 (C_{WV} - 0.5 h_o)$; maximum 0.1
 C_{WV} = wave coefficient as given in Ch 4 Sec 2 [2.2]
 h_o = vertical distance (m) from the waterline at draught T_{ms} 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, Ch 4 Sec 2
 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. 7.5.1, 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.

5.1.4. The thickness of shell plating in the bow region shall not be less than:

$$t = \frac{43.64 k_a s \sqrt{h_{sl}}}{\sqrt{\sigma_f}} + t_c \quad (\text{mm})$$

- k_a = $(k_{a1} - 0.25 k_{a2})^2$
 k_{a1} = 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_{a1} 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/mm², and shall not be taken less than the limit to the yield point given in Ch 2 Sec 2 [2.2.1]
 h_{sl} = as given in Sec [5.1.3]

s = stiffener spacing, in m.

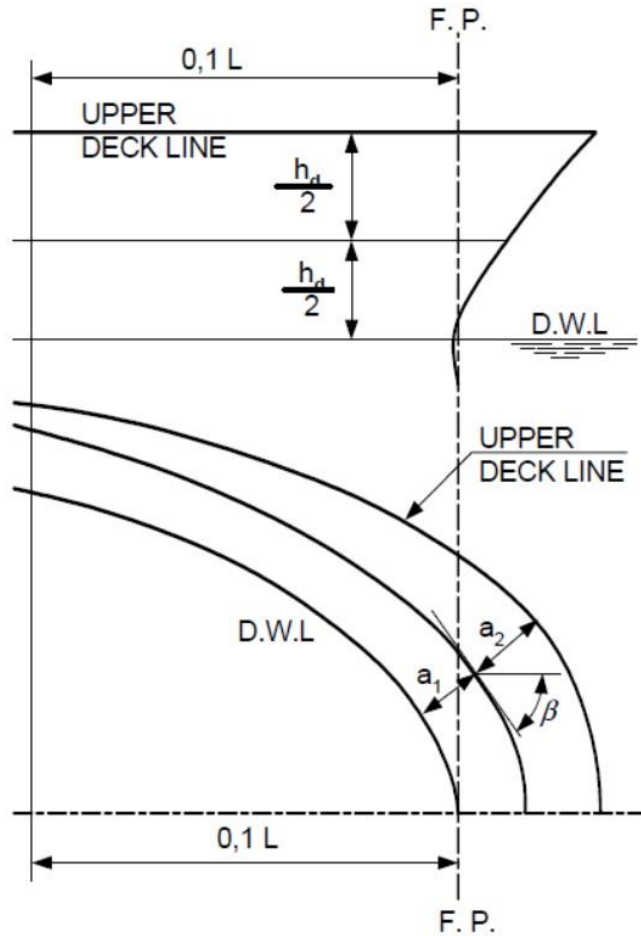


Fig. 7.5.1 Bow region

5.1.5. The net effective shear area A_{sa} , as defined in Ch 3 Sec 3 [3.10.6], of stiffeners supporting the shell plating in the bow region shall not be less than A_s , as given below:

$$A_s = \frac{125 \, l \, s \, h}{\sigma_f} \quad (\text{cm}^2)$$

l = stiffener span, in m, as given in Ch 7 Sec 1 [1.2.1]

h = $0.5 \, h_{sl}$, but is not to be taken less than $2 \, h_2$ as given in Table 7.2.1 and Table 7.2.2 for vessels with $L < 100 \, \text{m}$ and $L \geq 100 \, \text{m}$ respectively.

h_{sl} = as given in Sec [5.1.3]

σ_f = as defined in Sec [5.1.4].

The net effective plastic section modulus for the stiffener fitted, Z_{pa} , as determined according to in Ch 3 Sec 3 [3.10.6], is not to be less than Z_p , given below:

$$Z_p = \frac{1600 \, s \, l^2 \, h}{\left(1 + \frac{n_s}{2}\right) \sigma_f} + \frac{n_2 \left(1 - \sqrt{1 - \left(\frac{A_s}{A_{sa}}\right)^2}\right) \sin \varphi_w \, h_w \, (h_w + t_p) \, (t_w - t_c)}{8000} \quad (\text{cm}^3)$$

- l = stiffener span, in m, as given in Ch 7 Sec 1 [1.2.1]
 n_s = number of bending effective end supports of stiffener
= 2, 1 or 0 (Refer remark)
 A_s = as given above
 A_{sa} = net effective web area in cm² of the stiffener fitted, as determined in accordance with Ch 3 Sec 3 [3.10.6].
 φ_w = angle between stiffener web and shell plate

h_w, t_p, t_w, t_c are as defined in Ch 3 Sec 3 [3.10.6] for the stiffener fitted.

Remark:

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.

- 5.1.6. Outside the bow region the requirements, as calculated in Sec [5.1.4] and Sec [5.1.5], 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 degrees, the bow region in Sec [5.1.1] is extended to 0.15 L from F.P. with gradually decrease to 0.2 L from F.P.

- 5.1.7. The web thickness of shell stiffeners or breast hooks, stringers and web frames in lieu of shell stiffeners shall not be less than:

$$t_w = 0.054 \left(\frac{h s h_w^2}{\sin \varphi_w} \right)^{0.33} + t_c \quad (\text{mm})$$

- h = as given in Sec [5.1.5]
 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.

- 5.1.8. 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:

$$a = \sum_n 0.01 k_\tau (t_i - t_c) h_i \quad (\text{cm}^2)$$

- 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_0 , given by:

$$a_0 = \frac{95 (l_1 + l_2 - s) s h}{\sin \varphi_w \sigma_f} \quad (\text{cm}^2)$$

Where

- l_1, l_2 = the full length of the stiffener to the adjacent primary member supports, Refer Fig.7.5.2
 h = $0.5 h_{sl}$
 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:

$$t_w = \frac{(t_i - t_c) a_0 \sigma_f k_w}{450 a} + 0.5 t_c$$

k_w = as given in Ch 11 Sec 3 [3.1.3].

The end brackets of shell stiffeners are to be arranged with flange or edge stiffener in accordance with Ch 3 Sec 3 [3.2].

- 5.1.9. 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 Sec [5.1.11].

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.

- 5.1.10. 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:

$$t = \frac{10 f_p f_s h s_b}{\sin \varphi_w \sigma} - t_s + t_c \quad (\text{mm})$$

- f_p = $(h_w - h_p) / h_w$
 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_w = 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 centerline and need not be taken larger than the length h_m . Refer also Fig.7.5.2 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 midpoint 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. Refer also Fig.7.5.2 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 Ch 14 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 Sec [5.1.4].
- h = as given in Sec [5.1.5].
- 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.

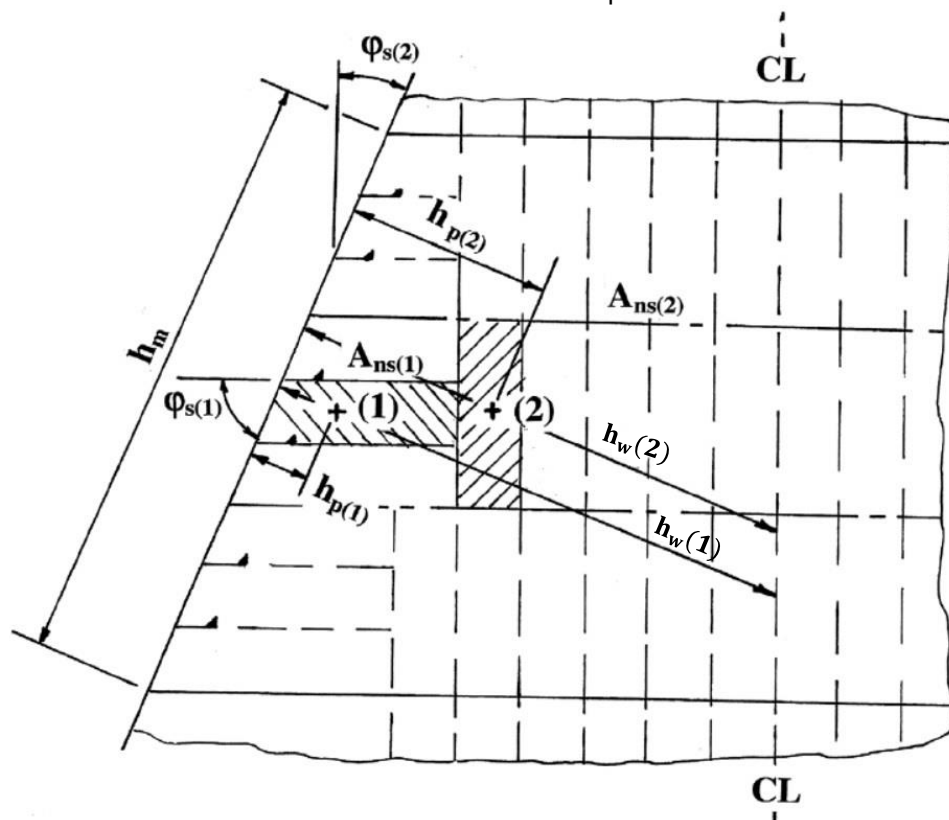


Fig. 7.5.2 Deck supporting shell frames

5.1.11. The section modulus of primary members supporting shell stiffeners (i.e. stringers and web frames) shall not be less than:

$$Z = \frac{1100 S^2 b h w_c}{\sin \varphi_w \sigma_f} \quad (\text{cm}^3)$$

The web area at each end support of primary members supporting shell stiffeners shall not to be less than:

$$A = \frac{125 n s b h}{\sin \varphi_w \sigma_f} + \frac{h_g t_c}{100} \quad (\text{cm}^2)$$

- b = breadth of load area supported by the stringer or web frame, in m
 = $0.5 (l_1 + l_2)$, Refer Fig.7.5.4.
 h_g = girder height, in mm
 n = number of stiffeners located within the span length S
 s = spacing of shell stiffeners, in m, as defined in Ch 7 Sec 1, [1.2.1]
 S = span of stringer or web frame as given in Ch 7 Sec 1, [1.2.1]
 φ_w = angle between web and shell plate, Refer Fig.7.5.3
 h = $0.4 h_{sl}$, but is not to be taken less than $2 h_2$ as given in Table 7.2.1 and Table 7.2.2 for vessels with $L < 100$ m and $L \geq 100$ m respectively.
 h_{sl} = as given in Sec [5.1.3]
 σ_f = as defined in Sec [5.1.4].

At the end supports of primary members supporting shell stiffeners, the shear and axial stress response of the web shall be assessed with respect to web buckling in accordance with Ch 14. In the assessment of the primary member, the shear stress, of the web plate may be taken as:

$$\tau = \frac{6000 n s b h}{\sin \varphi_w h_g (t_w - t_c)} \quad (\text{N/mm}^2)$$

The normal stress of the web plate at the face plate may be assumed given by:

$$\sigma = \frac{1000 S^2 b h w_c}{\sin \varphi_w Z_f} \quad (\text{N/mm}^2)$$

- 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.

GIRDER

φ_w

STIFFENER

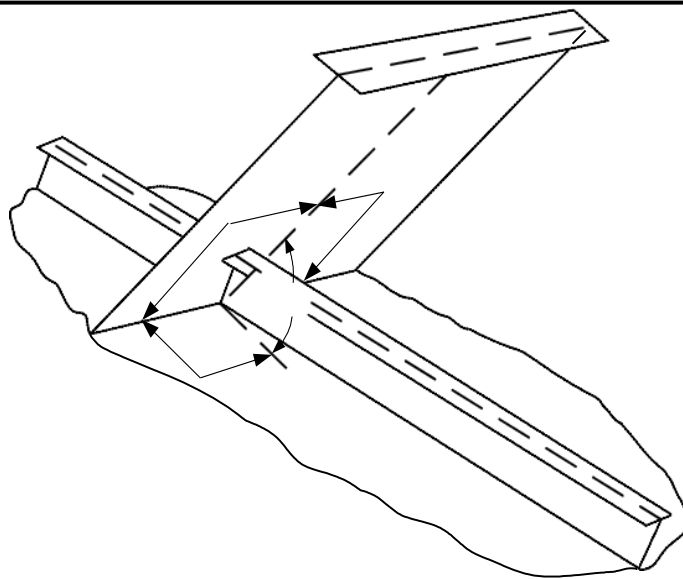


Fig. 7.5.3 The web angle φ_w of stringers and web frames

5.1.12. 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:

$$a = \sum_n 0.01 k_\tau (t_i - t_c) h_i \quad (\text{cm}^2)$$

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_0 , given by:

$$a_0 = \frac{95 (n_1 + n_2) s l h}{\sin \varphi_w \sigma_f} \quad (\text{cm}^2)$$

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, Refer Fig.7.5.4
- h = $0.4 h_{sl}$
- 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:

$$t_w = \frac{(t_i - t_c) a_0 \sigma_f k_w}{450 a} + 0.5 t_c$$

k_w = as given in Ch 11 Sec 3 [3.1.3].

End brackets of stringers and web frames shall be arranged with edge stiffener in accordance with Ch 3 Sec 3 [3.2].

- 5.1.13. Alternative to the requirements in Sec [5.1.10] and Sec [5.1.11], 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 head = $0.375 h_{sl}$ is generally to be assumed. This pressure head 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 Ch13, Sec 2[2.4.3] shall not exceed the yield stress, σ_f , as given in Sec [5.1.4] 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 Ch 14 Sec 2 [2.4] and Ch 14 Sec 2 [2.5], may be taken equal to 1.0.

h_{sl} = as given in Sec [5.1.3].

Remark:

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.

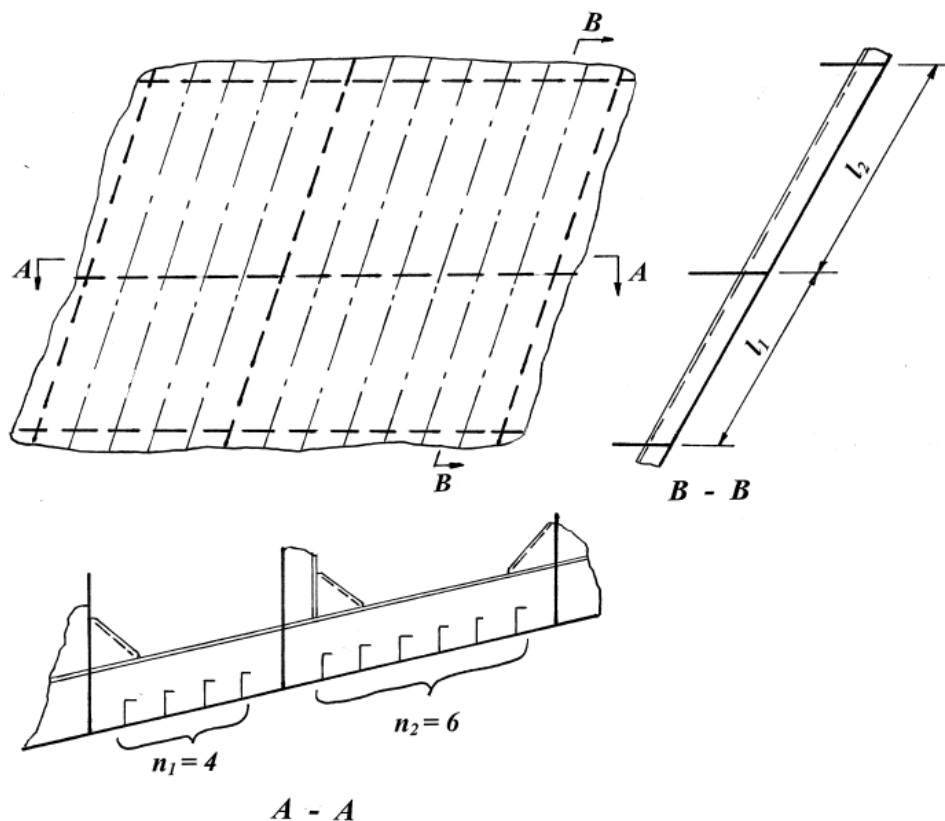


Fig. 7.5.4 Primary member supporting shell stiffeners

5.2. Stern slamming

5.2.1 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 Sec [5.2.2] and Sec [5.2.3].

5.2.2 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 Sec [5.1.4] and Sec [5.1.5] with respect to the impact pressure head given in Sec [5.2.3].

The shear area and the section modulus of the girders or / and web frames supporting shell stiffeners are to be strengthened in accordance with Sec [5.1.11] using $h = 0.4 h_{sl}$ given in Sec [5.2.3].

5.2.3 The design stern slamming pressure head shall be taken as:

$$h_{sl} = 2.2 C L \left(0.6 + \frac{1.65 a_0 (0.55 L - X) \sin^3 \alpha}{C_B L} \right)^2 \quad (m)$$

Not to be taken greater than:

$$h_{sl} = 2.2 C L \left(0.6 + \frac{1.65 a_0 \sin^3 \alpha}{2 C_B} \right)^2 \quad (m)$$

C = 0.018 ($C_{WV} - 2.0 h_o$); maximum 0.1; minimum 0.0
 C_{WV} = wave coefficient as given in Ch 4 Sec 2 [2.2]
 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, in m
 a_0 = a_{ca} from Ch 4 Sec 2 [2.2.3], with $C_{v1} = 0.8$
 α = flare angle as defined in Sec [5.1.3] of this chapter.

5.3. Strengthening against liquid impact pressure in larger tanks

5.3.1 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 Ch 9 Sec 5 [5.4] for impact loads referred to in Ch 4 Sec 3 [3.3.5].

5.4. Fatigue control of longitudinals, main frames and 'tween deck frames

5.4.1 Longitudinals in tanks shall have a section modulus not less than:

$$Z = \frac{830 s l^2 h_d w_c}{\sigma_d} \quad (cm^3)$$

h_d = single amplitude dynamic pressure head, in m
 $= 0.5 [\kappa + (T - z)]$; $(T - z)_{max} = \kappa$

$\kappa = \frac{B \phi}{2} + \frac{B}{32} \left(1 + \frac{z}{T} \right)$; $z_{max} = T$ for κ

σ_d = permissible single amplitude fluctuating dynamic stress
 $= \frac{110 c}{K}$ (N/mm²)

- 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, in m.
 K = stress concentration factor as given in Fig.7.5.5
 ϕ = rolling angle, in radians.

For designs which give larger deflections between transverse bulkheads and the side verticals, smooth two-sided brackets (arm length = 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 head h_d .

This stress shall be deducted from $110c/K$ to obtain the allowable stress σ_d in the formula for Z .

- 5.4.2 Main frames and 'tween deck frames in tanks are to have a section modulus, at their welded end supports, of not less than:

$$Z = \frac{830 s l^2 h_d w_c}{\sigma_d} \quad (\text{cm}^3)$$

h_d , σ_d and K are as given in Sec [5.4.1].

5.5. Bar stem

- 5.5.1 If bar stem is fitted, the scantlings are not to be less than:

- Width : 90 + 1.2 L (mm) below summer load waterline
70 + 0.9 L (mm) at the stem head
- Thickness : 12 + 0.48 L (mm)

The stem width is to be gradually tapered from the waterline to the stem head.

TYPE OF CONNECTION	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

Fig. 7.5.5 Stress concentration factors

K factors refer to indicated notch positions
() denotes overlap welded stiffener or bracket
[] denotes soft nose at notch point

CHAPTER 8 DECK STRUCTURES

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SECTION 1 GENERAL

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1.1. Introduction

1.1.1. The requirements in this chapter apply to ship's deck structure.

1.1.2. The formulae given for plating, stiffeners and girders are based on the structural design principles outlined in Ch 3 Sec 2. 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

The actual values for these parameters may be chosen and inserted in the formulae, wherever relevant.

Direct stress calculations based on said structural design principles and as outlined in Ch 13 will be considered as alternative basis for the scantlings.

1.2. Definitions

1.2.1 Symbols:

L	= rule length, in m ¹⁾
B	= rule breadth, in m ¹⁾
D	= rule depth, in m ¹⁾
T_{ms}	= rule draught, in m ¹⁾
C_B	= rule block coefficient ¹⁾
V	= maximum service speed, in knots, on draught T_{ms}
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
	$= \left(1.1 - 0.25 \frac{s}{l}\right)^2$
	= 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, Refer Ch 3 Sec 3 [3.1]. For curved stiffeners l may be taken as the cord length
w_c	= section modulus corrosion factor in tanks, Refer Ch 3 Sec 3 [3.10.5]
	= 1.0 in other compartments
σ	= nominal allowable bending stress in N/mm ² due to lateral pressure
h	= design pressure head, in m, as given in Sec 2.
k_m	= material factor. Refer Ch 2 Sec 2 and Ch 2 Sec 3
f_{2d}	= stress factor above the neutral axis of the hull girder depending on surplus in mid-ship section modulus and maximum value of the actual still water bending moments:

$$f_{2d} = \frac{5.7 (M_{ST} + M_{WV})}{Z_D}$$

Z_D	= mid-ship section modulus, in cm ³ , at deck as built
M_{ST}	= normally to be taken as the largest design still water bending moment, in kN m. M_{ST} shall not be taken less than 0.5 M_{SO} . When actual design moment is not known, M_{ST} may be taken equal to M_{SO}
M_{SO}	= design still water bending moment, in kN m, given in Ch 5 Sec 2

- M_{WV} = rule wave bending moment, in kN m, given in Ch 5 Sec 2. Hogging or sagging moment to be chosen in relation to the applied still water moment.
- Z_R = rule mid-ship section modulus, in cm^3 , as given in Ch 5 Sec 3 [3.3.9]
- S = girder span, in m. For definition of span point, Refer Ch 3 Sec 3 [3.1].
- 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 deck line to the point in question below or above the neutral axis, respectively

Remarks:

1) For details Refer Ch 1 Sec 2 [2.1.1]

2) In special cases, a more detailed evaluation of the actual still water moment M_{ST} to be used may be allowed. The simultaneous occurrence of a certain local load on a structure and the largest possible M_{ST} -value in the same area of the hull girder may be used as basis for estimating f_{2d} .

Example: Deck longitudinals. External load (h_1 or h_2 in Table 8.2.2) gives maximum local stress in compression, and M_{ST} may be taken as maximum sagging moment. Internal load (h_7 to h_{10} in Table 8.2.2) gives maximum load stress in tension, and M_{ST} may be taken as maximum hogging moment.

1.3. Documentation

1.3.1 Plans and particulars to be submitted for approval / information are specified in Ch 1 Sec 3.

1.4. Structural Arrangements and Details

1.4.1. Dry cargo ships with length $L > 150$ m are normally to have deck longitudinals in the strength deck clear of hatchway openings.

1.4.2. The deck in tankers are normally to be longitudinally stiffened in the cargo tank region.

1.4.3. 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 $50 \text{ m} < L < 150 \text{ m}$. 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 $L \leq 50$ m and in large ships outside 0.5 L amidships provided $Z_D > 2 Z_R$. Brackets to be fitted.

1.4.4. 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.

- 1.4.5. 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, Refer Ch 5.

R = corner radius.

- 1.4.6. 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.

A transition plate shall be laid between the thick plating and the thin deck area plating when 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.

The transition plate's material strength group is typically to be of an intermediate strength group to that of the connecting plates.

- 1.4.7. Weld connections shall satisfy the general requirements given in Ch 11.

- 1.4.8. For end connections of stiffeners and girders, Refer Ch 3 Sec 3.

1.5. Construction and initial testing of watertight decks, trunks etc.

- 1.5.1 Watertight decks, trunks, tunnels, duct keels and ventilators shall be of the same strength as watertight bulkheads at corresponding levels (Refer h_{12} of Table 8.2.1 or h_{13} of Table 8.2.2). The means for making them watertight, and the arrangements adopted for closing openings in them shall satisfy the requirements of this section and relevant sections of Pt 4 Ch 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.

- 1.5.2 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 the relevant requirements specified in SOLAS Ch II-1.

- 1.5.3 The trunk shall be capable of withstanding impact pressure due to internal water motions (sloshing) of water trapped on the ro-ro deck, where all or part of the penetration of the bulkhead deck is on the main ro-ro deck.

- 1.5.4 In ships constructed before 1 July 1997, the requirements of Section [1.5.2] shall apply not later than the date of the first periodical survey after 1 July 1997.

- 1.5.5 After completion, a hose or flooding test shall be applied to watertight decks and a hose test to watertight trunks, tunnels and ventilators.

SECTION 2 DESIGN LOADS

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2.1. Local loads on deck structures

- 2.1.1. All generally applicable local loads, expressed in terms of corresponding design pressure heads, on deck structures are given in Table 8.2.1 for ships with L less than 100 m and Table 8.2.2 for ships with L equal to or greater than 100 m, based upon the general loads given in Ch 4. In connection with the various local structures, reference is made to these tables, indicating the relevant loads in each case.

Table 8.2.1. Design loads for deck structures for ships with L < 100 m	
Structure	Design pressure head h (m)
Weather decks ^{(1) (3)}	$h_1 = a (h_{dp} - \{(0.4 + 0.02 k_s)h_0\})$ $= \text{minimum } 0.50$
Cargo 'tween decks	$h_2 = k q$ $h_3 = k \frac{\rho_c}{\rho_w} H_{st}$
Platform deck in machinery spaces	$h_4 = 1.6 k$
Accommodation decks	$h_5 = 0.35 k$
Deck as tank bottom or top in general ^{(2) (4)}	$h_6 = k \frac{\rho}{\rho_w} h_s$ $h_7 = 0.67 \left(\frac{\rho}{\rho_w} h_p + \Delta h_{dyn} \right)$ $h_8 = \frac{\rho}{\rho_w} h_s + h_{gen}$ $h_9 = \frac{\rho}{\rho_w} (h_s + 0.3 b)$ $h_{10} = \frac{\rho}{\rho_w} (h_s + 0.1 l)$
Top of deckhouse	$h_{11} = 0.4$
Watertight deck submerged in damaged condition ⁽⁵⁾	$h_{12} = h_b$
Remarks: 1) On weather decks combination of the design pressure heads h_1 and h_2 may be required for deck cargo with design stowage height less than 2.3 m. 2) For partly filled tanks, Refer Ch 9 Table 9.2.1. 3) For ships with service restrictions, h_1 may be reduced as given in Ch 3 Sec 2 Table 3.2.2. C_{wv} shall not be reduced for the calculation of h_1 . 4) h_9 and h_{10} refer to tank sides and ends, respectively. Adjacent structures are to be reinforced accordingly. 5) The strength may be calculated with allowable stresses for plating, stiffeners and girders increased by $60 / k_m$.	

Table 8.2.2. Design loads for deck structures for ships with $L \geq 100$ m		
Structure	Load Type	Design pressure head h (m)
Weather decks ⁽¹⁾	Sea pressure	$h_1 = a (h_{dp} - \{(0.4 + 0.02 k_s)h_0\})^{(2)}$ = minimum 0.50
	Deck cargo	$h_2 = \left(1 + \frac{0.5 a_{vert}}{g_0}\right) q$
Cargo 'tween decks	Deck cargo	$h_3 = \frac{\rho_c}{\rho_w} \left(1 + 0.5 \frac{a_{vert}}{g_0}\right) H_{st}$
Platform deck in machinery spaces	Machinery and equipment	$h_4 = 1.6 \left(1 + \frac{0.5 a_{vert}}{g_0}\right)$
Accommodation decks ⁽³⁾	Accommodation in general	$h_5 = 0.35 \left(1 + \frac{0.5 a_{vert}}{g_0}\right)$
Decks as tank bottom or top in general	Ballast, bunker or liquid cargo	$h_6 = \frac{\rho}{\rho_w} \left(1 + \frac{0.5 a_{vert}}{g_0}\right) h_s$ $h_7 = 0.67 \left(\frac{\rho}{\rho_w} h_p + \Delta h_{dyn}\right)$ $h_8 = \frac{\rho}{\rho_w} h_s + h_{gen}$
Deck as tank boundary in tanks with breadth $> 0.4 B$		$h_9 = \frac{\rho}{\rho_w} \left[0.67 (h_s + \phi b) - 0.12 \sqrt{H b_{top} \phi}\right]$
Deck as tank boundary towards ends of tanks with length $> 0.15 L$		$h_{10} = \frac{\rho}{\rho_w} \left[0.67 (h_s + \theta l) - 0.12 \sqrt{H l_{top} \theta}\right]$
Deck as tank boundary in tanks with breadth $> 0.4 B$ ⁽⁴⁾		$h_{11} = \frac{\rho}{\rho_w} \left(0.306 - \frac{B}{981}\right) b_b$
Deck as tank boundary in tanks with length $> 0.1 L$ ⁽⁵⁾		$h_{12} = \frac{\rho}{\rho_w} \left(0.408 - \frac{L}{1962}\right) l_b$
Watertight decks submerged in damaged condition ⁽⁶⁾	Sea pressure	$h_{13} = h_b$
Remarks: 1) On weather decks combination of the design pressure heads h_1 and h_2 may be required for deck cargo with design stowage height less than 2.3 m. 2) For ships with service restrictions, h_1 may be reduced as given in Ch 3 Sec 2 Table 3.2.2. C_{WV} shall not be reduced for the calculation of h_1 . 3) Refer also Ch 4 Sec 3 [3.4.1] 4) 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 Ch 4 Sec 3 [3.3.5] 5) 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 Ch 4 Sec 3 [3.3.5] 6) The strength may be calculated with allowable stresses for plating, stiffeners and girders increased by $60 / k_m$.		

The definition of parameters used in the above formulations contained in Table 8.2.1 and Table 8.2.2 is as follows:

- a_{vert} = for use in Table 8.2.2; vertical acceleration as given in Ch 4 Sec 2 [2.6]
- ϕ = for use in Table 8.2.2; roll angle in radians as given in Ch 4 Sec 2 [2.3]
- θ = for use in Table 8.2.2; pitch angle in radians as given in Ch 4 Sec 2 [2.4]
- ρ_w = as given in Ch 4 Sec 1 [1.2]
- ρ = density of liquid cargo in t/m^3 , normally not to be taken less than 1.025 t/m^3
- 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
- H = for use in Table 8.2.2; height, in m, of the tank
- b = for use in Table 8.2.1; breadth of the tank, in m
= for use in Table 8.2.2; the largest athwartship distance, in m, from the load point to the tank corner at top of the tank / hold most distant from the load point.
- l = for use in Table 8.2.1; total length of tanks, in m
= for use in Table 8.2.2; the largest longitudinal distance, in m, from the load point to the tank corner at top of the tank / hold most distant from the load point.
- b_{top} = for use in Table 8.2.2; breadth, in m, of top of tank / hold
- l_{top} = for use in Table 8.2.2; length, in m, of top of tank
- b_b = for use in Table 8.2.2; distance, in m, between tank sides or effective longitudinal wash bulkhead at the height at which the strength member is located.
- l_b = for use in Table 8.2.2; distance, in m, between transverse tank bulkheads or effective transverse wash bulkheads at the height at which the strength member is located. Transverse web frames covering part of the tank cross section (e.g. wing tank structures in tankers) may be regarded as wash bulkheads
- h_{gen} = $(0.03 L - 0.5) \text{ m}$, minimum 1 m, in general (for use in Table 8.2.1)
= 2.5 m, in general (for use in Table 8.2.2)
= 2.5 m, in cargo tanks (for use in Table 8.2.1)
= 1.5 m, in ballast holds of dry cargo vessels (for use in Table 8.2.2)
= pressure head corresponding to tank pressure valve opening pressure when exceeding the general value (for use in Table 8.2.1 and Table 8.2.2)
- Δh_{dyn} = as given in Ch 4 Sec 3 [3.3.2]
- h_{dp}, k_s = as given in Ch 4 Sec 3 [3.2.1]
- h_b = vertical distance, in m, 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
- H_{st} = stowage height, in m, of dry cargo. Normally the height to 'tween deck or top of cargo hatchway to be used.
- ρ_c = dry cargo density, in t/m^3 , if not otherwise specified to be taken as 0.7, Refer also Ch 4 Sec 3 [3.4.1]
- k = for use in Table 8.2.1; 1.3 aft of 0.2 L from F.P.
= 1.5 within 0.2 L from F.P.
- 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
- h_0 = vertical distance, in m, from the waterline at draught T_{ms} to the deck
- T_{ms} = rule draught, in m
- 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 $L \leq 100 \text{ m}$
 - = 1.3 for ships with $L > 150 \text{ m}$ when superstructure deck
 - = 1.75 for ships with $L > 150 \text{ m}$ 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

SECTION 3 PLATING AND STIFFENERS

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3.1. Strength deck plating

- 3.1.1 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:

$$b = 800 + 5 L \quad (\text{mm}); \quad \text{maximum } 1800 \text{ mm.}$$

- 3.1.2 The thickness requirement corresponding to lateral pressure is given by:

$$t = \frac{49.96 k_a s \sqrt{h}}{\sqrt{\sigma}} + t_c \quad (\text{mm})$$

- h = h_1 to h_{12} , whichever is relevant, as given in Table 8.2.1 for vessels with $L < 100$ m
 = h_1 to h_{13} , whichever is relevant, as given in Table 8.2.2 for vessels with $L \geq 100$ m
 σ = as given in Table 8.3.1 for vessels with $L < 100$ m
 = as given in Table 8.3.2 for vessels with $L \geq 100$ m

The definition of the parameters used in the above equation is given in Sec [1.2] of this chapter.

- 3.1.3 The longitudinal buckling strength of plating shall be checked according to Ch.14. In addition, the thickness of transversely stiffened strength deck shall comply with the requirements to buckling strength as given in Ch 14.

- 3.1.4 The thickness shall not be less than:

$$t = t_0 + k L_1 \sqrt{k_m} + t_c \quad (\text{mm})$$

- 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 0.7D from the baseline
 = 0.01 as minimum for weather decks forward of 0.2L from F.P.
 = 0.00 in vessels with more than two continuous decks above 0.7D from the baseline.

- 3.1.5 The stringer plate shall be increased in thickness for a length of 3 m on each side of the superstructure end bulkhead, if the end bulkhead of a long superstructure is located within 0.5 L amidships. The increase in thickness shall be 20%.

3.2. Plating of decks below or above strength deck

- 3.2.1. The thickness requirement corresponding to lateral pressure is given by the formula in Sec [3.1.2] with $\sigma = 160 / k_m$.

Table 8.3.1. Values of σ for vessels with $L < 100$ m	
Stiffening type	Allowable stress σ ⁽¹⁾
Transverse stiffening	$60 \frac{Z_D}{Z_R}$, maximum $\frac{120}{k_m}$; within 0.4 L $\frac{160}{k_m}$; within 0.1 L from the perpendiculars
Longitudinal stiffening	$\frac{120}{k_m}$; within 0.4 L $\frac{160}{k_m}$; within 0.1 L from the perpendiculars
Remarks: 1) Between specified regions, the σ -value may be varied linearly.	

Table 8.3.2. Values of σ for vessels with $L \geq 100$ m	
Stiffening type	Allowable stress σ ⁽¹⁾
Transverse stiffening	$\frac{175}{k_m} - 120 f_{2d}$, maximum $\frac{120}{k_m}$; within 0.4 L $\frac{160}{k_m}$; within 0.1 L from the perpendiculars and within line of large deck openings
Longitudinal stiffening	$\frac{120}{k_m}$; within 0.4 L $\frac{160}{k_m}$; within 0.1 L from the perpendiculars and within line of large deck openings
Remarks: 1) Between specified regions, the σ -value may be varied linearly. 2) f_{2d} = stress factor as given in Sec 1.2 of this chapter.	

3.2.2. The thickness of steel decks shall not be less than:

$$t = t_0 + k L_1 \sqrt{k_m} + t_c \quad (\text{mm}); \text{ for ships with } L \geq 100 \text{ m}$$

$$t = t_0 + t_c \quad (\text{mm}) ; \text{ for ships with } L < 100 \text{ m}$$

- t_0 = as given in Sec [3.1.4]
 k = 0.01 for 'tween deck above 0.7D in vessels with two continuous decks above 0.7D from the baseline and first tier of superstructure or deckhouse in vessels with single continuous deck when more than 50% of 0.4L amidships is covered
 = 0.01 for forecastle decks forward of 0.2L from F.P.
 = 0.00 for other decks.

3.3. Longitudinals

- 3.3.1. The section modulus requirement is given by:

$$Z = \frac{830 s h l^2 w_c}{\sigma} \quad (\text{cm}^3) ; \text{ minimum } 15 \text{ cm}^3$$

- h = h_1 to h_{12} , whichever is relevant, as given in Table 8.2.1 for vessels with $L < 100 \text{ m}$
 = h_1 to h_{13} , whichever is relevant, as given in Table 8.2.2 for vessels with $L \geq 100 \text{ m}$
 σ = as given in Table 8.3.3 for vessels with $L < 100 \text{ m}$
 = as given in Table 8.3.4 for vessels with $L \geq 100 \text{ m}$

The definition of the parameters used in the above equation is given in Sec 1.2 of this chapter.

- 3.3.2. The buckling strength of longitudinals shall be checked according to Ch 14.

- 3.3.3. The web and flange thickness shall not be less than the larger of:

$$t = 4.5 + k' + t_c \quad (\text{mm})$$

$$= 1.5 + \frac{h_w}{g \sqrt{k_m}} + t_c \quad (\text{mm})$$

- k' = $0.01L_1$ in general
 = $0.015L_1$ in peaks and for boundaries of cargo 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

The definition of the parameters used in the above equation is given in Sec [1.2] of this chapter.

- 3.3.4. Longitudinals supported by deck transverses subject to relatively large deflections shall be checked by direct strength calculation, Refer Ch 13. Increased bending stresses at transverse bulkheads shall be evaluated and may be absorbed by increased end brackets.

Table 8.3.3. Values of σ for vessels with $L < 100$ m	
Member type	Allowable stress σ ⁽¹⁾
Deck longitudinals	$\frac{95}{k_m}$; within 0.4 L when $Z_D = Z_R$ $\frac{160}{k_m}$; within 0.4 L when $Z_D \geq 2 Z_R$ $\frac{160}{k_m}$; within 0.1 L from the perpendiculars
Remarks: 1) Between specified regions, the σ -value may be varied linearly. 2) Z_D and Z_R are defined in Sec [1.2] of this chapter.	

Table 8.3.4. Values of σ for vessels with $L \geq 100$ m	
Member type	Allowable stress σ ^{(1) (4)}
Deck longitudinals	<p>Strength deck, long superstructures and effective deckhouses above strength deck:</p> $\frac{225}{k_m} - 130 f_{2d}$, maximum $\frac{160}{k_m}$; within 0.4 L <p>Continuous decks below strength deck:</p> $\frac{225}{k_m} - 130 f_{2d} \left(\frac{z_n - z_a}{z_n} \right)$, maximum $\frac{160}{k_m}$; within 0.4 L $\frac{160}{k_m}$; within 0.1 L from the perpendiculars for continuous decks deck longitudinals and other deck longitudinals in general
Remarks: 1) Between specified regions, the σ -value may be varied linearly. 2) f_{2d} = stress factor as given in Sec [1.2] of this chapter. 3) z_n and z_a are taken as defined in Sec [1.2] of this chapter. 4) For longitudinals $\sigma = 160 / k_m$ may be used in any case in combination with heeled condition pressure head h_g and sloshing load pressure heads, h_{11} and h_{12} .	

3.4. Transverse Beams

3.4.1 The section modulus requirement is given by:

$$Z = 6.3 s h l^2 w_c k_m \quad (\text{cm}^3); \quad \text{minimum } 15 \text{ cm}^3$$

h = h_1 to h_{12} whichever is relevant as given in Table 8.2.1 for vessels with $L < 100 \text{ m}$
 = h_1 to h_{13} whichever is relevant as given in Table 8.2.2 for vessels with $L \geq 100 \text{ m}$

The definition of the parameters used in the above equation is given in Sec [1.2] of this chapter.

3.4.2 The thickness of web and flange shall not be less than given in Sec [3.3.3]

3.4.3 For end connections, Refer Ch 3 Sec 3 [3.2].

3.4.4 For beam-panel buckling, Refer Ch 14.

SECTION 4 GIRDERS

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4.1. General

- 4.1.1 The thickness of web plates, flanges, brackets and stiffeners of girders shall not be less than:

$$t = 5.0 + k \sqrt{k_m} + t_c \quad (\text{mm})$$

- k = 0.01 L₁ in general
 = 0.02 L₁ for girder webs, flanges and brackets in cargo oil tanks and ballast tanks in cargo area
 = 0.03 L₁ (= 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:

$$t = 12 s + t_c \quad (\text{mm})$$

- s = spacing of web stiffening, in m.

- 4.1.2 The buckling strength of web plates subject to in- plane compressive and shear stresses shall be checked according to Ch.14. In addition, the deck flange of the girder is to also comply with the requirements to buckling strength as given in Ch 14.
- 4.1.3 Longitudinal deck girders above tanks shall be fitted in line with transverse bulkhead verticals. The flange area shall be minimum 1/7 of the sectional area of the web plate, and the flange thickness shall be minimum 1/30 of the flange width. The thickness shall be taken as 0.1 b_f for flanges subject to compressive stresses, b_f being the flange width when asymmetric and half the flange width when symmetric.
- 4.1.4 Deck transverses shall be fitted in the lowest deck in engine room, in line with side verticals. The depth of the deck transverses shall be minimum 50% of the depth of the side verticals, web thickness and face plate scantlings being as for side verticals.
- 4.1.5 The thickness of girder stiffeners and brackets shall not be less than given in Sec [4.1.1]
- 4.1.6 The end connections and stiffening of girders shall be arranged as given in Ch 3 Sec 3.

4.2. Simple girders

- 4.2.1 The section modulus requirement for simple girders is given by:

$$Z = \frac{1000 b h^2 w_c}{\sigma} \quad (\text{cm}^3)$$

- h = h₁ to h₆ as given in Table 8.2.1 and Table 8.2.2 for vessels with L < 100 m and L ≥ 100 m respectively.
 = 1.15 h₇ as given in Table 8.2.1 and Table 8.2.2 for vessels with L < 100 m and L ≥ 100 m respectively.
 = h₈ to h₁₂ whichever is relevant as given in Table 8.2.1 for vessels with L < 100 m
 = h₈ to h₁₃ whichever is relevant as given in Table 8.2.2 for vessels with L ≥ 100 m
- b = loading breadth, in m
- σ = as given in Table 8.4.1 for vessels with L < 100 m
 = as given in Table 8.4.2 for vessels with L ≥ 100 m

- 4.2.2 The web area requirement (after deduction of cut-outs) at the girder ends is given by:

$$A = k S b h k_m + 10 h_g t_c \quad (\text{cm}^2)$$

- k = 0.7 for vessels with $L \geq 100$ m
 = 0.6 for vessels with $L < 100$ m
 b = as given in Sec 4.2.1
 h_g = girder height, in m
 h = as given in Sec 4.2.1

The web area at the middle of the span shall not be less than 0.5 A.

4.2.3 For stiffness in connection with panel buckling, Refer Ch 14.

4.3. Complex girder systems

4.3.1 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 Ch 13, in addition to satisfying the general local requirements given in Sec [4.1]

Table 8.4.1. Values of σ for vessels with $L < 100$ m	
<i>Member type</i>	<i>Allowable stress σ</i>
Simple girders	For longitudinal girders ⁽¹⁾ :
	$\frac{95}{k_m}$; within 0.4 L when $Z_D = Z_R$
	$\frac{160}{k_m}$; within 0.4 L when $Z_D \geq 2 Z_R$
	$\frac{160}{k_m}$; within 0.1 L from the perpendiculars
	For other girders:
	$\frac{160}{k_m}$
Remarks:	
1) Between specified regions, the σ -value may be varied linearly.	
2) Z_D and Z_R are defined in Sec [1.2] of this chapter.	

Table 8.4.2. Values of σ for vessels with $L \geq 100$ m	
<i>Member type</i>	<i>Allowable stress σ</i>
Simple girders	For continuous longitudinal girders ^{(1) (3)} :
	$\frac{190}{k_m} - 130 f_{2d} \left(\frac{z_n - z_a}{z_n} \right)$, maximum $\frac{160}{k_m}$; within 0.4 L amidships
	$\frac{160}{k_m}$; within 0.1 L from the perpendiculars
	For other girders:
	$\frac{160}{k_m}$

Remarks:

- 1) Between specified regions, the σ -value may be varied linearly.
- 2) f_{2d} = stress factor as given in Sec [1.2] of this chapter.
- 3) For longitudinal girders $\sigma = 160 / k_m$ may be used in any case in combination with heeled condition pressure heads h_9 and h_{11} as specified in Table 8.2.2
- 4) z_n and z_a are taken as defined in Sec [1.2] of this chapter.

SECTION 5 SPECIAL REQUIREMENTS

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5.1. Transverse strength of deck between hatches

- 5.1.1 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 may need to 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 $120 / k_m$ N/mm² 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.

5.2. Strength of deck outside large hatches

- 5.2.1 The strength of deck and ship's side in way of long and wide hatches as given in Ch 5 Sec 1 [1.1.6], as applicable, is 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.

5.3. Pillars in tanks

- 5.3.1 Solid pillars shall be used. Hollow pillars in tanks are not accepted.

- 5.3.2 The sectional area of pillars, where the hydrostatic pressure may give tensile stresses in the pillars, shall not be less than:

$$A = 0.7 A_{DK} h_t \quad (\text{cm}^2)$$

A_{DK} = deck area, in m², supported by the pillar

h_t = design pressure head h , in m, giving tensile stress in the pillar.

Doubling plates at ends are not allowed.

5.4. Strengthening against liquid impact pressure in larger tanks

- 5.4.1. The deck structure shall have scantlings according to Ch 9 Sec 5 [5.4] for impact loads referred to in Ch 4 Sec 3 [3.3.5], if the deck forms boundary of larger ballast or cargo tanks with free sloshing length $l_s > 0.13 L$ and or breadth $b_s > 0.56 B$

CHAPTER 9 BULKHEAD STRUCTURES

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SECTION 1 GENERAL

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1.1. Introduction

1.1.1. The requirements given in this section are applicable to bulkhead structures.

1.1.2. The formulae given for plating, stiffeners and girders are based on the structural design principles outlined in Ch 3 Sec 2. 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

The actual values for these parameters may be chosen and inserted in the formulae, wherever relevant.

Direct stress calculations based on said structural design principles and as outlined in Ch 13 will be considered as alternative basis for the scantlings.

1.2. Definitions

1.2.1. Symbols:

L	= rule length, in m ¹⁾
B	= rule breadth, in m ¹⁾
D	= rule depth, in m ¹⁾
T_{ms}	= rule draught, in m ¹⁾
C_B	= rule block coefficient ¹⁾
V	= maximum service speed, in knots, on draught T_{ms}
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
	$= \left(1.1 - 0.25 \frac{s}{l} \right)^2$
	= 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, Refer Sec 1.2.3
l	= stiffener span, in m, measured along the top flange of the member. For definition of span point, Refer Ch 3 Sec 3 [3.1]. For curved stiffeners l may be taken as the cord length
S	= girder span, in m. For definition of span point, Refer Ch 3 Sec 3 [3.1].
w_c	= section modulus corrosion factor in tanks, Refer Ch 3 Sec 3 [3.10.5]
	= 1.0 in other compartments
σ	= nominal allowable bending stress in N/mm ² due to lateral pressure
h	= design pressure head, in m, as given in Sec 2.
k_m	= material factor. Refer Ch 2 Sec 2 and Ch 2 Sec 3
f_{2b}	= stress factor below the neutral axis of the hull girder as defined in Ch 6 Sec 1 [1.2.1]
f_{2d}	= stress factor below the neutral axis of the hull girder as defined in Ch 8 Sec 1 [1.2.1]
Z_A	= mid-ship section modulus, in cm ³ , as built, at deck or bottom respectively
Z_R	= rule mid-ship section modulus, in cm ³ , as given in Ch 5 Sec 3 [3.3.9]
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

Remarks:

1) For details Refer Ch 1 Sec 2 [2.1.1]

1.2.2. The load point where the design pressure head acts shall be calculated for various strength members is defined as mentioned below:

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 head shall be taken as the greater of:

$$h_m \text{ and } \frac{h_a + h_b}{2}$$

h_m , h_a and h_b are the calculated pressure heads at midpoint and at each end respectively.

c) For girders: midpoint of load area.

1.2.3. For corrugated bulkheads the following definition of spacing applies (Refer Fig.9.1.1):

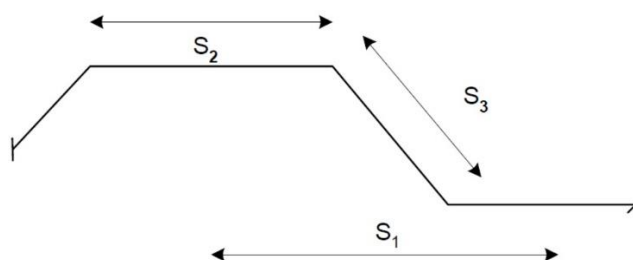


Fig. 9.1.1 Corrugated bulkhead

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.

1.3. Documentation

1.3.1. Plans and particulars which have to be submitted for approval or information are specified in Ch 1 Sec 3.

1.4. Structural arrangement and details

1.4.1. Location and number of transverse watertight bulkheads shall be in accordance with the requirements specified in Ch 3.

1.4.2. The peak tanks shall have centre line wash bulkheads when the breadth of the tank is greater than $2/3$ of the ship's moulded breadth.

1.4.3. Within $0.5 L$ amidships, in the areas $0.15 D$ above the bottom and $0.15 D$ below the strength deck, continuity of bulkhead longitudinals shall be as required for bottom and deck longitudinals respectively.

- 1.4.4. For ships with $L < 100$ m, the free distance between transverse tank bulkheads is normally not to exceed 10 m. The free distance may be increased to $0.13 L$ (when $L > 77$ m) provided the tank structure is strengthened to resist the additional dynamic load h_g in tanks with unrestricted filling heights. If the free distance exceeds $0.13 L$ (when $L > 77$ m) the dynamic load will be specially considered.
- 1.4.5. For ships with $L < 100$ m, the free breadth of tanks should normally not exceed $0.56 B$. For greater breadths the strength of the tank structure will be specially considered.
- 1.4.6. The general requirements given in Ch 11 shall be satisfied for weld connections.
- 1.4.7. Refer Ch 3 Sec 3 for end connections of stiffeners and girders.
- 1.4.8. "Stern tubes shall be enclosed in a watertight space (or spaces) of moderate volume". (SOLAS Ch.II-1/Reg.12.11). 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.

SECTION 2 DESIGN LOADS

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2.1. Local loads on bulkhead structures

2.1.1. All applicable general local loads on bulkhead structures, expressed in terms of corresponding design pressure heads, are given in Table 9.2.1 for ships with L less than 100 m and Table 9.2.2 for ships with L equal to or greater than 100 m, based upon the general loads given in Ch 4. In connection with the various local structures, reference is made to these tables, indicating the relevant loads in each case.

Table 9.2.1. Design loads for bulkhead structures for ships with L < 100 m		
Structure		Design pressure head h (m)
Watertight bulkheads		$h_1 = h_b$
Cargo hold bulkheads		$h_2 = k \frac{\rho_c}{\rho_w} K h_c^{(1)}$
Tank bulkheads	general	$h_3 = k \frac{\rho}{\rho_w} h_s^{(1)}$ $h_4 = 0.67 \left(\frac{\rho}{\rho_w} h_p + \Delta h_{dyn} \right)$ $h_5 = \frac{\rho}{\rho_w} h_s + h_{gen}$
	sides	$h_6 = \frac{\rho}{\rho_w} (h_s + 0.3 b)^{(2)}$
	ends	$h_7 = \frac{\rho}{\rho_w} (h_s + 0.1 l)^{(2)}$ $h_8 = \frac{\rho}{\rho_w} \left(0.408 - \frac{L}{1962} \right) l_b^{(2)(3)}$
<p>Remarks:</p> <p>1) For ships with service restrictions, h_2 and h_3 may be reduced as given in Ch 3 Sec 2 Table 3.2.2.</p> <p>2) Adjacent ends and sides are to be reinforced for 25% of the breadth and length, respectively. When $b > 0.56 B$, h_6 is to be specially considered.</p> <p>3) h_8 refers to tanks with unrestricted filling heights and $10 < l_b < 0.13 L$. When $l > 0.13 L$, h_8 is to be specially considered.</p>		

Table 9.2.2. Design loads for bulkhead structures for ships with L ≥ 100 m			
Structure		Load Type	Design pressure head h (m)
Watertight bulkheads		Sea pressure when flooded or general dry cargo minimum	$h_1 = h_b$
Cargo hold bulkheads		Dry bulk cargo	$h_2 = \frac{\rho_c}{\rho_w} \left(1 + 0.5 \frac{a_{vert}}{g_0} \right) K h_c$
Tank bulkheads in general		Ballast, bunker or liquid cargo	$h_3 = \frac{\rho}{\rho_w} \left(1 + \frac{0.5 a_{vert}}{g_0} \right) h_s$ $h_4 = 0.67 \left(\frac{\rho}{\rho_w} h_p + \Delta h_{dyn} \right)$ $h_5 = \frac{\rho}{\rho_w} h_s + h_{gen}$
Longitudinal bulkheads as well as transverse bulkheads at sides in wide tanks	In tanks with breadth > 0.4B		$h_6 = \frac{\rho}{\rho_w} \left[0.67 (h_s + \phi b) - 0.12 \sqrt{H b_{top} \phi} \right]$
	Note ⁽¹⁾		$h_7 = \frac{\rho}{\rho_w} \left(0.306 - \frac{B}{981} \right) b_b$
Transverse bulkheads and longitudinal bulkheads at ends in long tanks	In tanks with length > 0.15L		$h_8 = \frac{\rho}{\rho_w} \left[0.67 (h_s + \theta l) - 0.12 \sqrt{H l_{top} \theta} \right]$
	Note ⁽²⁾		$h_9 = \frac{\rho}{\rho_w} \left(0.408 - \frac{L}{1962} \right) l_b$
Longitudinal wash bulkheads			$h_7 = \frac{\rho}{\rho_w} \left(0.306 - \frac{B}{981} \right) b_b$
Transverse wash bulkheads			$h_9 = \frac{\rho}{\rho_w} \left(0.408 - \frac{L}{1962} \right) l_b$
Remarks:			
<p>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 head will be specially considered according to Ch 4 Sec 3 [3.3.5]</p> <p>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 head will be specially considered according to Ch 4 Sec 3 [3.3.5]</p>			

The definition of parameters used in the above formulations contained in Table 9.2.1 and Table 9.2.2 is as follows:

a_{vert}	= for use in Table 9.2.2; vertical acceleration as given in Ch 4 Sec 2 [2.6]
ϕ	= for use in Table 9.2.2; roll angle in radians as given in Ch 4 Sec 2 [2.3]
θ	= for use in Table 9.2.2; pitch angle in radians as given in Ch 4 Sec 2 [2.4]
ρ_w	= as given in Ch 4 Sec 1 [1.2]
ρ	= density of ballast, bunker or liquid cargo in t/m^3 , normally not to be taken less than 1.025 t/m^3
h_s	= vertical distance, in m, from the load point to the top of tank, 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
H	= for use in Table 9.2.2; height, in m, of the tank
b	= for use in Table 9.2.1; breadth of the tank, in m = for use in Table 9.2.2; the largest athwartship distance, in m, from the load point to the tank corner at top of the tank / hold most distant from the load point.
l	= for use in Table 9.2.1; total length of tanks, in m = for use in Table 9.2.2; the largest longitudinal distance, in m, from the load point to the tank corner at top of the tank / hold most distant from the load point.
b_{top}	= for use in Table 9.2.2; breadth, in m, of top of tank / hold
l_{top}	= for use in Table 9.2.2; length, in m, of top of tank
b_b	= for use in Table 9.2.2; distance, in m, between tank sides or effective longitudinal wash bulkhead at the height at which the strength member is located.
l_b	= for use in Table 9.2.1; free tank length, in m. = for use in Table 9.2.2; distance, in m, between transverse tank bulkheads or effective transverse wash bulkheads at the height at which the strength member is located. Transverse web frames covering part of the tank cross section (e.g. wing tank structures in tankers) may be regarded as wash bulkheads
h_{gen}	= $(0.03 L - 0.5) \text{ m}$, minimum 1 m, in general (for use in Table 9.2.1) = 2.5 m, in general (for use in Table 9.2.2) = 2.5 m, in cargo tanks (for use in Table 9.2.1) = 1.5 m, in ballast holds of dry cargo vessels (for use in Table 9.2.2) = pressure head corresponding to tank pressure valve opening pressure when exceeding the general value (for use in Table 9.2.1 and Table 9.2.2)
Δh_{dyn}	= as given in Ch 4 Sec 3 [3.3.2]
h_b	= vertical distance, in m, 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
ρ_c	= dry cargo density, in t/m^3 , if not otherwise specified to be taken as 0.7.
k	= for use in Table 9.2.1; 1.3 aft of 0.2 L from F.P. = 1.5 within 0.2 L from F.P.
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)

SECTION 3 PLATING AND STIFFENERS

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3.1. Bulkhead plating

3.1.1. The thickness requirement corresponding to lateral pressure is as given by:

$$t = \frac{49.96 k_a s \sqrt{h}}{\sqrt{\sigma}} + t_c \quad (\text{mm})$$

- h = h_1 to h_8 , whichever is relevant, in Table 9.2.1 for vessels with $L < 100$ m
 = h_1 to h_9 , whichever is relevant, in Table 9.2.2 for vessels with $L \geq 100$ m
 σ = as given in Table 9.3.1 for vessels with $L < 100$ m
 = as given in Table 9.3.2 for vessels with $L \geq 100$ m

The definition of the parameters used in the above equation is given in Sec 1.2 of this chapter.

In corrugated bulkheads formed by welded plate strips, thickness in flange and web plates may be differing. The thickness requirement is then given by the following modified formula:

$$t = \sqrt{\frac{5000 s^2 h}{\sigma}} - t_n^2 + t_c \quad (\text{mm})$$

t_n = thickness, in mm, of neighbouring plate (flange or web), not to be taken greater than t .

3.1.2. The thickness shall not be less than:

$$t = 5.0 + k L_1 \sqrt{k_m} + t_c \quad (\text{mm})$$

- 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.

3.1.3. The longitudinal bulkhead plating thickness shall also satisfy the buckling strength requirements specified in Ch 14, taking into account combined shear and in-plane compressive stresses, where relevant.

3.1.4. In longitudinal bulkheads within the cargo area, the thickness shall not be less than:

$$t = \frac{1000s}{120 - 3\sqrt{L_1}} + t_c \quad (\text{mm})$$

3.1.5. The buckling strength of corrugation flanges at the middle length of corrugations shall be controlled according to Ch 14, taking k_l in Ch 14 Sec 2 [2.2.1] equal to 5. Usage factors to be applied are as given below:

- 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.

3.1.6. For plates in afterpeak bulkhead in way of sterntube, increased thickness or doubling may be required.

3.1.7. For wash bulkhead plating, requirement for thicknesses may have to be based on the reaction forces imposed on the bulkhead by boundary structures.

Table 9.3.1. Values of σ for vessels with $L < 100$ m	
Structure	Allowable stress σ ⁽¹⁾
Longitudinal bulkhead	Transverse stiffening: $\frac{140}{k_m}$; within 0.4 L at neutral axis $60 \frac{Z_A}{Z_R}$; maximum $\frac{120}{k_m}$; within 0.4 L at deck or bottom $\frac{160}{k_m}$; within 0.1 L from the perpendiculars
	Longitudinal stiffening: $\frac{160}{k_m}$; within 0.4 L at neutral axis $\frac{120}{k_m}$; within 0.4 L at deck or bottom $\frac{160}{k_m}$; within 0.1 L from the perpendiculars
Transverse tank bulkheads	$\frac{160}{k_m}$
Collision bulkheads	$\frac{160}{k_m}$
Watertight bulkheads	$\frac{220}{k_m}$
Remarks: 1) Between specified regions, the σ -value may be varied linearly.	

Table 9.3.2. Values of σ for vessels with $L \geq 100$ m	
Structure	Allowable stress σ ⁽¹⁾
Longitudinal bulkhead ⁽²⁾	Transverse stiffening ⁽³⁾ : $\frac{140}{k_m}$; within 0.4 L amidships at neutral axis
	Longitudinal stiffening: $\frac{160}{k_m}$; at neutral axis irrespective of ship length
	$\frac{160}{k_m}$; for bulkheads outside 0.05 L from F. P and 0.1 L from A. P
Transverse bulkheads	$\frac{160}{k_m}$
Watertight bulkheads ⁽⁴⁾	$\frac{220}{k_m}$
Remarks: 1) Between specified regions, the σ -value may be varied linearly. 2) 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. 3) Allowable stress σ may however be taken as $160 / k_m$ when pressure heads h_6 or h_7 are used. 4) Allowable stress mentioned is for watertight bulkheads except collision bulkhead, when pressure heads h_1 is applied.	

3.2. Longitudinals

3.2.1. The section modulus requirement for stiffeners and corrugations is given by:

$$Z = \frac{830 s h l^2 w_c}{\sigma} \quad (\text{cm}^3), \quad \text{minimum } 15 \text{ cm}^3$$

- h = h_1 to h_8 , whichever is relevant, in Table 9.2.1 for vessels with $L < 100$ m
 = h_1 to h_9 , whichever is relevant, in Table 9.2.2 for vessels with $L \geq 100$ m
 σ = as given in Table 9.3.3 for vessels with $L < 100$ m
 = as given in Table 9.3.4 for vessels with $L \geq 100$ m

The definition of the parameters used in the above equation is given in Sec 1.2 of this chapter.

3.2.2. The web and flange thickness shall not be less than the larger of:

$$t = 4.5 + k' + t_c \quad (\text{mm})$$

$$= 1.5 + \frac{h_w}{g \sqrt{k_m}} + t_c \quad (\text{mm})$$

- 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.

3.2.3. Longitudinals supported by vertical girders are subject to relatively large deflections shall be checked by direct strength calculations, Refer Ch 13 Sec 3. Increased bending stresses at transverse bulkheads shall be evaluated and may be absorbed by increased end brackets.

3.2.4. The buckling strength of longitudinals shall be checked as per Ch 14.

Table 9.3.3. Values of σ for vessels with $L < 100$ m	
Member type	Allowable stress σ ⁽¹⁾
Bulkhead longitudinals	$\frac{95}{k_m}$; within 0.4 L at deck or bottom when $Z_A = Z_R$
	$\frac{160}{k_m}$; within 0.4 L at deck or bottom when $Z_A \geq 2 Z_R$
	$\frac{160}{k_m}$; within 0.25 D above and below the neutral axis
	$\frac{160}{k_m}$; within 0.1 L from the perpendiculars
Remarks:	
1) Between specified regions, the σ -value may be varied linearly. 2) Z_A and Z_R are defined in Sec [1.2] of this chapter.	

Table 9.3.4. Values of σ for vessels with $L \geq 100$ m	
Member type	Allowable stress σ ^{(1) (3)}
Bulkhead longitudinals	$\frac{225}{k_m} - 130 f_2 \left(\frac{z_n - z_a}{z_n} \right), \text{ maximum } \frac{160}{k_m}; \text{ within } 0.4 L \text{ amidships}$ $\frac{160}{k_m}; \text{ within } 0.1 L \text{ from the perpendiculars}$
<p>Remarks:</p> <p>1) Between specified regions, the σ-value may be varied linearly.</p> <p>2) f_2 = stress factor f_{2b} below the neutral axis, as specified in Sec [1.2] of this chapter. = stress factor f_{2d} above the neutral axis, as specified in Sec [1.2] of this chapter.</p> <p>3) For longitudinals $\sigma = 160 / k_m$ may be used in any case in combination with heeled condition pressure heads h_6 to h_7 and sloshing pressure head h_9 as specified in Table 9.2.2</p> <p>4) z_n and z_a are taken as defined in Sec [1.2] of this chapter.</p>	

3.3. Vertical and transverse stiffeners on tank, wash, dry bulk cargo, collision and watertight bulkheads

3.3.1. 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 deck structure and double bottom, Refer Ch 13.

3.3.2. For simple stiffeners and corrugations, section modulus requirement is given by following:

$$Z = \frac{10000 s h l^2 w_c}{m \sigma} \quad (\text{cm}^3) \quad \text{for ships with } L \geq 100 \text{ m}$$

$$Z = \frac{62.5 s h l^2 w_c}{m} \quad (\text{cm}^3) \quad \text{for ships with } L < 100 \text{ m}$$

h = h_1 to h_8 , whichever is relevant, in Table 9.2.1 for vessels with $L < 100$ m
= h_1 to h_9 , whichever is relevant, in Table 9.2.2 for vessels with $L \geq 100$ m
 σ = $160 / k_m$ for tank, cargo and collision bulkheads .Refer also Sec [3.1.5]
= $220 / k_m$ for watertight bulkheads Refer also Sec [3.1.5]

For ships with $L < 100$ m:

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

For ships with $L \geq 100$ m:

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 the middle of the 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, Refer Ch13.

- 3.3.3. The web and flanges thickness shall not be less than as given in Sec [3.2.2]. For corrugations, the flanges shall have thicknesses satisfying buckling as given in Sec [3.1.5].
- 3.3.4. Brackets are normally to be fitted at ends of non-continuous stiffeners. For end connections, also refer to Ch 3 Sec 3 [3.2].
- 3.3.5. 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.
- 3.3.6. 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 Sec [3.3.2] and controlled for buckling as given in Ch 14.

3.4. Stiffeners on watertight bulkheads and wash bulkheads (for ships with $L < 100$ m)

3.4.1. The section modulus requirement is given by:

$$Z = \frac{10000 s h l^2 w_c}{m \sigma} \quad (\text{cm}^3)$$

h = h_1 as given in Table 9.2.1 for vessels with $L < 100$ m for watertight bulkheads

= h_g as given in Table 9.2.2 for vessels with $L \geq 100$ m for wash bulkheads

σ = $160 / k_m$ for collision bulkhead

- m
- = $220 / k_m$ for other watertight bulkheads
 - = 16 for members fixed at both ends
 - = 12 for members fixed at one end (lower) and simply supported at the other end
 - = 8 for members simply supported at both ends

The m -value may be adjusted for members with boundary condition not corresponding to the above specification.

Remark:

The m -value is based on plastic deformation at fixed supports and is not to be compared with the bending moment factor corresponding to elastic bending.

- 3.4.2. The web and flanges thickness shall not be less than as given in Sec [3.2.2.]

SECTION 4 GIRDERS

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4.1. General

- 4.1.1. The thickness of flanges, web plates, brackets and stiffeners of girders shall not be less than:

$$t = 5.0 + k \sqrt{k_m} + t_c \quad (\text{mm})$$

- 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:

$$t = 12 s + t_c \quad (\text{mm})$$

- s = spacing of web stiffening, in m.

- 4.1.2. The buckling strength of web plates is subject to in-plane compressive and shear stresses shall be checked as per Ch 14.

- 4.1.3. The end connections and stiffening of girders shall be arranged as per Ch 3 Sec 3.

4.2. Simple girders

- 4.2.1. The section modulus requirement for simple girders is given by:

$$Z = \frac{1000 b h S^2 w_c}{\sigma} \quad (\text{cm}^3)$$

- h = h_1 to h_3 as given in Table 9.2.1 and Table 9.2.2 for vessels with $L < 100$ m and $L \geq 100$ m respectively.
 = 1.15 h_4 as given in Table 9.2.1 and Table 9.2.2 for vessels with $L < 100$ m and $L \geq 100$ m respectively.
 = h_5 to h_8 whichever is relevant as given in Table 9.2.1 for vessels with $L < 100$ m
 = h_5 to h_9 whichever is relevant as given in Table 9.2.2 for vessels with $L \geq 100$ m
 b = loading breadth, in m
 σ = as given in Table 9.4.1 for vessels with $L < 100$ m
 = as given in Table 9.4.2 for vessels with $L \geq 100$ m

- 4.2.2. The web area requirement (after deduction of cut-outs) at the girder ends is given by following:

$$A = k S b h k_m + 10 h_g t_c \quad (\text{cm}^2)$$

- k = 0.6 for stringers and upper end of vertical girders
 = 0.8 for lower end of vertical girders
 b = as given in Sec [4.2.1]

- h_g = girder height, in m
 h = as given in Sec [4.2.1]

k may be reduced by 25% when watertight bulkheads, except the collision bulkhead, when pressure head h_1 is applied.

The web area at the middle of the span shall not be less than 0.5 A.

4.3. Complex girder systems

- 4.3.1. In addition to fulfilling the general local requirements given in Sec [4.1], 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 Ch 13.

Table 9.4.1. Values of σ for vessels with $L < 100$ m	
Member type	Allowable stress σ ⁽³⁾
Simple girders	For continuous longitudinal girders ⁽¹⁾ :
	$\frac{95}{k_m}$; within 0.4 L at deck or bottom when $Z_A = Z_R$
	$\frac{160}{k_m}$; within 0.4 L at deck or bottom when $Z_A \geq 2 Z_R$
	$\frac{160}{k_m}$; within 0.25 D above and below the neutral axis
	$\frac{160}{k_m}$; within 0.1 L from the perpendiculars
	For other girders:
	$\frac{160}{k_m}$
Remarks: 1) Between specified regions, the σ -value may be varied linearly. 2) Z_A and Z_R are defined in Sec [1.2] of this chapter. 3) The allowable stress may be increased by $60 / k_m$ for watertight bulkheads, except the collision bulkhead, when pressure head h_1 is applied.	

Table 9.4.2. Values of σ for vessels with $L \geq 100$ m	
Member type	Allowable stress σ ^{(1) (3) (4)}
Simple girders	<p>For continuous longitudinal girders:</p> $\frac{190}{k_m} - 130 f_2 \left(\frac{z_n - z_a}{z_n} \right), \text{ minimum } \frac{160}{k_m}; \text{ within } 0.4 L \text{ amidships}$ <p>For other girders:</p> $\frac{160}{k_m}$
<p>Remarks:</p> <p>1) Between specified regions, the σ-value may be varied linearly.</p> <p>2) f_{2b} = stress factor f_{2b} below the neutral axis, as specified in Sec [1.2] of this chapter. = stress factor f_{2d} above the neutral axis, as specified in Sec [1.2] of this chapter.</p> <p>3) For longitudinal girders $\sigma = 160 / k_m$ may be used in any case in combination with heeled condition pressure heads h_6 and h_7 as specified in Table 9.2.2</p> <p>4) The allowable stress may be increased by $60 / k_m$ ($40 / k_m$ for longitudinal girders within 0.4L amidships) for watertight bulkheads, except the collision bulkhead, when pressure head h_1 is applied.</p> <p>5) z_n and z_a are taken as defined in Sec [1.2] of this chapter.</p>	

SECTION 5 SPECIAL REQUIREMENTS

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5.1. Shaft tunnels

- 5.1.1. A watertight shaft tunnel shall be arranged in ships with engine room situated amidships. 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.
- 5.1.2. The curved top plating thickness may be taken as 90% of the requirement to plane plating with same stiffener spacing.
- 5.1.3. The thickness shall be increased by 2 mm, if ceiling is not fitted on top plating under dry cargo hatchway openings.
- 5.1.4. 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.

5.2. Corrugated bulkheads

- 5.2.1. The upper and lower 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.
- 5.2.2. Girders on corrugated bulkheads are normally to be arranged in such a way that application of the bulkhead as girder flange is avoided.
- 5.2.3. 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.

5.3. Supporting bulkheads

- 5.3.1. Bulkheads supporting decks shall be considered as pillars. The compressive loads and buckling strength shall be calculated as per Ch 14 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.

- 5.3.2. Section modulus requirement to stiffeners:

$$Z = 2 l^2 s \quad (\text{cm}^3)$$

- 5.3.3. The distance between stiffeners shall not be greater than 2 frame spacings, and shall not exceed 1.5 m.
- 5.3.4. The plate thickness shall not be less than 7.5 mm in the lowest hold and 6.5 mm in 'tween decks.
- 5.3.5. 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.

5.4. Strengthening against liquid impact pressure in larger tanks

- 5.4.1. Tanks with free sloshing length $l_s > 0.13 L$ and or breadth $b_s > 0.56 B$ shall be strengthened for the impact pressure as specified in Ch 4 Sec 3 [3.3.5].

5.4.2. Plating subjected to impact pressure head h_i . The thickness shall not be less than:

$$t = 2.85 k_a s \sqrt{h_i k_m} + t_c \quad (\text{mm})$$

5.4.3. Stiffeners supporting plating are subjected to impact pressure head h_i . The section modulus shall not be taken less than:

$$Z = 5 l l_p s h_i k_p w_c k_m \quad (\text{cm}^3)$$

The shear area at each end shall not be less than:

$$A_s = \frac{0.5 l (l_p - s) s h_i k_p k_m}{l_p} + 10 h_s t_c \quad (\text{cm}^2)$$

l_p = loaded length of stiffener, maximum l , but need not be taken greater than $0.1l_s$ or $0.1b_s$, respectively, for longitudinal or transverse impact pressure

k_p = correction factor for resulting impact pressure

$$= 1.1 - 10 \frac{l}{l'_s}; \text{ minimum } 0.35$$

l'_s = l_s or b_s as defined in Ch 4 Sec 3 [3.3.6]

h_s = height of stiffener, in m.

If the impact pressure is acting on the stiffener side, the stiffener web thickness shall not be less than:

$$t = 5 + \frac{s h_i k_m}{10} + t_c \quad (\text{mm})$$

The throat thickness of continuous fillet welding of the stiffener to the plating in cases where the impact pressure is acting on the stiffener side shall not be less than:

$$t = \frac{s h_i}{12} + \frac{t_c}{2} \quad (\text{mm})$$

A proper fit up between plating and stiffener is assumed.

The net connection area of continuous stiffeners at girders shall satisfy following expression:

$$1.7 A_F + A_W = 2 A_s$$

A_W = connection area at web, in cm^2

A_F = connection area at flange, in cm^2

5.4.4. Girders supporting stiffeners subjected to impact pressure head h_i .

The section modulus shall not be less than:

$$Z = 5 S S_p b h_i k_p w_c k_m \quad (\text{cm}^3)$$

The shear area at each end shall not be taken less than:

$$A_s = 0.5 S b h_i k_p k_m + 10 h_g t_c \quad (\text{cm}^2)$$

S_p = loaded length of girder, maximum S , but need not be taken greater than $0.1l_s$ or $0.1b_s$, respectively, for longitudinal or transverse impact pressure

k_p = correction factor for impact pressure

$$= 1.1 - 10 \frac{b}{l'_s}; \text{ minimum } 0.25 \text{ for horizontals}$$

$$= 1.1 - 10 \frac{S_p}{l'_s} ; \text{ minimum } 0.25 \text{ for verticals}$$

l'_s = l_s or b_s as defined in Ch 4 Sec 3 [3.3.6]

h_g = height of girder web, in m.

b = loading breadth of girder, in m.

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

$$t = 6.5 + 0.63 \sqrt{h_i k_m} + t_c \quad (\text{mm})$$

The throat thickness of continuous fillet welding of girder webs to the plating in cases where the impact pressure is acting on the girder web side shall not be less than:

$$t = \frac{s h_i}{12} + \frac{t_c}{2} \quad (\text{mm})$$

A proper fit up between plating and stiffener 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:

$$s = \frac{0.38 (t - t_c)}{\sqrt{h_i}} \quad (\text{m})$$

h_i = impact pressure head at panel near girder.

CHAPTER 10 SUPERSTRUCTURE ENDS, DECKHOUSE SIDES AND ENDS, BULWARKS

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SECTION 1 GENERAL

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1.1. Introduction

- 1.1.1 All the applicable requirements of superstructure end bulkheads, deckhouse sides and ends and bulwarks are specified in this section. However, the requirements for sides of superstructures and decks above superstructures and deckhouses are outlined in Ch 7 and Ch 8 respectively. Requirements for protection of crew and other relevant requirements based on ICLL regulations applicable to superstructures, deckhouses and bulwarks are included and outlined in Part 4.

1.2. Definitions**1.2.1 Symbols**

L	= rule length, in m ¹⁾
B	= rule breadth, 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
	$= \left(1.1 - 0.25 \frac{s}{l}\right)^2$
	= 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, Refer Ch 3 Sec 3 [3.1]. For curved stiffeners l may be taken as the cord length
σ	= nominal allowable bending stress in N/mm ² due to lateral pressure
h	= design pressure head, in m, as given in Sec 3.
k _m	= material factor. Refer Ch 2 Sec 2 and Ch 2 Sec 3

Remarks:

1) For details Refer Ch 1 Sec 2 [2.1.1]

- 1.2.2 *Superstructure* is defined as a decked structure on the freeboard deck that extends 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).
- 1.2.3 *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.

SECTION 2 STRUCTURAL ARRANGEMENT AND DETAILS

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2.1. Structural continuity

- 2.1.1. In superstructures and deckhouses aft, the front bulkhead shall be in line with a transverse bulkhead in the hull below or is to be supported by a combination of partial transverse bulkheads, pillars and girders. 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.
- 2.1.2. Adequate transverse strength shall be provided by means of transverse bulkheads or girder structures.
- 2.1.3. 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 superstructure ends 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.
- 2.1.4. The end bulkheads of long superstructures shall be effectively supported by heavy girders or bulkheads below deck.
- 2.1.5. Openings in the sides in long deckhouses shall have well rounded corners. At the upper and lower edge of large openings for windows, horizontal stiffeners shall be fitted.

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.

Remark:

Expansion of long deckhouse sides should be taken into account by setting in parts of the sides towards the centre line of the ship.

- 2.1.6. 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 prevent buckling that arises due to longitudinal compression forces.

2.2. Connections between steel and aluminum

- 2.2.1. When bolted connections are used, a non-hygroscopic insulation material shall be applied between aluminum and steel to prevent galvanic corrosion.
- 2.2.2. As far as possible, aluminum plating connected to steel boundary bar at deck is to be arranged on the side exposed to moisture.
- 2.2.3. A rolled compound (aluminum/steel) bar may be used in a welded connection after special approval.

- 2.2.4. Direct contact between exposed wooden materials, e.g. deck planking, and aluminum shall be avoided.
- 2.2.5. Bolts with washers and nuts 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.
- 2.2.6. For earthing of insulated aluminum superstructures, refer to relevant sections of Pt 6.

2.3. Miscellaneous

- 2.3.1. Companionways located on exposed decks shall be made of steel and are to be efficiently stiffened.
- 2.3.2. In general, bulwark plates are not to be welded to side plating or deck plating .Refer also Ch 7 Sec 3 [3.2.8]. Long bulwarks shall have expansion joints within 0.6 L amidships.
- 2.3.3. Where bulwarks on exposed decks form wells, ample provision shall be made for freeing decks of water.
- 2.3.4. Weld connections shall meet the general requirements given in Ch 11.

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3.1. External Pressure

3.3.1. Table 10.3.1 below specifies the design sea pressure heads for the various end and side structures.

Table 10.3.1 Design Loads for all ships irrespective of length		
Structure		Design pressure head h (m)
Unprotected front bulkheads	General	$h_1 = 0.57 a (k C_{WV} - h_0) c$
	Minimum lowest tier	$h_2 = 1.25 + 0.005 L_1$
	Minimum elsewhere	$h_3 = 0.625 + 0.0025 L_1$
Unprotected sides in deckhouses		$h_4 = h_{dp} - (0.4 + 0.02 k_s) h_0$; minimum h_3
Unprotected aft end bulkheads		$h_5 = 0.085 h_4$; minimum h_3
Remarks: 1) For ships with service restrictions, h_1 and h_4 may be reduced with the percentages given in Ch 3 Sec 2 Table 3.2.2. C_{WV} shall not be reduced. 2) The minimum design pressure head for sides and aft end of deckhouses 1.7 C_{WV} (m) above S.W.L. may be reduced to 0.25 m.		

$$a = 2.0 + \frac{L}{120} \quad ; \text{ maximum 4.5 for the lowest tier front}$$

$$= 1.0 + \frac{L}{120} \quad ; \text{ maximum 3.5 for 2nd tier front}$$

$$= 0.5 + \frac{L}{150} \quad ; \text{ maximum 2.5 for 3rd tier front and above}$$

$$k = 1.3 - 0.6 \frac{x}{L} \quad \text{for } \frac{x}{L} \leq 0.5$$

$$= 0.3 + 1.4 \frac{x}{L} \quad \text{for } \frac{x}{L} > 0.5$$

x = longitudinal distance, in m, from A.P. to the load point

h_0 = vertical distance, in m, from the waterline at draught T_{ms} 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_{WV} = wave coefficient as given in Ch 4 Sec 2

h_{dp}, k_s = as given in Ch 4 Sec 3 [3.2.1]

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4.1. End bulkheads of superstructures and deckhouses, and exposed sides in deckhouses

4.1.1. The thickness requirement for plating corresponding to lateral external pressure is given by:

$$t = \frac{49.96 k_a s \sqrt{h}}{\sqrt{\sigma}} \quad (\text{mm})$$

h = h_1 to h_5 , whichever is relevant, as given in Table 10.3.1
 σ = $160 / k_m$ N/mm²

The definition of the parameters used in the above equation is given in Sec [1.2] of this chapter.

4.1.2. The thickness shall not be less than:

For the lowest tier:

$$t = 5 + 0.01 L \quad (\text{mm}); \quad \text{maximum } 8 \text{ mm}$$

For the higher tiers:

$$t = 4 + 0.01 L \quad (\text{mm}); \quad \text{maximum } 7 \text{ mm, minimum } 5 \text{ mm}$$

4.1.3. The section modulus requirement for stiffeners is given by:

$$Z = \frac{1000 s h l^2}{\sigma} \quad (\text{cm}^3)$$

h = as specified in Sec [4.1.1]
 σ = $160 / k_m$ for longitudinals, vertical and transverse stiffeners in general
= $90 / k_m$ 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.

4.1.4. Front stiffeners shall be connected to deck at both ends with a connection area not less than:

$$a = 0.7 k_m l s h \quad (\text{cm}^2)$$

However, sniped ends may be allowed for stiffeners above the 3rd tier, provided the requirement specified in Ch 3 Sec 3 [3.2.4] is fulfilled.

Side and after end stiffeners in the lowest tier of erections shall have end connections.

4.1.5. 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.

4.2. Protected Casings

4.2.1. The plating thickness 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 pathway of accommodation.

s = stiffener spacing, in m, measured along the plating

4.2.2. The section modulus of stiffeners shall not be less than:

$$Z = 3 k_m l^2 s \quad (\text{cm}^3)$$

l = length of stiffeners, in m, minimum 2.5 m.

4.2.3. Adequate strengthening shall be provided for casings supporting one or more decks above.

4.3. Bulwarks

4.3.1. If the height of the bulwarks is 1.8 m, 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 bulwark is 1 m or less, the thickness need not be greater than 6.0 mm.

For intermediate heights, thickness of the bulwark may be determined by interpolation.

4.3.2. 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 local transverse stiffening or transverse beams. Alternatively, the toe of stay may be supported by a longitudinal member. The stays shall have sufficient width at the 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 the ends of bulwark openings. Openings in bulwarks shall not be situated near the end of superstructures.

4.4. Aluminum Deckhouses

4.4.1. The strength of aluminum deckhouses shall be related to that required for steel deckhouses, refer below. The scantlings shall be based on the mechanical properties of the applied alloy, refer to *Ch 2 Sec 3*.

4.4.2. The minimum thicknesses given in *Sec [4.1.2]* and *Sec [4.2.1]* shall be increased by 1 mm.

4.4.3. For the section moduli requirements given in *Sec [4.1]* and *Sec [4.2]* k_m need not be taken greater than 1.67.

CHAPTER 11 WELD CONNECTIONS AND WELDING

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SECTION 1 GENERAL

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1.1. Introduction

- 1.1.1. Requirements related to various weld connection details and welding are specified in this chapter.

1.2. Definitions

- 1.2.1. Symbols:
 t_c = corrosion addition, in mm, as specified in Ch 2 Sec 4.

SECTION 2 TYPES OF WELDED JOINTS

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2.1 Butt joints

- 2.1.1 The joints are normally to be butt welded with edges prepared as indicated in Fig.11.2.1 for panels with plates of equal thickness.
- 2.1.2 The thicker plate is normally to be tapered for butt welded joints of plates with thickness difference exceeding 4 mm. The taper is generally not to exceed 1:3. After tapering, the end preparation may be as indicated in above Sec [2.1.1] for plates of equal thickness.
- 2.1.3 All types of butt joints are normally to be welded from both sides. Unsound weld metal shall be removed at the root by a suitable method prior to carrying out welding from the second side.
- 2.1.4 Butt welding from one side against permanent backing will only be permitted after special consideration when the stress level is low.

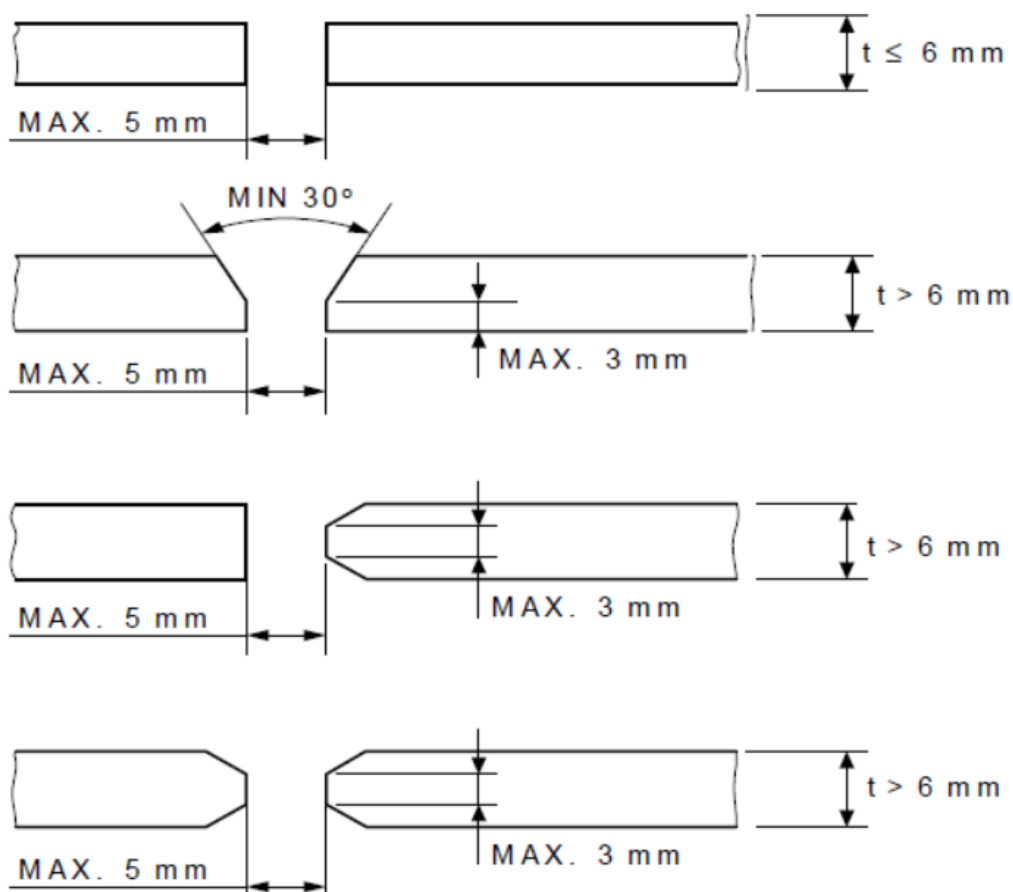


Fig. 11.2.1 Manually welded butt joint edges

2.2 Lap joints and slot welds

- 2.2.1 Various types of overlapped joints are shown in Fig. 11.2.2.
- 2.2.2 For connections dominated by shear or in plane stresses acting parallel to the weld, Type "A" (lap joint) may be used. Such overlaps will normally not be accepted for connections with

high in plane stresses transverse to the weld. Stresses above 0.5 times yield are considered as high in this context.

- 2.2.3 For connection of plating to internal webs, where access for welding is not practicable, Type "B" (slot weld) may be used.
- 2.2.4 For plates subject to larger in plane transverse stresses where type "B" slot welding is not acceptable, Type "C" (filled slot weld) may be used.
- 2.2.5 Type "B" and "C" joints shall not be used in case of pressure from abutting plate side or in tank boundaries.
- 2.2.6 For requirements to size of slot welds, Refer Sec [3.6] of this chapter.

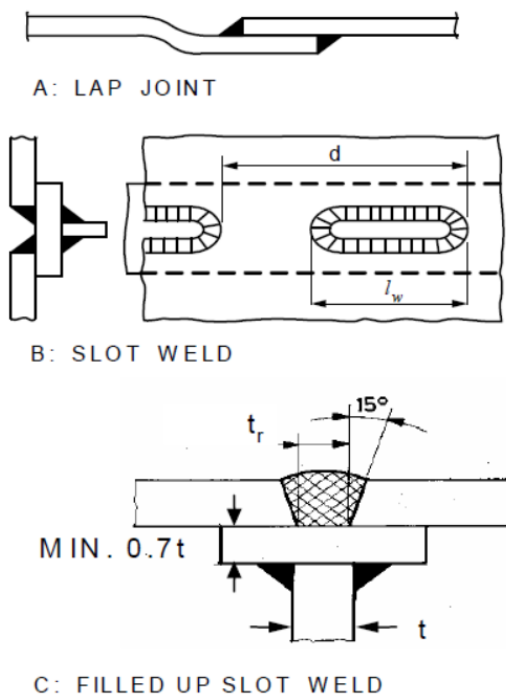


Fig. 11.2.2 Lap joints and slot welds

2.3 Tee or cross joints

- 2.3.1 Fillet welds are normally to be used for the connection of girder and stiffener webs to plate panel as well as plating abutting on another plate panel, as indicated in Fig.11.2.3. For fillet weld with opening angle θ (refer Fig.11.2.3) less than 75 deg., the net requirement specified in Sec [3.1.3], Sec [3.2.2] and Sec [3.3.2] of this chapter shall be increased by a factor $\sqrt{2} \cos(\theta/2)$.
- 2.3.2 The edge of the abutting plate may have to be bevelled to give partial or full penetration welding in cases where the connection is highly stressed or otherwise considered critical. Refer also Sec [2.3.7]. For penetration welds, root face r and throat thickness t_w are defined as shown in Fig.11.2.3. In case of partial penetration welding with an abutting plate bevelled only at one side, the fillet weld at opposite side shall not be less than 80% of that required for a double continuous fillet weld specified in Sec [3.1.3] and Sec [3.2.2] of this chapter.

- 2.3.3 Intermittent welds may be used in cases where the connection is moderately stressed. With reference to Fig.11.2.4, the various types of intermittent welds are as follows:
- chain weld
 - staggered weld
 - scallop weld (closed).
- 2.3.4 For size of welds, Refer Sec [3.5] of this chapter.
- 2.3.5 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 as required by Sec [3.5.1] of this chapter.
- 2.3.6 Where intermittent welding or one sided continuous welding is permitted, double continuous welds are to be applied for each ends in accordance with Sec [3.1.3] of this chapter.
- 2.3.7 Double continuous welds are required in the following connections irrespective of the stress level:
- connections in rudders, except where access difficulties necessitate slot welds
 - connections at supports and ends of stiffeners, pillars, cross ties and girders
 - Center line girder to keel plate.
 - Weather tight, watertight and oil tight connections
 - connections in foundations and supporting structures for machinery
 - all connections in after peak
- 2.3.8 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, refer Fig.11.2.5.
- 2.3.9 Full penetration welds are to be used, in any case, in the following connections:
- rudder horns and shaft brackets to shell structure
 - rudder side plating to rudder stock connection areas
 - lower end of vertical corrugated bulkheads that are situated in the cargo area and arranged without lower stool.
 - 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, refer Fig.11.2.6. For machine cut holes, partial penetration with root face $r = t / 3$ may be accepted
 - abutting plate panels (refer Fig.11.2.3) 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.

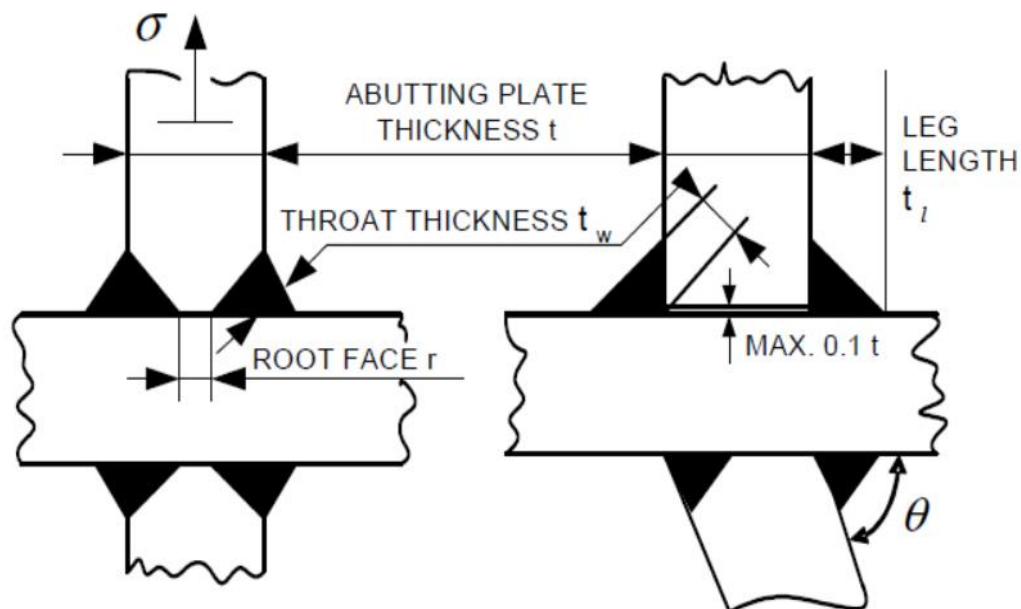


Fig. 11.2.3 Tee or cross joints

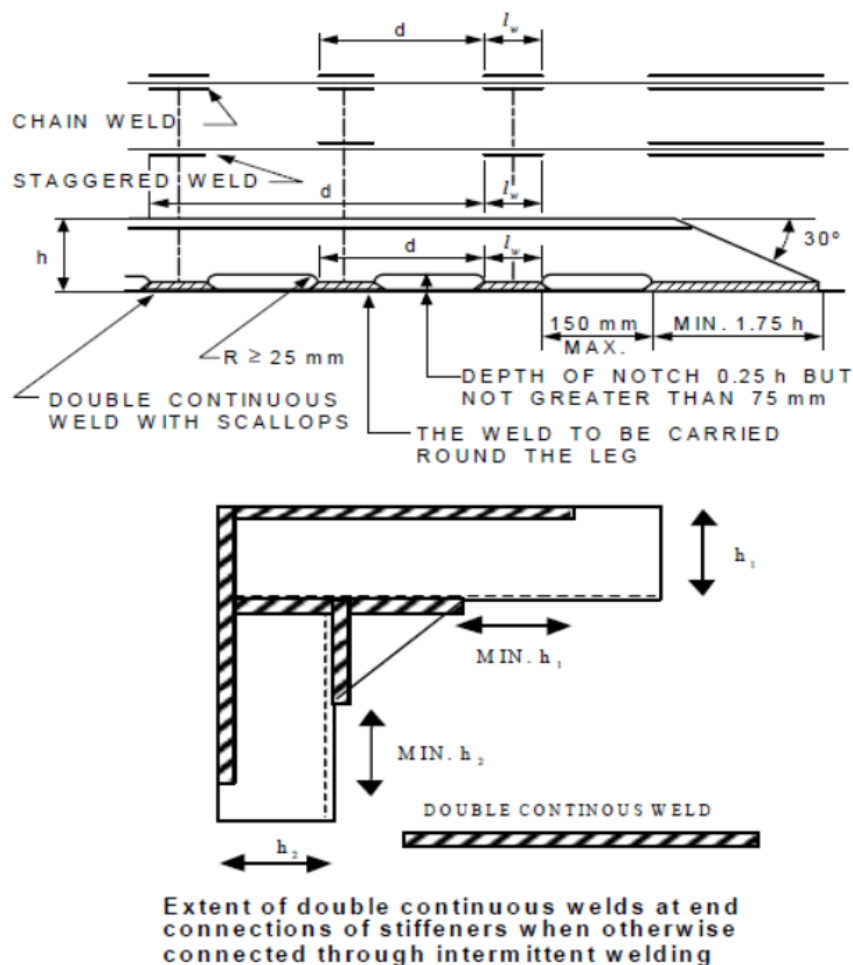


Fig. 11.2.4 Intermittent welds

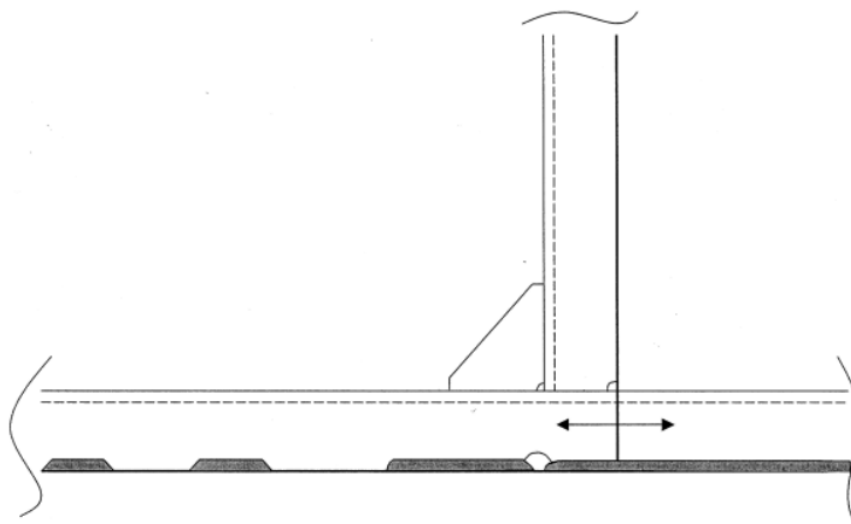


Fig. 11.2.5 Weld termination towards tank boundary

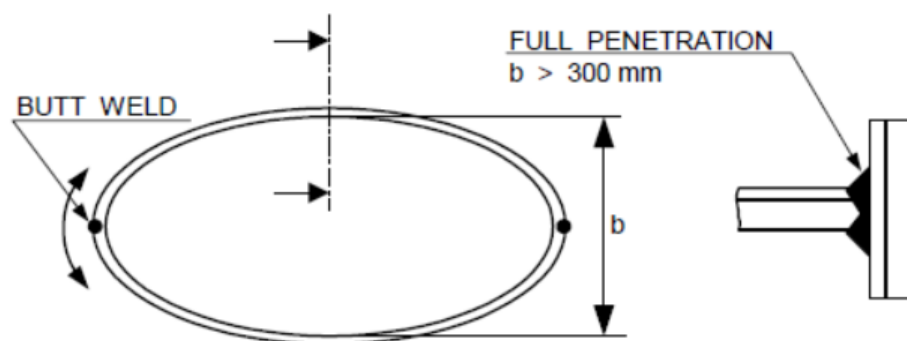


Fig. 11.2.6 Bottom and deck penetrations

SECTION 3 SIZE OF WELD CONNECTIONS

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3.1. General requirements for continuous fillet welds

- 3.1.1 Unless otherwise specified, it is assumed that the welding consumables used will give weld deposit with yield strength σ_{fw} as follows:

$$\begin{aligned}\sigma_{fw} &= 355 \text{ N/mm}^2 \text{ for welding of normal strength steel} \\ &= 375 \text{ N/mm}^2 \text{ for welding of the high strength steels HT-32 and HT-36} \\ &= 390 \text{ N/mm}^2 \text{ for welding of high strength steel HT-40.}\end{aligned}$$

Refer to Ch 2 Sec 2 [2.2] for material classes and designations referenced above.

If welding consumables with deposits of lower yield strength than specified above are used, the σ_{fw} value shall be specified on the drawings submitted for approval. The yield strength of the weld deposit is in no case to be less than the requirement specified in relevant chapter of Pt 2.

- 3.1.2 The required throat thicknesses may be reduced by 15% of that required in Sec [3.1.3] in cases where deep penetrating welding processes are applied, provided that sufficient weld penetration is demonstrated.

Remarks:

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.

- 3.1.3 For double continuous fillet welds, the throat thickness shall not be less than:

$$t_w = \frac{W t_0 k_w}{\sqrt{k_m}} + 0.5 t_c \text{ (mm); minimum as given in Sec [3.1.4]}$$

W = weld factor as given in Table 11.3.1
 t_0 = net thickness, in mm, of abutting plate, corrosion addition not included
 $= t - t_c$, where:
 t = gross thickness of abutting plate, in mm .Refer Fig.11.2.3
 t_c = as given in Sec [1.2] of this chapter
 k_m = material factor. Refer Ch 2 Sec 2
 k_w = material factor for weld deposit

$$= \left(\frac{235}{\sigma_{fw}} \right)^{0.75} ; \text{ maximum } \sqrt{\frac{2}{k_m}}$$

σ_{fw} = yield strength in N/mm² of the weld deposit

When welding consumables with deposits as mentioned in Sec [3.1.1] are used, k_w may be taken as mentioned below dependent on parent material:

k_w = 0.74 for MS
 = 0.70 for HT-32 and HT-36
 = 0.68 for HT-40.

Refer to Ch 2 Sec 2 [2.2] for material classes and designations referenced above.

Table 11.3.1 Weld factor W		
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 ¹⁾	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 center 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 Sec [3.2] to Sec [3.4], e.g. boundary connection of watertight compartments and fuel oil tanks	0.43	
Remarks:		
1) Welding of longitudinals of flat-bar type may normally be according to Sec [3.1.4].		

3.1.4 The throat thickness of fillet welds is in no case to be taken less than given in Table 11.3.2

Table 11.3.2 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
$t_0 > 12.5$	$0.21t_0$, minimum 3.25 ⁽²⁾
<p>Remarks:</p> <p>1) Corrosion addition $0.5 t_c$ to be added where relevant, Refer Ch 2 Sec 2. The values may be reduced by 10% for local buckling stiffeners (sniped ends).</p> <p>2) $0.18 t_0$, minimum 3.0 when automatic deep penetration welding is applied.</p> <p>3) Net thickness of abutting plate as defined in Sec [3.1.3] with the following reductions:</p> <p>$t_0 = 0.5 (25 + t - t_c)$ for net plate thicknesses $(t - t_c)$ above 25 mm</p> <p>$t_0 = 25 + 0.25 (t - t_c - 25)$ for longitudinals of flat-bar type with net plate thickness $(t - t_c)$ above 25 mm</p>	

3.2. Penetration welds and fillet welds subject to high tensile stresses

3.2.1. Where high tensile stresses act through an intermediate plate in structural parts (refer Fig.11.2.3), 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 top of stool tank or directly to inner bottom
- stool tanks to inner bottom and hopper tank
- structural elements in double bottoms below bulkhead and stool tanks
- transverse girders in center tanks to longitudinal bulkheads.

3.2.2. The throat thickness of double continuous welds, in cases where full penetration welding is not used, shall not be less than:

$$t_w = W_1 t_0 + 0.5 t_c \quad (\text{mm})$$

$$W_1 = 1.36 k_w \left[0.2 + \left(\frac{\sigma}{270} - 0.25 \right) \frac{r}{t_0} \right]$$

- σ = calculated maximum tensile stress in abutting plate in N/mm^2
 t_0 = net thickness, in mm, of abutting plate as given in Sec [3.1.3]
 r = root face, in mm (refer Fig.11.2.3)
 k_w = as given in Sec [3.1.3]

Typical design values for W_1 are given in Table 11.3.3.

Table 11.3.3 Values of W_1			
Plate material	σ	W_1	
		Fillet weld: $r = t_0$	Partial penetration weld with root face: $r = t_0 / 3$
MS	160	0.54	0.31
HT-32	205	0.68	0.35
HT-36	222	0.74	0.37

Refer to Ch 2 Sec 2 [2.2] for material classes and designations referenced above.

3.3. End connections of pillars, girders and cross ties

- 3.3.1. 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 Sec [3.2] 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.

- 3.3.2. The throat thickness of double continuous boundary fillet welds, in cases with high shear stresses in web plates, shall not be less than:

$$t_w = \frac{t_0 \tau}{2 \tau_w} + 0.5 t_c \quad (\text{mm})$$

τ = calculated shear stress in N/mm^2

τ_w = $100 / k_w$ when calculated shear stress (τ) is average shear stress in web plate

τ_w = $115 / k_w$ when calculated shear stress (τ) is local shear stress in web plate

t_0 = net thickness of abutting plate, in mm, as given in Sec [3.1.3]

k_w = as given in Sec [3.1.3].

- 3.3.3. The weld area at the end connection of pillars and cross ties shall not be less than:

$$a = k P k_w + a_c \quad (\text{cm}^2)$$

P = axial load, in kN, in pillar of cross tie

a_c = corrosion addition corresponding to t_c

k_w = as given in Sec [3.1.3]

k = 0.05 when pillar in compression only
= 0.14 when pillar in tension.

3.4. End connections of stiffeners

- 3.4.1. Stiffeners may be connected to the web plate of girders in any of 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.

A double-sided connection or a stiffening of the unconnected web plate edge is normally required in locations with great shear stresses in the web plate. A double-sided connection may be taken into account when calculating the effective web area.

3.4.2. The connection area at supports of stiffeners is normally not to be less than:

$$a_0 = 10 w k (l - 0.5 s) s h \quad (\text{cm}^2)$$

- w = factor as given in Table 11.3.4
 k = $r_1 r_2$
 r_1 = 0.125 when pressure acting on stiffener side
 = 0.100 when pressure acting on opposite side
 r_2 = 1.0 k_m 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
 k_m = material factor. Refer Ch 2 Sec 2
 l = distance between girder web plates, in m
 s = spacing between stiffeners, in m
 h = design pressure head, in m.

Corrosion addition as specified in Ch 2 Sec 4 [4.2] is not included in the formulae for a_0 , and shall be added where relevant.

Weld area shall not be less than:

$$a_w = \frac{1.15 a_0 k_w}{\sqrt{k_m}} + a_c \quad (\text{cm}^2)$$

- a_c = corrosion addition corresponding to t_c
 k_w = as given in Sec [3.1.3]

Table 11.3.4 Values of w			
Type of connection (Refer Fig. 11.3.1)	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

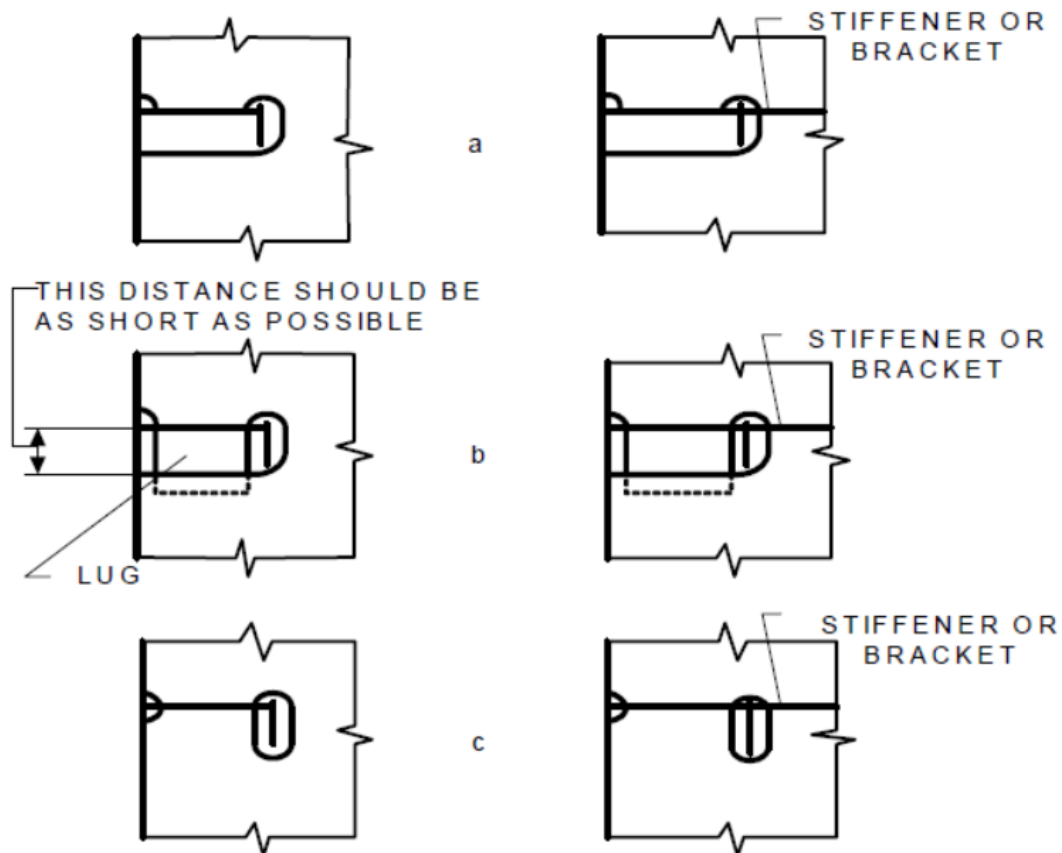


Fig. 11.3.1 Various types of end connections

- 3.4.3. Various standard types of connections are shown in Fig.11.3.1. Other types of connection will be considered in each case. When stiffeners and supporting web frames are made of high strength steel, stiffeners on ship's side in ballast and cargo tanks are to be specially considered.

Remark:

In ballast and cargo tanks the connection type b or c should be used for longitudinals on ship sides, unless double-sided brackets are arranged, Refer also Ch 7 Sec 5 [5.4].

- 3.4.4. Connection lugs shall have a thickness not less than 75% of the web plate thickness.
- 3.4.5. Lower ends of peak frames shall be connected to the floors by a weld area not less than:

$$a = 1.05 l s h + a_c \quad (\text{cm}^2)$$

l , s , h and a_c = as given in Sec [3.4.2].

- 3.4.6. For stiffeners which may be sniped at the ends according to the requirements given in Ch 3 Sec 3 [3.2], the required connection area is satisfied by the plating.
- 3.4.7. The weld area of bracketed end connections, as mentioned below, shall not be less than:

$$a = \frac{kZ}{h} + a_c \quad (\text{cm}^2)$$

- 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_c = corrosion addition corresponding to t_c .

- 3.4.8. The weld area of brackets between transverse deck beams and frames or bulkhead stiffeners shall not be less than:

$$a = 0.41 \sqrt{Z t_b} + a_c \quad (\text{cm}^2)$$

- t_b = net thickness, in mm, of bracket
 Z = as defined in Sec [3.4.7]
 a_c = as defined in Sec [3.4.7].

- 3.4.9. 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.

3.5. Intermittent welds

- 3.5.1. Throat thickness of intermittent fillet welds shall not be less than:

$$t_w = \frac{W t_0 k_w}{\sqrt{k_m}} \frac{d}{l_w} + 0.5 t_c \quad (\text{mm})$$

W , t_0 , k_w and k_m are as given in Sec [3.1.3]. W – values given in Table 11.3.1 for 60% of the span may be applied.

- d = distance, in mm, between successive welds, Refer Fig.11.2.4
 l_w = length, in mm, of weld fillet, not to be less than 75 mm, Refer Fig.11.2.4.

- 3.5.2. In addition to the minimum requirements specified in Sec [3.5.1], the following shall also 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 are to be applied at ends, Refer Fig.11.2.4.

3.6. Slot welds

- 3.6.1. Slots shall have a minimum length of 75 mm and, normally, a width of twice the plate thickness. The ends shall be well rounded, Refer Fig.11.2.2. The distance d between slots shall not exceed $3l$, maximum 250 mm.

- 3.6.2. Fillet welds in slots shall have a throat thickness as given by the formula in Sec [3.5.1] with:

- t_0 = net thickness of adjoining web plate

d = distance between slots, Refer Fig.11.2.2
 l = length of slots.

- 3.6.3. For ships with $L \geq 100$ m, slot weld is not acceptable for areas with high in plane stresses transversely to the slots.
- 3.6.4. For ships with $L < 100$ m, slots through plating subject to large in-plane tensile stresses across the slots may be required to be completely filled by weld. Narrow slots with inclined sides (minimum 15° to the vertical) and a minimum opening of t_r at bottom should then be used. t_r should be minimum $0.75 t$ but not less than 6 mm (Refer Fig.11.2.2). A continuous slot weld may, however, in such cases be more practical.

CHAPTER 12 STRUCTURES FOR HIGH TEMPERATURE CARGO

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SECTION 1 GENERAL

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1.1. Introduction

- 1.1.1. This chapter outlines the requirements that apply to ships intended to carry liquid cargo at a temperature higher than 80°C at atmospheric pressure.
- 1.1.2. Liquid cargo may be carried and transported in integral cargo tanks or independent cargo tanks, based on the structural and strength requirements. A list of cargoes which may be covered by these rules is given in Sec 6 of this chapter.
- 1.1.3. Cargoes of different temperatures and natures shall not be carried simultaneously in adjacent tanks or in the cargo area unless especially investigated and accepted.
- 1.1.4. Temperature stresses in the cargo containment area with surroundings shall be evaluated and documented for both partial cargo and full cargo conditions, Refer Sec 4 of this chapter.
- 1.1.5. Heat balance calculations for partial cargo and full cargo conditions are also to be available, Refer Sec 4 of this chapter.
- 1.1.6. For a specific gravity of cargo exceeding 1.025 t/m³ refer Ch 4 Sec 3 [3.3].

1.2. Special features notations

- 1.2.1 Ships constructed according to these rules may be given the additional notation **HTC** e.g. **HTC (...°C cargo tank no....)**.
- 1.2.2 Ships constructed for carrying and transporting cargoes with specific gravity heavier than sea water may be given the additional notation **HLC(p) (cargo tank no....)**, refer Ch 4 Sec 3 [3.3].

1.3. Signboards

Refer to Ch 1, Sec 1, [1.1.2]

1.4. Survey and Testing

Refer to Ch 1, Sec 1, [1.1.2]

SECTION 2 MATERIALS AND MATERIAL PROTECTION

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2.1. Hull and tank material

- 2.1.1 Refer Ch 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/mm² per 50°C increase in temperature above 80°C and shall be taken into account when calculating the strength.
- 2.1.2 Use of high strength steel in the cargo containment area may be necessary or beneficial to absorb the temperature stresses added.
- 2.1.3 The elements in the hull structure intended to buckle shall be excluded, when calculating the f_{2b} and f_{2d} factors defined in Ch 6 Sec 1 [1.2.1] and Ch 8 Sec 1 [1.2.1] respectively. Such elements may, however, be included when they are in tension.

2.2. Insulation material

- 2.2.1 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.

2.3. Corrosion Protection

- 2.3.1 Ballast tanks within the cargo area or adjacent to the cargo area shall be coated to prevent corrosion.

Remark:

The coating material must be compatible with expected environmental conditions e.g. resistive against heat, elastic against expansion.

- 2.3.2 Corrosion additions above table values given in Ch 2 Sec 4 [4.2] should be considered. Specific attention shall be given to the upper part of side tanks, hot sides of ballast tanks and upper deck subject to the salt atmosphere.

SECTION 3 SHIP ARRANGEMENT

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3.1. Location and separation of spaces

- 3.1.1 The cargo pump rooms shall be separated from the cargo area by cofferdam or insulation, preferably an open, ventilated cofferdam.

3.2. Equipment within the cargo area

- 3.2.1 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.

3.3. Equipment within the cargo area

Refer to Ch 1, Sec 1, [1.1.2]

3.4. Equipment within the cargo area

Refer to Ch 1, Sec 1, [1.1.2]

SECTION 4 LOAD CONDITIONS

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4.1. Full and partial cargo conditions

- 4.1.1. 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 the less is, where h is the depth of the longitudinal bulkhead or the tank depth. Alternative tank filling in longitudinal direction should be basis for the thermal stresses.

4.2. Water ballast conditions

- 4.2.1. Water ballast is at no time to be carried adjacent to the tanks with hot cargo. A defined safe zone must be specified.
- .

SECTION 5 SCANTLINGS OF THE CARGO AREA

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5.1. Construction considerations

- 5.1.1 Hot cargo directly on the outer side shell plating shall be avoided.
- 5.1.2 An integral cargo stiffening system consisting of single bottom, deck and double boundary at sides, transverse/longitudinal girders and stiffeners may be feasible with a cargo temperature of up to about 140°C. Longitudinal and transverse cargo separation bulkheads may be of non-corrugated type, preferably without deep girders/stringers. The dimensions and details are to be calculated and considered with due respect to the temperature stresses.
- 5.1.3 An integral cargo system consisting of double skin may be feasible with a cargo temperature of up to about 200°C. The inner containment is to be transverse stiffened while outer system should be longitudinal stiffened. Single deck may be accepted. Longitudinal and transverse cargo separation bulkheads are 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.
- 5.1.4 Independent cargo system will normally be required with a cargo containment temperature above about 200°C.
- 5.1.5 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.
- 5.1.6 All transitions in the main structures shall be carefully designed with respect to high shear forces where the temperatures as well as temperature gradients are high.
- 5.1.7 Weld dimensions in structures where high shear forces are involved shall be specifically calculated.

5.2. Thermal stress analysis

- 5.2.1 It will normally be accepted that the temperature stresses are established within the parallel midship portion of the cargo area and then generally used for the whole cargo area.

Remark:

The coefficients mentioned in the below table may be used in the heat balance calculations for a ship with class notation Tanker for Asphalt.

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 kcal / hour / m² / °C

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 + 59.196 kcal/h m °C.

The effect from various scantlings is negligible.

	kcal / hour / m ² / °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 between inner and outer shell	10
Air to outer ship side:	10
Air to inner ship side:	10
Air to web in transverse web frame:	5

- 5.2.2 The calculated temperature loadings shall represent full load and partial load conditions, seagoing as well as harbor conditions.
- 5.2.3 The ambient temperature in the sea water and in the air shall be 0°C when heat flow is calculated.
- 5.2.4 The temperature stresses shall be combined with still water and wave bending stresses as well as static and dynamic stresses from cargo and seawater.
- 5.2.5 The total results shall be checked against allowable stresses, refer below, and the global and local buckling strength.

Local elastic buckling is acceptable, refer also Appendix A. Reduced stiffness of plating shall be used in the calculations. The final results shall include correct stiffnesses.

Remark:

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 centerline.

5.3. Acceptable stress level

- 5.3.1 The stress level shall not exceed the values given in this chapter, where actual loading conditions are calculated without taking temperature into account.
- 5.3.2 The following stresses are acceptable (all values are given at 180°C), when the temperature stresses are included:
- Transverse and longitudinal girders

Nominal stress for MS	σ_{\max}	= 190 N/mm ²
Nominal stress for HT-32	σ_{\max}	= 260 N/mm ²
Nominal stress for HT-36	σ_{\max}	= 300 N/mm ²
Shear stress for MS	τ_{\max}	= 110 N/mm ²
Shear stress for HT-32	τ_{\max}	= 155 N/mm ²
Shear stress for HT-36	τ_{\max}	= 175 N/mm ²
Equivalent stress for MS	$\sigma_{e \max}$	= 205 N/mm ²
Equivalent stress for HT-32	$\sigma_{e \max}$	= 280 N/mm ²
Equivalent stress for HT-36	$\sigma_{e \max}$	= 315 N/mm ²

When the thermal stresses are the dominant part of the stress level, higher stresses than above may be acceptable locally

$$\left(\text{up to } \sigma_{\max} = \sigma_F \text{ and } \tau_{\max} = \frac{\sigma_F}{\sqrt{3}} \right)$$

- Hull section modulus
Stresses from cargo conditions shall be as given by Ch 5 Sec 3 [3.3.5] when Sec 4 [4.1.2] of this chapter is taken account of. The same effect applies to the minimum requirement.
- Longitudinals
The stresses shall be as given in this chapter increased by 30 N/mm² for MS or 80 N/mm² for HT-36 steel when the temperature in elements is 180°C.
- Beams, frames
The stresses shall be as given in this chapter increased by 30 N/mm² for MS or 80 N/mm² for HT-36 steel when the temperature in elements is 180°C.
- Plating
Minimum thicknesses to be as for an ordinary ship without high temperatures.

Refer to Ch 2 Sec 2 [2.2] for material classes and designations referenced above.

5.4. Girders

- 5.4.1 Due to the temperature rise (i.e. the temperature gradients), the forces introduced to the girder system 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.

SECTION 6 TYPE OF CARGOES

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6.1 List of Cargoes

6.1.1 Examples of cargoes which may be covered by these rules:

<i>Cargo</i>	<i>Specific Gravity (t/m³)</i>	<i>Temperature (°C)</i>
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 1.20	about 100
Sulphur (molten)	1.80	155 ¹⁾
Remark: 1) Independent tanks required		

CHAPTER 13 DIRECT STRENGTH CALCULATION

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SECTION 1 GENERAL

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1.1. Introduction

- 1.1.1. In the previous chapters the scantlings of various primary and secondary hull structures have been specified explicitly, based on design principles defined in Ch 3 Sec 2. In some cases references has been given to direct strength or stress calculations in the text.

This section specifies loads, acceptance criteria and essential documentation for direct strength calculations.

1.2. Application

- 1.2.1. 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 carried out by finite element analysis or beam analysis if finite element analysis has not been explicitly required elsewhere in the rules.

- As supplementary basis for the scantlings.

- 1.2.2. For ships where direct calculations for the midship region based on finite element methods are required by the rules, such analysis shall be carried out 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 specified in Sec 2 [2.4] of this chapter.

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.

Additional descriptions of such calculations are given in Sec 4, Sec 5 and Sec 6 of this chapter.

1.3. Documentation

- 1.3.1. When direct strength analyses are submitted for information, such analyses shall be supported by documentation satisfactory for verifying results obtained from the analyses.
- 1.3.2. 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.

- 1.3.3. Modelled geometry, material parameters, plate thickness, beam properties, boundary conditions and loads shall be documented preferably as an extract directly from the generated model.
- 1.3.4. Reaction forces and displacements shall be presented to the extent necessary to verify the load cases considered.
- 1.3.5. The documentation of results shall contain all significant results such as:
 - Type of stress (element/nodal, membrane/surface, normal/ shear/equivalent)
 - Magnitude
 - Unit
 - Load case
 - Name of structure
 - Structural part presented.
- 1.3.6. Evaluation of the results with respect to the acceptance criteria shall be submitted for information.

SECTION 2 CALCULATION METHODS

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2.1. General

- 2.1.1. A complete structural analysis may have to be performed for girders which are parts of a complex 2- or 3-dimensional structural system, to demonstrate that the stresses are acceptable when the structure is loaded as described in Sec 2 [2.3] of this chapter.
- 2.1.2. Detailed requirements for the extent of direct calculations have (as applicable) been specified 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 specific class notation has not been requested.
- 2.1.3. 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.

Finite element analysis or equivalent methods shall be applied for deep girders, bulkhead panels, bracket zones, etc. where results obtained by applying beam theory are unreliable.

- 2.1.4. Objectives of analyses together with their applicable acceptance criteria are described in Sec 3 to Sec 6 of this chapter for the following levels of calculations:
- Global analysis
 - Cargo hold/tank analysis
 - Frame and girder analysis
 - Local structure analysis.
- 2.1.5. A direct calculation may generally be undertaken as a frame and girder analysis as described in Sec 5 of this chapter, supplemented by local structure analyses as described in Sec 6 of this chapter, if necessary, for structures such as decks, bulkheads, hatch covers, ramps etc.
- 2.1.6. Corrosion addition, t_c , shall be deducted from the material thickness.
- 2.1.7. According to Ch 3 Sec 3 [3.4], areas representing girder flanges shall be adjusted for effective width.
- 2.1.8. 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.

2.2. Computer program

- 2.2.1 The calculations specified in the requirements shall be performed by computer programs recognized by the Society. Programs applied where reliable results have been demonstrated to the satisfaction of the Society are considered as recognized programs.

2.3. Loading conditions and load application

- 2.3.1. Calculations shall be based on the most severe realistic loading conditions with the ship:
- Fully loaded
 - Partly loaded
 - Ballasted
 - During loading/discharging
- 2.3.2. General design loads are given in Ch 4 and design loads for specific structures are given in Ch 6 to Ch 10.
- 2.3.3. Local dynamic loads shall be taken at a probability of exceedance of 10^{-4} , when used together with acceptance criteria as given in Sec 2 [2.4] of this chapter.
- 2.3.4. For sea-going conditions realistic combinations of external and internal dynamic loads shall be considered.
- 2.3.5. For harbor conditions, only static loads need to be considered. Harbor conditions with asymmetric loading are relevant to the extent that they do not result in unrealistic heeling.
- 2.3.6. Pressures given in the below sections are expressed in terms of corresponding pressure heads. Refer Ch 4 Sec 1 [1.1.5] to derive pressures from pressure heads for application in the analysis model.

- 2.3.7. Pressure head corresponding to external sea pressures in the upright seagoing condition shall be taken in accordance with Ch 4 Sec 3 [3.2] with h_0 defined as follows:

h_0 = vertical distance, in m, from the waterline considered to the load-point.

- 2.3.8. In harbor conditions, pressure head corresponding to the external sea pressure, h shall be taken as:

$$h = h_0 \quad (\text{m})$$

- 2.3.9. Pressure head corresponding to external sea pressures, h , in heeled conditions are normally to be taken as:

$$h = (T_a - z) + 0.67 y \tan \left(\frac{\phi}{2} \right) \quad (\text{m}) ; \text{ on the submerged side}$$

$$h = (T_a - z) - 1.00 y \tan \left(\frac{\phi}{2} \right) \quad (\text{m}) ; \text{ on the emerged side}$$

$$h = 0 \quad (\text{m}) ; \text{ minimum}$$

T_a = actual considered draught, in m

z = vertical distance, in m, from base line

y = transverse distance, in m, from center line

ϕ = as given in Ch 4 Sec 2.

- 2.3.10. Pressure head corresponding to the liquid pressure in tanks in the upright condition is normally to be taken as given in Ch 4 Sec 3 [3.3] .

- 2.3.11. In heeled condition, pressure head corresponding to the liquid pressure in tanks, h , shall be taken as:

$$h = \frac{\rho}{\rho_w} \left[(h_s + 0.5 \phi b) - 0.10 \sqrt{H b_{\text{top}} \phi} \right] \quad (m)$$

- 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 0.5ϕ
 H = height of hold (including hatch coaming) or tank, in m, with the vessel on even keel
 b_{top} = breadth of top of tank or hold, in m, with the vessel on even keel
 ϕ = as given in Ch 4 Sec 2.

- 2.3.12. Pressure head corresponding to pressures and forces from cargo and heavy units are generally to be taken as given in Ch 4 Sec 3 [3.4] and Ch 4 Sec 3 [3.5]. Pressure head corresponding to the pressure from dry bulk cargoes is, however, generally to be taken as:

$$h = \frac{\rho_c}{\rho_w} \left(1 + 0.5 \frac{a_{\text{vert}}}{g_0} \right) K h_c \quad (m)$$

- 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_{vert} = as given in Ch. 4 Sec 2 [2.6]
= 0 in static loading conditions
 δ = angle of repose of cargo, in degrees
 ρ_c = stowage rate of cargo, in t/m³
 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 Ch 9 Sec 2 [2.1] for cargo bulkhead structures.

For watertight bulkheads between cargo holds, pressure head corresponding to the pressure load, h , shall be taken as given in Ch 9 Sec 2 [2.1].

- 2.3.13. Mass of deck structures is generally to be included when greater than 5% of the applied loads. Vertical acceleration shall be included when relevant.

2.4. Acceptance criteria

- 2.4.1. 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.

- 2.4.2. The final thickness of the considered structure shall not be less than the minimum thickness specified in Ch 6 to Ch 10, regardless of the acceptance criteria presented in the following.
- 2.4.3. 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 $245 / k_m$ N/mm². The local bending in the middle of the plate field shall not exceed $160 / k_m$ N/mm². σ_e is defined in Sec [2.4.9] of this chapter.
- 2.4.4. The allowable nominal stresses may be taken as given in Table 13.2.1. Buckling strength with usage factors as given in Ch 14 is generally to be complied with.
- 2.4.5. The allowable nominal girder stresses in a flooded condition may be taken as $220 / k_m$ N/mm² for normal stresses and $120 / k_m$ N/mm² for shear stresses.
- 2.4.6. 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 $190 / k_m$ N/mm². The hull girder stresses may in general be calculated as given in Ch 5 Sec 3 [3.3], applying relevant combinations of hogging and sagging stresses, and with wave bending moments taken as given in Ch 5 Sec 2 [2.2.5].
- 2.4.7. When performing preliminary strength calculations of longitudinal stiffeners in double bottom, the values of longitudinal bottom girder stresses may normally be taken as follows:

Nominal stress, light bulk cargoes:	$\sigma = 20 / k_m$	N/mm ²
Nominal stress, ballast condition:	$\sigma = 50 / k_m$	N/mm ²
Nominal stress, liquid cargo condition:	$\sigma = \frac{85 b}{k_m B}$	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 that the combined stress including hull girder stress and longitudinal bottom girder stress, as given in Table 13.2.1 and requirements specified in Sec [2.4.2] of this chapter, are complied with.

- 2.4.8. Allowable stresses given in Table 13.2.1 are based on the assumption that appropriate considerations and conditions are taken with respect to the model definition and result analysis. In particular, the following should be noted:
 - a) Calculated stresses based on constant stress elements may have to be considered with respect to the stress variation within each element length.
 - b) Allowable nominal stresses, given in Table 13.2.1, do not refer to local stress concentrations in the structure or to local modelling deficiencies in finite element models. 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.

- c) Allowable shear stresses given in Table 13.2.1 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 Ch 3 Sec 3 [3.5], based on the integrated shear force over the girder web height.
- d) Equivalent stresses for girder webs of longitudinal structures shall not be considered in relation to the allowable limits given in Table 13.2.1, unless global forces and moments are applied.
- e) 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.

2.4.9. 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 13.2.1 Allowable nominal stresses

Structure	Seagoing or harbor condition	Type of stress				Normal stress σ (N/mm ²)	Shear stress τ (N/mm ²)		Equivalent stress σ_e (N/mm ²)
		Hull girder stresses	Transverse bottom, side or deck girder stresses	Longitudinal bottom, side or deck girder stresses	Local stiffener bending		One plate flange	Two plate flange	
Longitudinal girders	Seagoing	X ⁽¹⁾		X		190 / k _m	90 / k _m	100 / k _m	
	Harbor	X ⁽¹⁾		X		190 / k _m	100 / k _m	110 / k _m	
Transverse and vertical girders	Seagoing		X			160 / k _m	90 / k _m	100 / k _m	180 / k _m
	Harbor		X			180 / k _m	100 / k _m	110 / k _m	200 / k _m
Girder brackets	Seagoing		(X)	(X)		200 / k _m ⁽²⁾			
	Harbor		(X)	(X)		220 / k _m ⁽²⁾			
Longitudinal stiffeners	Seagoing and harbor				X	160 / k _m			
	Seagoing and harbor			X	X	180 / k _m	90 / k _m		
	Seagoing and harbor	X ⁽¹⁾		X	X	245 / k _m			
Transverse and vertical girders	Seagoing and harbor		(X)	(X)	X	180 / k _m			
Stiffener brackets	Seagoing and harbor		(X)	(X)	X	225 / k _m			
Remarks: 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 , Refer Sec. [2.4.6]. 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, Ch 13 Sec 6 [6.3]									

SECTION 3 GLOBAL ANALYSIS

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3.1. General

- 3.1.1. A global analysis covers the whole ship.
- 3.1.2. A global analysis may be necessary 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.

Remark:

A torsional calculation covering the entire ship hull length may have to be carried out 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,.

- 3.1.3. Generally, global analyses are 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.
- 3.1.4. 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 relevant standards or procedures for "Fatigue Assessment of Ship Structures" by any IACS member societies.
- 3.1.5. 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.

3.2. Acceptance criteria

- 3.2.1 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 specified in Sec 2 [2.4] of this chapter. Other acceptance criteria may be relevant depending on the type of analysis and applied loads.

SECTION 4 CARGO HOLD OR TANK ANALYSIS

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4.1. General

4.1.1. Cargo tank or hold analysis may be used to examine deformations and nominal stresses of primary hull structural members. Model and the analysis shall be designed and performed in a suitable way for obtaining results as listed below.

- Stresses in transverse bulkheads
- Stresses in longitudinal bottom, side, bulkhead and deck girders (Refer below remark)
- Stresses in transverse bottom, side, bulkhead and deck girders (Refer below remark)
- Stresses in girders and stringers on transverse bulkheads
- Relative deflections of deep supporting members such as floors, frames and girders.

Remark:

Shear stresses of plate flanges of the mentioned girders forming ship's sides or longitudinal bulkheads should not be taken from the model unless special boundary conditions are applied to represent the global shear forces correctly.

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.

4.1.2. 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 needed if the structure or loads are substantially different from that of the midship region.

4.2. Loading conditions and load application

4.2.1. Selection of design loading conditions and application of local loads are specified in Sec 2 [2.3] of this chapter.

4.3. Acceptance criteria

4.3.1 Nominal and local stresses derived from a cargo hold or tank analyses for the main girder system shall be checked according to the acceptance criteria specified in Sec 2 [2.4] of this chapter.

SECTION 5 FRAME AND GIRDER ANALYSIS

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5.1. General

5.1.1. Frame and girder analysis may be used to examine stresses and deformations in the framing and girder systems within or outside of the midship region. Model and the analysis shall be designed and performed in a suitable way for obtaining results as listed below.

- 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.

Shear stresses in plate flanges of the mentioned girders, forming ship's 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.

5.1.2. Analysis may be carried out as a part of a larger 3- dimensional analysis, or performed separately with prescribed boundary assumptions, deformations or forces. Prescribed boundary deformations may be taken from a cargo hold or tank analysis as specified in Sec 4 of this chapter.

5.2. Loading conditions and load application

5.2.1. Selection of design loading conditions and application of local loads are specified in Sec 2 [2.3] of this chapter.

5.3. Acceptance criteria

5.3.1. Nominal and local stresses derived from a frame and girder analysis for the main girder system shall be checked according to the acceptance criteria specified in Sec 2 [2.4] of this chapter.

5.3.2. 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 be accepted, for proven design details, based on the nominal stress response of the adjacent structures.

SECTION 6 LOCAL STRUCTURE ANALYSIS

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6.3.	Acceptance criteria	327

6.1. General

6.1.1. Local structure analysis may be used to analyze nominal stresses in laterally loaded local stiffeners and their connected brackets, subject to relative deformation between supports. 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.

6.1.2. Analysis may be carried out as a part of a larger 3-dimensional analysis, or performed separately with prescribed boundary assumptions, deformations or forces. Prescribed boundary deformations may be taken from a cargo hold or tank analysis as specified in Sec 4 of this chapter.

6.2. Loading conditions and load application

6.2.1. Selection of design loading conditions and application of local loads are specified in Sec 2 [2.3] of this chapter.

6.2.2. 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.

6.2.3. If the local structure analysis is performed 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.

6.3. Acceptance criteria

6.3.1. Allowable nominal stresses are, in general, specified in Sec 2 [2.4] and Table 13.2.1 of this chapter.

6.3.2. Equivalent nominal allowable stress for brackets attached to longitudinal stiffeners may be taken as $\sigma_e = 245 / k_m \text{ N/mm}^2$, when longitudinal stresses are included.

CHAPTER 14 BUCKLING CONTROL

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SECTION 1 GENERAL

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1.1. Introduction

1.1.1. This chapter specifies the requirements for buckling control of:

- Plating subject to in-plane compressive and or shear stresses
- Axially compressed stiffeners and pillars
- Panel ultimate strength.

1.1.2. 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.

1.2. Definitions

1.2.1. 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 = 2.06×10^5 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 Ch 2 Sec 2 [2.1.1].
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 $= \frac{\sigma_a}{\sigma_c} = \frac{\tau_a}{\tau_c}$
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
k_m	= material factor. Refer Ch 2 Sec 2 and Ch 2 Sec 3

SECTION 2 PLATING FOR SHIPS WITH $L \geq 100$ M

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2.1. General

2.1.1. Local plate panels between stiffeners may be subject to uni-axial or bi-axial compressive stresses, and in some cases, also combined with shear stresses. Procedures for calculating the critical buckling stresses for the various load combinations are given below.

2.1.2. Formulae are given in subsequent sections for calculating the ideal compressive buckling stress σ_{el} . From this stress the critical buckling stress σ_c may be determined as follows:

$$\begin{aligned}\sigma_c &= \sigma_{el} && \text{when } \sigma_{el} < \frac{\sigma_f}{2} \\ &= \sigma_f \left(1 - \frac{\sigma_f}{4 \sigma_{el}}\right) && \text{when } \sigma_{el} > \frac{\sigma_f}{2}\end{aligned}$$

2.1.3. Formulae are given in subsequent sections for calculating the ideal shear buckling stress τ_{el} . From this stress the critical buckling stress τ_c may be determined as follows:

$$\begin{aligned}\tau_c &= \tau_{el} && \text{when } \tau_{el} < \frac{\tau_f}{2} \\ &= \tau_f \left(1 - \frac{\tau_f}{4 \tau_{el}}\right) && \text{when } \tau_{el} > \frac{\tau_f}{2}\end{aligned}$$

$$\begin{aligned}\tau_f &= \text{yield stress in shear of material, in N/mm}^2 \\ &= \frac{\sigma_f}{\sqrt{3}}\end{aligned}$$

2.2. Plate panel in uni-axial compression

2.2.1. The ideal elastic buckling stress may be taken as:

$$\sigma_{el} = 0.9 k E \left(\frac{t - t_c}{1000 s} \right)^2 \quad (\text{N/mm}^2)$$

For plating with longitudinal stiffeners (in direction of compression stress):

$$k = k_l = \frac{8.4}{\Psi + 1.1} \quad \text{for } (0 \leq \Psi \leq 1)$$

For plating with transverse stiffeners (perpendicular to compression stress):

$$k = k_s = c \left[1 + \left(\frac{s}{l} \right)^2 \right]^2 \left(\frac{2.1}{\Psi + 1.1} \right) \quad \text{for } (0 \leq \Psi \leq 1)$$

- c = 1.21 when stiffeners are angles or T-sections
- c = 1.10 when stiffeners are bulb flats
- c = 1.05 when stiffeners are flat bars
- c = 1.30 when the plating is supported by floors or deep girders.

The c-values may be multiplied by 1.1 for longitudinally stiffened double bottom panels and longitudinally stiffened double side panels.

Ψ is the ratio between the smaller and the larger compressive stress assuming linear variation, refer Fig.14.2.1.

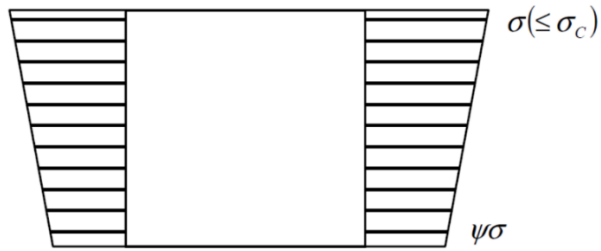


Fig. 14.2.1 Buckling stress correction factor

The above correction factors are not valid for negative Ψ values.

The critical buckling stress is further estimated using formulae specified in Sec [2.1.2].

- 2.2.2. 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 Sec 2.2.1, refer Fig. 14.2.1
 d = diameter of cut-out, in m

With edge reinforcement of thickness t at least equal to plate thickness t_0 , 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.

- 2.2.3. For plate panels stiffened in direction of the compressive stress and with stadium formed cut-outs (refer Fig.14.2.2), the ideal buckling stress σ_{el} shall be found by substituting the expression for factor k_l in Sec [2.2.1] with the following:

$$k = \left[\frac{0.58}{0.35 \Psi + 1} + \left(\frac{s-b}{2a} \right)^2 \right] \left[1 + 2.7 \left(\frac{b}{a} \right)^2 \right]$$

Refer Fig. 14.2.2 for definition of parameters used in the above formulae.

Ψ = as given in Sec 2.2.1.

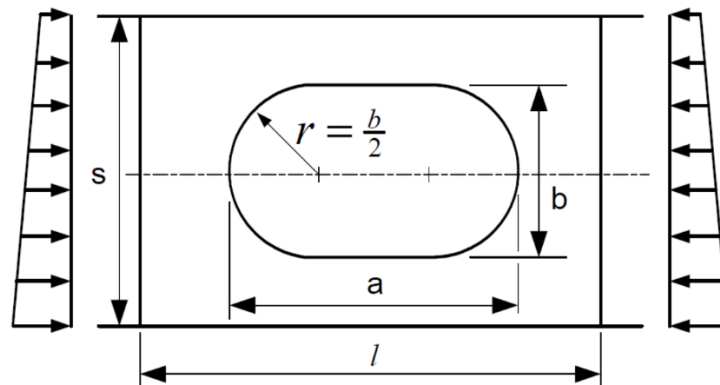


Fig. 14.2.2 Stiffening in direction of compressive stress

Remark:

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 Sec [2.2.2] may then be applied.

- 2.2.4. For plate panels stiffened perpendicular to the compressive stress and with stadium formed cut-outs (refer Fig.14.2.3), the ideal buckling stress σ_{el} may be found by multiplying the factor k_s with the reduction factor:

$$r = 1 - (0.5 + 0.25 \Psi) \frac{a}{l}$$

Refer Fig. 14.2.3 for definition of parameters used in the above formulae.

Ψ = as given in Sec [2.2.1]

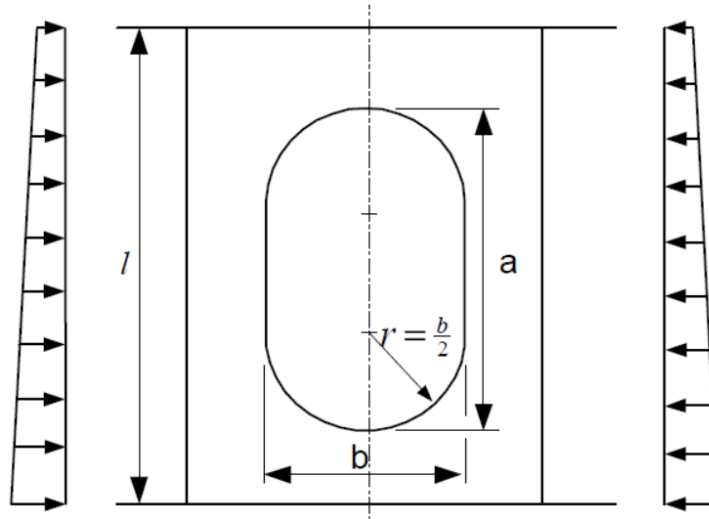


Fig. 14.2.3 Stiffening perpendicular to compressive stress

- 2.2.5. The critical buckling stress calculated in Sec [2.2.1] shall be related to the actual compressive stresses as follows:

$$\sigma_c \geq \frac{\sigma_a}{\eta}$$

σ_a = calculated compressive stress in plate panels. With linearly varying stress across the plate panel, σ_a shall be taken as the largest stress.

In plate panels subject to longitudinal stresses, σ_a is given by:

$$\begin{aligned} \sigma_{al} &= \frac{M_{ST} + M_{WV}}{I_N} (z_n - z_a) 10^5 \quad (\text{N/mm}^2) \\ &= \text{minimum } \frac{30}{k_m} (\text{N/mm}^2) \text{ at side} \end{aligned}$$

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_{ST} = still water bending moment as given in Ch 5
 M_{WV} = wave bending moment as given in Ch 5
 I_N = moment of inertia, in cm^4 , of the hull girder.

For reduction of plate panels subject to elastic buckling, refer Sec [2.2.7].

M_{ST} and M_{WV} shall be taken as sagging or hogging values for members above or below the neutral axis respectively. σ_a shall be taken as the nominal stress in panel without cut-outs for local plate panels with cut-outs subject to local compression loads only.

An increase of the critical buckling strength may be necessary in plate panels subject to combined in-plane stresses, refer Sec [2.4] and Sec [2.5].

- 2.2.6. For ships with high speed and large flare in the forebody, the requirement for critical buckling stress σ_c of the strength deck as specified in Sec [2.2.5] shall be based on the following σ -value forward of 0.3 L from F.P.:

$$\sigma_{al} = \sigma_{l1} + \sigma_{l2} \left(1 - \frac{x}{0.3 L} \right) \quad (\text{N/mm}^2)$$

σ_{l1} = σ_a as calculated in Sec [2.2.5]
 σ_{l2} = 0 for $C_{AF} \leq 0.4$
 = $50 / k_m$ 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 Ch 5 Sec 2 [2.2].

For intermediate values of C_{AF} , the σ_{l2} - value shall be varied linearly.

- 2.2.7. 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 ($\sigma_{el} < 0.50 \sigma_f$) is outlined 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 Appendix A Sec 2[2.5]. The M_A -value to be applied is given by:

$$M_A = M_{ST} + M_{WV}$$

M_{ST} and M_{WV} are defined in Sec 2[2.5].

Appendix A shall not be applied for plate panels subject to the combined effect of compression and shear.

2.3. Plate panel in shear

- 2.3.1 The ideal elastic buckling stress may be taken as:

$$\tau_{el} = 0.9 k_t E \left(\frac{t - t_c}{1000 s} \right)^2 \quad (\text{N/mm}^2)$$

$$k_t = 5.34 + 4 \left(\frac{s}{l} \right)^2$$

The critical shear buckling stress is further estimated using formulae specified in Sec [2.1.3].

2.3.2 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 :

$$r = 1 - \left(\frac{d}{s}\right)$$

With edge reinforcement of thickness t at least equal to plate thickness t_0 , factor r may be multiplied by:

$$0.94 + 0.023 \frac{h}{t_0}, \quad \frac{h}{t} \leq 8$$

h = height of reinforcement, in mm.

As an alternative to the above, in cases with buckling stiffeners on both sides of opening, factor r may be multiplied by 1.3.

b) The reduction factor may be found from Fig.14.2.4 for rectangular openings. In cases with edge reinforcement of thickness t at least twice the plate thickness and height at least equal to $8t$, the factor may be multiplied by 2.1.

As an alternative to the above, in cases with buckling stiffeners along the longer edges, the factor may be multiplied by 1.4 and in cases with stiffeners along the shorter edges, the factor may be multiplied by 1.5, refer Fig.14.2.5.

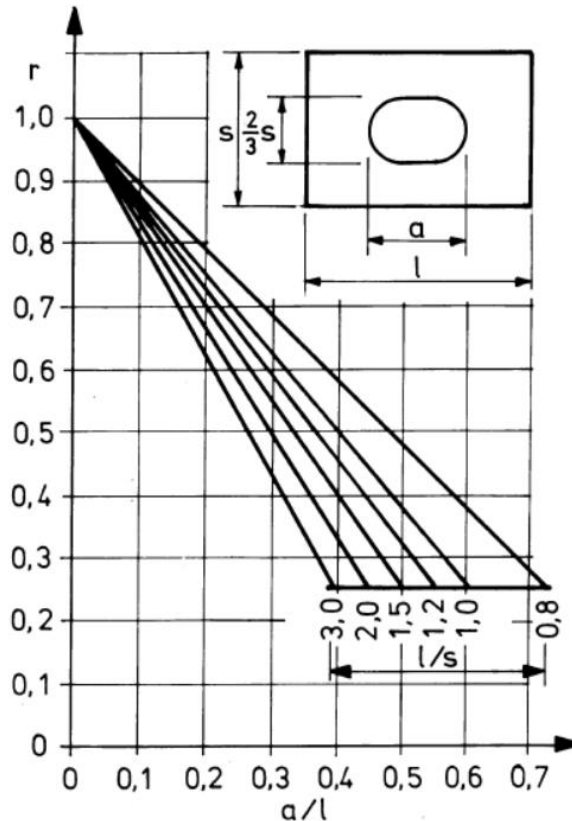


Fig. 14.2.4 Buckling stress reduction factor

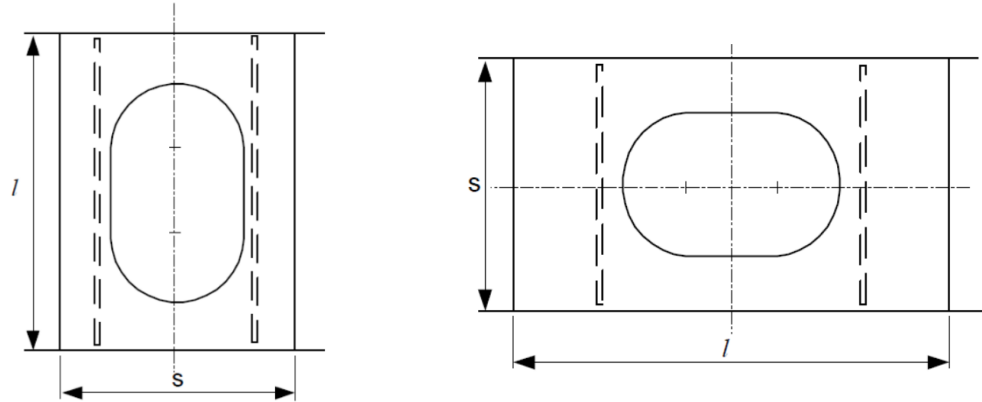


Fig. 14.2.5 Buckling stiffeners

2.3.3. Critical shear stress calculated in Sec 2.3.1 are related to 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 Ch 5 Sec 4. τ_a shall be taken as the stress in web plate without cut-out for local panels in girder webs with cut-outs
- 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, i.e. ($\tau_a = Q/A$)
 = 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, refer Sec [2.4] and Sec [2.5].

2.4. Plate panel in bi-axial compression

2.4.1. The interaction between the longitudinal and transverse buckling strength ratios is given by below formulae for plate panels subject to bi-axial compression:

$$\frac{\sigma_{ax}}{\eta_x \sigma_{cx}} - K \frac{\sigma_{ax} \sigma_{ay}}{\eta_x \eta_y \sigma_{cx} \sigma_{cy}} + \left(\frac{\sigma_{ay}}{\eta_y \sigma_{cy}} \right)^n \leq 1$$

- 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 Sec [2.2]
 σ_{cy} = critical buckling stress in transverse direction as calculated in Sec [2.2]
 η_x, η_y = 1.0 for plate panels where the longitudinal stress σ_{ax} as given in Sec [2.2.5] is incorporated in σ_{ax} or σ_{ay}
 = 0.85 in other cases
 K = $c \beta^a$
 β = $1000 \left(\frac{s}{t - t_c} \right) \sqrt{\frac{\sigma_f}{E}}$
 c, a, n = factors as given in Table 14.2.1.

Table 14.2.1 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 $\sigma_{el} < 0.65 \sigma_f$).

2.5. Plate panel in bi-axial compression and shear

2.5.1. The interaction is given by below formulae for plate panels subject to bi-axial compression and in addition to in-plane shear stresses:

$$\frac{\sigma_{ax}}{\eta_x \sigma_{cx} q} - K \frac{\sigma_{ax} \sigma_{ay}}{\eta_x \eta_y \sigma_{cx} \sigma_{cy} q} + \left(\frac{\sigma_{ay}}{\eta_y \sigma_{cy} q} \right)^n \leq 1$$

$\sigma_{ax}, \sigma_{ay}, \sigma_{cx}, \sigma_{cy}, \eta_x, \eta_y, K$ and n are as given in Sec [2.4.1]

$$q = 1 - \left(\frac{\tau_a}{\tau_c} \right)^2$$

τ_a and τ_c are as given in Sec 2.3.3

Only stress components acting simultaneously shall be inserted in the formula, refer also Sec [2.4.1].

SECTION 3 STIFFENERS AND PILLARS FOR SHIPS WITH $L \geq 100$ M

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3.1. General

- 3.1.1. This section specifies the methods for calculating the critical buckling stress for the various buckling modes of axially compressed stiffeners and pillars. 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:

$$\begin{aligned}\sigma_c &= \sigma_{el} && \text{when } \sigma_{el} < \frac{\sigma_f}{2} \\ &= \sigma_f \left(1 - \frac{\sigma_f}{4 \sigma_{el}}\right) && \text{when } \sigma_{el} > \frac{\sigma_f}{2}\end{aligned}$$

3.2. Lateral buckling mode

- 3.2.1. The ideal elastic lateral buckling stress for longitudinals subject to longitudinal hull girder compressive stresses, supporting bulkhead stiffeners, pillars, cross ties, panting beams etc., may be taken as:

$$\sigma_{el} = 0.001 E \frac{I_A}{A l^2} \quad (\text{N/mm}^2)$$

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, refer Sec 2 [2.2.7] of this chapter and Appendix A.

t_c shall be subtracted from flanges and web plates when calculating I_A and A , where relevant.

The critical buckling stress is to be found using method specified in Sec [3.1.1] of this chapter.

The formula given for σ_{el} is based on hinged ends and axial force only. However, in special cases, if it is verified that one end can be regarded as fixed, the value of σ_{el} may be multiplied by 2. In addition, 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.

- 3.2.2. For longitudinals and other stiffeners the critical buckling stress calculated in Sec [3.2.1] 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 Sec 2 [2.2.5] of this chapter. For ships with high speed and large flare, refer Sec 2 [2.2.6] of this chapter.

η = 0.85.

- 3.2.3. The critical buckling stress for pillars, cross ties and panting beams, as calculated in Sec [3.2.1], shall not be less than:

$$\sigma_c = \frac{10 P}{A \eta} \quad (\text{N/mm}^2)$$

$$\eta = \frac{k}{\left(1 + \frac{l}{i}\right)}, \quad \text{minimum } 0.3$$

P = axial load, in kN, as given for various strength members in Sec [3.2.4] and Sec [3.2.5]. Alternatively, P may be obtained from direct stress analysis, refer Ch 13.

l = length of member, in m

i = radius of gyration, in cm

$$= \sqrt{\frac{I_A}{A}}$$

I_A and A as given in Sec [3.2.1]

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.

3.2.4. 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:

$$F = 10 h A_D \quad (\text{kN})$$

h = design pressure head on deck as given in Table 8.2.2 in Ch 8 Sec 2

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 center line pillars supporting hatch end beams (refer Fig. 14.3.1 and Fig. 14.3.2):

$$A_D = 4 (A_1 + A_2) \frac{b_1}{B}, \quad \text{when transverse beams}$$

$$A_D = 4 (A_3 + A_4 + A_5) \frac{b_1}{B}, \quad \text{when longitudinals}$$

b_1 = distance from hatch side to ship's side.

3.2.5. The nominal axial force in cross ties and panting beams is normally to be taken as:

$$P = 10 e b h \quad (\text{kN})$$

e = mean value of spans, in m, on both sides of the cross tie

b = load breadth, in m

h = the larger of the pressure heads, in m, 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).

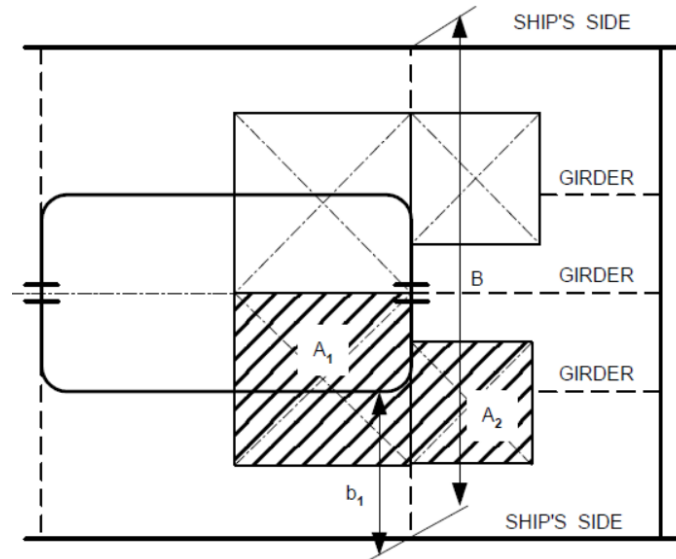


Fig. 14.3.1 Deck with transverse beams

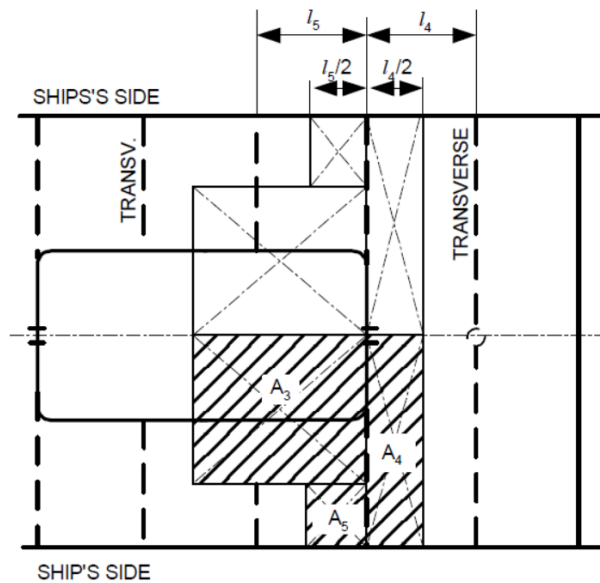


Fig. 14.3.2 Deck with longitudinals

3.3. Torsional buckling mode

3.3.1. The ideal elastic buckling stress for the torsional mode for longitudinals and other stiffeners in the direction of compressive stresses, 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)

$$= \frac{h_w t_w^3}{3} 10^{-4} \quad \text{for flat bars (slabs)}$$

$$= \frac{1}{3} \left[h_w t_w^3 + b_f t_f^3 \left(1 - 0.63 \frac{t_f}{b_f} \right) \right] 10^{-4} \quad \text{for flanged profiles}$$

I_p = polar moment of inertia, in cm^4 , of profile about connection of stiffener to plate

$$= \frac{h_w^3 t_w}{3 \times 10^4} \quad \text{for flat bars}$$

$$= \left(\frac{h_w^3 t_w}{3} + h_w^2 b_f t_f \right) 10^{-4} \quad \text{for flanged profiles}$$

I_w = sectorial moment of inertia, in cm^6 , of profile about connection of stiffener to plate

$$= \frac{h_w^3 t_w^3}{36} 10^{-6} \quad \text{for flat bars}$$

$$= \frac{t_f b_f^3 h_w^2}{12} 10^{-6} \quad \text{for T – profiles}$$

$$= \frac{b_f^3 h_w^2}{12 (b_f + h_w)^2} \left[t_f (b_f^2 + 2 b_f h_w + 4 h_w^2) + 3 t_w b_f h_w \right] 10^{-6}$$

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_c shall be subtracted from all thicknesses (t_w , t_f and t_p).

C = spring stiffness exerted by supporting plate panel

$$= \frac{k E t_p^3}{3 s \left(1 + \frac{1.33 k h_w t_p^3}{1000 s t_w^3} \right)} 10^{-3}$$

k = $1 - \eta_p^a$; not to be taken less than zero

$$\eta_p = \frac{\sigma_a}{\sigma_{ep}}$$

a = 2 in general

= 1 for flat bar profiles

σ_a = calculated compressive stress. For longitudinals, refer Sec 2[2.2.5] and Sec 2 [2.2.6] of this chapter for the methodology of calculating compressive stress.

σ_{ep} = elastic buckling stress of supporting plate as calculated in Sec 2 [2.2.1] of this chapter.

For flanged profiles k need not be taken less than 0.2.

3.3.2. The critical buckling stress as found from Sec [3.3.1] and Sec [3.1.1] shall not be less than:

$$\sigma_c \geq \frac{\sigma_a}{\eta}$$

σ_a = calculated compressive stress. For longitudinals $\sigma_a = \sigma_{al}$ as given in Sec 2 [2.2.5] of this chapter. For ships with high speed and large flare, refer also Sec 2 [2.2.6] of this chapter.

η = 0.9 in general
= 0.85 when the adjacent plating is allowed to buckle in the elastic mode, according to Sec 2 [2.2.7] of this chapter.

3.3.3. Torsional buckling mode is to be evaluated for open thin walled and short columns, such as cross ties. 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_c shall be subtracted from flanges and web when calculating I_T , I_p and C_W .

G = shear modulus

$$= \frac{E}{2(1 + \mu)}$$

μ = Poisson's ratio
= 0.3

I_T = St. Venant's 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

3.3.4. The critical buckling stress as found from Sec [3.3.3] and Sec [3.1.1] shall not be less than:

$$\sigma_c \geq \frac{\sigma_a}{\eta}$$

σ_a = calculated compressive stress obtained from direct stress analysis. Refer Ch 13.

η = 0.7

3.4. Web and flange buckling

3.4.1 The σ_{el} -value required for the web buckling mode for flanged profiles may be taken as:

$$\sigma_{el} = 3.8 E \left(\frac{t_w - t_c}{h_w} \right)^2 \quad (\text{N/mm}^2)$$

The critical buckling stress σ_c found from Sec 3.1.1 of this chapter shall not be less than as given in Sec [3.3.2] of this chapter.

- 3.4.2 The thickness for flanges on angles and T-sections of longitudinals and other highly compressed stiffeners shall not be less than:

$$t_f = 0.1 b_f + t_c \quad (\text{mm})$$

b_f = flange width, in mm, for angles, half the flange width for T-sections.

3.5. Transverse beams and girders

- 3.5.1 The moment of inertia of the stiffener section (including effective plate flange) for beams and stiffeners supporting plating subject to compressive stresses perpendicular to the stiffener direction shall not be less than:

$$I = \frac{0.09 \sigma_a \sigma_{el} l^4 s}{t} \quad (\text{cm}^4)$$

l = span, in m, of beams or stiffeners

s = spacing, in m, of beams or stiffeners

t = plate thickness, in mm

σ_{el} = $1.18 \sigma_a$ 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.

- 3.5.2 The moment of inertia of the girder section (including effective plate flange) for transverse girders supporting longitudinals or stiffeners subject to axial compression stresses shall not be less than:

$$I = 0.3 \frac{S^4}{l^3 s} I_s \quad (\text{cm}^4)$$

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 Sec [3.2.1] and Sec [3.2.2] of this chapter.

$$= \frac{\sigma_{el} A l^2}{0.001 E}$$

σ_{el} = as given in Sec [3.5.1] of this chapter

A = as given in Sec [3.2.1] of this chapter.

SECTION 4 PLATING AND STIFFENERS FOR SHIPS WITH $L < 100$ M

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4.1. General

4.1.1. This section specifies the requirements to buckling control of plating and stiffeners subject to longitudinal compressive stresses in ships with $L < 100$ m.

4.1.2. Symbols:

t	= thickness, in mm, of plating
s	= spacing, in m, of transverse beams
l	= distance, in m, between longitudinal stiffeners
M_{ST}	= still water bending moment as given in Ch 5
M_{WV}	= wave bending moment as given in Ch 5
Z_A	= Z_D or Z_B
Z_R	= rule mid-ship section modulus, in cm^3 , as given in Ch 5 Sec 3 [3.3.9]
Z_D, Z_B	= mid-ship section modulus, in cm^3 , as built at deck or bottom respectively.
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 Ch 2 Sec 2 [2.1.1].
σ_c	= the critical compressive buckling stress, in N/mm^2
σ_l	= calculated actual longitudinal compressive stress, in N/mm^2

4.2. Plating subject to longitudinal compressive bending stresses

4.2.1. The longitudinal bending stresses to be used for buckling control of deck and bottom plating is generally given by:

$$\sigma_l = \frac{M_{ST} + M_{WV}}{Z_A} 10^3 \quad (\text{N/mm}^2)$$

4.2.2. Formulae are given in subsequent sections for calculating the ideal compressive buckling stress σ_{el} . From this stress the critical buckling stress σ_c may be determined as follows:

$$\begin{aligned} \sigma_c &= \sigma_{el} && \text{when } \sigma_{el} < \frac{\sigma_f}{2} \\ &= \sigma_f \left(1 - \frac{\sigma_f}{4 \sigma_{el}} \right) && \text{when } \sigma_{el} > \frac{\sigma_f}{2} \end{aligned}$$

4.2.3. The ideal elastic buckling stress of a transversely stiffened plate may be found from the following formulae:

$$\sigma_{el} = 2.3 \left[1 + \left(\frac{s}{l} \right)^2 \right]^2 \left(\frac{t - t_c}{1000 s} \right)^2 10^5 \quad (\text{N/mm}^2)$$

4.2.4. The ideal elastic buckling stress of a longitudinally stiffened plate may be found based on the formulations provided in Sec 2 [2.2.1] of this chapter.

4.2.5. The plating thickness in deck and bottom amidships should comply with the requirement:

$$\sigma_c \geq \sigma_l$$

4.2.6. For deck plating, sagging bending moments are to be applied in the formulae specified in Sec [4.2.1]. If it is confirmed that the stillwater bending moments for all relevant loading conditions will not be sagging moments it may be accepted to use $M_{ST} = 0$ for the buckling control of the deck plating.

Remark:

When M_{ST} is as given in Sec [4.2.6] and $l \geq s$, the buckling strength of a transversely stiffened strength deck will normally be satisfactory when:

$$t \geq 2.2 s \sqrt{L} \sqrt{\frac{Z_R}{Z_D}} + t_c \quad (\text{mm})$$

- 4.2.7. For bottom plating, hogging bending moments are to be applied in the formulae specified in Sec [4.2.1].

Remark:

When M_{ST} is as given in Sec [4.2.7] and $l \geq s$, the buckling strength of a transversely stiffened bottom plating will normally be satisfactory when:

$$t \geq 2.8 s \sqrt{L} \sqrt{\frac{Z_R}{Z_B}} + t_c \quad (\text{mm})$$

4.3. Deck plating acting as effective flange for deck girders

- 4.3.1. Deck plating acting as effective flange for deck girders which support crossing stiffeners should have a satisfactory buckling strength.
- 4.3.2. Compressive stresses arising in the deck plating due to local loading of girders are to be less than 80% of the critical buckling strength, refer Sec [4.3.3]. When calculating the compressive stress the section modulus of the girder may be based on a deck plate flange breadth equal to the distance between girders (100% effective flange).
- 4.3.3. The critical buckling strength is given in Sec [4.2], where l = span of stiffener or distance from girder to any buckling stiffener parallel to the girder.
- 4.3.4. Elastic buckling of deck plating may be accepted after special consideration. Reference is made to Appendix A.

4.4. Longitudinals subject to longitudinal compressive bending stresses

- 4.4.1. The buckling strength of longitudinals is to comply with the requirements given in Sec [4.2.1] and Sec [4.2.2] when using:

$$\sigma_{el} = 210 \frac{I_A}{A l^2} \quad (\text{N/mm}^2)$$

I_A = moment of inertia, in cm^4 , about the axis perpendicular to the expected direction of buckling of the longitudinal
 A = cross-sectional area, in cm^2 , of the longitudinal
 l = span, in m, between of longitudinals

When calculating I_A and A , a plate flange equal to 0.8 times the longitudinal spacing is included.

- 4.4.2. The buckling strength of longitudinals is to comply with the requirement:
 $\sigma_c \geq 1.2 \sigma_l$

CHAPTER 15 FATIGUE CONTROL

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SECTION 1 GENERAL

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1.1. Introduction

- 1.1.1. This chapter specifies the background and assumptions for carrying out fatigue calculations in addition to or as a substitute to the specific rule requirements detailed in in Ch 5 to Ch 11. Load conditions, design criteria and applicable calculation methods are specified.

1.2. Application

- 1.2.1. Following cases governs the application of direct fatigue calculations:

- 1) When simplified formulations do not represent the dynamic stress distribution and a direct stress analysis has been required with a reference to this chapter, then the calculations are required as part of rule scantling determination.
- 2) Direct stress calculations may give reduced scantlings compared to the explicit fatigue requirements serving as an alternative basis for the scantlings.

1.3. Loads

- 1.3.1. Vessel shall be evaluated for fatigue due to global and local dynamic loads. For the local loads, calculation of the 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 may be used based on relevant standards or procedures for "Fatigue Assessment of Ship Structures" by any IACS member societies. Simplified loads may be substituted by directly computed dynamic loads.

Remark:

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:

Vessel type	<i>Tanker</i>		<i>Bulk carrier</i>		<i>Container carrier</i>	
	K_r	GM	K_r	GM	K_r	GM
Loaded condition	0.35B	0.12B	0.39B	0.17B	0.39B	0.04B
Ballast condition	0.45B	0.33B	0.39B	0.25B	0.39B	0.04B

- 1.3.2. 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. The values in Table 15.1.1 shall be used if nothing else is specified.

Table 15.1.1 Distribution of design load conditions				
<i>Vessel type</i>	<i>Tankers</i>	<i>Gas carriers</i>	<i>Bulk carriers</i>	<i>Container carriers</i>
Loaded condition	0.425	0.450	0.500	0.650
Ballast condition	0.425	0.400	0.350	0.200

1.4. Design criteria

- 1.4.1. The fatigue analysis shall be based on a period equal to the planned life of the vessel. However, the period is normally not to be taken less than 20 years. The fatigue calculation shall be based on 80% of North Atlantic wave scatter diagram as contained in relevant standards or procedures for "Fatigue Assessment of Ship Structures" by any IACS member societies, unless specified otherwise.
- 1.4.2. 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.

1.5. Calculation methods

- 1.5.1. Calculation methods specified in relevant standards or procedures for "Fatigue Assessment of Ship Structures" by any IACS member societies are accepted.
- 1.5.2. 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.

1.6. Basic requirements

- 1.6.1. If not specified otherwise, global stress components may be calculated based on gross scantlings.

Calculation of the local stress components should be 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.

- 1.6.2. Fatigue evaluation may be carried out based on direct calculation of the stresses for longitudinals. 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.

SECTION 2 FATIGUE LIFE IMPROVEMENT BY FABRICATION

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2.1. Weld improvement method

2.1.1. 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.

2.1.2. 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.

2.1.3. 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.

Remark:

Information concerning grinding method and particulars are available in relevant standards or procedures for "Fatigue Assessment of Ship Structures" by any IACS member societies.

2.1.4. 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.

Remark:

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.

2.1.5. When weld improvement methods in accordance with Sec [2.1.3] 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

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SECTION 1 INTRODUCTION

Contents

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1.1. Scope and description

- 1.1.1. 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 this appendix.

The ultimate stress limit and effective width of local plate panels are given in Sec [2.1] and Sec 2.2 of this chapter. The ultimate strength of stiffened panels, simple girders and ship hull girders is given in Sec [2.3] to Sec [2.5] of this chapter.

SECTION 2 CALCULATION PROCEDURE

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2.1. Estimation of ultimate stress

- 2.1.1. 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 Ch 14 Sec 2 [2.2.1]

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 longitudinally stiffened plating (compressive stress perpendicular to the longest side l of plate panel :

$$\psi_u = 1 + c \left(\frac{\sigma_f}{\sigma_{el}} - 2 \right)$$

$$c = \frac{0.75}{\frac{l}{s} + 1}$$

2.2. Calculation of effective width

- 2.2.1. Due to the elastic buckling, the effective width of plating taking part in the compression area will be reduced.

- 2.2.2. 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 as calculation in Sec 2.1.1 of this chapter

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.

2.3. Ultimate load of stiffened panels

- 2.3.1. The ultimate load capacity of a stiffened plate panel in compression is given by:

$$P_U = 0.1 [\sigma_{el} A + (\sigma_m - \sigma_{el}) A_R] \quad (\text{kN})$$

A = total area, in cm^2 , of panel
 $= 10 b (t - t_c) + \Sigma a_s$

A_R = reduced area of panel
 $= 10 b_e (t - t_c) + \Sigma a_s$

b = total width, in m, of panel

b_e = reduced width, in m, as given in Sec [2.2] of this chapter

t = thickness, in mm, of plating

a_s = area, in cm^2 , of stiffener/girder in direction of compressive stress

σ_{el} = elastic buckling stress, in N/mm^2 , of plating

σ_m = σ_{cl} or $0.9 \sigma_f$, whichever is the smaller, when stiffeners in direction of stress

= $0.9 \sigma_f$ when stiffeners perpendicular to stress

σ_{cl} = critical buckling stress of stiffeners in direction of compressive stresses, as calculated in Ch 14 Sec 3 [3.2] and Ch 14 Sec 3 [3.3].

The design condition is given by:

$$P_U > \frac{P_A}{\eta_u}$$

P_A = actual compressive load in panel, based on extreme dynamic load
 $= 0.1 \sigma_a A$
 $\eta_u = 0.85$.

2.4. Ultimate strength of simple girders with stiffened plate flange

2.4.1. The ultimate bending moment capacity of girders with a stiffened plate flange in compression is given by:

$$M_U = M_E + \Delta M_U \quad (\text{kN m})$$

M_E = moment capacity corresponding to the elastic buckling limit
 $= \frac{\sigma_{el} I}{1000 z_p} \quad (\text{kN m})$

σ_{el} = elastic buckling stress, in N/mm^2 , of plating in compression flange calculated with 100% effective plate

I = moment of inertia of girder, in cm^4 , with intact plate flange b (100% effective)

z_p = distance, in cm, from neutral axis to compression flange, refer Fig. A.2.1

ΔM_U = additional moment due to increase in allowable stress above elastic buckling limit
 $= \Delta M_{UP}$ or ΔM_{UF} whichever is the smaller

$$\Delta M_{UP} = \frac{\sigma_m - \sigma_{el}}{1000 z_{pb}} I_B \quad (\text{kN m})$$

$$\Delta M_{UF} = \frac{0.9 \sigma_f - \sigma_{el} \left(\frac{z_f}{z_p} \right)}{1000 z_{fb}} I_B \quad (\text{kN m})$$

z_f = distance, in cm, from neutral axis to tension flange of intact section

z_{pb} = distance, in cm, from neutral axis to compression flange of buckled section

z_{fb} = distance, in cm, from neutral axis to tension flange of buckled section

I_B = moment of inertia, in cm^4 , of girder with buckled plate flange b_e

σ_m = as given in Sec [2.3] of this chapter.

The area of the buckled plate flange (A_R) is estimated as outlined in Sec [2.3] of this chapter.

The design condition is given by:

$$M_U > \frac{M_A}{\eta_u}$$

M_A = actual moment in girder, based on extreme dynamic load
 $\eta_u = 0.85$.

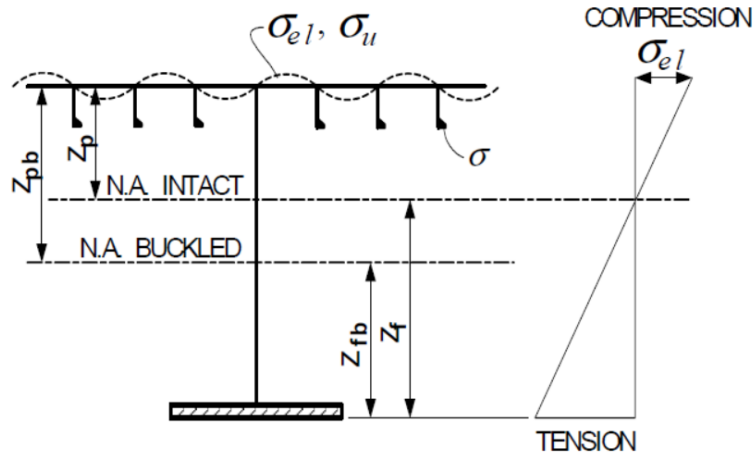


Fig. A.2.1 Simple girder with panel flange

2.5. Ultimate strength of complex girders

2.5.1. The ultimate bending moment capacity of a ship hull girder with stiffened plate panels at various levels is given by:

$$M_U = M_E + \Delta M_U \quad (\text{kN m})$$

M_E = moment capacity corresponding to the elastic buckling limit of the local plate panel subject to elastic buckling (refer remark provided below)

$$= \frac{\sigma_{el} I}{1000 z_e} \quad (\text{kN m})$$

σ_{el} = elastic buckling stress, in N/mm^2 , of local plate panel

I = moment of inertia of hull girder, in cm^4 , with intact plating (100% effective plating)

z_e = vertical distance, in cm, from neutral axis of intact section to middle of buckled plate panel, refer Fig. A.2.2

ΔM_U = additional moment above elastic buckling limit, to be taken as the smaller of ΔM_{UP1} , ΔM_{UP2} , ΔM_{UP3} and ΔM_{UF}

$$\Delta M_{UP1} = \frac{1.18 \sigma_{cp} - \sigma_{ep}}{1000 z_{pb}} I_B \quad (\text{kN m})$$

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 Ch 14 Sec 2 [2.2]

$\sigma_{ep} = \sigma_{el} z_p / z_e$

z_p = vertical distance, in cm, from neutral axis of intact section to middle of intact plate panel

z_{pb} = vertical distance, in cm, from neutral axis of buckled section to middle of intact plate panel

I_B = moment of inertia, in cm^4 , of hull section with buckled plate panel, which is inserted with effective width as given in Sec [2.2] of this appendix

$$\Delta M_{UP2} = \frac{\sigma_{cl} - \sigma_{en}}{1000 z_{lb}} I_B \quad (\text{kN m})$$

σ_{cl} = critical buckling stress of the longitudinal (on compression side) with the smallest buckling safety (σ_c / σ_a) as calculated in Ch 14 Sec 3 [3.2] or Ch 14 Sec 3 [3.3]

$\sigma_{en} = \sigma_{el} z_l / z_e$

z_l = vertical distance, in cm, from neutral axis of intact section to longitudinal in question
 z_{lb} = vertical distance, in cm, from neutral axis of buckled section longitudinal in question

$$\Delta M_{UP3} = \frac{0.9 \sigma_f - \sigma_{em}}{1000 z_{mb}} I_B \quad (\text{kN m})$$

σ_{em} = $\sigma_{el} z_m / z_e$
 z_m = vertical distance, in cm, from neutral axis of intact section to deck or bottom, whichever is in compression

z_{mb} = vertical distance, in cm, from neutral axis of buckled section to deck or bottom, whichever is in compression

$$\Delta M_{UF} = \frac{0.9 \sigma_f - \sigma_{ef}}{1000 z_{fb}} I_B \quad (\text{kN m})$$

σ_{ef} = $\sigma_{el} z_f / z_e$
 z_f = vertical distance, in cm, from neutral axis of intact section to deck or bottom, whichever is in tension

z_{fb} = vertical distance, in cm, from neutral axis of buckled section to deck or bottom, whichever is in tension.

The design condition is given by:

$$M_U > \frac{M_A}{\eta_u}$$

M_A = actual moment in hull girder

η_u = 0.85.

Remark:

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:

$$M_E = \sum_{i=1}^n \Delta M_{Ei}$$

$$\Delta M_{Ei} = \frac{\sigma_{ei} - \sigma_{e(i-1)} \left(\frac{z_{ei}}{z_{e(i-1)}} \right)}{1000 z_{ei}} I_{E(i-1)}$$

σ_{ei} = elastic buckling stress, in N/mm², 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, in 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 (ΔM_{En}) 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 .

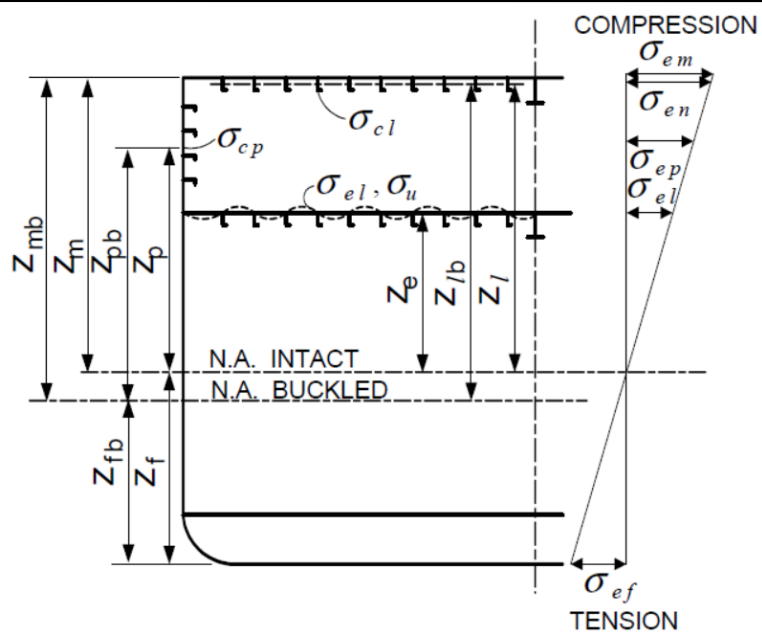


Fig. A.2.2 Hull girder