S4

(1973)
(Rev.1 1974)
(Rev.2 Apr 2007)
(Rev.3 May 2010)
(Rev.4 Apr 2017)

Criteria for the Use of High Tensile Steel with Minimum Yield Stress of 315 N/mm^2, 355 N/mm^2 and 390 N/mm^2

This UR does not apply to CSR Bulk Carriers and Oil Tankers.

The material factor *k* is defined as follows:

k = 0.78 for steel with R_{eH} = 315 N/mm^2

k = 0.72 for steel with R_{eH} = 355 N/mm^2

k = 0.66 for steel with R_{eH} = 390 N/mm^2 provided that a fatigue assessment of the structure is performed to verify compliance with the requirements of the Society,

k = 0.68 for steel with R_{eH} = 390 N/mm^2 in other cases.

Where:

R_{eH} : Minimum yield stress, in N/mm^2

End of Document

S5
(1975)
(Rev.1
May 2010)
(Corr.1
June 2019)

Calculation of Midship Section Moduli for Conventional Ship for Ship's Scantlings

This UR does not apply to CSR Bulk Carriers and Oil Tankers.

When calculating the midship section modulus within 0.4*L* amidships the sectional area of all continuous longitudinal strength members is to be taken into account.

Large openings, i.e. openings exceeding 2.5 m in length or 1.2 m in breadth and scallops, where scallop-welding is applied, are always to be deducted from the sectional areas used in the section modulus calculation.

Smaller openings (manholes, lightening holes, single scallops in way of seams, etc.) need not be deducted provided that the sum of their breadths or shadow area breadths in one transverse section does not reduce the section modulus at deck or bottom by more than 3% and provided that the height of lightening holes, draining holes and single scallops in longitudinals or longitudinal girders does not exceed 25% of the web depth, for scallops maximum 75 mm.

A deduction-free sum of smaller opening breadths in one transverse section in the bottom or deck area of 0.06 (B - $\sum b$) (where B = breadth of ship, $\sum b$ = total breadth of large openings) may be considered equivalent to the above reduction in section modulus.

The shadow area will be obtained by drawing two tangent lines with an opening angle of 30°.

The deck modulus is related to the moulded deck line at side.

The bottom modulus is related to the base line.

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

$$y_t = y\left(0.9 + 0.2\frac{x}{B}\right)$$

y = distance from neutral axis to top of continuous strength member

x = distance from top of continuous strength member to centreline of the ship

x and y to be measured to the point giving the largest value of y_t.

Longitudinal girders between multi-hatchways will be considered by special calculations.

End of Document

S6
(1978)
(Rev.1 1980)
(Rev.2 1996)
(Rev.3 May 2002)
Rev.4 July 2003)
(Rev.5 Sept 2007)
(Rev.6 May 2010)
(Rev.7 Apr 2013)
(Rev.8 Dec 2015)
(Rev.9 July 2018)

Use of Steel Grades for Various Hull Members - Ships of 90 m in Length and Above

S6.0 Application

This UR does not apply to CSR Bulk Carriers and Oil Tankers.

S6.1 Ships in normal worldwide service

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 1 to Table 7. General requirements are given in Table 1, while additional minimum requirements are given in the following:

Table 2: for ships, excluding liquefied gas carriers covered in Table 3, with length exceeding 150 m and single strength deck,

Table 3: for membrane type liquefied gas carriers with length exceeding 150 m,

Table 4: for ships with length exceeding 250 m,

Table 5: for single side bulk carriers subjected to SOLAS regulation XII/6.5.3,

Table 6: for ships with ice strengthening.

The material grade requirements for hull members of each class depending on the thickness are defined in Table 7.

For strength members not mentioned in Tables 1 to 6, Grade A/AH may generally be used. The steel grade is to correspond to the as-built plate thickness and material class.

Plating materials for sternframes 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. 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.

Notes:

1. Changes introduced in Rev.5 are to be uniformly implemented by IACS Members and Associates from 1 July 2008.

2. Changes introduced in Rev.7 are to be uniformly implemented by IACS Members from 1 July 2014.

3. Changes introduced in Rev.8 are to be uniformly implemented by IACS Members from 1 January 2017.

4. Changes introduced in Rev.9 are to be uniformly implemented by IACS Members from 1 July 2019.

S6 (cont)

Table 1 - Material Classes and Grades for ships in general

Structural member category	Material class/grade
SECONDARY: A1. Longitudinal bulkhead strakes, other than that belonging to the Primary category A2. Deck plating exposed to weather, other than that belonging to the Primary or Special category A3. Side plating	- Class I within 0.4L amidships - Grade A/AH outside 0.4L amidships
PRIMARY: B1. Bottom plating, including keel plate B2. Strength deck plating, excluding that belonging to the Special category B3. Continuous longitudinal plating of strength members above strength deck, excluding hatch coamings B4. Uppermost strake in longitudinal bulkhead B5. Vertical strake (hatch side girder) and uppermost sloped strake in top wing tank	- Class II within 0.4L amidships - Grade A/AH outside 0.4L amidships
SPECIAL: C1. Sheer strake at strength deck (*) C2. Stringer plate in strength deck (*) C3. Deck strake at longitudinal bulkhead, excluding deck plating in way of inner-skin bulkhead of double-hull ships (*)	- Class III within 0.4L amidships - Class II outside 0.4L amidships - Class I outside 0.6L amidships
C4. Strength deck plating at outboard corners of cargo hatch openings in container carriers and other ships with similar hatch opening configurations	- Class 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 C5.1 Trunk deck and inner deck plating at corners of openings for liquid and gas domes in membrane type liquefied gas carriers	- Class III within 0.6L amidships - Class II within rest of cargo region
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 (*)	- 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 C9. End brackets and deck house transition of longitudinal cargo hatch coamings	- 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

(*) 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.

S6
(cont)

Table 2 - Minimum Material Grades for ships, excluding liquefied gas carriers covered in Table 3, with length exceeding 150 m and single strength deck

Structural member category	Material grade
• Longitudinal plating of strength deck where contributing to the longitudinal strength • Continuous longitudinal plating of strength members above strength deck	Grade B/AH within 0.4L amidships
Single side strakes for ships without inner continuous longitudinal bulkhead(s) between bottom and the strength deck	Grade B/AH within cargo region

Table 3 - Minimum Material Grades for membrane type liquefied gas carriers with length exceeding 150 m *

<table>
<tr><th colspan="2">Structural member category</th><th>Material grade</th></tr>
<tr><td colspan="2">Longitudinal plating of strength deck where contributing to the longitudinal strength</td><td>Grade B/AH within 0.4L amidships</td></tr>
<tr><td rowspan="2">Continuous longitudinal plating of strength members above the strength deck</td><td>Trunk deck plating</td><td>Class II within 0.4L amidships</td></tr>
<tr><td>• Inner deck plating
• Longitudinal strength member plating between the trunk deck and inner deck</td><td>Grade B/AH within 0.4L amidships</td></tr>
</table>

(*) Table 3 is applicable to membrane type liquefied gas carriers with deck arrangements as shown in Fig. 1. Table 3 may apply to similar ship types with a “double deck” arrangement above the strength deck.

S6
(cont)

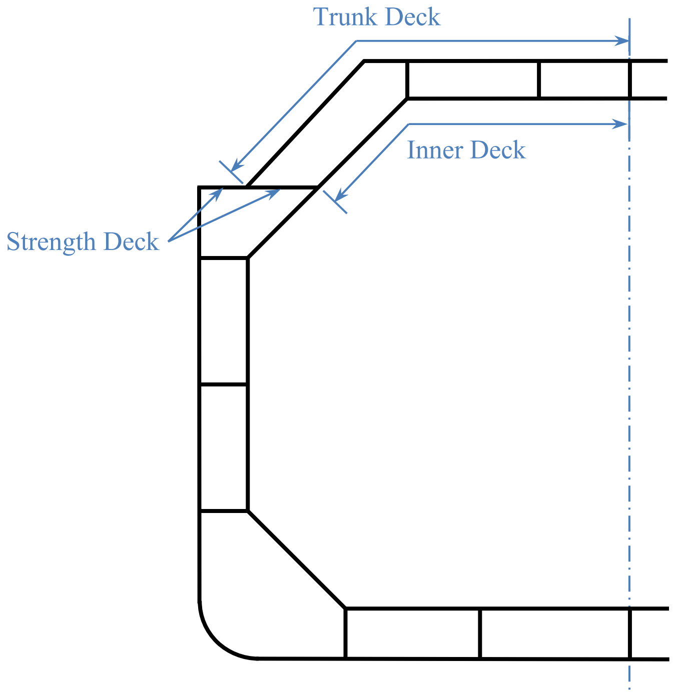

Fig. 1 Typical deck arrangement for membrane type Liquefied Natural Gas Carriers

Table 4 - Minimum Material Grades for ships with length exceeding 250 m

Structural member category	Material grade
Shear strake at strength deck (*)	Grade E/EH within 0.4L amidships
Stringer plate in strength deck (*)	Grade E/EH within 0.4L amidships
Bilge strake (*)	Grade D/DH within 0.4L amidships

(*) Single strakes required to be of Grade E/EH and within 0.4L amidships are to have breadths not less than 800+5L (mm), need not be greater than 1800 (mm), unless limited by the geometry of the ship's design.

S6
(cont)

Table 5 - Minimum Material Grades for single-side skin bulk carriers subjected to SOLAS regulation XII/6.5.3

Structural member category	Material grade
Lower bracket of ordinary side frame (*), (**)	Grade D/DH
Side shell strakes included totally or partially between the two points located to 0.125ℓ above and below the intersection of side shell and bilge hopper sloping plate or inner bottom plate (**)	Grade D/DH

(*) The term "lower bracket" means webs of lower brackets and webs of the lower part of side frames up to the point of 0.125ℓ above the intersection of side shell and bilge hopper sloping plate or inner bottom plate.

(**) The span of the side frame, ℓ, is defined as the distance between the supporting structures.

Table 6 - Minimum Material Grades for ships with ice strengthening

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

S6
(cont)

Table 7 - Material Grade Requirements for Classes I, II and III

Class	I		II		III	
Thickness, in mm	MS	HT	MS	HT	MS	HT
t ≤ 15	A	AH	A	AH	A	AH
15 < t ≤ 20	A	AH	A	AH	B	AH
20 < t ≤ 25	A	AH	B	AH	D	DH
25 < t ≤ 30	A	AH	D	DH	D	DH
30 < t ≤ 35	B	AH	D	DH	E	EH
35 < t ≤ 40	B	AH	D	DH	E	EH
40 < t ≤ 50	D	DH	E	EH	E	EH

S6.2 Ships exposed to low air temperatures

For ships intended to operate in areas with low air temperatures (below -10ºC), e.g. regular service during winter seasons to Arctic or Antarctic waters, the materials in exposed structures are to be selected based on the design temperature t_D, to be taken as defined in S6.3.

Materials in the various strength members above the lowest ballast water line (BWL) exposed to air (including the structural members covered by the Note [5] of Table 8) and materials of cargo tank boundary plating for which S6.4 is applicable are not to be of lower grades than those corresponding to Classes I, II and III, as given in Table 8, depending on the categories of structural members (SECONDARY, PRIMARY and SPECIAL). For non-exposed structures (except as indicated in Note [5] of Table 8) and structures below the lowest ballast water line, S6.1 applies.

S6
(cont)

Table 8 - Application of Material Classes and Grades – Structures Exposed at Low Temperatures

Structural member category	Material class: Within 0.4L amidships	Material class: Outside 0.4L amidships
SECONDARY: Deck plating exposed to weather, in general Side plating above BWL Transverse bulkheads above BWL[5] Cargo tank boundary plating exposed to cold cargo [6]	I	I
PRIMARY: Strength deck plating [1] Continuous longitudinal members above strength deck, excluding longitudinal hatch coamings Longitudinal bulkhead above BWL[5] Top wing tank bulkhead above BWL[5]	II	I
SPECIAL: Sheer strake at strength deck [2] Stringer plate in strength deck [2] Deck strake at longitudinal bulkhead [3] Continuous longitudinal hatch coamings [4]	III	II

Notes:

[1] Plating at corners of large hatch openings to be specially considered. Class III or Grade E/EH to be applied in positions where high local stresses may occur.

[2] Not to be less than Grade E/EH within 0.4L amidships in ships with length exceeding 250 metres.

[3] In ships with breadth exceeding 70 metres at least three deck strakes to be Class III.

[4] Not to be less than Grade D/DH.

[5] Applicable to plating attached to hull envelope plating exposed to low air temperature. At least one strake is to be considered in the same way as exposed plating and the strake width is to be at least 600 mm.

[6] For cargo tank boundary plating exposed to cold cargo for ships other than liquefied gas carriers, see S6.4.

The material grade requirements for hull members of each class depending on thickness and design temperature are defined in Table 9. For design temperatures t_D < -55ºC, materials are to be specially considered by each Classification Society.

S6 (cont)

Table 9 - Material Grade Requirements for Classes I, II and III at Low Temperatures

Class I

Plate thickness, in mm	-11/-15⁰C MS	HT	-16/-25⁰C MS	HT	-26/-35⁰C MS	HT	-36/-45⁰C MS	HT	-46/-55⁰C MS	HT
t ≤ 10	A	AH	A	AH	B	AH	D	DH	D	DH
10 < t ≤ 15	A	AH	B	AH	D	DH	D	DH	D	DH
15 < t ≤ 20	A	AH	B	AH	D	DH	D	DH	E	EH
20 < t ≤ 25	B	AH	D	DH	D	DH	D	DH	E	EH
25 < t ≤ 30	B	AH	D	DH	D	DH	E	EH	E	EH
30 < t ≤ 35	D	DH	D	DH	D	DH	E	EH	E	EH
35 < t ≤ 45	D	DH	D	DH	E	EH	E	EH	∅	FH
45 < t ≤ 50	D	DH	E	EH	E	EH	∅	FH	∅	FH

∅ = Not applicable

Class II

Plate thickness, in mm	-11/-15⁰C MS	HT	-16/-25⁰C MS	HT	-26/-35⁰C MS	HT	-36/-45⁰C MS	HT	-46/-55⁰C MS	HT
t ≤ 10	A	AH	B	AH	D	DH	D	DH	E	EH
10 < t ≤ 20	B	AH	D	DH	D	DH	E	EH	E	EH
20 < t ≤ 30	D	DH	D	DH	E	EH	E	EH	∅	FH
30 < t ≤ 40	D	DH	E	EH	E	EH	∅	FH	∅	FH
40 < t ≤ 45	E	EH	E	EH	∅	FH	∅	FH	∅	∅
45 < t ≤ 50	E	EH	E	EH	∅	FH	∅	FH	∅	∅

∅ = Not applicable

Class III

Plate thickness, in mm	-11/-15⁰C MS	HT	-16/-25⁰C MS	HT	-26/-35⁰C MS	HT	-36/-45⁰C MS	HT	-46/-55⁰C MS	HT
t ≤ 10	B	AH	D	DH	D	DH	E	EH	E	EH
10 < t ≤ 20	D	DH	D	DH	E	EH	E	EH	∅	FH
20 < t ≤ 25	D	DH	E	EH	E	EH	E	FH	∅	FH
25 < t ≤ 30	D	DH	E	EH	E	EH	∅	FH	∅	FH
30 < t ≤ 35	E	EH	E	EH	∅	FH	∅	FH	∅	∅
35 < t ≤ 40	E	EH	E	EH	∅	FH	∅	FH	∅	∅
40 < t ≤ 50	E	EH	∅	FH	∅	FH	∅	∅	∅	∅

∅ = Not applicable

Single strakes required to be of Class III or of Grade E/EH or FH are to have breadths not less than 800+ 5L mm, maximum 1800 mm.

Plating materials for sternframes, rudder horns, rudders and shaft brackets are not to be of lower grades than those corresponding to the material classes given in 6.1.

S6
(cont)

S6.3 Design temperature t_D

The design temperature t_D is to be taken as the lowest mean daily average air temperature in the area of operation.

Mean: Statistical mean over observation period
Average: Average during one day and night
Lowest: Lowest during year

For seasonally restricted service the lowest value within the period of operation applies.

For the purpose of issuing a Polar Ship Certificate in accordance with the Polar Code, the design temperature t_D shall be no more than 13°C higher than the Polar Service Temperature (PST) of the ship.

In the Polar Regions, the statistical mean over observation period is to be determined for a period of at least 10 years.

Fig. 2 illustrates the temperature definition.

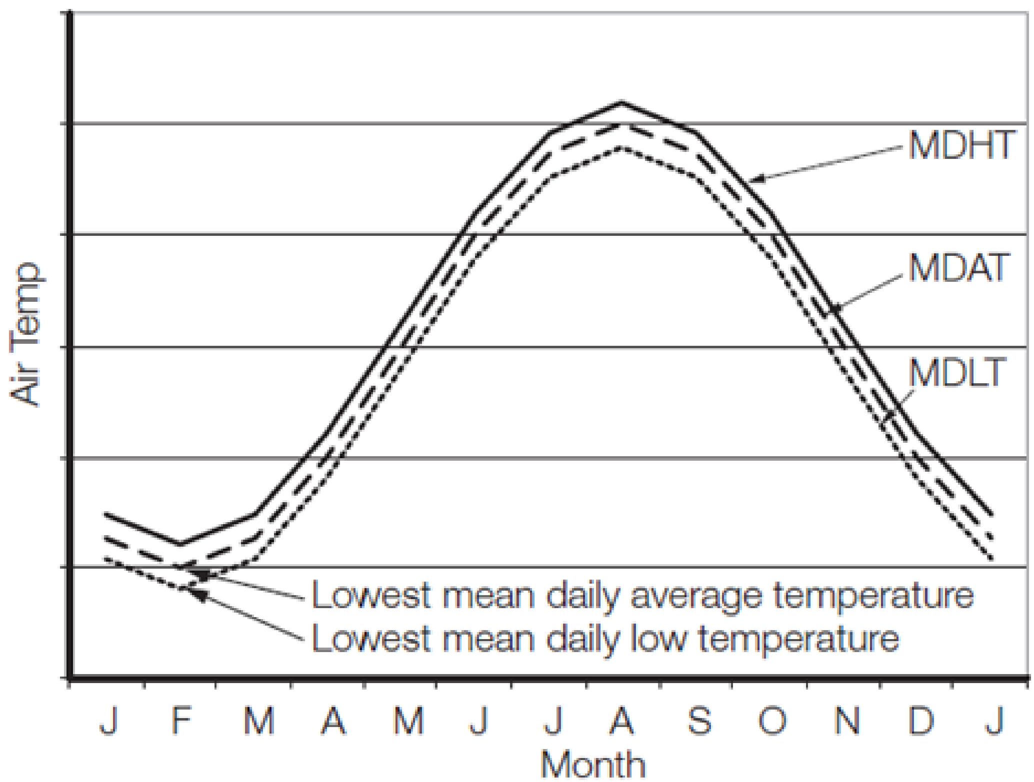

Fig. 2 Commonly used definitions of temperatures

MDHT = Mean Daily High (or maximum) Temperature
MDAT = Mean Daily Average Temperature
MDLT = Mean Daily Low (or minimum) Temperature

S6
(cont)

S6.4 Cold cargo for ships other than liquefied gas carriers

For ships other than liquefied gas carriers, intended to be loaded with liquid cargo having a temperature below -10° C, e.g. loading from cold onshore storage tanks during winter conditions, the material grade of cargo tank boundary plating is defined in Table 9 based on the following:

- t_c design minimum cargo temperature in °C
- steel grade corresponding to Class I as given in Table 8

The design minimum cargo temperature, t_c is to be specified in the loading manual.

End of
Document

S7 Minimum Longitudinal Strength Standards†

(1973)
(Rev.1 1976)
(Rev.2 1978)
(Rev.3 1989)
(Rev.4 May 2010)

S7.0 Application

This UR does not apply to CSR Bulk Carriers and Oil Tankers.

S7.1 The minimum midship section modulus at deck and keel for ships 90 m ≤ L ≤ 500 m and made of hull structural steel is

$$W_{min} = cL^2B\,(C_b + 0.7)\,k \quad (cm^3)$$

where L = Rule length (m)

B = Rule breadth (m)

C_b = Rule block coefficient; C_b is not to be taken less than 0.60

c = c_n for new ships
c = c_s for ships in service = 0.9 c_n

$$c_n = 10.75 - \left(\frac{300 - L}{100}\right)^{3/2} \quad \text{for } 90\text{ m} \le L \le 300\text{ m}$$

$$= 10.75 \quad \text{for } 300\text{ m} < L < 350\text{ m}$$

$$= 10.75 - \left(\frac{L - 350}{150}\right)^{3/2} \quad \text{for } 350\text{ m} \le L \le 500\text{ m}$$

k = material factor
k = 1.0 for ordinary hull structural steel,
k < 1.0 for higher tensile steel according to S4.

S7.2 Scantlings of all continuous longitudinal members of hull girder based on the section modulus requirement in S7.1 are to be maintained within 0.4 L amidships.

However, in special cases, based on consideration of type of ship, hull form and loading conditions, the scantlings may be gradually reduced towards the end of the 0.4 L part, bearing in mind the desire not to inhibit the vessel's loading flexibility.

S7.3 In ships where part of the longitudinal strength material in the deck or bottom area are forming boundaries of tanks for oil cargoes or ballast water and such tanks are provided with an effective corrosion protection system, certain reductions in the scantlings of these boundaries are allowed. These reductions, however, should in no case reduce the minimum hull girder section modulus for a new ship by more than 5%.

NOTE

The above standard refers in unrestricted service with minimum midship section modulus only. However, it may not be applicable to ships of unusual type or design, e.g. for ships of unusual main proportions and/or weight distributions.

'New Ships' are ships in the stage directly after completion.

† This Requirement is subject to periodical updating.

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S8 Bow Doors and Inner Doors

(1982)
(Rev. 2 1995)
(Corr. 1997)
(Rev.3 Nov 2003)
(Rev.4 Dec 2010)

S8.1 General

S8.1.1 Application

S8.1.1a These requirements are for the arrangement, strength and securing of bow doors and inner doors leading to a complete or long forward enclosed superstructures, or to a long non-enclosed superstructure, where fitted to attain minimum bow height equivalence.

The requirements apply to all ro-ro passenger ships and ro-ro cargo ships engaged on international voyages and also to ro-ro passenger ships and ro-ro cargo ships engaged only in domestic (non-international) voyages, except where specifically indicated otherwise herein.

The requirements are not applicable to high speed, light displacement craft as defined in the IMO Code of Safety for High Speed Craft.

S8.1.1b Two types of bow door are provided for:

- **Visor doors** opened by rotating upwards and outwards about a horizontal axis through two or more hinges located near the top of the door and connected to the primary structure of the door by longitudinally arranged lifting arms,

- **Side-opening doors** opened either by rotating outwards about a vertical axis through two or more hinges located near the outboard edges or by horizontal translation by means of linking arms arranged with pivoted attachments to the door and the ship. It is anticipated that side-opening bow doors are arranged in pairs.

Other types of bow door will be specially considered in association with the applicable requirements of these rules.

S8.1.2 Arrangement

S8.1.2a Bow doors are to be situated above the freeboard deck. A watertight recess in the freeboard deck located forward of the collision bulkhead and above the deepest waterline fitted for arrangement of ramps or other related mechanical devices may be regarded as a part of the freeboard deck for the purpose of this requirement.

Footnote:

It was agreed by IACS Council in August 1995 that this UR S8 should be uniformly applied by IACS Members to new ships as soon as possible but not later than 1 July 1996 and, with immediate effect, when approving plans for bow arrangements on new ships, Members should strongly recommend that the requirements as set out in the revised UR S8 are complied in full.

Note:

Changes introduced in Rev.4 are to be uniformly implemented by IACS Members from 1 January 2012.

S8
(cont)

S8.1.2b An inner door is to be fitted. The inner door is to be part of the collision bulkhead. The inner door needs not be fitted directly above the bulkhead below, provided it is located within the limits specified for the position of the collision bulkhead, refer to regulation II-1/12 of the SOLAS Convention. A vehicle ramp may be arranged for this purpose, provided its position complies with regulation II-1/12 of the SOLAS Convention. If this is not possible a separate inner weathertight door is to be installed, as far as practicable within the limits specified for the position of the collision bulkhead.

S8.1.2c Bow doors are to be so fitted as to ensure tightness consistent with operational conditions and to give effective protection to inner doors. Inner doors forming part of the collision bulkhead are to be weathertight over the full height of the cargo space and arranged with fixed sealing supports on the aft side of the doors.

S8.1.2d Bow doors and inner doors are to be arranged so as to preclude the possibility of the bow door causing structural damage to the inner door or to the collision bulkhead in the case of damage to or detachment of the bow door. If this is not possible, a separate inner weathertight door is to be installed, as indicated in S8.1.2b.

S8.1.2e The requirements for inner doors are based on the assumption that vehicle are effectively lashed and secured against movement in stowed position.

S8.1.3 Definitions

Securing device - a device used to keep the door closed by preventing it from rotating about its hinges.

Supporting device - a device used to transmit external or internal loads from the door to a securing device and from the securing device to the ship's structure, or a device other than a securing device, such as a hinge, stopper or other fixed device, that transmits loads from the door to the ship's structure.

Locking device - a device that locks a securing device in the closed position.

Ro-ro passenger ship - a passenger ship with ro-ro spaces or special category spaces.

Ro-ro spaces - are spaces not normally sub-divided in any way and normally extending to either a substantial length or the entire length of the ship, in which motor vehicles with fuel in their tanks for their own propulsion and/or goods (packaged or in bulk, in or on rail or road cars, vehicles (including road or rail tankers), trailers, containers, pallets, demountable tanks or in or on similar stowage units or, other receptacles) can be loaded and unloaded normally in a horizontal direction.

Special category spaces - are those enclosed vehicle spaces above or below the bulkhead deck, into and from which vehicles can be driven and to which passengers have access. Special category spaces may be accommodated on more than one deck provided that the total overall clear height for vehicles does not exceed 10m.

S8
(cont)

S8.2 Strength Criteria

S8.2.1 Primary structure and Securing and Supporting devices

S8.2.1a Scantlings of the primary members, securing and supporting devices of bow doors and inner doors are to be determined to withstand the design loads defined in S8.3, using the following permissible stresses:

sheer stress: $\tau = \frac{80}{k} N/mm^2$

bending stress: $\sigma = \frac{120}{k} N/mm^2$

equivalent stress: $\sigma_c = \sqrt{\sigma^2 + 3\tau^2} = \frac{150}{k} N/mm^2$

where *k* is the material factor as given in S4, but is not to be taken less than 0.72 unless a direct fatigue analysis is carried out.

S8.2.1b The buckling strength of primary members is to be verified as being adequate.

S.8.2.1c For steel to steel bearings in securing and supporting devices, the nominal bearing pressure calculated by dividing the design force by the projected bearing area is not to exceed $0.8\sigma_F$, where σ_F is the yield stress of the bearing material. For other bearing materials, the permissible bearing pressure is to be determined according to the manufacturer's specification.

S8.2.1d The arrangement of securing and supporting devices is to be such that threaded bolts do not carry support forces. The maximum tension in way of threads of bolts not carrying support forces is not to exceed:

$$\frac{125}{k} N/mm^2$$

S8
(cont)

S8.3 Design loads

S8.3.1 Bow doors

S8.3.1a The design external pressure, in kN/m^2, to be considered for the scantlings of primary members, securing and supporting devices of bow doors is not to be less than the pressure normally used by the Society nor than:

$$P_e = 2.75\lambda C_H (0.22 + 0.15 \tan\alpha)(0.4V \sin\beta + 0.6L^{0.5})^2$$

where:

V contractual ship's speed, in knots,

L ship's length, in m, but need not be taken greater than 200 metres,

λ coefficient depending on the area where the ship is intended to be operated:

λ = 1 for seagoing ships,

λ = 0.8 for ships operated in coastal waters,

λ = 0.5 for ships operated in sheltered waters,

Note: Coastal waters and sheltered waters are defined according to the practice of each Classification Society. As an example, coastal waters may be defined as areas where significant wave heights do not exceed 4m for more than three hours a year and sheltered waters as areas where significant wave heights do not exceed 2m for more than three hours a year.

C_H = 0.0125 L for L < 80m
1 for L ≥ 80m

α flare angle at the point to be considered, defined as the angle between a vertical line and the tangent to the side shell plating, measured in a vertical plane normal to the horizontal tangent to the shell plating,

β entry angle at the point to be considered, defined as the angle between a longitudinal line parallel to the centreline and the tangent to the shell plating in a horizontal plane.

S8.3.1b The design external forces, in kN, considered for the scantlings of securing and supporting devices of bow doors are not to be less than:

$F_x = P_e A_x$
$F_y = P_e A_y$
$F_z = P_e A_z$

where:

A_x area, in m^2, of the transverse vertical projection of the door between the levels of the bottom of the door and the top of the upper deck bulwark, or between the bottom of the door and the top of the door, including the bulwark, where it is part

S8
(cont)

of the door, whichever is lesser. Where the flare angle of the bulwark is at least 15 degrees less than the flare angle of the adjacent shell plating, the height from the bottom of the door may be measured to the upper deck or to the top of the door, whichever is lesser. In determining the height from the bottom of the door to the upper deck or to the top of the door, the bulwark is to be excluded.

A_y area, in m^2, of the longitudinal vertical projection of the door between the levels of the bottom of the door and the top of the upper deck bulwark, or between the bottom of the door and the top of the door, including the bulwark, where it is part of the door, whichever is lesser. Where the flare angle of the bulwark is at least 15 degrees less than the flare angle of the adjacent shell plating, the height from the bottom of the door may be measured to the upper deck or to the top of the door, whichever is lesser.

A_z area, in m^2, of the horizontal projection of the door between the bottom of the door and the top of the upper deck bulwark, or between the bottom of the door and the top of the door, including the bulwark, where it is part of the door, whichever is the lesser. Where the flare angle of the bulwark is at least 15 degrees less than the flare angle of the adjacent shell plating, the height from the bottom of the door may be measured to the upper deck or to the top of the door, whichever is lesser.

h height, in m, of the door between the levels of the bottom of the door and the upper deck or between the bottom of the door and the top of the door, whichever is the lesser,

l length, in m, of the door at a height h/2 above the bottom of the door,

W breadth, in m, of the door at a height h/2 above the bottom of the door,

P_e external pressure, in kN/m^2, as given in S8.3.1a with angles α and β defined as follows:

α flare angle measured at the point on the bow door, $l/2$ aft of the stem line on the plane h/2 above the bottom of the door, as shown in Figure 1,

β entry angle measured at the same point as α .

For bow doors, including bulwark, of unusual form or proportions, e.g. ships with a rounded nose and large stem angles, the areas and angles used for determination of the design values of external forces may require to be specially considered.

S8.3.1c For visor doors the closing moment M_y under external loads, in kN**.**m, is to be taken as:

$$M_y = F_x a + 10Wc - F_z b$$

where:

W mass of the visor door, in t,

a vertical distance, in m, from visor pivot to the centroid of the transverse vertical projected area of the visor door, as shown in Figure 2,

S8
(cont)

b horizontal distance, in m, from visor pivot to the centroid of the horizontal projected area of the visor door, as shown in Figure 2,

c horizontal distance, in m, from visor pivot to the centre of gravity of visor mass, as shown in Figure 2.

S8.3.1d Moreover, the lifting arms of a visor door and its supports are to be dimensioned for the static and dynamic forces applied during the lifting and lowering operations, and a minimum wind pressure of 1.5kN/m^2 is to be taken into account.

S8.3.2 Inner doors

S8.3.2a The design external pressure p_e, in kN/m^2, considered for the scantlings of primary members, securing and supporting devices and surrounding structure of inner doors is to be taken as the greater of the following:

- $p_e = 0.45\ L$,
- hydrostatic pressure $p_h = 10h$, where h is the distance, in m, from the load point to the top of the cargo space,

where L is the ship's length, as defined in S8.3.1a.

S8.3.2b The design internal pressure p_i, in kN/m^2, considered for the scantlings of securing devices of inner doors is not to be less than:

$p_i = 25$

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(cont)

S8.4 Scantlings of bow doors

S8.4.1a The strength of bow doors is to be commensurate with that of the surrounding structure.

S8.4.1b Bow doors are to be adequately stiffened and means are to be provided to prevent lateral or vertical movement of the doors when closed. For visor doors adequate strength for the opening and closing operations is to be provided in the connections of the lifting arms to the door structure and to the ship structure.

S8.4.2 Plating and secondary stiffeners

S8.4.2a The thickness of the bow door plating is not to be less than that required for the side shell plating, using bow door stiffener spacing, but in no case less than the minimum required thickness of fore end shell plating.

S8.4.2b The section modulus of horizontal or vertical stiffeners is not to be less than that required for end framing. Consideration is to be given, where necessary, to differences in fixity between ship's frames and bow doors stiffeners.

S.8.4.2c The stiffener webs are to have a net sectional area, in cm^2, not less than:

$$A = \frac{Qk}{10}$$

where:

Q shear force, in kN, in the stiffener calculated by using uniformly distributed external pressure p_e as given in S8.3.1a.

S8.4.3 Primary structure

S8.4.3a The bow door secondary stiffeners are to be supported by primary members constituting the main stiffening of the door.

S8.4.3b The primary members of the bow door and the hull structure in way are to have sufficient stiffness to ensure integrity of the boundary support of the door.

S8.4.3c Scantlings of the primary members are generally to be supported by direct strength calculations in association with the external pressure given in S8.3.1a and permissible stresses given in S8.2.1a. Normally, formulae for simple beam theory may be applied to determine the bending stress. Members are to be considered to have simply supported end connections.

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(cont)

S8.5 Scantlings of inner doors

S8.5.1 General

S8.5.1a Scantlings of the primary members are generally to be supported by direct strength calculations in association with the external pressure given in S8.3.2a and permissible stresses given in S8.2.1a. Normally, formulae for simple beam theory may be applied.

S8.5.1b Where inner doors also serve as a vehicle ramps, the scantlings are not to be less than those required for vehicle decks.

S8.5.1c The distribution of the forces acting on the securing and supporting devices is generally to be supported by direct calculations taking into account the flexibility of the structure and the actual position and stiffness of the supports.

S8 (cont)

S8.6 Securing and supporting of bow doors

S8.6.1 General

S8.6.1a Bow doors are to be fitted with adequate means of securing and supporting so as to be commensurate with the strength and stiffness of the surrounding structure. The hull supporting structure in way of the bow doors is to be suitable for the same design loads and design stresses as the securing and supporting devices. Where packing is required, the packing material is to be of a comparatively soft type, and the supporting forces are to be carried by the steel structure only. Other types of packing may be considered. Maximum design clearance between securing and supporting devices is not generally to exceed 3 mm.

A means is to be provided for mechanically fixing the door in the open position.

S8.6.1b Only the active supporting and securing devices having an effective stiffness in the relevant direction are to be included and considered to calculate the reaction forces acting on the devices. Small and/or flexible devices such as cleats intended to provide load compression of the packing material are not generally to be included in the calculations called for in S8.6.2e. The number of securing and supporting devices are generally to be the minimum practical whilst taking into account the requirements for redundant provision given in S8.6.2f and S8.6.2g and the available space for adequate support in the hull structure.

S8.6.1c For opening outwards visor doors, the pivot arrangement is generally to be such that the visor is self closing under external loads, that is $M_y>0$. Moreover, the closing moment M_y as given in S8.3.1c is to be not less than:

$$M_{yo} = 10Wc + 0.1(a^2 + b^2)^{0.5}(F_x^2 + F_z^2)^{0.5}$$

S8.6.2 Scantlings

S8.6.2a Securing and supporting devices are to be adequately designed so that they can withstand the reaction forces within the permissible stresses given in S8.2.1a.

S8.6.2b For visor doors the reaction forces applied on the effective securing and supporting devices assuming the door as a rigid body are determined for the following combination of external loads acting simultaneously together with the self weight of the door:

i) case 1 F_x and F_z

ii) case 2 $0.7F_y$ acting on each side separately together with $0.7F_x$ and $0.7F_z$

where F_x, F_y and F_z are determined as indicated in S8.3.1b and applied at the centroid of projected areas.

S8.6.2c For side-opening doors the reaction forces applied on the effective securing and supporting devices assuming the door as a rigid body are determined for the following combination of external loads acting simultaneously together with the self weight of the door:

i) case 1 F_x, F_y and F_z acting on both doors

ii) case 2 $0.7 F_x$ and $0.7F_z$ acting on both doors and $0.7F_y$ acting on each door separately,

S8
(cont)

where F_x, F_y and F_z are determined as indicated in S8.3.1b and applied at the centroid of projected areas.
S8.6.2d The support forces as determined according to S8.6.2b i) and S8.6.2c i) shall generally give rise to a zero moment about the transverse axis through the centroid of the area A_x. For visor doors, longitudinal reaction forces of pin and/or wedge supports at the door base contributing to this moment are not to be of the forward direction.

S8.6.2e The distribution of the reaction forces acting on the securing and supporting devices may require to be supported by direct calculations taking into account the flexibility of the hull structure and the actual position and stiffness of the supports.

S8.6.2f The arrangement of securing and supporting devices in way of these securing devices is to be designed with redundancy so that in the event of failure of any single securing or supporting device the remaining devices are capable to withstand the reaction forces without exceeding by more than 20 per cent the permissible stresses as given in S8.2.1.

S8.6.2g For visor doors, two securing devices are to be provided at the lower part of the door, each capable of providing the full reaction force required to prevent opening of the door within the permissible stresses given in S8.2.1a. The opening moment M_o, in kN.m, to be balanced by this reaction force, is not to be taken less than:

$$M_o = 10\ W\ d + 5A_x a$$

where:

d vertical distance, in m, from the hinge axis to the centre of gravity of the door, as shown in Figure 2,

a as defined in S8.3.1c.

S8.6.2.h For visor doors, the securing and supporting devices excluding the hinges should be capable of resisting the vertical design force (F_z - 10W), in kN, within the permissible stresses given in S8.2.1a.

S8.6.2.i All load transmitting elements in the design load path, from door through securing and supporting devices into the ship structure, including welded connections, are to be to the same strength standard as required for the securing and supporting devices. These elements include pins, supporting brackets and back-up brackets.

S8.6.2j For side-opening doors, thrust bearing has to be provided in way of girder ends at the closing of the two leaves to prevent one leaf to shift towards the other one under effect of unsymmetrical pressure (see example of Figure 3). Each part of the thrust bearing has to be kept secured on the other part by means of securing devices. Any other arrangement serving the same purpose may be proposed.

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S8.7 Securing and locking arrangement

S8.7.1 Systems for operation

S8.7.1a Securing devices are to be simple to operate and easily accessible.

Securing devices are to be equipped with mechanical locking arrangement (self locking or separate arrangement), or to be of the gravity type. The opening and closing systems as well as securing and locking devices are to be interlocked in such a way that they can only operate in the proper sequence.

S8.7.1b Bow doors and inner doors giving access to vehicle decks are to be provided with an arrangement for remote control, from a position above the freeboard deck, of:

- the closing and opening of the doors, and
- associated securing and locking devices for every door.

Indication of the open/closed position of every door and every securing and locking device is to be provided at the remote control stations. The operating panels for operation of doors are to be inaccessible to unauthorized persons. A notice plate, giving instructions to the effect that all securing devices are to be closed and locked before leaving harbour, is to be placed at each operating panel and is to be supplemented by warning indicator lights.

S8.7.1c Where hydraulic securing devices are applied, the system is to be mechanically lockable in closed position. This means that, in the event of loss of the hydraulic fluid, the securing devices remain locked.

The hydraulic system for securing and locking devices is to be isolated from other hydraulic circuits, when in closed position.

S8.7.2 Systems for indication/monitoring

S8.7.2a Separate indicator lights and audible alarms are to be provided on the navigation bridge and on the operating panel to show that the bow door and inner door are closed and that their securing and locking devices are properly positioned.

The indication panel is to be provided with a lamp test function. It shall not be possible to turn off the indicator light.

S8.7.2b The indicator system is to be designed on the fail safe principle and is to show by visual alarms if the door is not fully closed and not fully locked and by audible alarms if securing devices become open or locking devices become unsecured. The power supply for the indicator system for operating and closing doors is to be independent of the power supply for operating and closing the doors and is to be provided with a back-up power supply from the emergency source of power or other secure power supply e.g. UPS. The sensors of the indicator system are to be protected from water, ice formation and mechanical damage.

Note: The indicator system is considered designed on the fail - safe principal when:

1) The indication panel is provided with:

- a power failure alarm
- an earth failure alarm
- a lamp test
- separate indication for door closed, door locked, door not closed and door not locked.

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2) Limit switches electrically closed when the door is closed (when more limit switches are provided they may be connected in series).

3) Limit switches electrically closed when securing arrangements are in place (when more limit switches are provided they may be connected in series).

4) Two electrical circuits (also in one multicore cable), one for the indication of door closed / not closed and the other for door locked / not locked.

5) In case of dislocation of limit switches, indication to show: not closed / not locked / securing arrangement not in place - as appropriate.

S8.7.2c The indication panel on the navigation bridge is to be equipped with a mode selection function "harbour/sea voyage", so arranged that audible alarm is given on the navigation bridge if the vessel leaves harbour with the bow door or inner door not closed or with any of the securing devices not in the correct position.

S8.7.2d A water leakage detection system with audible alarm and television surveillance is to be arranged to provide an indication to the navigation bridge and to the engine control room of leakage through the inner door.

Note: The indicator system is considered designed on the fail - safe principal when:

1) The indication panel is provided with:

- a power failure alarm
- an earth failure alarm
- a lamp test
- separate indication for door closed, door locked, door not closed and door not locked.

2) Limit switches electrically closed when the door is closed (when more limit switches are provided they may be connected in series).

3) Limit switches electrically closed when securing arrangements are in place (when more limit switches are provided they may be connected in series).

4) Two electrical circuits (also in one multicore cable), one for the indication of door closed / not closed and the other for door locked / not locked.

5) In case of dislocation of limit switches, indication to show: not closed / not locked / securing arrangement not in place - as appropriate.

S8.7.2e Between the bow door and the inner door a television surveillance system is to be fitted with a monitor on the navigation bridge and in the engine control room. The system is to monitor the position of the doors and a sufficient number of their securing devices. Special consideration is to be given for the lighting and contrasting colour of objects under surveillance.

Note: The indicator system is considered designed on the fail - safe principal when:

1) The indication panel is provided with:

- a power failure alarm
- an earth failure alarm
- a lamp test

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(cont)

- separate indication for door closed, door locked, door not closed and door not locked.

2) Limit switches electrically closed when the door is closed (when more limit switches are provided they may be connected in series).

3) Limit switches electrically closed when securing arrangements are in place (when more limit switches are provided they may be connected in series).

4) Two electrical circuits (also in one multicore cable), one for the indication of door closed / not closed and the other for door locked / not locked.

5) In case of dislocation of limit switches, indication to show: not closed / not locked / securing arrangement not in place - as appropriate.

S8.7.2f A drainage system is to be arranged in the area between bow door and ramp, or where no ramp is fitted, between the bow door and inner door. The system is to be equipped with an audible alarm function to the navigation bridge being set off when the water levels in these areas exceed 0.5m or the high water level alarm, whichever is lesser.

Note: The indicator system is considered designed on the fail - safe principal when:

1) The indication panel is provided with:

- a power failure alarm
- an earth failure alarm
- a lamp test
- separate indication for door closed, door locked, door not closed and door not locked.

2) Limit switches electrically closed when the door is closed (when more limit switches are provided they may be connected in series).

3) Limit switches electrically closed when securing arrangements are in place (when more limit switches are provided they may be connected in series).

4) Two electrical circuits (also in one multicore cable), one for the indication of door closed / not closed and the other for door locked / not locked.

5) In case of dislocation of limit switches, indication to show: not closed / not locked / securing arrangement not in place - as appropriate.

S8.7.2.g For ro-ro passenger ships on international voyages, the special category spaces and ro-ro spaces are to be continuously patrolled or monitored by effective means, such as television surveillance, so that any movement of vehicles in adverse weather conditions or unauthorized access by passengers thereto, can be detected whilst the ship is underway.

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S8.8 Operating and Maintenance Manual

S8.8.1 An Operating and Maintenance Manual for the bow door and inner door is to be provided on board and is to contain necessary information on:

- main particulars and design drawings
  special safety precautions
  details of vessel
  equipment and design loading (for ramps)
  key plan of equipment (doors and ramps)
  manufacturer's recommended testing for equipment
  description of equipment for
    bow doors
    inner bow doors
    bow ramp/doors
    side doors
    stern doors
    central power pack
    bridge panel
    engine control room panel

- service conditions
  limiting heel and trim of ship for loading/unloading
  limiting heel and trim for door operations
  doors/ramps operating instructions
  doors/ramps emergency operating instructions

- maintenance
  schedule and extent of maintenance
  trouble shooting and acceptable clearances
  manufacturer's maintenance procedures

- register of inspections, including inspection of locking, securing and supporting devices, repairs and renewals.

This Manual is to be submitted for approval that the above mentioned items are contained in the OMM and that the maintenance part includes the necessary information with regard to inspections, troubleshooting and acceptance / rejection criteria.

Note: It is recommended that recorded inspections of the door supporting and securing devices be carried out by the ship's staff at monthly intervals or following incidents that could result in damage, including heavy weather or contact in the region of the shell doors. Any damages recorded during such inspections are to be reported to the Classification Society.

S8.8.2 Documented operating procedures for closing and securing the bow door and inner door are to be kept on board and posted at appropriate place.

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Fig. 1 Definition of α and β

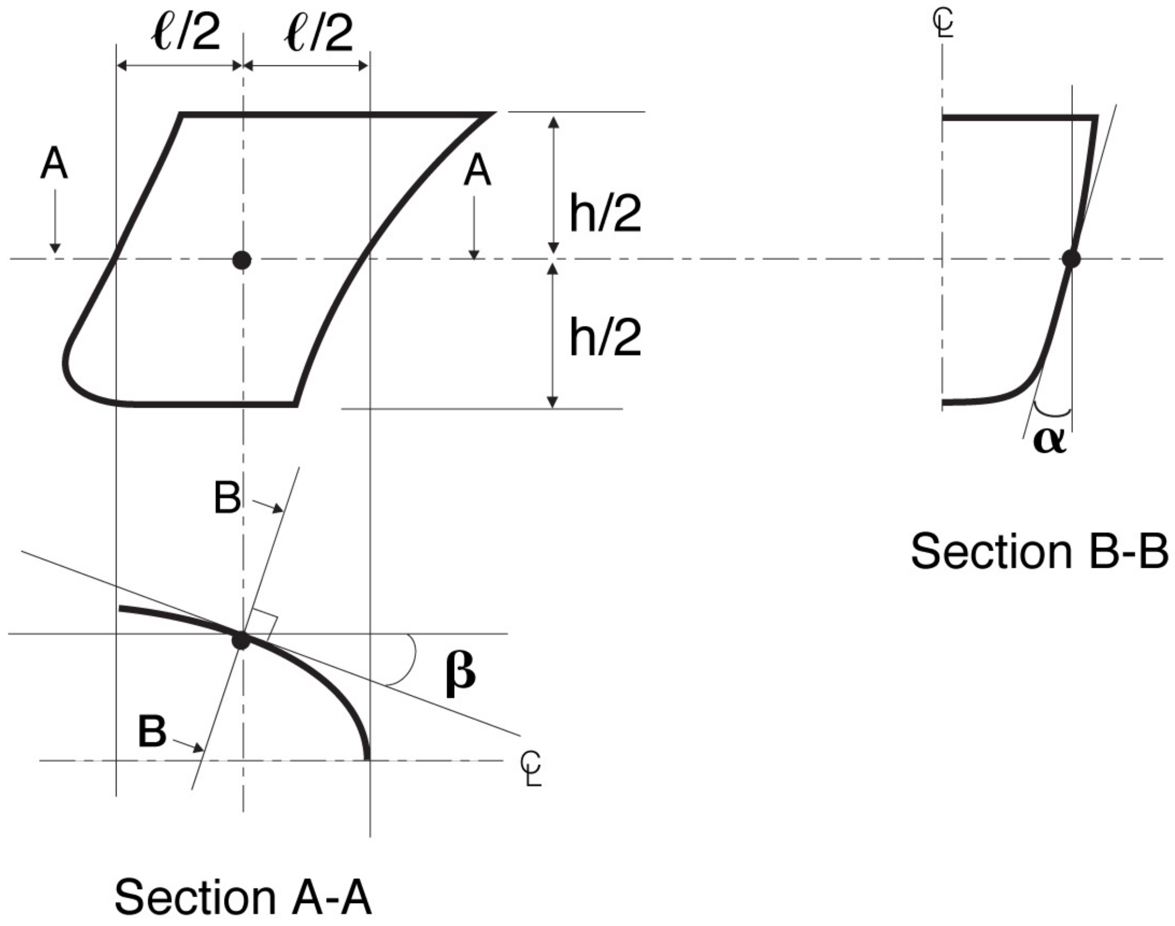

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Fig. 2 Bow Door of Visor Type

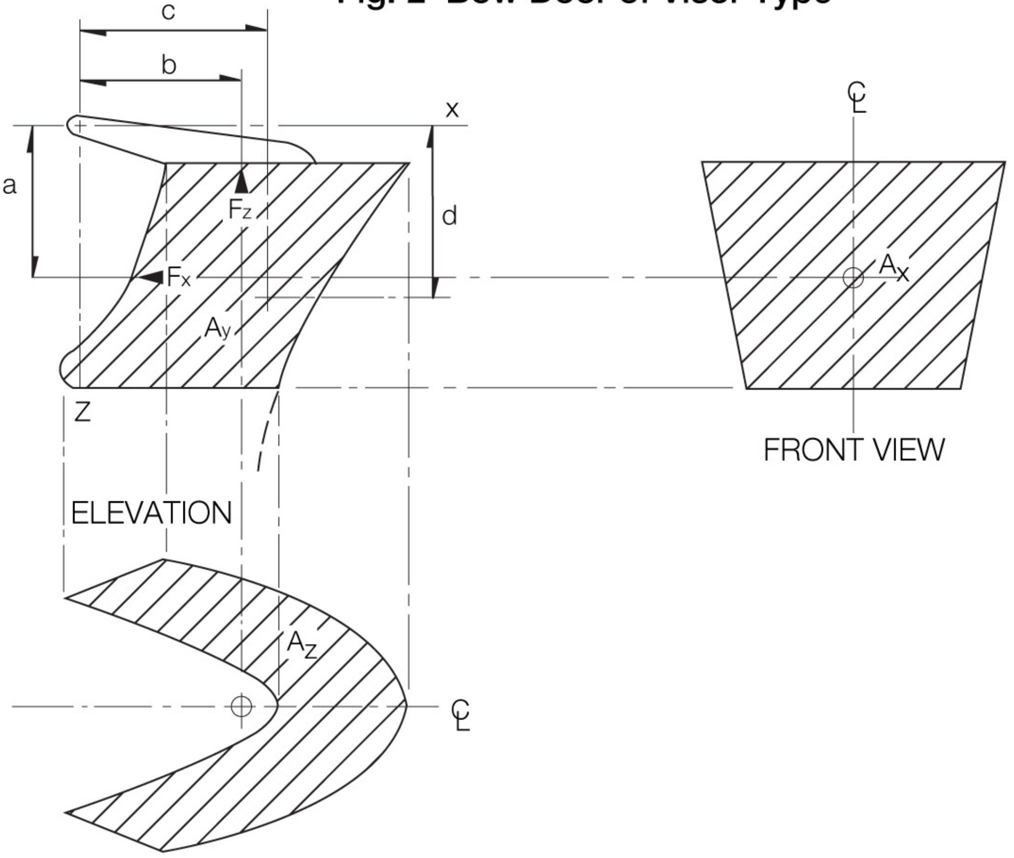
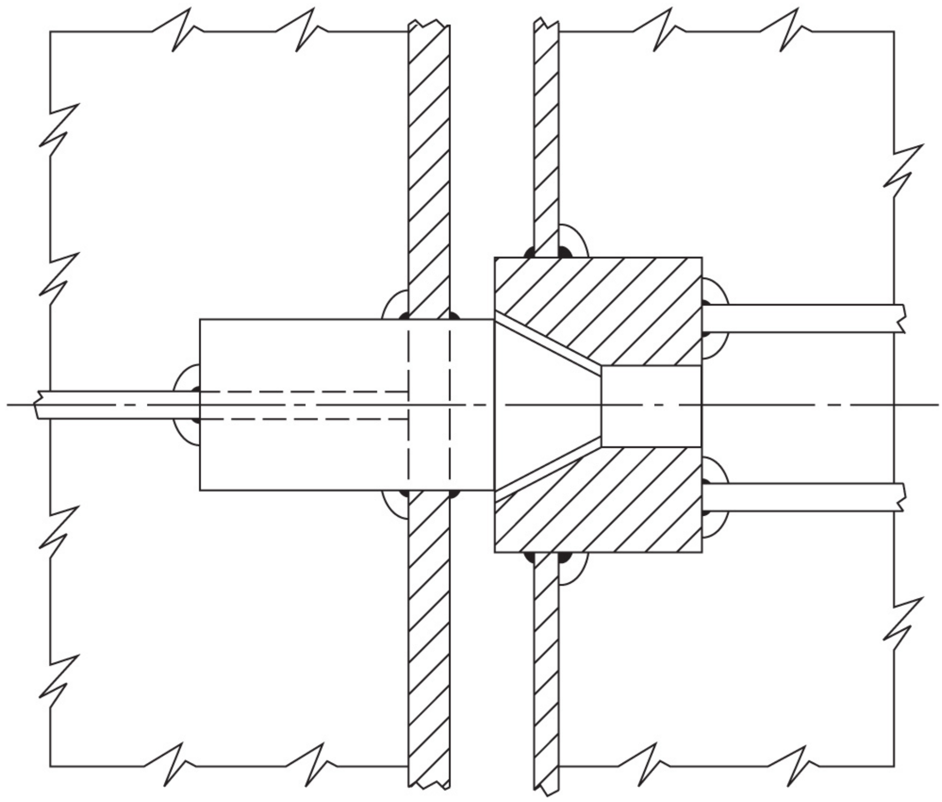


Fig. 3 Thrust Bearing



End of Document

S9
(1984)
(Rev.1 1990)
(Rev.2 1993)
(Rev.3 1996)
(Rev.4 1996)
(Rev.5 Nov 2003)
(Rev.6 Dec 2010)

Side Shell Doors and Stern Doors

S9.1 General

S9.1.1 Application

S9.1.1a These requirements are for the arrangement, strength and securing of side shell doors, abaft the collision bulkhead, and of stern doors leading to enclosed spaces.

The requirements apply to all ro-ro passenger ships and ro-ro cargo ships engaged on international voyages and also to ro-ro passenger ships and ro-ro cargo ships engaged only in domestic (non international) voyages, except where specifically indicated otherwise herein. The requirements are not applicable to high speed, light displacement craft as defined in the IMO Code of Safety for High Speed Craft.

S9.1.2 Arrangement

S9.1.2a Stern doors for passenger vessels are to be situated above the freeboard deck. Stern doors for Ro-Ro cargo ships and side shell doors may be either below or above the freeboard deck.

S9.1.2b Side shell doors and stern doors are to be so fitted as to ensure tightness and structural integrity commensurate with their location and the surrounding structure.

S9.1.2c Where the sill of any side shell door is below the uppermost load line, the arrangement is to be specially considered (see IACS Interpretation LL 21).

S9.1.2d Doors should preferably open outwards.

S9.1.3 Definitions

Securing device - a device used to keep the door closed by preventing it from rotating about its hinges or about pivotted attachments to the ship.

Supporting device - a device used to transmit external or internal loads from the door to a securing device and from the securing device to the ship's structure, or a device other than a securing device, such as a hinge, stopper or other fixed device, that transmits loads from the door to the ship's structure.

Locking device - a device that locks a securing device in the closed position.

Notes:

1. Revision 4 of the UR is applicable to new ships for which the request for classification is received on or after 1 July 1997.

2. Changes introduced in Rev.6 are to be uniformly implemented by IACS Members from 1 January 2012.

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Ro-ro passenger ship	-	a passenger ship with ro-ro spaces or special category spaces.
Ro-ro spaces	-	are spaces not normally sub-divided in any way and extending to either a substantial length or the entire length of the ship, in which motor vehicles with fuel in their tanks for their own propulsion and/or goods (packaged or in bulk, in or on rail or road cars, vehicles (including road or rail tankers), trailers, containers, pallets, demountable tanks or in or on similar stowage units or, other receptacles) can be loaded and unloaded normally in a horizontal direction.
Special category spaces	-	are those enclosed vehicle spaces above or below the bulkhead deck, into and from which vehicles can be driven and to which passengers have access. Special category spaces may be accommodated on more than one deck provided that the total overall clear height for vehicles does not exceed 10m.

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S9.2 Strength Criteria

S9.2.1 Primary structure and Securing and Supporting devices

S9.2.1a Scantlings of the primary members, securing and supporting devices of side shell doors and stern doors are to be determined to withstand the design loads defined in S9.3, using the following permissible stresses:

sheer stress: $$\tau = \frac{80}{k} N/mm^2$$

bending stress: $$\sigma = \frac{120}{k} N/mm^2$$

equivalent stress: $$\sigma_c = \sqrt{\sigma^2 + 3\tau^2} = \frac{150}{k} N/mm^2$$

where k is the material factor as given in S4, but is not to be taken less than 0.72 unless a direct strength analysis with regard to relevant modes of failures is carried out.

S9.2.1b The buckling strength of primary members is to be verified as being adequate.

S9.2.1c For steel to steel bearings in securing and supporting devices, the nominal bearing pressure calculated by dividing the design force by the projected bearing area is not to exceed $0.8\sigma_F$, where σ_F is the yield stress of the bearing material. For other bearing materials, the permissible bearing pressure is to be determined according to the manufacturer's specification.

S9.2.1d The arrangement of securing and supporting devices is to be such that threaded bolts do not carry support forces. The maximum tension in way of threads of bolts not carrying support forces is not to exceed 125/k N/mm^2, with k defined in S9.2.1a.

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S9.3 Design loads

S9.3.1 The design forces, in kN, considered for the scantlings of primary members, securing and supporting devices of side shell doors and stern doors are to be not less than:

(i) Design forces for securing or supporting devices of doors opening inwards:

. external force: $F_e = A p_e + F_p$

. internal force: $F_i = F_o + 10 W$

(ii) Design forces for securing or supporting devices of doors opening outwards:

. external force: $F_e = A p_e$

. internal force: $F_i = F_o + 10 W + F_p$

(iii) Design forces for primary members:

. external force: $F_e = A p_e$

. internal force: $F_i = F_o + 10 W$

whichever is the greater,

where:

A area, in m^2, of the door opening,

W mass of the door, in t,

F_p total packing force in kN. Packing line pressure is normally not to be taken less than 5N/mm,

F_o the greater of F_c and 5 A (kN),

F_c accidental force, in kN, due to loose of cargo etc., to be uniformly distributed over the area A and not to be taken less than 300kN. For small doors such as bunker doors and pilot doors, the value of F_c may be appropriately reduced. However, the value of F_c may be taken as zero, provided an additional structure such as an inner ramp is fitted, which is capable of protecting the door from accidental forces due to loose cargoes.

p_e external design pressure, in kN/m^2, determined at the centre of gravity of the door opening and not taken less than:

$10 (T - Z_G) + 25$ for $Z_G < T$
25 for $Z_G \geq T$

Moreover, for stern doors of ships fitted with bow doors, p_e is not to be taken less than:

$$P_e = 0.6 \lambda C_H (0.8 + 0.6 L^{0.5})^2$$

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λ coefficient depending on the area where the ship is intended to be operated:

λ = 1 for sea going ships,

λ = 0.8 for ships operated in coastal waters,

λ = 0.5 for ships operated in sheltered waters.

Note: Coastal waters and sheltered waters are defined according to the practice of each Classification Society. As an example, coastal waters may be defined as areas where significant wave heights do not exceed 4m for more than three hours a year and sheltered waters as areas where significant wave heights do not exceed 2m for more than three hours a year.

C_H = 0.0125 L for $L < 80$m
= 1 for $L \geq 80$m

L ship's length, in m, but need not be taken greater than 200 metres,

T draught, in m, at the highest subdivision load line,

Z_G height of the centre of area of the door, in m, above the baseline.

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S9.4 Scantlings of side shell doors and stern doors

S9.4.1 General

S9.4.1a The strength of side shell doors and stern doors is to be commensurate with that of the surrounding structure.

S9.4.1b Side shell doors and stern doors are to be adequately stiffened and means are to be provided to prevent any lateral or vertical movement of the doors when closed. Adequate strength is to be provided in the connections of the lifting/manoeuvring arms and hinges to the door structure and to the ship's structure.

S9.4.1c Where doors also serve as vehicle ramps, the design of the hinges should take into account the ship angle of trim and heel which may result in uneven loading on the hinges.

S9.4.1d Shell door openings are to have well-rounded corners and adequate compensation is to be arranged with web frames at sides and stringers or equivalent above and below.

S9.4.2 Plating and secondary stiffeners

S9.4.2a The thickness of the door plating is not to be less than the required thickness for the side shell plating, using the door stiffener spacing, but in no case less than the minimum required thickness of shell plating.

Where doors serve as vehicle ramps, the plating thickness is to be not less than required for vehicle decks.

S9.4.2b The section modulus of horizontal or vertical stiffeners is not to be less than that required for side framing. Consideration is to be given, where necessary, to differences in fixity between ship's frames and door stiffeners.

Where doors serve as vehicle ramps, the stiffener scantlings are not to be less than required for vehicle decks.

S9.4.3 Primary Structure

S9.4.3a The secondary stiffeners are to be supported by primary members constituting the main stiffening of the door.

S9.4.3b The primary members and the hull structure in way are to have sufficient stiffness to ensure structural integrity of the boundary of the door.

S9.4.3c Scantlings of the primary members are generally to be supported by direct strength calculations in association with the design forces given in S9.3 and permissible stresses given in S9.2.1a. Normally, formulae for simple beam theory may be applied to determine the bending stresses. Members are to be considered to have simply supported end connections.

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S9.5 Securing and Supporting of Doors

S9.5.1 General

S9.5.1a Side shell doors and stern doors are to be fitted with adequate means of securing and supporting so as to be commensurate with the strength and stiffness of the surrounding structure. The hull supporting structure in way of the doors is to be suitable for the same design loads and design stresses as the securing and supporting devices.

Where packing is required, the packing material is to be of a comparatively soft type, and the supporting forces are to be carried by the steel structure only. Other types of packing may be considered.

Maximum design clearance between securing and supporting devices is not generally to exceed 3mm.

A means is to be provided for mechanically fixing the door in the open position.

S9.5.1b Only the active supporting and securing devices having an effective stiffness in the relevant direction are to be included and considered to calculate the reaction forces acting on the devices. Small and/or flexible devices such as cleats intended to provide local compression of the packing material are not generally to be included in the calculations called for in S9.5.2b. The number of securing and supporting devices are generally to be the minimum practical whilst taking into account the requirement for redundant provision given in S9.5.2c and the available space for adequate support in the hull structure.

S9.5.2 Scantlings

S9.5.2a Securing and supporting devices are to be adequately designed so that they can withstand the reaction forces within the permissible stresses given in S9.2.1a.

S9.5.2b The distribution of the reaction forces acting on the securing devices and supporting devices may require to be supported by direct calculations taking into account the flexibility of the hull structure and the actual position of the supports.

S9.5.2c The arrangement of securing devices and supporting devices in way of these securing devices is to be designed with redundancy so that in the event of failure of any single securing or supporting device the remaining devices are capable to withstand the reaction forces without exceeding by more than 20 per cent the permissible stresses as given in S9.2.1a.

S9.5.2d All load transmitting elements in the design load path, from the door through securing and supporting devices into the ship's structure, including welded connections, are to be to the same strength standard as required for the securing and supporting devices. These elements include pins, support brackets and back-up brackets.

S9
(cont)

S9.6 Securing and Locking Arrangement

S9.6.1 Systems for operation

S9.6.1a Securing devices are to be simple to operate and easily accessible.

Securing devices are to be equipped with mechanical locking arrangement (self locking or separate arrangement), or are to be of the gravity type. The opening and closing systems as well as securing and locking devices are to be interlocked in such a way that they can only operate in the proper sequence.

S9.6.1b Doors which are located partly or totally below the freeboard deck with a clear opening area greater than $6m^2$ are to be provided with an arrangement for remote control, from a position above the freeboard deck, of:

- the closing and opening of the doors,
- associated securing and locking devices.

For doors which are required to be equipped with a remote control arrangement, indication of the open/closed position of the door and the securing and locking device is to be provided at the remote control stations. The operating panels for operation of doors are to be inaccessible to unauthorized persons. A notice plate, giving instructions to the effect that all securing devices are to be closed and locked before leaving harbour, is to be placed at each operating panel and is to be supplemented by warning indicator lights.

S9.6.1c Where hydraulic securing devices are applied, the system is to be mechanically lockable in closed position. This means that, in the event of loss of the hydraulic fluid, the securing devices remain locked.

The hydraulic system for securing and locking devices is to be isolated from other hydraulic circuits, when closed position.

S9.6.2 Systems for indication/monitoring

S9.6.2a The following requirements apply to doors in the boundary of special category spaces or ro-ro spaces, as defined in S9.1.3, through which such spaces may be flooded. For cargo ships, where no part of the door is below the uppermost waterline and the area of the door opening is not greater than $6m^2$, then the requirements of this section need not be applied.

S9.6.2b Separate indicator lights and audible alarms are to be provided on the navigation bridge and on each operating panel to indicate that the doors are closed and that their securing and locking devices are properly positioned.

The indication panel is to be provided with a lamp test function. It shall not be possible to turn off the indicator light.

S9.6.2c The indicator system is to be designed on the fail safe principle and is to show by visual alarms if the door is not fully closed and not fully locked and by audible alarms if securing devices become open or locking devices become unsecured. The power supply for the indicator system is to be independent of the power supply for operating and closing the doors and is to be provided with a backup power supply from the emergency source of power or secure power supply e.g. UPS.

Note: see 8.7.2b for fail safe principal design.

S9
(cont)

The sensors of the indicator system are to be protected from water, ice formation and mechanical damages.

S9.6.2d The indication panel on the navigation bridge is to be equipped with a mode selection function "harbour/sea voyage", so arranged that audible alarm is given on the navigation bridge if the vessel leaves harbour with any side shell or stern door not closed or with any of the securing devices not in the correct position.

S9.6.2e For passenger ships, a water leakage detection system with audible alarm and television surveillance is to be arranged to provide an indication to the navigation bridge and to the engine control room of any leakage through the doors.

For cargo ships, a water leakage detection system with audible alarm is to be arranged to provide an indication to the navigation bridge.

S9.6.2f For ro-ro passenger ships, on international voyages, the special category spaces and ro-ro spaces are to be continuously patrolled or monitored by effective means, such as television surveillance, so that any movement of vehicles in adverse weather conditions and unauthorized access by passengers thereto, can be detected whilst the ship is underway.

S9
(cont)

S9.7 Operating and Maintenance Manual

S9.7.1 An Operating and Maintenance Manual for the side shell doors and stern doors is to be provided on board and is to contain the necessary information on:

- main particulars and design drawings
  special safety precautions
  details of vessel
  equipment and design loading (for ramps)
  key plan of equipment (doors and ramps)
  manufacturer's recommended testing for equipment
  description of equipment for
    bow doors
    inner bow doors
    bow ramp/doors
    side doors
    stern doors
    central power pack
    bridge panel
    engine control room panel

- service conditions
  limiting heel and trim of ship for loading/unloading
  limiting heel and trim for door operations
  doors/ramps operating instructions
  doors/ramps emergency operating instructions

- maintenance
  schedule and extent of maintenance
  trouble shooting and acceptable clearances
  manufacturer's maintenance procedures

- register of inspections, including inspection of locking, securing and supporting devices, repairs and renewals.

This Manual is to be submitted for approval that the above mentioned items are contained in the OMM and that the maintenance part includes the necessary information with regard to inspections, troubleshooting and acceptance / rejection criteria.

Note: It is recommended that recorded inspections of the door supporting and securing devices be carried out by the ship's staff at monthly intervals or following incidents that could result in damage, including heavy weather or contact in the region of side shell and stern doors. Any damage recorded during such inspections is to be reported to the Classification Society.

S9.7.2 Documented operating procedures for closing and securing side shell and stern doors are to be kept on board and posted at the appropriate places.

S9
(cont)

Explanatory Note

The external pressure applied on stern doors is derived from the formula considered in UR S8 for bow doors, assuming:

α = 0 degree
β = 90 degrees
V = 2 knots

End of Document

S10 Rudders, Sole Pieces and Rudder Horns

(1986)
(Rev.1 1990)
(Corr.1 July 1999)
(Corr.2 July 2003)
(Rev.2 May 2010)
(Rev.3 Mar 2012)
(Corr.1 May 2015)
(Rev.4 Apr 2015)
(Corr.1 Dec 2015)
(Rev.5 May 2018)

S10.1 General

1.1 Basic assumptions

1.1.1 This UR applies to ordinary profile rudders, and to some enhanced profile rudders with special arrangements for increasing the rudder force.

1.1.2 This UR applies to rudders made of steel.

1.2 Design considerations

1.2.1 Effective means are to be provided for supporting the weight of the rudder without excessive bearing pressure, e.g. by a rudder carrier attached to the upper part of the rudder stock. The hull structure in way of the rudder carrier is to be suitably strengthened.

1.2.2 Suitable arrangements are to be provided to prevent the rudder from lifting.

1.2.3 In rudder trunks which are open to the sea, a seal or stuffing box is to be fitted above the deepest load waterline, to prevent water from entering the steering gear compartment and the lubricant from being washed away from the rudder carrier. If the top of the rudder trunk is below the deepest waterline, two separate stuffing boxes are to be provided.

1.3 Materials

1.3.1 Welded parts of rudders are to be made of approved rolled hull materials.

1.3.2 Material factor k for normal and high tensile steel plating may be taken into account when specified in each individual rule requirement. The material factor k is to be taken as defined in UR S4, unless otherwise specified.

1.3.3 Steel grade of plating materials for rudders and rudder horns are to be in accordance with UR S6.

1.3.4 Rudder stocks, pintles, coupling bolts, keys and cast parts of rudders are to be made of rolled, forged or cast carbon manganese steel in accordance with UR W7, W8 and W11.

Note:

1. Changes introduced in Rev.3 are to be uniformly implemented by IACS Members for ships contracted for construction on or after 1 January 2013.

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

3. Changes introduced in Rev.4 are to be uniformly implemented by IACS Members for ships contracted for construction on or after 1 July 2016.

4. Changes introduced in Rev.5 are to be uniformly implemented by IACS Members for ships contracted for construction on or after 1 July 2019.

S10 (cont)

1.3.5 For rudder stocks, pintles, keys and bolts the minimum yield stress is not to be less than 200 N/mm^2. The requirements of this UR are based on a material's yield stress of 235 N/mm^2. If material is used having a yield stress differing from 235 N/mm^2 the material factor *k* is to be determined as follows:

$$k = \left(\frac{235}{\sigma_F}\right)^e$$

with

e = 0.75 for σ_F > 235 N/mm^2

e = 1.00 for σ_F ≤ 235 N/mm^2

σ_F = yield stress (N/mm^2) of material used, and is not to be taken greater than 0.7σ_T or 450 N/mm^2, whichever is the smaller value

σ_T = tensile strength (N/mm^2) of material used

1.4 Welding and design details

1.4.1 Slot-welding is to be limited as far as possible. Slot welding is not to be used in areas with large in-plane stresses transversely to the slots or in way of cut-out areas of semi-spade rudders.

When slot welding is applied, the length of slots is to be minimum 75 mm with breadth of 2 t, where t is the rudder plate thickness, in mm. The distance between ends of slots is not to be more than 125 mm. The slots are to be fillet welded around the edges and filled with a suitable compound, e.g. epoxy putty. Slots are not to be filled with weld.

Continuous slot welds are to be used in lieu of slot welds. When continuous slot welding is applied, the root gap is to be between 6-10 mm. The bevel angle is to be at least 15°.

1.4.2 In way of the rudder horn recess of semi-spade rudders, the radii in the rudder plating are not to be less than 5 times the plate thickness, but in no case less than 100 mm. Welding in side plate is to be avoided in or at the end of the radii. Edges of side plate and weld adjacent to radii are to be ground smooth.

1.4.3 Welds between plates and heavy pieces (solid parts in forged or cast steel or very thick plating) are to be made as full penetration welds. In way of highly stressed areas e.g. cut-out of semi-spade rudder and upper part of spade rudder, cast or welding on ribs is to be arranged. Two sided full penetration welding is normally to be arranged. Where back welding is impossible welding is to be performed against ceramic backing bars or equivalent. Steel backing bars may be used and are to be continuously welded on one side to the heavy piece.

1.4.4 Requirements for welding and design details of rudder trunks are described in S10.9.3.

1.4.5 Requirements for welding and design details when the rudder stock is connected to the rudder by horizontal flange coupling are described in S10.6.1.4.

1.4.6 Requirements for welding and design details of rudder horns are described in S10.9.2.3.

S10 (cont)

1.5 Equivalence

1.5.1 The Society may accept alternatives to requirements given in this UR, provided they are deemed to be equivalent.

1.5.2 Direct analyses adopted to justify an alternative design are to take into consideration all relevant modes of failure, on a case by case basis. These failure modes may include, amongst others: yielding, fatigue, buckling and fracture. Possible damages caused by cavitation are also to be considered.

1.5.3 If deemed necessary by the Society, lab tests, or full scale tests may be requested to validate the alternative design approach.

S10.2 Rudder force and rudder torque

2.1 Rudder blades without cut-outs

2.1.1 The rudder force upon which the rudder scantlings are to be based is to be determined from the following formula:

$$C_R = K_1 \cdot K_2 \cdot K_3 \cdot 132 \cdot A \cdot V^2 \quad [N]$$

Where:

C_R = rudder force [N];

A = area of rudder blade [m^2];

V = maximum service speed (knots) with the ship on summer load waterline. When the speed is less than 10 knots, V is to be replaced by the expression:

$V_{min} = (V + 20) / 3$

For the astern condition the maximum astern speed is to be used, however, in no case less than:

$V_{astern} = 0.5 V$

K_1 = factor depending on the aspect ratio λ of the rudder area;

K_1 = (λ + 2) / 3, with λ not to be taken greater than 2;

λ = b^2 / A_t;

b = mean height of the rudder area [m]. Mean breadth and mean height of rudder are calculated according to the coordinate system in Fig. 1;

A_t = sum of rudder blade area A and area of rudder post or rudder horn, if any, within the height b [m^2];

K_2 = coefficient depending on the type of the rudder and the rudder profile according to Table 1;

K_3 = 0.8 for rudders outside the propeller jet;
= 1.15 for rudders behind a fixed propeller nozzle;
= 1.0 otherwise;

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(cont)

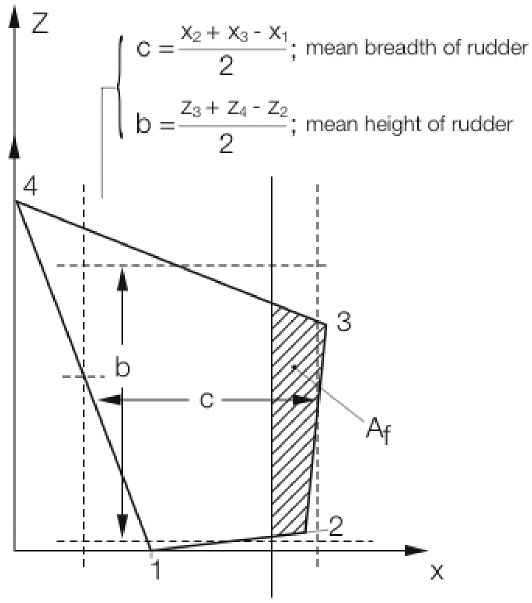
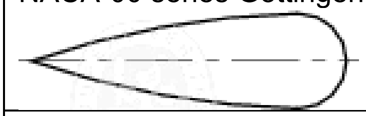
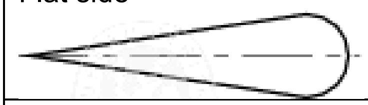
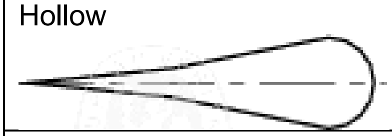
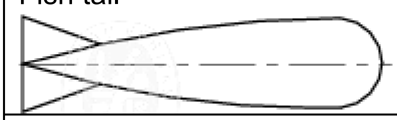
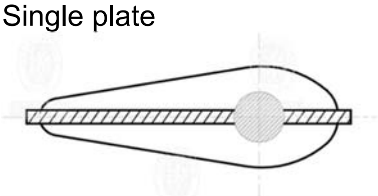


Figure 1

Table 1

Profile Type	**K_2**	
	Ahead condition	**Astern condition**
NACA-00 series Göttingen 	1.10	0.80
Flat side 	1.10	0.90
Hollow 	1.35	0.90
High lift rudders 	1.70	to be specially considered; if not known: 1.30
Fish tail 	1.40	0.80
Single plate 	1.00	1.00
Mixed profiles (e.g. HSVA)	1.21	0.90

S10 (cont)

2.1.2 The rudder torque is to be calculated for both the ahead and astern condition according to the formula:

$Q_R = C_R\, r$ [Nm]

$r = c\,(\alpha - k_1)$ [m]

c = mean breadth of rudder area [m], see Fig. 1

α = 0.33 for ahead condition

α = 0.66 for astern condition

$k_1 = A_f / A$

A_f = portion of the rudder blade area situated ahead of the centre line of the rudder stock

$r_{min} = 0.1c$ [m] for ahead condition

2.2 Rudder blades with cut-outs (semi-spade rudders)

The total rudder force C_R is to be calculated according to S10.2.1.1. The pressure distribution over the rudder area, upon which the determination of rudder torque and rudder blade strength is to be based, is to be derived as follows:

The rudder area may be divided into two rectangular or trapezoidal parts with areas A_1 and A_2, so that $A = A_1 + A_2$ (see Figure 2).

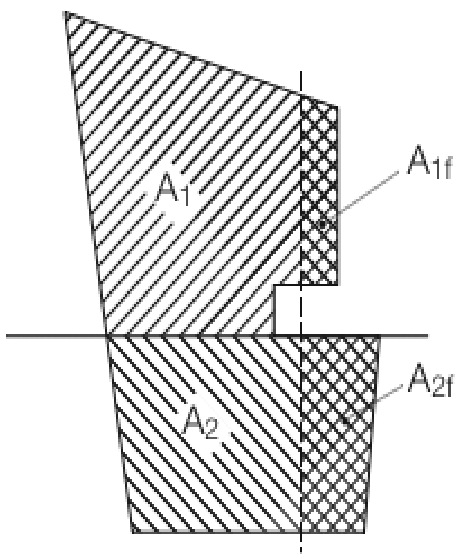


Figure 2

S10 (cont)

The levers r_1 and r_2 are to be determined as follows:

r_1 = $c_1 (\alpha - k_1)$ [m]

r_2 = $c_2 (\alpha - k_2)$ [m]

c_1, c_2 = mean breadth of partial areas A_1, A_2 determined, where applicable, in accordance with Figure 1

k_1 = A_{1f} / A_1,

k_2 = A_{2f} / A_2,

A_{1f} = portion of A_1 situated ahead of the centre line of the rudder stock

A_{2f} = portion of A_2 situated ahead of the centre line of the rudder stock

α = 0.33 for ahead condition

α = 0.66 for astern condition

For parts of a rudder behind a fixed structure such as the rudder horn:

α = 0.25 for ahead condition

α = 0.55 for astern condition

The resulting force of each part may be taken as:

C_{R1} = $C_R \frac{A_1}{A}$ [N]

C_{R2} = $C_R \frac{A_2}{A}$ [N]

The resulting torque of each part may be taken as:

Q_{R1} = $C_{R1} r_1$ [Nm]

Q_{R2} = $C_{R2} r_2$ [Nm]

The total rudder torque is to be calculated for both the ahead and astern condition according to the formula:

Q_R = $Q_{R1} + Q_{R2}$ [Nm]

For ahead condition Q_R is not to be taken less than:

$$Q_{R\min} = 0.1 C_R \frac{A_1 c_1 + A_2 c_2}{A}$$

S10
(cont)

S10.3 Rudder strength calculation

3.1 The rudder force and resulting rudder torque as given in S10.2 causes bending moments and shear forces in the rudder body, bending moments and torques in the rudder stock, supporting forces in pintle bearings and rudder stock bearings and bending moments, shear forces and torques in rudder horns and heel pieces. The rudder body is to be stiffened by horizontal and vertical webs enabling it to act as a bending girder.

3.2 The bending moments, shear forces and torques as well as the reaction forces are to be determined by a direct calculation or by an approximate simplified method considered appropriate by each individual society. For rudders supported by sole pieces or rudder horns these structures are to be included in the calculation model in order to account for the elastic support of the rudder body. Guidelines for calculation of bending moment and shear force distribution are given in an annex to this UR.

S10.4 Rudder stock scantlings

4.1 The rudder stock diameter required for the transmission of the rudder torque is to be dimensioned such that the torsional stress is not exceeding the following value:

τ_T = 68 / k [N/mm^2]

The rudder stock diameter for the transmission of the rudder torque is therefore not to be less than:

$$d_t = 4.2\sqrt[3]{Q_R k} \quad \text{[mm]}$$

Q_R = total rudder torque [Nm] as calculated in S10.2.1.2 and/or S10.2.2.
k = material factor for the rudder stock as given in S10.1.3.5

4.2 Rudder stock scantlings due to combined loads

If the rudder stock is subjected to combined torque and bending, the equivalent stress in the rudder stock is not to exceed 118 / k N/mm^2.

k = material factor for the rudder stock as given in S10.1.3.5

The equivalent stress is to be determined by the formula:

$$\sigma_c = \sqrt{\sigma_b^2 + 3\tau_t^2} \quad \text{[N/mm}^2\text{]}$$

Bending stress: $\sigma_b = 10.2 \times 10^3\, M / d_c^3$ [N/mm^2]

Torsional stress: $\tau_t = 5.1 \times 10^3\, Q_R / d_c^3$ [N/mm^2]

The rudder stock diameter is therefore not to be less than:

$$d_c = d_t \sqrt[6]{1 + 4/3\left[M/Q_R\right]^2} \quad \text{[mm]}$$

M = bending moment [Nm] at the station of the rudder stock considered

S10
(cont)

4.3 Before significant reductions in rudder stock diameter due to the application of steels with yield stresses exceeding 235 N/mm^2 are granted, the Society may require the evaluation of the rudder stock deformations. Large deformations of the rudder stock are to be avoided in order to avoid excessive edge pressures in way of bearings.

S10.5 Rudder blade

5.1 Permissible stresses

The section modulus and the web area of a horizontal section of the rudder blade are to be such that the following stresses will not be exceeded:

a) In general, except in way of rudder recess sections where b) applies

(i) bending stress σ_b	110/k N/mm^2
(ii) shear stress τ	50/k N/mm^2
(iii) equivalent stress $\sigma_e = \sqrt{\sigma_b^2 + 3\tau^2}$	120/k N/mm^2

k = material factor for the rudder plating as given in S10.1.3.2

b) In way of the recess for the rudder horn pintle on semi-spade rudders

(i) bending stress σ_b	75 N/mm^2
(ii) shear stress τ	50 N/mm^2
(iii) equivalent stress $\sigma_e = \sqrt{\sigma_b^2 + 3\tau^2}$	100 N/mm^2

Note: The stresses in b) apply equally to high tensile and ordinary steels.

5.2 Rudder plating

The thickness of the rudder side, top and bottom plating is not to be less than:

$$t = 5.5 s\beta\sqrt{k}\sqrt{d + C_R 10^{-4}/A} + 2.5 \quad \text{[mm]}$$

d = summer loadline draught [m];

C_R = rudder force [N] according to S10.2.1.1;

A = rudder area [m^2];

$\beta = \sqrt{1.1 - 0.5[s/b]^2}$; max. 1.00 if b/s ≥ 2.5

s = smallest unsupported width of plating in [m];

b = greatest unsupported width of plating in [m].

k = material factor for the rudder plating as given in S10.1.3.2

The thickness of the nose plates may be increased to the discretion of each Society. The thickness of web plates is not to be less than the greater of 70% of the rudder side plating thickness and 8 mm.

S10
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The rudder plating in way of the solid part is to be of increased thickness per S10.5.3.4.

5.3 Connections of rudder blade structure with solid parts

5.3.1 Solid parts in forged or cast steel, which house the rudder stock or the pintle, are to be provided with protrusions, except where not required as indicated below.

These protrusions are not required when the web plate thickness is less than:

- 10 mm for web plates welded to the solid part on which the lower pintle of a semi-spade rudder is housed and for vertical web plates welded to the solid part of the rudder stock coupling of spade rudders.

- 20 mm for other web plates.

5.3.2 The solid parts are in general to be connected to the rudder structure by means of two horizontal web plates and two vertical web plates.

5.3.3 Minimum section modulus of the connection with the rudder stock housing.

The section modulus of the cross-section of the structure of the rudder blade, in cm^3, formed by vertical web plates and rudder plating, which is connected with the solid part where the rudder stock is housed is to be not less than:

$$W_s = c_s d_c^{\,3} \left(\frac{H_E - H_x}{H_E} \right)^2 \frac{k}{k_s} 10^{-4} \ [cm^3]$$

where:

c_s = coefficient, to be taken equal to:

= 1.0 if there is no opening in the rudder plating or if such openings are closed by a full penetration welded plate

= 1.5 if there is an opening in the considered cross-section of the rudder

d_c = rudder stock diameter, in [mm]

H_E = vertical distance between the lower edge of the rudder blade and the upper edge of the solid part, in [m]

H_X = vertical distance between the considered cross-section and the upper edge of the solid part, in [m]

k = material factor for the rudder blade plating as given in S10.1.3.2.

k_s = material factor for the rudder stock as given in S10.1.3.5.

The actual section modulus of the cross-section of the structure of the rudder blade is to be calculated with respect to the symmetrical axis of the rudder.

S10
(cont)

The breadth of the rudder plating, in m, to be considered for the calculation of section modulus is to be not greater than:

$b = s_V + 2 H_x / 3$ [m]

where:

s_V = spacing between the two vertical webs, in [m] (see Figure 3)

Where openings for access to the rudder stock nut are not closed by a full penetration welded plate, they are to be deducted.

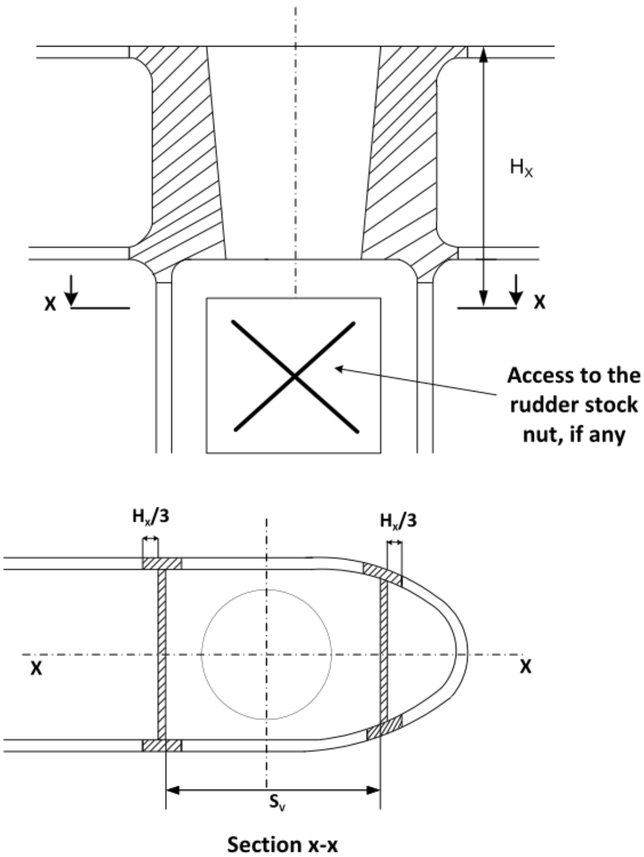

Figure 3 Cross-section of the connection between rudder blade structure and rudder stock housing

5.3.4 The thickness of the horizontal web plates connected to the solid parts, in mm, as well as that of the rudder blade plating between these webs, is to be not less than the greater of the following values:

$t_H = 1.2\ t$ [mm]

$t_H = 0.045\ d_s^2 / s_H$ [mm]

where:

t = defined in S10.5.2

S10 (cont)

d_S = diameter, in [mm], to be taken equal to:

= d_c, as per S10.4.2, for the solid part housing the rudder stock

= d_p, as per S10.7.1, for the solid part housing the pintle

s_H = spacing between the two horizontal web plates, in [mm]

The increased thickness of the horizontal webs is to extend fore and aft of the solid part at least to the next vertical web.

5.3.5 The thickness of the vertical web plates welded to the solid part where the rudder stock is housed as well as the thickness of the rudder side plating under this solid part is to be not less than the values obtained, in mm, from Table 2.

Table 2 Thickness of side plating and vertical web plates

Type of rudder	Thickness of vertical web plates, in mm		Thickness of rudder plating, in mm	
	Rudder blade without opening	Rudder blade with opening	Rudder blade without opening	Area with opening
Rudder supported by sole piece	1.2 t	1.6 t	1.2 t	1.4 t
Semi-spade and spade rudders	1.4 t	2.0 t	1.3 t	1.6 t
t = thickness of the rudder plating, in mm, as defined in S10.5.2				

The increased thickness is to extend below the solid piece at least to the next horizontal web.

5.4 Single plate rudders

5.4.1 Mainpiece diameter

The mainpiece diameter is calculated according to S10.4.1 and S10.4.2 respectively. For spade rudders the lower third may taper down to 0.75 times stock diameter.

5.4.2 Blade thickness

The blade thickness is not to be less than:

$$t_b = 1.5 s V \sqrt{k} + 2.5 \qquad \text{[mm]}$$

where:

s = spacing of stiffening arms in [m], not to exceed 1 m;

V = speed in knots, see S10.2.1.1.

k = material factor for the rudder plating as given in S10.1.3.2

S10
(cont)

5.4.3 Arms

The thickness of the arms is not to be less than the blade thickness

$t_a = t_b$ [mm]

The section modulus is not to be less than:

$Z_a = 0.5\ s\ C_1^2\ V^2\ k$ [cm^3];

C_1 = horizontal distance from the aft edge of the rudder to the centreline of the rudder stock, in m

k = material factor as given in S10.1.3.2 or S10.1.3.5 respectively

S10.6 Rudder stock couplings

6.1 Horizontal flange couplings

6.1.1 The diameter of the coupling bolts is not to be less than:

$$d_b = 0.62\sqrt{d^3\, k_b / n\, e_m k_s} \quad \text{[mm]}$$

d = stock diameter, taken equal to the greater of the diameters d_t or d_c according to S10.4.1 and S10.4.2 [mm];

n = total number of bolts, which is not to be less than 6;

e_m = mean distance [mm] of the bolt axes from the centre of the bolt system;

k_s = material factor for the stock as given in S10.1.3.5;

k_b = material factor for the bolts as given in S10.1.3.5.

6.1.2 The thickness of the coupling flanges, in mm, is not to be less than the greater of the following formulae:

$$t_f = d_b\sqrt{k_f / k_b}$$

$$t_f = 0.9 d_b$$

k_f = material factor for flange as given in S10.1.3.5;

k_b = material factor for the bolts as given in S10.1.3.5;

d_b = bolt diameter, in mm, calculated for a number of bolts not exceeding 8.

6.1.3 The width of material between the perimeter of the bolt holes and the perimeter of the flange is not to be less than 0.67 d_b.

6.1.4 The welded joint between the rudder stock and the flange is to be made in accordance with Figure 4 or equivalent.

S10
(cont)

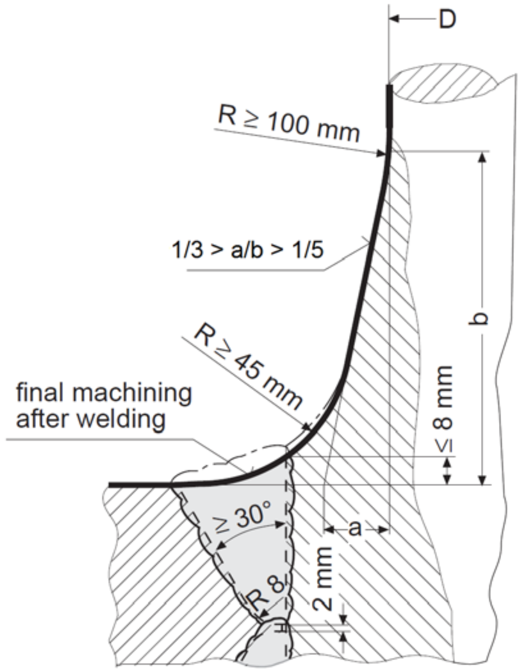

Figure 4 Welded joint between rudder stock and coupling flange

6.1.5 Coupling bolts are to be fitted bolts and their nuts are to be locked effectively.

6.2 Vertical flange couplings

6.2.1 The diameter of the coupling bolts, in mm, is not to be less than:

$$d_b = 0.81 d / \sqrt{n} \times \sqrt{k_b / k_s}$$

where:

d = stock diameter [mm] in way of coupling flange;

n = total number of bolts, which is not to be less than 8;

k_b = material factor for bolts as given in S10.1.3.5

k_s = material factor for stock as given in S10.1.3.5

6.2.2 The first moment of area of the bolts about the centre of the coupling, m, is to be not less than:

m = $0.00043\, d^3$ [cm^3]

6.2.3 The thickness of the coupling flanges is to be not less than the bolt diameter, and the width of the flange material between the perimeter of the bolt holes and the perimeter of the flange is to be not less than 0.67 d_b.

6.2.4 Coupling bolts are to be fitted bolts and their nuts are to be locked effectively.

S10
(cont)

6.3 Cone couplings with key

6.3.1 Tapering and coupling length

Cone couplings without hydraulic arrangements for mounting and dismounting the coupling should have a taper c on diameter of 1:8 - 1:12,

where:

$c = (d_0 - d_u) / \ell$ (see Figure 5)

The cone coupling is to be secured by a slugging nut. The nut is to be secured, e.g. by a securing plate.

The cone shapes are to fit exactly. The coupling length ℓ is to be, in general, not less than $1.5d_0$.

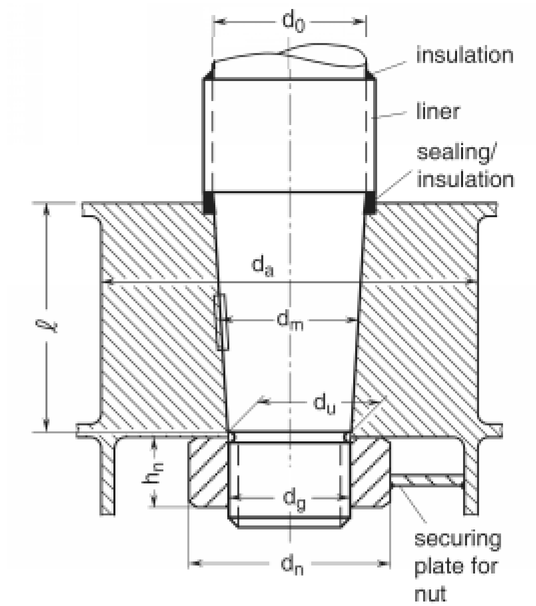

Figure 5 Cone coupling with key

6.3.2 Dimensions of key

For couplings between stock and rudder a key is to be provided, the shear area of which, in cm^2, is not to be less than:

$$a_s = \frac{17.55 Q_F}{d_k \sigma_{F1}}$$

where:

Q_F = design yield moment of rudder stock, in Nm

S10
(cont)

$$Q_F = 0.02664 \frac{d_t^{\,3}}{k}$$

Where the actual diameter d_{ta} is greater than the calculated diameter d_t, the diameter d_{ta} is to be used. However, d_{ta} applied to the above formula need not be taken greater than 1.145 d_t.

d_t = stock diameter, in mm, according to S10.4.1.

k = material factor for stock as given in S10.1.3.5

d_k = mean diameter of the conical part of the rudder stock, in mm, at the key

σ_{F1} = minimum yield stress of the key material, in N/mm^2

The effective surface area, in cm^2, of the key (without rounded edges) between key and rudder stock or cone coupling is not to be less than:

$$a_k = \frac{5Q_F}{d_k \sigma_{F2}}$$

where:

σ_{F2} = minimum yield stress of the key, stock or coupling material, in N/mm^2, whichever is less.

6.3.3 The dimensions of the slugging nut are to be as follows (see Figure 5):

external thread diameter: $d_g \geq 0.65\ d_o$

height: $h_n \geq 0.6\ d_g$

outer diameter: $d_n \geq 1.2\ d_u$, or 1.5 d_g

whichever is the greater.

6.3.4 Push up

It is to be proved that 50% of the design yield moment is solely transmitted by friction in the cone couplings. This can be done by calculating the required push-up pressure and push-up length according to S10.6.4.2 and S10.6.4.3 for a torsional moment $Q'_F = 0.5Q_F$.

6.3.5 Notwithstanding the requirements in S10.6.3.2 and S10.6.3.4, where a key is fitted to the coupling between stock and rudder and it is considered that the entire rudder torque is transmitted by the key at the couplings, the scantlings of the key as well as the push-up force and push-up length are to be at the discretion of the Society.

S10
(cont)

6.4 Cone couplings with special arrangements for mounting and dismounting the couplings

6.4.1 Where the stock diameter exceeds 200 mm, the press fit is recommended to be effected by a hydraulic pressure connection. In such cases the cone is to be more slender, c ≈1:12 to ≈1:20.

In case of hydraulic pressure connections the nut is to be effectively secured against the rudder stock or the pintle.

For the safe transmission of the torsional moment by the coupling between rudder stock and rudder body the push-up pressure and the push-up length are to be determined according to S10.6.4.2 and S10.6.4.3 respectively.

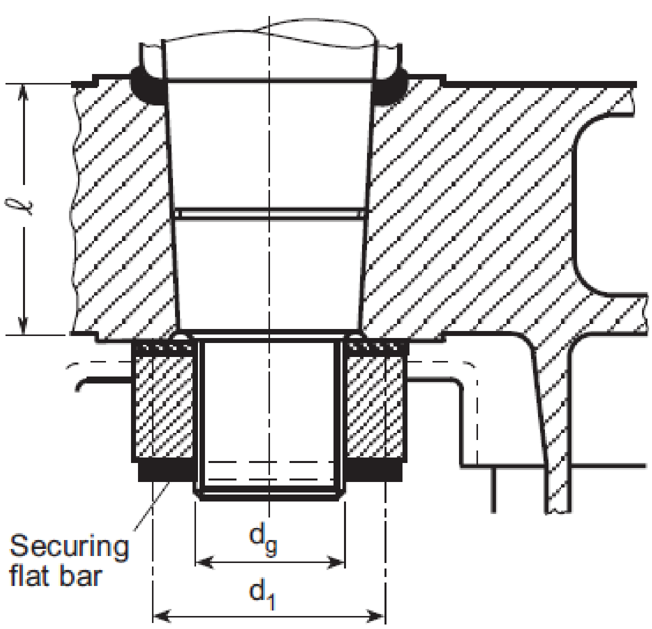

Figure 6 Cone coupling without key

6.4.2 Push-up pressure

The push-up pressure is not to be less than the greater of the two following values:

$$p_{req1} = \frac{2Q_F}{d_m^2 \ell \pi \mu_0} 10^3 \quad [\text{N/mm}^2]$$

$$p_{req2} = \frac{6M_b}{\ell^2 d_m} 10^3 \quad [\text{N/mm}^2]$$

where:

Q_F = design yield moment of rudder stock, as defined in S10.6.3.2, in [Nm]

d_m = mean cone diameter in [mm], see Figure 5

ℓ = cone length in [mm]

S10
(cont)

μ_0 = frictional coefficient, equal to 0.15

M_b = bending moment in the cone coupling (e.g. in case of spade rudders), in [Nm]

It has to be proved by the designer that the push-up pressure does not exceed the permissible surface pressure in the cone. The permissible surface pressure, in N/mm², is to be determined by the following formula:

$$p_{perm} = \frac{0.95 R_{eH}(1-\alpha^2)}{\sqrt{3+\alpha^4}} - p_b \quad \text{[N/mm}^2\text{]}$$

where:

$$p_b = \frac{3.5 M_b}{d_m l^2} 10^3$$

R_{eH} = minimum yield stress of the material of the gudgeon in [N/mm^2]

α = d_m / d_a

d_m = diameter, in [mm], see Figure 5

d_a = outer diameter of the gudgeon, in [mm], see Figure 5

The outer diameter of the gudgeon in mm shall not be less than 1.25 d_0, with d_0 defined in Figure 5.

6.4.3 Push-up length

The push-up length $\Delta\ell$, in mm, $\Delta\ell$ is to comply with the following formula:

$$\Delta\ell_1 \le \Delta\ell \le \Delta\ell_2$$

where:

$$\Delta\ell_1 = \frac{p_{req} d_m}{E\left(\frac{1-\alpha^2}{2}\right)c} + \frac{0.8 R_{tm}}{c} \quad \text{[mm]}$$

$$\Delta\ell_2 = \frac{p_{perm} d_m}{E\left(\frac{1-\alpha^2}{2}\right)c} + \frac{0.8 R_{tm}}{c} \quad \text{[mm]}$$

R_{tm} = mean roughness, in [mm] taken equal to 0.01

c = taper on diameter defined in S10.6.3.1

S10 (cont)

Note: In case of hydraulic pressure connections the required push-up force P_e, in [N], for the cone may be determined by the following formula:

$$P_e = p_{req} d_m \pi \ell \left(\frac{c}{2} + 0.02 \right)$$

The value 0.02 is a reference for the friction coefficient using oil pressure. It varies and depends on the mechanical treatment and roughness of the details to be fixed. Where due to the fitting procedure a partial push-up effect caused by the rudder weight is given, this may be taken into account when fixing the required push-up length, subject to approval by the Society.

S10.7 Pintles

7.1 Scantlings

The pintle diameter, in mm, is not to be less than:

$$d_p = 0.35\sqrt{Bk_p}$$

where:

B = relevant bearing force, in N

k_p = material factor for pintle as given in S10.1.3.5

7.2 Couplings

7.2.1 Tapering

Pintles are to have a conical attachment to the gudgeons with a taper on diameter not greater than:

1:8 - 1:12 for keyed and other manually assembled pintles applying locking by slugging nut,

1:12 - 1:20 on diameter for pintles mounted with oil injection and hydraulic nut.

7.2.2 Push-up pressure for pintle

The required push-up pressure for pintle, in N/mm², is to be determined by the following formula:

$$p_{req} = 0.4 \frac{B_1 d_0}{d_m^2 \ell} \quad \text{[N/mm}^2\text{]}$$

where:

B_1 = Supporting force in the pintle, in [N]

d_0 = Pintle diameter, in [mm], see Figure 5

The push-up length is to be calculated similarly as in S10.6.4.3, using required push-up pressure and properties for the pintle.

S10
(cont)

7.3 The minimum dimensions of threads and nuts are to be determined according to S10.6.3.3.

7.4 Pintle housing

The length of the pintle housing in the gudgeon is not to be less than the pintle diameter d_p. d_p is to be measured on the outside of liners.

The thickness of the pintle housing is not to be less than 0.25 d_p.

S10.8 Rudder stock bearing, rudder shaft bearing and pintle bearing

8.1 Liners and bushes

8.1.1 Rudder stock bearing

Liners and bushes are to be fitted in way of bearings. The minimum thickness of liners and bushes is to be equal to:

- t_{min} = 8 mm for metallic materials and synthetic material
- t_{min} = 22 mm for lignum material

8.1.2 Pintle bearing

The thickness of any liner or bush, in mm, is neither to be less than:

$$t = 0.01\sqrt{B}$$

where:

B = relevant bearing force, in [N]

nor than the minimum thickness defined in S10.8.1.1.

8.2 Minimum bearing surface

An adequate lubrication is to be provided.

The bearing surface A_b (defined as the projected area: length x outer diameter of liner) is not to be less than:

A_b = P / q_a [mm^2]

where:

P = reaction force [N] in bearing as determined in S10.3.2;

q_a = allowable surface pressure according to the table below.

The maximum surface pressure q_a for the various combinations is to be taken as reported in Table 3. Higher values than given in the table may be taken in accordance with makers' specifications if they are verified by tests:

S10 (cont)

Table 3 Maximum surface pressure q_a

Bearing material	q_a [N/mm²]
lignum vitae	2.5
white metal, oil lubricated	4.5
synthetic material with hardness between 60 and 70 Shore D[1)]	5.5[2)]
steel[3)] and bronze and hot-pressed bronze-graphite materials	7.0

Notes:

1) Indentation hardness test at 23°C and with 50% moisture, are to be carried out according to a recognized standard. Synthetic bearing materials are to be of an approved type.

2) Surface pressures exceeding 5.5 N/mm² may be accepted in accordance with bearing manufacturer's specification and tests, but in no case more than 10 N/mm².

3) Stainless and wear-resistant steel in an approved combination with stock liner.

8.3 Bearing Dimensions

The length/diameter ratio of the bearing surface is not to be greater than 1.2.

The bearing length L_p of the pintle is to be such that

$$D_p \le L_p \le 1.2\, D_p$$

where:

D_p = Actual pintle diameter measured on the outside of liners.

8.4 Bearing clearances

With metal bearings, clearances should not be less than d_b / 1000 + 1.0 [mm] on the diameter. If non-metallic bearing material is applied, the bearing clearance is to be specially determined considering the material’s swelling and thermal expansion properties. This clearance is not to be taken less than 1.5 mm on bearing diameter unless a smaller clearance is supported by the manufacturer’s recommendation and there is documented evidence of satisfactory service history with a reduced clearance.

S10
(cont)

S10.9 Strength of sole pieces and of rudder horns

9.1 Sole piece

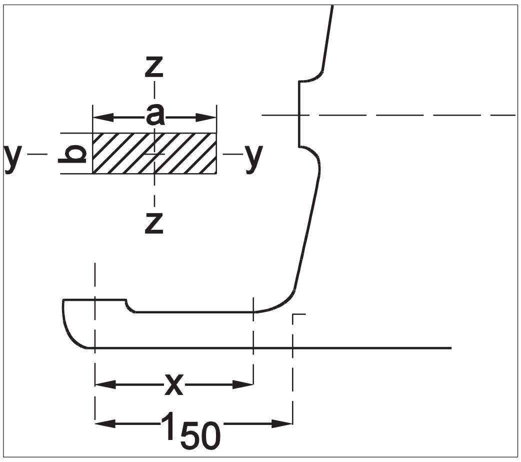

Figure 7 Sole piece

The section modulus around the vertical (z)-axis is not to be less than:

Z_z = M_b k / 80 [cm³]

The section modulus around the transverse (y)-axis is not to be less than:

Z_y = 0.5 Z_z

The sectional area is not to be less than:

A_s = B_1 k / 48 [mm²]

k = material factor as given in S10.1.3.2 or S10.1.3.5 respectively.

9.1.1 Equivalent stress

At no section within the length ℓ_{50} is the equivalent stress to exceed 115 / k N/mm². The equivalent stress is to be determined by the following formula:

$$\sigma_e = \sqrt{\sigma_b^2 + 3\tau^2} \quad [N/mm^2];$$

where:

σ_b = M_b / $Z_z(x)$ [N/mm²];

τ = B_1 / A_s [N/mm²];

M_b = bending moment at the section considered [Nm];

M_b = B_1 x [Nm];

S10
(cont)

$M_{bmax} = B_1 \ell_{50}$ [Nm];

B_1 = supporting force in the pintle bearing [N] (normally $B_1 = C_R / 2$).

k = material factor as given in S10.1.3.2 or S10.1.3.5 respectively.

9.2 Rudder horn

When the connection between the rudder horn and the hull structure is designed as a curved transition into the hull plating, special consideration is to be given to the effectiveness of the rudder horn plate in bending and to the stresses in the transverse web plates.

The bending moments and shear forces are to be determined by a direct calculation or in line with the guidelines given in Annex S10.5 and Annex S10.6 for semi spade rudder with one elastic support and semi spade rudder with 2-conjugate elastic support respectively.

The section modulus around the horizontal x-axis is not to be less than:

$Z_x = M_b k / 67$ [cm³].

M_b = bending moment at the section considered [Nm];

The shear stress is not to be larger than:

$\tau = 48 / k$ [N/mm²].

k = material factor as given in S10.1.3.2 or S10.1.3.5 respectively.

9.2.1 Equivalent stress

At no section within the height of the rudder horn is the equivalent stress to exceed 120 / k N/mm². The equivalent stress is to be calculated by the following formula:

$$\sigma_e = \sqrt{\sigma_b^2 + 3\left(\tau^2 + \tau_T^2\right)} \quad [\text{N/mm}^2];$$

$\sigma_b = M_b / Z_x$ [N/mm²];

$\tau = B_1 / A_h$ [N/mm²];

B_1 = supporting force in the pintle bearing [N];

A_h = effective shear area of rudder horn in y-direction [mm²];

$\tau_T = M_T 10^3 / 2 A_T t_h$ [N/mm²];

M_T = torsional moment [Nm];

A_T = area in the horizontal section enclosed by the rudder horn [mm²];

t_h = plate thickness of rudder horn [mm];

k = material factor as given in S10.1.3.2 or S10.1.3.5 respectively.

S10
(cont)

9.2.2 Rudder horn plating

The thickness of the rudder horn side plating is not to be less than:

$$t = 2.4\sqrt{Lk} \quad \text{[mm]}$$

where:

L = Rule length as defined in UR S2;

k = material factor as given in S10.1.3.2 or S10.1.3.5 respectively.

9.2.3 Welding and connection to hull structure

The rudder horn plating is to be effectively connected to the aft ship structure, e.g. by connecting the plating to side shell and transverse/ longitudinal girders, in order to achieve a proper transmission of forces, see Figure 8.

Brackets or stringer are to be fitted internally in horn, in line with outside shell plate, as shown in Figure 8.

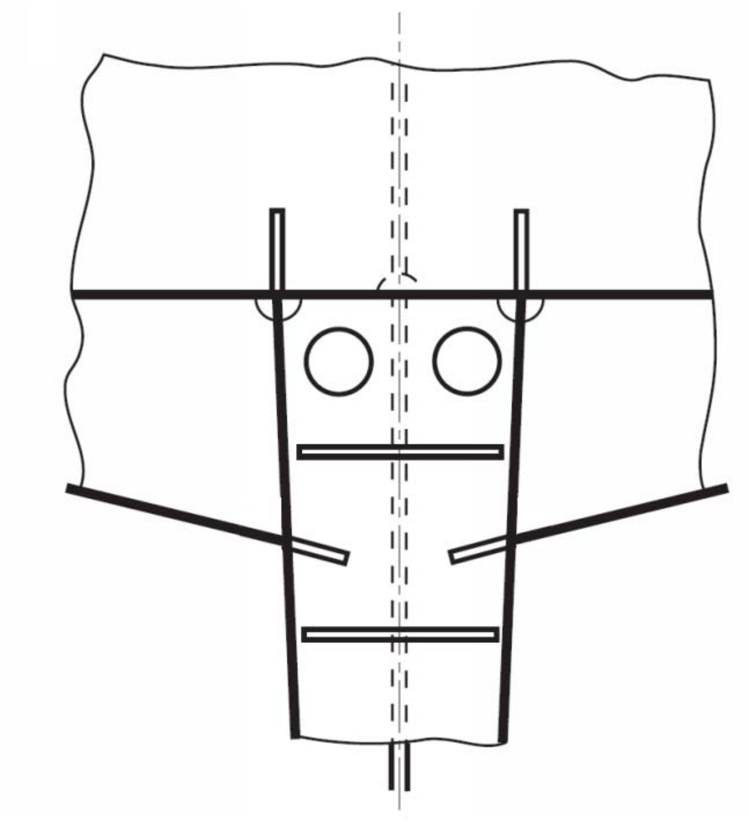

Figure 8 Connection of rudder horn to aft ship structure

Transverse webs of the rudder horn are to be led into the hull up to the next deck in a sufficient number.

Strengthened plate floors are to be fitted in line with the transverse webs in order to achieve a sufficient connection with the hull.

S10
(cont)

The centre line bulkhead (wash-bulkhead) in the after peak is to be connected to the rudder horn.

Scallops are to be avoided in way of the connection between transverse webs and shell plating.

The weld at the connection between the rudder horn plating and the side shell is to be full penetration. The welding radius is to be as large as practicable and may be obtained by grinding.

9.3 Rudder trunk

9.3.1 Materials, welding and connection to hull

This requirement applies to both trunk configurations (extending or not below stern frame).

The steel used for the rudder trunk is to be of weldable quality, with a carbon content not exceeding 0.23% on ladle analysis or a carbon equivalent C_{EQ} not exceeding 0.41%.

Plating materials for rudder trunks are in general not to be of lower grades than corresponding to class II as defined in UR S6.
The weld at the connection between the rudder trunk and the shell or the bottom of the skeg is to be full penetration.

The fillet shoulder radius r, in mm (see Figure 9) is to be as large as practicable and to comply with the following formulae:

r = 60 [mm] when $\sigma \geq 40 / k$ [N/mm²]

r = $0.1d_c$, without being less than 30 [mm] when $\sigma < 40 / k$ [N/mm²]

where:

d_c = rudder stock diameter axis defined in S10.4.2.

σ = bending stress in the rudder trunk in N/mm².

k = material factor as given in S10.1.3.2 or S10.1.3.5 respectively.

The radius may be obtained by grinding. If disk grinding is carried out, score marks are to be avoided in the direction of the weld. The radius is to be checked with a template for accuracy. Four profiles at least are to be checked. A report is to be submitted to the Surveyor.

Rudder trunks comprising of materials other than steel are to be specially considered by the Society.

S10
(cont)

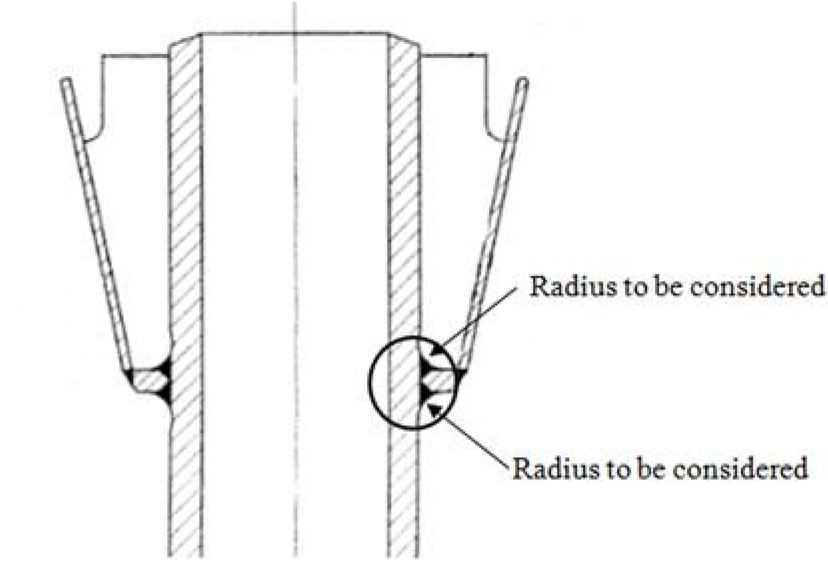

Figure 9 Fillet shoulder radius

9.3.2 Scantlings

Where the rudder stock is arranged in a trunk in such a way that the trunk is stressed by forces due to rudder action, the scantlings of the trunk are to be such that:

- the equivalent stress due to bending and shear does not exceed 0.35 σ_F,
- the bending stress on welded rudder trunk is to be in compliance with the following formula: $\sigma \leq 80 / k$ [N/mm²]

with:

σ = bending stress in the rudder trunk, as defined in S10.9.3.1.

k = material factor for the rudder trunk as given in S10.1.3.2 or S10.1.3.5 respectively, not to be taken less than 0.7

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

For calculation of bending stress, the span to be considered is the distance between the mid-height of the lower rudder stock bearing and the point where the trunk is clamped into the shell or the bottom of the skeg.

S10
(cont)

Annex

Guidelines for calculation of bending moment and shear force distribution

AnnexS10.1 General

The evaluation of bending moments, shear forces and support forces for the system rudder–rudder stock may be carried out for some basic rudder types as outlined in AnnexS10.2-AnnexS10.6.

S10
(cont)

AnnexS10.2 Spade rudder

Data for the analysis

ℓ_{10} - ℓ_{30} = Lengths of the individual girders of the system in [m]

I_{10} – I_{30} = Moments of inertia of these girders in [cm^4]

Load of rudder body:

P_R = C_R / (ℓ_{10} 10^3) [kN/m]

Moments and forces

The moments and forces may be determined by the following formulae:

M_b = C_R (ℓ_{20} + (ℓ_{10} (2 c_1 + c_2) / 3 (c_1 + c_2))) [Nm]

B_3 = M_b / ℓ_{30} [N]

B_2 = C_R + B_3 [N]

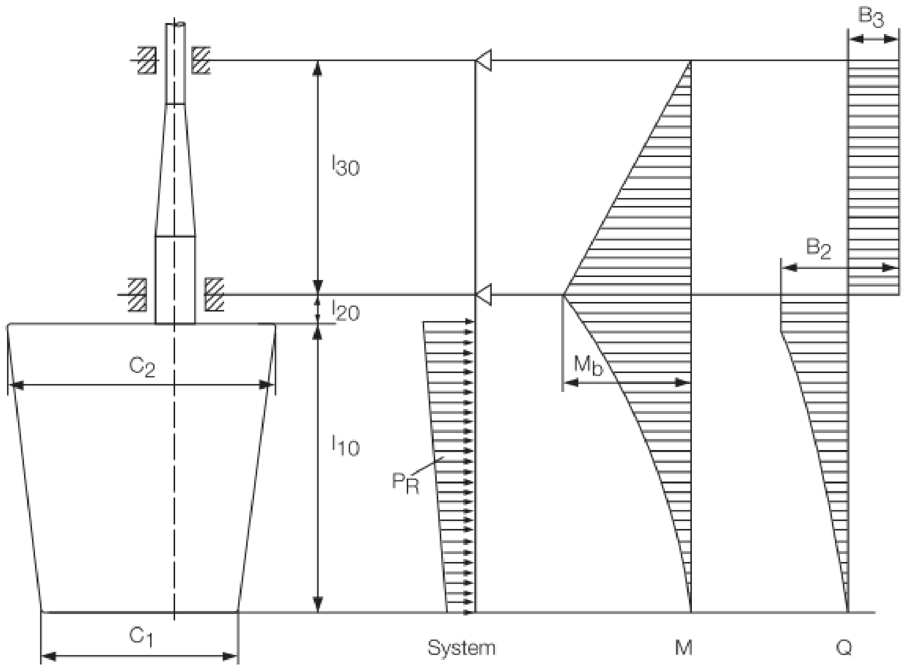

Figure A 1

S10 (cont)

AnnexS10.3 Spade rudder with trunk

Data for the analysis

ℓ_{10} - ℓ_{30} = Lengths of the individual girders of the system in [m]

I_{10} – I_{30} = Moments of inertia of these girders in [cm^4]

Load of rudder body:

$P_R = C_R / ((\ell_{10} + \ell_{20})10^3)$ [kN/m]

Moments and forces

For spade rudders with rudders trunks the moments, in Nm, and forces, in N, may be determined by the following formulae:

M_R is the greatest of the following values:

$M_{CR1} = C_{R1} (CG_{1Z} – \ell_{10})$

$M_{CR2} = C_{R2} (\ell_{10} – CG_{2Z})$

where:

C_{R1} : Rudder force over the rudder blade area A_1

C_{R2} : Rudder force over the rudder blade area A_2

CG_{1Z} : Vertical position of the centre of gravity of the rudder blade area A_1 from base

CG_{2Z} : Vertical position of the centre of gravity of the rudder blade area A_2 from base

$C_R = C_{R1} + C_{R2}$

$B_3 = (M_{CR2} - M_{CR1}) / (\ell_{20} + \ell_{30})$

$B_2 = C_R + B_3$

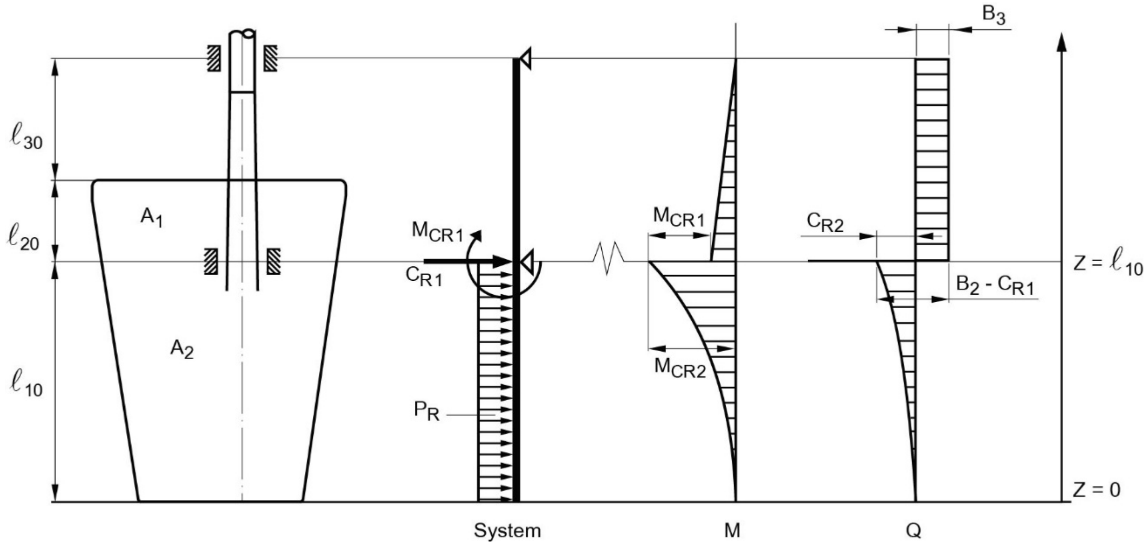

Figure A 2

S10
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AnnexS10.4 Rudder supported by sole piece

Data for the analysis

ℓ_{10} - ℓ_{50} = Lengths of the individual girders of the system in [m]

I_{10} – I_{50} = Moments of inertia of these girders in [cm^4]

For rudders supported by a sole piece the length ℓ_{20} is the distance between lower edge of rudder body and centre of sole piece and I_{20} the moment of inertia of the pintle in the sole piece.

I_{50} = moment of inertia of sole piece around the z-axis [cm^4];

ℓ_{50} = effective length of sole piece in [m];

Load of rudder body:

P_R = C_R / (ℓ_{10} 10^3) [kN/m]

Z = spring constant of support in the sole piece

Z = 6.18 x I_{50} / ℓ_{50}^3 [kN/m]

Moments and forces

Moments and shear forces are indicated in Figure A 3

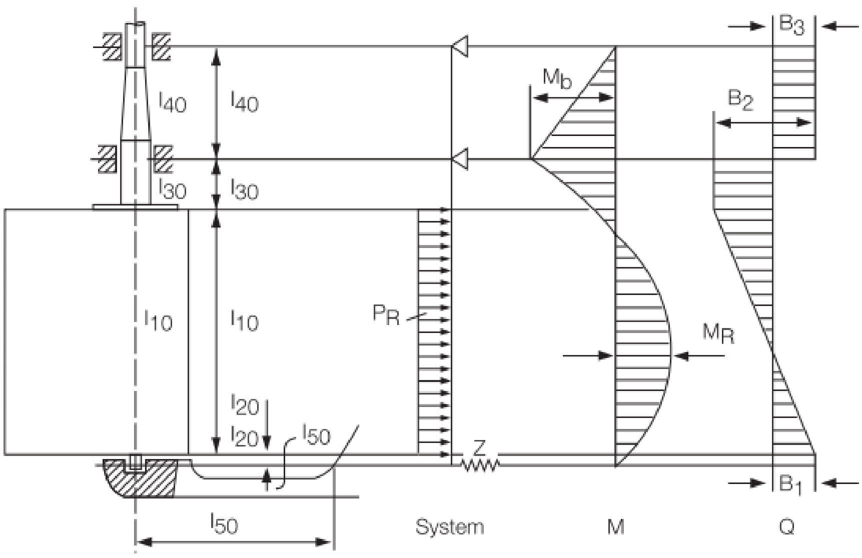

Figure A 3

S10 (cont)

AnnexS10.5 Semi spade rudder with one elastic support

Data for the analysis

ℓ_{10} - ℓ_{50} =Lengths of the individual girders of the system in [m];

I_{10} – I_{50} =Moments of inertia of these girders in [cm^4];

Z = spring constant of support in the rudder horn;

Z = 1 / (f_b + f_t) [kN/m] for the support in the rudder horn (Figure A 4);

f_b = unit displacement of rudder horn in [m] due to a unit force of 1 kN acting in the centre of support;

f_b = 1.3 d^3 / (6.18 I_n) [m/kN] (guidance value);

I_n = moment of inertia of rudder horn around the x-axis in [cm^4] (see also Figure A 4);

f_t = unit displacement due to torsion;

f_t = $de^2 \sum u_i / t_i / \left(3.14 \times 10^8 F_T^2\right)$ [m/kN];

F_T = mean sectional area of rudder horn in [m^2];

u_i = breadth in [mm] of the individual plates forming the mean horn sectional area;

t_i = thickness within the individual breadth u_i in [mm];

d = Height of the rudder horn, in m, defined in Figure A 4. This value is measured downwards from the upper rudder horn end, at the point of curvature transition, to the mid-line of the lower rudder horn pintle;

e = distance as defined in Figure A 5

Load of rudder body:

P_{R10} = C_{R2} / (ℓ_{10} x 10^3) [kN/m];

P_{R20} = C_{R1} / (ℓ_{20} x 10^3) [kN/m];

for C_R, C_{R1}, C_{R2}, see S10.2.

Moments and forces

Moments and shear forces are indicated in Figure A 4.

Rudder horn

The loads on the rudder horn are as follows:

M_b = bending moment = B_1 z [Nm], M_{bmax} = B_1 d [Nm]

S10 (cont)

q = shear force = B_1 [N]

$M_T(z)$ = torsional moment = B_1 e (z) [Nm]

An estimate for B_1 is:

$B_1 = C_R\, b / (\ell_{20} + \ell_{30})$ [N]

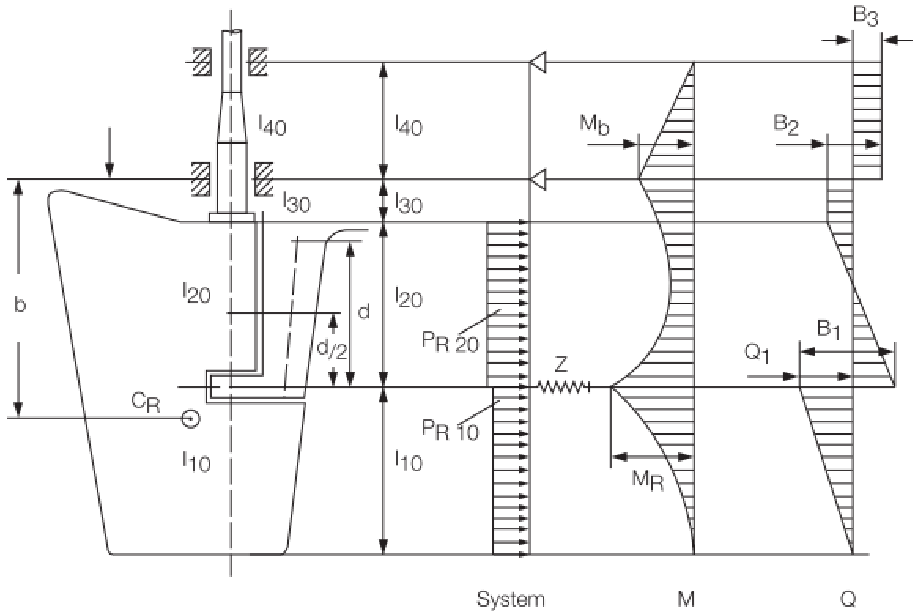

Figure A 4

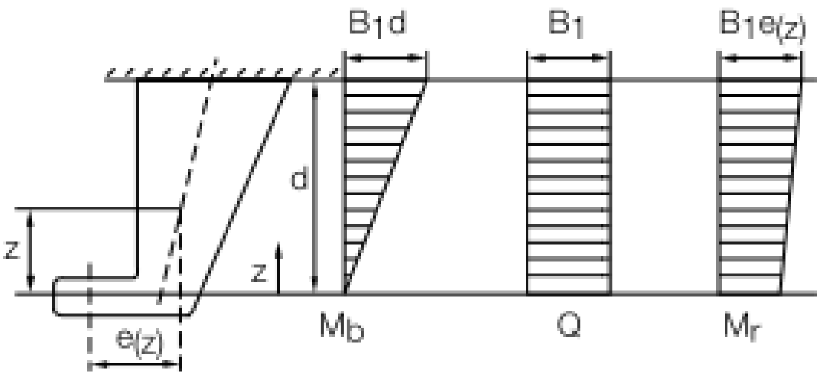

Figure A 5

S10
(cont)

AnnexS10.6 Semi spade rudder with 2-conjugate elastic support

Data for the analysis

K_{11}, K_{22}, K_{12} : Rudder horn compliance constants calculated for rudder horn with 2-conjugate elastic supports (Figure A 6).The 2-conjugate elastic supports are defined in terms of horizontal displacements, y_i, by the following equations:

at the lower rudder horn bearing:

$y_1 = - K_{12} B_2 - K_{22} B_1$

at the upper rudder horn bearing:

$y_2 = - K_{11} B_2 - K_{12} B_1$

where:

y_1, y_2 : Horizontal displacements, in m, at the lower and upper rudder horn bearings, respectively.

B_1, B_2 : Horizontal support forces, in kN, at the lower and upper rudder horn bearings, respectively.

K_{11}, K_{22}, K_{12} : Obtained, in m/kN, from the following formulae:

$$K_{11} = 1.3 \frac{\lambda^3}{3EJ_{1h}} + \frac{e^2 \lambda}{GJ_{th}}$$

$$K_{22} = 1.3 \left[\frac{\lambda^3}{3EJ_{1h}} + \frac{\lambda^2 (d \quad \lambda)}{2EJ_{1h}} \right] + \frac{e^2 \lambda}{GJ_{th}}$$

$$K_{12} = 1.3 \left[\frac{\lambda^3}{3EJ_{1h}} + \frac{\lambda^2 (d \quad \lambda)}{EJ_{1h}} + \frac{\lambda (d \quad \lambda)^2}{EJ_{1h}} + \frac{(d \quad \lambda)^3}{3EJ_{2h}} \right] + \frac{e^2 d}{GJ_{th}}$$

d : Height of the rudder horn, in m, defined in Figure A 6. This value is measured downwards from the upper rudder horn end, at the point of curvature transition, to the mid-line of the lower rudder horn pintle.

λ : Length, in m, as defined in Figure A 6. This length is measured downwards from the upper rudder horn end, at the point of curvature transition, to the mid-line of the upper rudder horn bearing. For λ = 0, the above formulae converge to those of spring constant Z for a rudder horn with 1-elastic support, and assuming a hollow cross section for this part.

e : Rudder-horn torsion lever, in m, as defined in Figure A 6 (value taken at z = d/2).

J_{1h} : Moment of inertia of rudder horn about the x axis, in m^4, for the region above the upper rudder horn bearing. Note that J_{1h} is an average value over the length λ (see Figure A 6).

S10
(cont)

J_{2h} : Moment of inertia of rudder horn about the x axis, in m^4, for the region between the upper and lower rudder horn bearings. Note that J_{2h} is an average value over the length d - λ (see Figure A 6).

J_{th} : Torsional stiffness factor of the rudder horn, in m^4.

For any thin wall closed section:

$$J_{th} = \frac{4F_T^{\ 2}}{\sum_i \frac{u_i}{t_i}}$$

F_T : Mean of areas enclosed by outer and inner boundaries of the thin walled section of rudder horn, in m^2.

u_i : Length, in mm, of the individual plates forming the mean horn sectional area.

t_i : Thickness, in mm, of the individual plates mentioned above.

Note that the J_{th} value is taken as an average value, valid over the rudder horn height.

Load of rudder body:

P_{R10} = $C_{R2} / (\ell_{10} \times 10^3)$ [kN/m];

P_{R20} = $C_{R1} / (\ell_{20} \times 10^3)$ [kN/m];

for C_R, C_{R1}, C_{R2}, see S10.2.2

Moments and forces

Moments and shear forces are indicated in Figure A 6

Rudder horn bending moment

The bending moment acting on the generic section of the rudder horn is to be obtained, in Nm, from the following formulae:

- between the lower and upper supports provided by the rudder horn:

  $M_H = F_{A1}\, z$

- above the rudder horn upper-support:

  $M_H = F_{A1}\, z + F_{A2}\, (z - d_{lu})$

where:

F_{A1} : Support force at the rudder horn lower-support, in N, to be obtained according to Figure A 6, and taken equal to B_1.

F_{A2} : Support force at the rudder horn upper-support, in N, to be obtained according to Figure A 6, and taken equal to B_2.

S10
(cont)

z : Distance, in m, defined in Figure A 7, to be taken less than the distance d, in m, defined in the same figure.

d_{lu} : Distance, in m, between the rudder-horn lower and upper bearings (according to Figure A 6, $d_{lu} = d - \lambda$).

Rudder horn shear force

The shear force Q_H acting on the generic section of the rudder horn is to be obtained, in N, from the following formulae:

- between the lower and upper rudder horn bearings:

$$Q_H = F_{A1}$$

- above the rudder horn upper-bearing:

$$Q_H = F_{A1} + F_{A2}$$

where:

F_{A1}, F_{A2} : Support forces, in N.

The torque acting on the generic section of the rudder horn is to be obtained, in Nm, from the following formulae:

- between the lower and upper rudder horn bearings:

$$M_T = F_{A1}\, e_{(z)}$$

- above the rudder horn upper-bearing:

$$M_T = F_{A1}\, e_{(z)} + F_{A2}\, e_{(z)}$$

where:

F_{A1}, F_{A2} : Support forces, in N

$e_{(z)}$: Torsion lever, in m, defined in Figure A 7.

Rudder horn shear stress calculation

For a generic section of the rudder horn, located between its lower and upper bearings, the following stresses are to be calculated:

τ_S: Shear stress, in N/mm^2, to be obtained from the following formula:

$$\tau_S = \frac{F_{A1}}{A_H}$$

S10 (cont)

τ_T : Torsional stress, in N/mm^2, to be obtained for hollow rudder horn from the following formula:

$$T_T = \frac{M_T 10^{-3}}{2F_T t_H}$$

For solid rudder horn, τ_T is to be considered by the Society on a case by case basis.

For a generic section of the rudder horn, located in the region above its upper bearing, the following stresses are to be calculated:

τ_S: Shear stress, in N/mm^2, to be obtained from the following formula:

$$\tau_S = \frac{F_{A1} + F_{A2}}{A_H}$$

τ_T : Torsional stress, in N/mm^2, to be obtained for hollow rudder horn from the following formula:

$$T_T = \frac{M_T 10^{-3}}{2F_T t_H}$$

For solid rudder horn, τ_T is to be considered by the Society on a case by case basis where:

F_{A1}, F_{A2} : Support forces, in N;

A_H : Effective shear sectional area of the rudder horn, in mm^2, in y-direction;

M_T : Torque, in Nm;

F_T : Mean of areas enclosed by outer and inner boundaries of the thin walled section of rudder horn, in m^2;

t_H : Plate thickness of rudder horn, in mm. For a given cross section of the rudder horn, the maximum value of τ_T is obtained at the minimum value of t_H.

Rudder horn bending stress calculation

For the generic section of the rudder horn within the length *d*, the following stresses are to be calculated:

σ_B : Bending stress, in N/mm^2, to be obtained from the following formula:

$$\sigma_B = \frac{M_H}{W_X}$$

where:

M_H : Bending moment at the section considered, in Nm.

W_X : Section modulus, in cm^3, around the X-axis (see Figure A 7).

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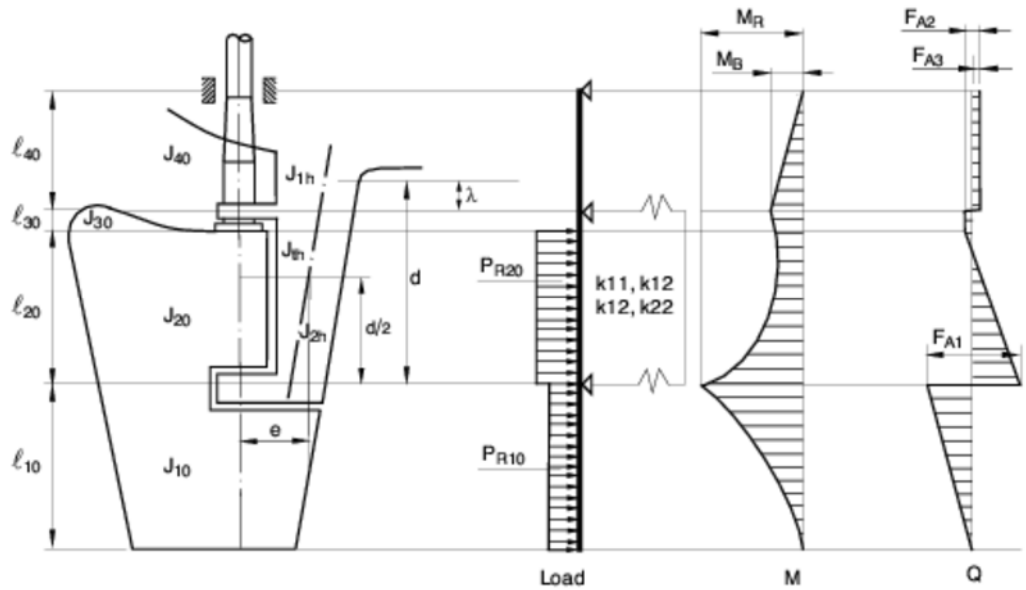

Figure A 6

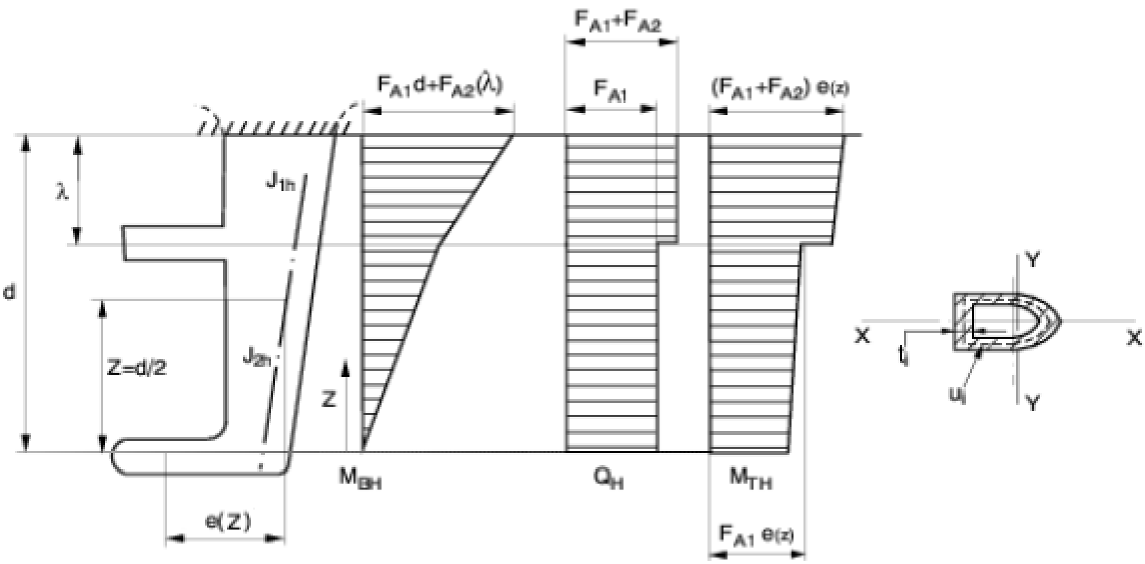

Figure A 7

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S11A Longitudinal Strength Standard for Container Ships

(June 2015)

S11A.1 General

S11A.1.1 Application

S11A.1.1.1 Application

This UR applies to the following types of steel ships with a length L of 90 m and greater and operated in unrestricted service:

1. Container ships
2. Ships dedicated primarily to carry their load in containers.

S11A.1.1.2 Load limitations

The wave induced load requirements apply to monohull displacement ships in unrestricted service and are limited to ships meeting the following criteria:

(i)	Length	$90 \text{ m} \le L \le 500 \text{ m}$
(ii)	Proportion	$5 \le L/B \le 9$; $2 \le B/T \le 6$
(iii)	Block coefficient at scantling draught	$0.55 \le C_B \le 0.9$

For ships that do not meet all of the aforementioned criteria, special considerations such as direct calculations of wave induced loads may be required by the Classification Society.

S11A.1.1.3 Longitudinal extent of strength assessment

The stiffness, yield strength, buckling strength and hull girder ultimate strength assessment are to be carried out in way of 0.2L to 0.75L with due consideration given to locations where there are significant changes in hull cross section, e.g. changing of framing system and the fore and aft end of the forward bridge block in case of two-island designs.

In addition, strength assessments are to be carried out outside this area. As a minimum assessments are to be carried out at forward end of the foremost cargo hold and the aft end of the aft most cargo hold. Evaluation criteria used for these assessments are determined by the Classification Society.

Note:

1. This UR is to be uniformly implemented by IACS Societies for ships contracted for construction on or after 1 July 2016.

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

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S11A.1.2 Symbols and definitions

S11A.1.2.1 Symbols

L	Rule length, in m, as defined in UR S2
B	Moulded breadth, in m
C	Wave parameter, see 2.3.1
T	Scantling draught in m
C_B	Block coefficient at scantling draught
C_w	Waterplane coefficient at scantling draught, to be taken as: $C_W = \frac{A_W}{(LB)}$
A_w	Waterplane area at scantling draught, in m^2
R_{eH}	Specified minimum yield stress of the material, in N/mm^2
k	Material factor as defined in UR S4 for higher tensile steels, k=1.0 for mild steel having a minimum yield strength equal to 235 N/mm^2
E	Young's modulus in N/mm^2 to be taken as $E = 2.06*10^5$ N/mm^2 for steel
M_S	Vertical still water bending moment in seagoing condition, in kNm, at the cross section under consideration
M_{Smax}, M_{Smin}	Permissible maximum and minimum vertical still water bending moments in seagoing condition, in kNm, at the cross section under consideration, see 2.2.2
M_W	Vertical wave induced bending moment, in kNm, at the cross section under consideration
F_S	Vertical still water shear force in seagoing condition, in kN, at the cross section under consideration
F_{Smax}, F_{Smin}	Permissible maximum and minimum still water vertical shear force in seagoing condition, in kN, at the cross section under consideration, see 2.2.2
F_W	Vertical wave induced shear force, in kN, at the cross section under consideration
q_v	Shear flow along the cross section under consideration, to be determined according to Annex 1
$f_{NL\text{-}Hog}$	Non-linear correction factor for hogging, see 2.3.2
$f_{NL\text{-}Sag}$	Non-linear correction factor for sagging, see 2.3.2

S11A
(cont)

f_R	Factor related to the operational profile, see 2.3.2
t_{net}	Net thickness, in mm, see 1.3.1
t_{res}	Reserve thickness, to be taken as 0.5mm
I_{net}	Net vertical hull girder moment of inertia at the cross section under consideration, to be determined using net scantlings as defined in 1.3, in m^4
σ_{HG}	Hull girder bending stress, in N/mm^2, as defined in 2.5
τ_{HG}	Hull girder shear stress, in N/mm^2, as defined in 2.5
x	Longitudinal co-ordinate of a location under consideration, in m
z	Vertical co-ordinate of a location under consideration, in m
z_n	Distance from the baseline to the horizontal neutral axis, in m.

S11A.1.2.2 Fore end and aft end

The fore end (FE) of the rule length L, see Figure 1, is the perpendicular to the scantling draught waterline at the forward side of the stem.

The aft end (AE) of the rule length L, see Figure 1, is the perpendicular to the scantling draught waterline at a distance L aft of the fore end (FE).

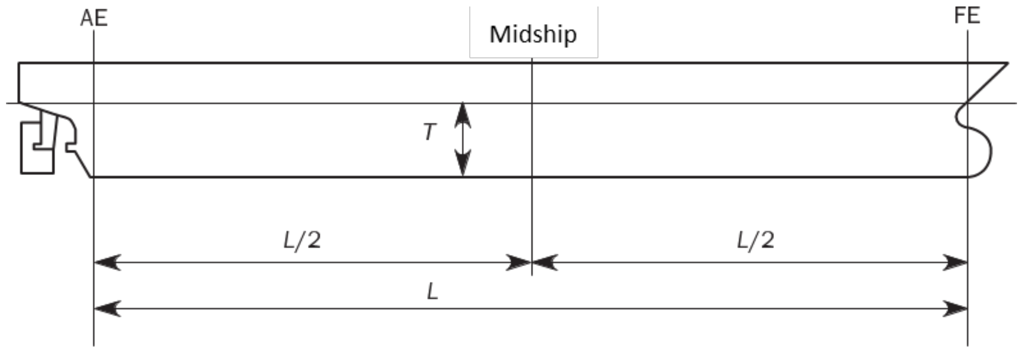

Figure 1: Ends of length L

S11A.1.2.3 Reference coordinate system

The ships geometry, loads and load effects are defined with respect to the following right-hand coordinate system (see Figure 2):

Origin: At the intersection of the longitudinal plane of symmetry of ship, the aft end of L and the baseline.
X axis: Longitudinal axis, positive forwards.
Y axis: Transverse axis, positive towards portside.
Z axis: Vertical axis, positive upwards.

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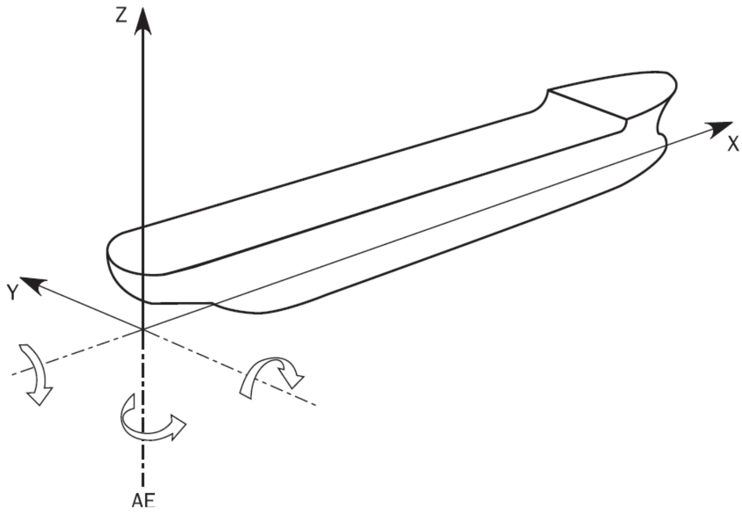


Figure 2: Reference coordinate system

S11A.1.3 Corrosion margin and net thickness

S11A.1.3.1 Net scantling definitions

The strength is to be assessed using the net thickness approach on all scantlings.

The net thickness, t_{net}, for the plates, webs and flanges is obtained by subtracting the voluntary addition t_{vol_add} and the factored corrosion addition t_c from the as built thickness t_{as_built}, as follows:

$$t_{net} = t_{as\_built} - t_{vol\_add} - \alpha t_c$$

where α is a corrosion addition factor whose values are defined in Table 1.

The voluntary addition, if being used, is to be clearly indicated on the drawings.

Table 1: Values of corrosion addition factor

Structural requirement	Property / analysis type	α
Strength assessment (S11A.3)	Section properties	0.5
Buckling strength (S11A.4)	Section properties (stress determination)	0.5
	Buckling capacity	1.0
Hull girder ultimate strength (S11A.5)	Section properties	0.5
	Buckling / collapse capacity	0.5

S11A.1.3.2 Determination of corrosion addition

The corrosion addition for each of the two sides of a structural member, t_{c1} or t_{c2} is specified in Table 2. The total corrosion addition, t_c, in mm, for both sides of the structural member is obtained by the following formula:

$$t_c = (t_{c1} + t_{c2}) + t_{res}$$

S11A (cont)

For an internal member within a given compartment, the total corrosion addition, t_c is obtained from the following formula:

$$t_c = (2t_{c1}) + t_{res}$$

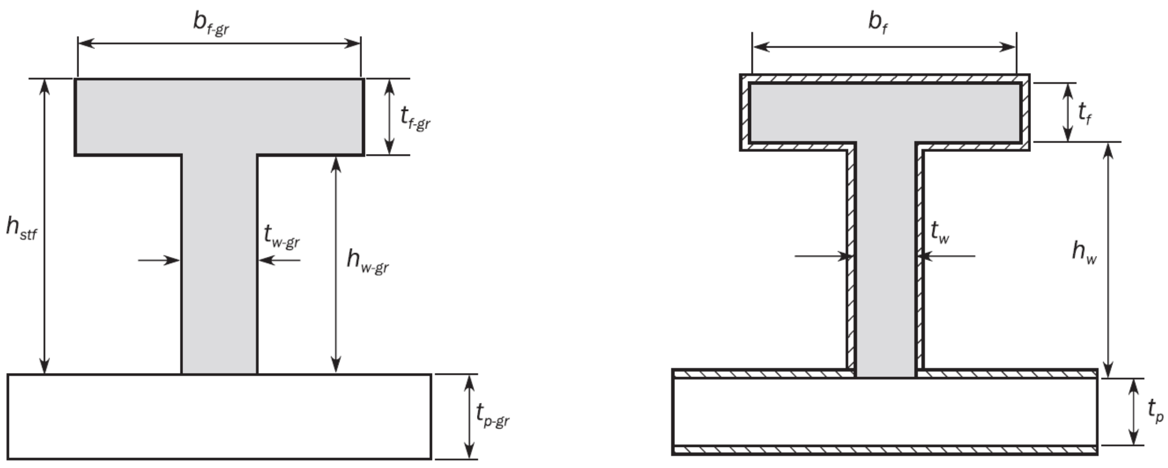
The corrosion addition of a stiffener is to be determined according to the location of its connection to the attached plating.

Table 2: Corrosion addition for one side of a structural member

Compartment type	One side corrosion addition t_{c1} or t_{c2} [mm]
Exposed to sea water	1.0
Exposed to atmosphere	1.0
Ballast water tank	1.0
Void and dry spaces	0.5
Fresh water, fuel oil and lube oil tank	0.5
Accommodation spaces	0.0
Container holds	1.0
Compartment types not mentioned above	0.5

S11A.1.3.3 Determination of net section properties

The net section modulus, moment of inertia and shear area properties of a supporting member are to be calculated using the net dimensions of the attached plate, web and flange, as defined in Figure 3. The net cross-sectional area, the moment of inertia about the axis parallel to the attached plate and the associated neutral axis position are to be determined through applying a corrosion magnitude of 0.5 αt_c deducted from the surface of the profile cross-section.



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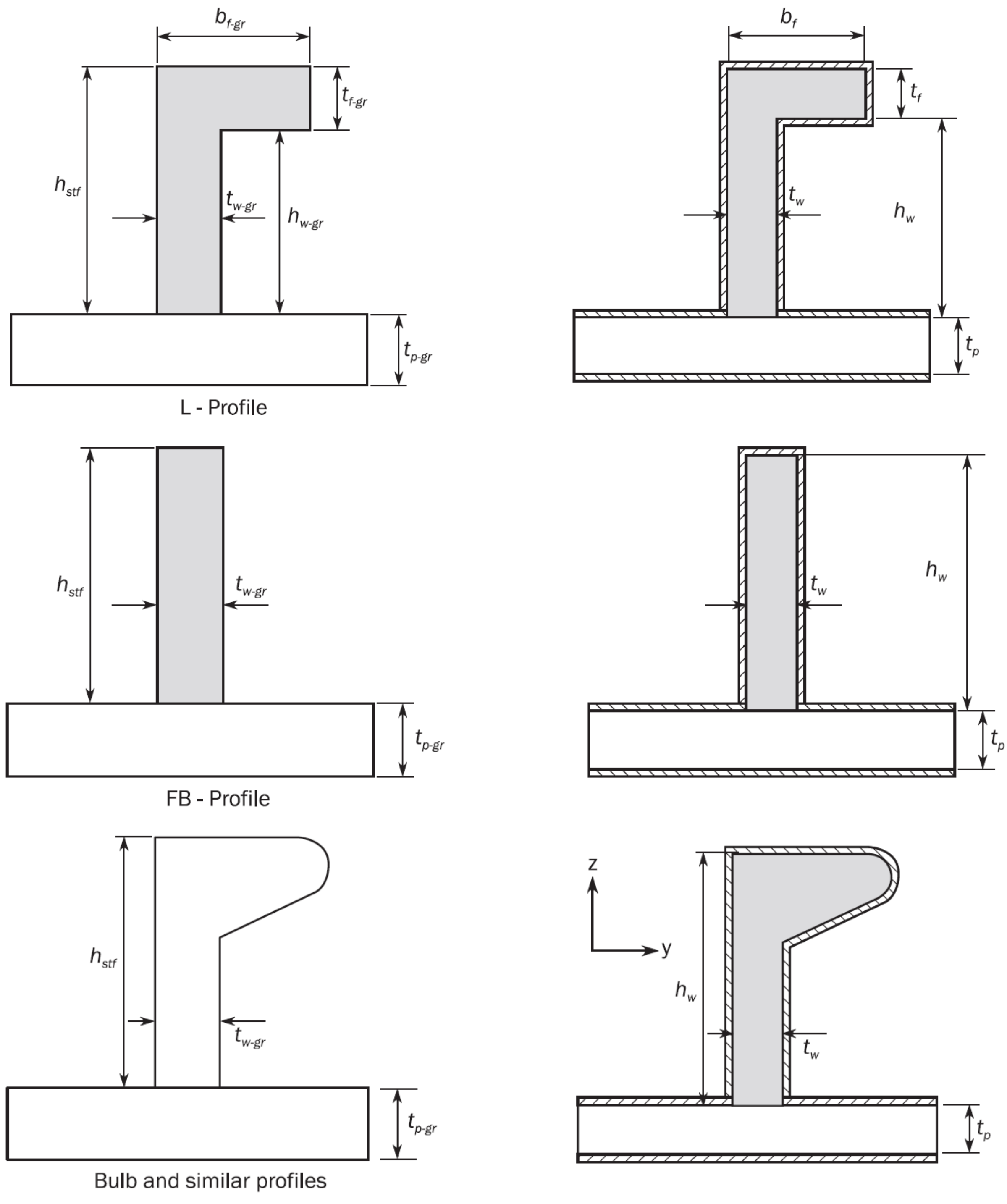

Figure 3: Net sectional properties of supporting members

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S11A.2 Loads

S11A.2.1 Sign convention for hull girder loads

The sign conventions of vertical bending moments and vertical shear forces at any ship transverse section are as shown in Figure 4, namely:

- The vertical bending moments M_S and M_W are positive when they induce tensile stresses in the strength deck (hogging bending moment) and negative when they induce tensile stresses in the bottom (sagging bending moment).
- The vertical shear forces F_S, F_W are positive in the case of downward resulting forces acting aft of the transverse section and upward resulting forces acting forward of the transverse section under consideration. The shear forces in the directions opposite to above are negative.

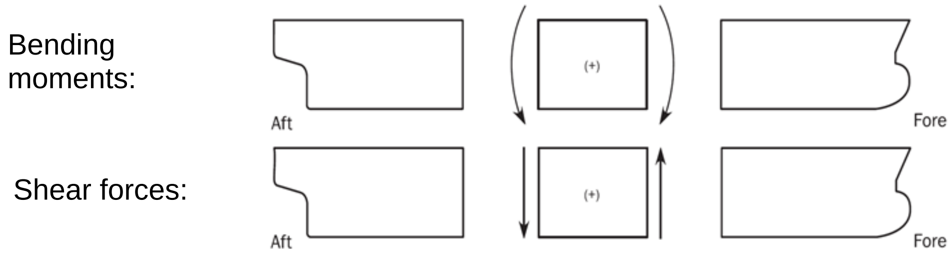

Figure 4: Sign conventions of bending moments and shear forces

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S11A.2.2 Still water bending moments and shear forces

S11A.2.2.1 General

Still water bending moments, M_S in kNm, and still water shear forces, F_S in kN, are to be calculated at each section along the ship length for design loading conditions as specified in 2.2.2.

S11A.2.2.2 Design loading conditions

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

The permissible vertical still water bending moments M_{Smax} and M_{Smin} and the permissible vertical still water shear forces F_{Smax} and F_{Smin} in seagoing conditions at any longitudinal position are to envelop:

- The maximum and minimum still water bending moments and shear forces for the seagoing loading conditions defined in the Loading Manual.

- The maximum and minimum still water bending moments and shear forces specified by the designer

The Loading Manual should include the relevant loading conditions, which envelop the still water hull girder loads for seagoing conditions, including those specified in UR S1 Annex 1.

S11A (cont)

S11A.2.3 Wave loads

S11A.2.3.1 Wave parameter

The wave parameter is defined as follows:

$$C = 1 - 1.50\left(1 - \sqrt{\frac{L}{L_{ref}}}\right)^{2.2} \quad \text{for } L \le L_{ref}$$

$$C = 1 - 0.45\left(\sqrt{\frac{L}{L_{ref}}} - 1\right)^{1.7} \quad \text{for } L > L_{ref}$$

where:

L_{ref} Reference length, in m, taken as:

$L_{ref} = 315 C_W^{-1.3}$ for the determination of vertical wave bending moments according to 2.3.2

$L_{ref} = 330 C_W^{-1.3}$ for the determination of vertical wave shear forces according to 2.3.3

S11A.2.3.2 Vertical wave bending moments

The distribution of the vertical wave induced bending moments, M_W in kNm, along the ship length is given in Figure 6, where:

$$M_{W-Hog} = +1.5 f_R L^3 C C_W \left(\frac{B}{L}\right)^{0.8} f_{NL-Hog}$$

$$M_{W-Sag} = -1.5 f_R L^3 C C_W \left(\frac{B}{L}\right)^{0.8} f_{NL-Sag}$$

where:

f_R: Factor related to the operational profile, to be taken as:
$f_R = 0.85$

f_{NL-Hog}: Non-linear correction for hogging, to be taken as:
$f_{NL-Hog} = 0.3 \frac{C_B}{C_W} \sqrt{T}$, not to be taken greater than 1.1

f_{NL-Sag}: Non-linear correction for sagging, to be taken as:
$f_{NL-Sag} = 4.5 \frac{1 + 0.2 f_{Bow}}{C_W \sqrt{C_B} L^{0.3}}$, not to be taken less than 1.0

S11A
(cont)

f_{Bow}: Bow flare shape coefficient, to be taken as:

$$f_{Bow} = \frac{A_{DK} - A_{WL}}{0.2Lz_f}$$

A_{DK}: Projected area in horizontal plane of uppermost deck, in m^2 including the forecastle deck, if any, extending from 0.8*L* forward (see Figure 5). Any other structures, e.g. plated bulwark, are to be excluded.

A_{WL}: Waterplane area, in m^2, at draught *T*, extending from 0.8*L* forward

z_f: Vertical distance, in m, from the waterline at draught *T* to the uppermost deck (or forecastle deck), measured at FE (see Figure 5). Any other structures, e.g. plated bulwark, are to be excluded.

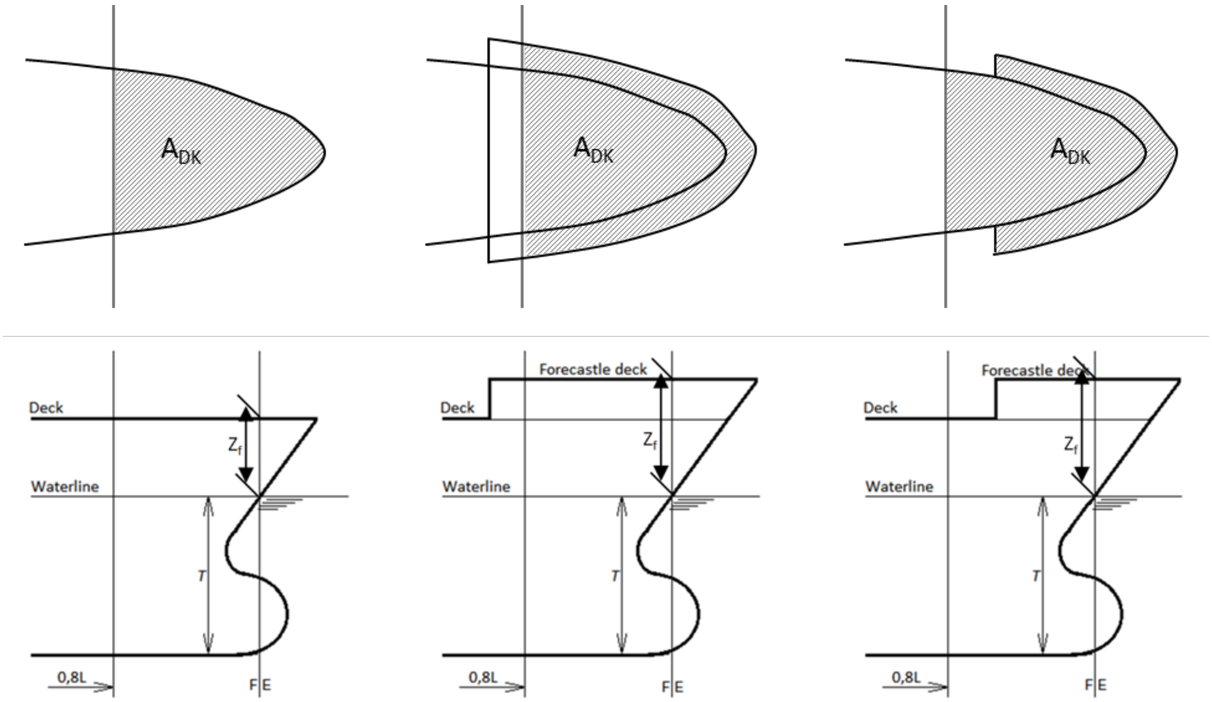

Figure 5: Projected area A_{DK} and vertical distance z_f

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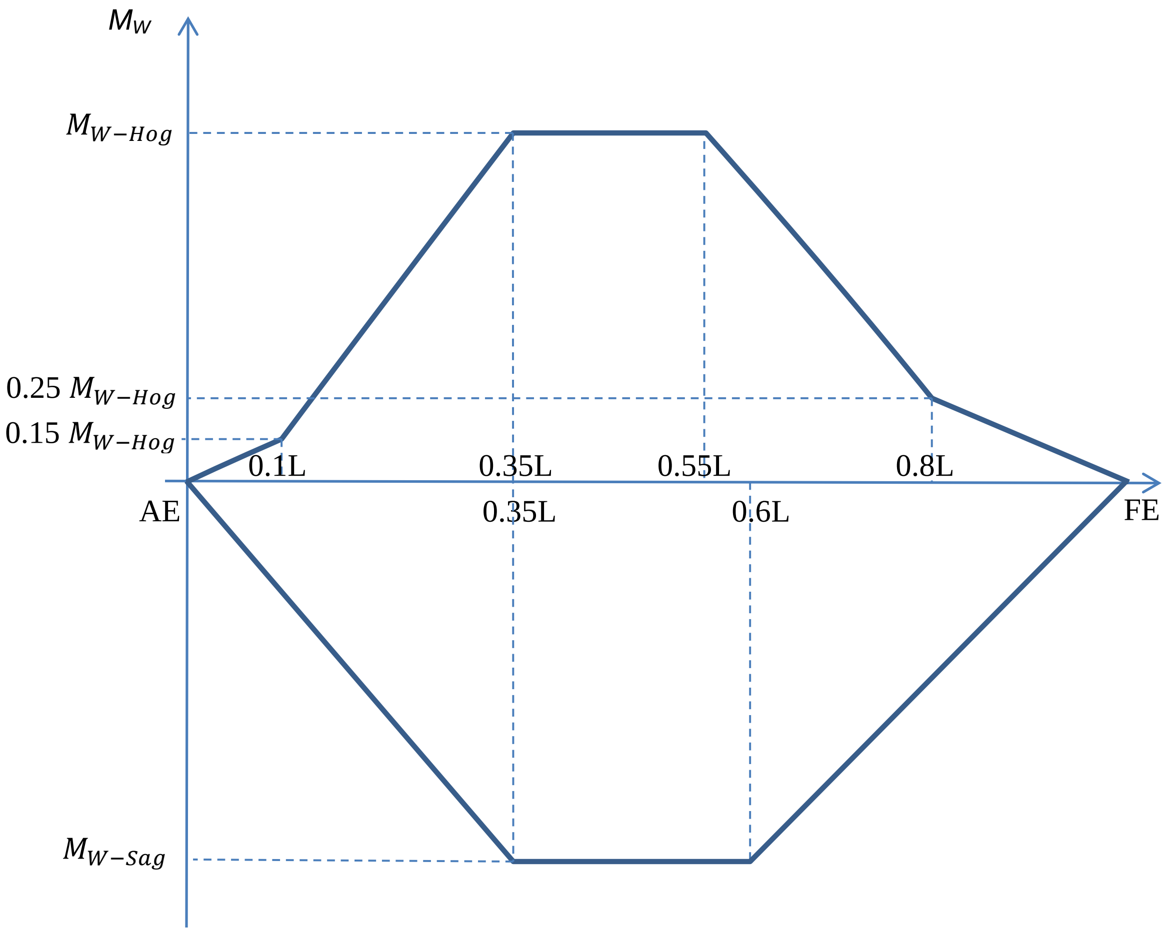

Figure 6: Distribution of vertical wave bending moment M_W along the ship length

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S11A.2.3.3 Vertical wave shear force

The distribution of the vertical wave induced shear forces, F_W in kN, along the ship length is given in Figure 7, where,

$$F_{W\,Hog}^{\;Aft} = +5.2\, f_R L^2 C C_W \left(\frac{B}{L}\right)^{0.8} (0.3 + 0.7\, f_{NL-Hog})$$

$$F_{W\,Hog}^{\;Fore} = -5.7\, f_R L^2 C C_W \left(\frac{B}{L}\right)^{0.8} f_{NL-Hog}$$

$$F_{W\,Sag}^{\;Aft} = -5.2\, f_R L^2 C C_W \left(\frac{B}{L}\right)^{0.8} (0.3 + 0.7\, f_{NL-Sag})$$

$$F_{W\,Sag}^{\;Fore} = +5.7\, f_R L^2 C C_W \left(\frac{B}{L}\right)^{0.8} (0.25 + 0.75\, f_{NL-Sag})$$

$$F_W^{\;Mid} = +4.0\, f_R L^2 C C_W \left(\frac{B}{L}\right)^{0.8}$$

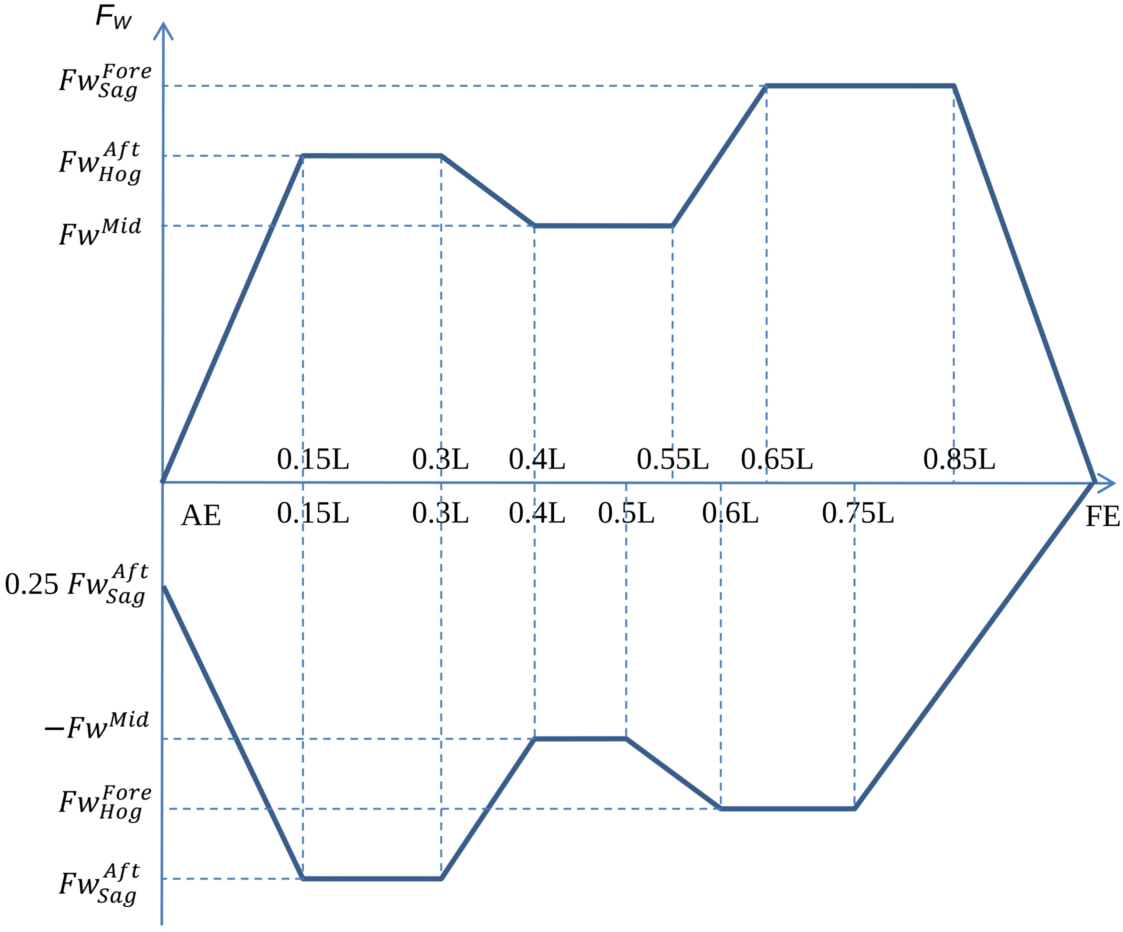

Figure 7: Distribution of vertical wave shear force F_W along the ship length

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S11A.2.4 Load cases

For the strength assessment, the maximum hogging and sagging load cases given in Table 3 are to be checked. For each load case the still water condition at each section as defined in 2.2 is to be combined with the wave condition as defined in 2.3, refer also to Figure 8.

Table 3: Combination of still water and wave bending moments and shear forces

Load case	Bending moment		Shear force	
	M_S	M_W	F_S	F_W
Hogging	M_{Smax}	M_{WH}	F_{Smax} for x ≤ 0.5L	F_{Wmax} for x ≤ 0.5L
			F_{Smin} for x > 0.5L	F_{Wmin} for x > 0.5L
Sagging	M_{Smin}	M_{WS}	F_{Smin} for x ≤ 0.5L	F_{Wmin} for x ≤ 0.5L
			F_{Smax} for x > 0.5L	F_{Wmax} for x > 0.5L

M_{WH}: Wave bending moment in hogging at the cross section under consideration, to be taken as the positive value of M_W as defined in Figure 6.

M_{WS}: Wave bending moment in sagging at the cross section under consideration, to be taken as the negative value of M_W as defined Figure 6.

F_{Wmax}: Maximum value of the wave shear force at the cross section under consideration, to be taken as the positive value of F_W as defined Figure 7.

F_{Wmin}: Minimum value of the wave shear force at the cross section under consideration, to be taken as the negative value of F_W as defined Figure 7.

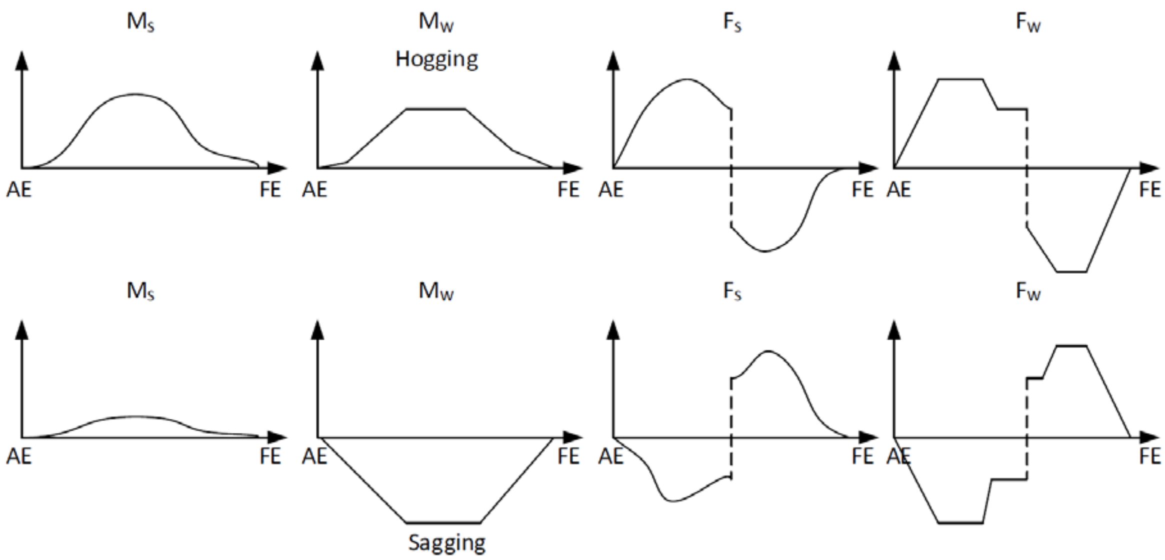

Figure 8: Load combination to determine the maximum hogging and sagging load cases as given in Table 3

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S11A.2.5 Hull girder stress

The hull girder stresses in N/mm^2 are to be determined at the load calculation point under consideration, for the "hogging" and "sagging" load cases defined in 2.4 as follows:

Bending stress:

$$\sigma_{HG} = \frac{\gamma_s M_s + \gamma_W M_W}{I_{net}} (Z - Z_n) 10^{-3}$$

Shear stress:

$$\tau_{HG} = \frac{\gamma_s F_s + \gamma_W F_W}{t_{net}/q_v} 10^{3}$$

where:

γ_s, γ_W : Partial safety factors, to be taken as:

γ_s = 1.0

γ_W = 1.0

S11A.3 Strength Assessment

S11A.3.1 General

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

S11A.3.2 Stiffness criterion

The two load cases "hogging" and "sagging" as listed in 2.4 are to be checked.

The net moment of inertia, in m^4, is not to be less than:

$$I_{net} \geq 1.55 L \left| M_s + M_W \right| 10^{-7}$$

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S11A.3.3 Yield strength assessment

S11A.3.3.1 General acceptance criteria

The yield strength assessment is to check, for each of the load cases “hogging” and “sagging” as defined in 2.4, that the equivalent hull girder stress σ_{eq}, in N/mm^2, is less than the permissible stress σ_{perm}, in N/mm^2, as follows:

$$\sigma_{eq} < \sigma_{perm}$$

where:

$$\sigma_{eq} = \sqrt{\sigma_x^2 + 3\tau^2}$$

$$\sigma_{perm} = \frac{R_{eH}}{\gamma_1 \gamma_2}$$

γ_1: Partial safety factor for material, to be taken as: $\gamma_1 = k\frac{R_{eH}}{235}$

γ_2: Partial safety factor for load combinations and permissible stress, to be taken as:

- $\gamma_2 = 1.24$, for bending strength assessment according to 3.3.2.
- $\gamma_2 = 1.13$, for shear stress assessment according to 3.3.3.

S11A.3.3.2 Bending strength assessment

The assessment of the bending stresses is to be carried out according to 3.3.1 at the following locations of the cross section:

- At bottom
- At deck
- At top of hatch coaming
- At any point where there is a change of steel yield strength

The following combination of hull girder stress as defined in 2.5 is to be considered:

$$\sigma_x = \sigma_{HG}$$

$$\tau = 0$$

S11A.3.3.3 Shear strength assessment

The assessment of shear stress is to be carried out according to 3.3.1 for all structural elements that contribute to the shear strength capability.

The following combination of hull girder stress as defined in 2.5 is to be considered:

$$\sigma_x = 0$$

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$\tau = \tau_{HG}$

S11A.4 Buckling strength

S11A.4.1 Application

These requirements apply to plate panels and longitudinal stiffeners subject to hull girder bending and shear stresses.

Definitions of symbols used in the present article S11A.4 are given in Annex 2 “Buckling Capacity”.

S11A.4.2 Buckling criteria

The acceptance criterion for the buckling assessment is defined as follows:

$$\eta_{act} \leq 1$$

where:

η_{act} : Maximum utilisation factor as defined in S11A 4.3.

S11A.4.3 Buckling utilisation factor

The utilisation factor, η_{act}, is defined as the inverse of the stress multiplication factor at failure γ_c, see figure 9.

$$\eta_{act} = \frac{1}{\gamma_c}$$

Failure limit states are defined in:

- Annex 2, 2 for elementary plate panels,
- Annex 2, 3 for overall stiffened panels,
- Annex 2, 4 for longitudinal stiffeners.

Each failure limit state is defined by an equation, and γ_c is to be determined such that it satisfies the equation.

Figure 9 illustrates how the stress multiplication factor at failure γ_c, of a structural member is determined for any combination of longitudinal and shear stress. Where:

σ_x, τ : Applied stress combination for buckling given in S11A.4.4.1

σ_c, τ_c : Critical buckling stresses to be obtained according to Annex 2 for the stress combination for buckling σ_x and τ.

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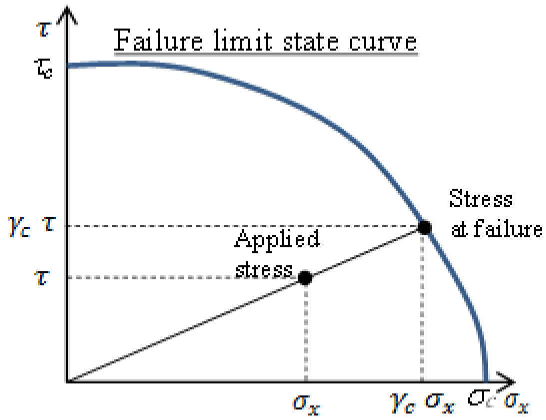

Figure 9: Example of failure limit state curve and stress multiplication factor at failure

S11A.4.4 Stress determination

S11A.4.4.1 Stress combinations for buckling assessment

The following two stress combinations are to be considered for each of the load cases "hogging" and "sagging" as defined in S11A.2.4. The stresses are to be derived at the load calculation points defined in S11A.4.4.2

a) Longitudinal stiffening arrangement:

Stress combination 1 with:

$$\sigma_x = \sigma_{HG}$$
$$\sigma_y = 0$$
$$\tau = 0.7\tau_{HG}$$

Stress combination 2 with:

$$\sigma_x = 0.7\sigma_{HG}$$
$$\sigma_y = 0$$
$$\tau = \tau_{HG}$$

b) Transverse stiffening arrangement:

Stress combination 1 with:

$$\sigma_x = 0$$
$$\sigma_y = \sigma_{HG}$$
$$\tau = 0.7\tau_{HG}$$

Stress combination 2 with:

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$$\sigma_x = 0$$
$$\sigma_y = 0.7\sigma_{HG}$$
$$\tau = \tau_{HG}$$

S11A.4.4.2 Load calculation points

The hull girder stresses for elementary plate panels (EPP) are to be calculated at the load calculation points defined in Table 4.

Table 4: Load calculation points (LCP) coordinates for plate buckling assessment

LCP coordinates	Hull girder bending stress		Hull girder shear stress
	Non horizontal plating	Horizontal plating	
x coordinate	Mid-length of the EPP		
y coordinate	Both upper and lower ends of the EPP (points A1 and A2 in Figure 10)	Outboard and inboard ends of the EPP (points A1 and A2 in Figure 10)	Mid-point of EPP (point B in Figure 10)
z coordinate	Corresponding to *x* and *y* values		

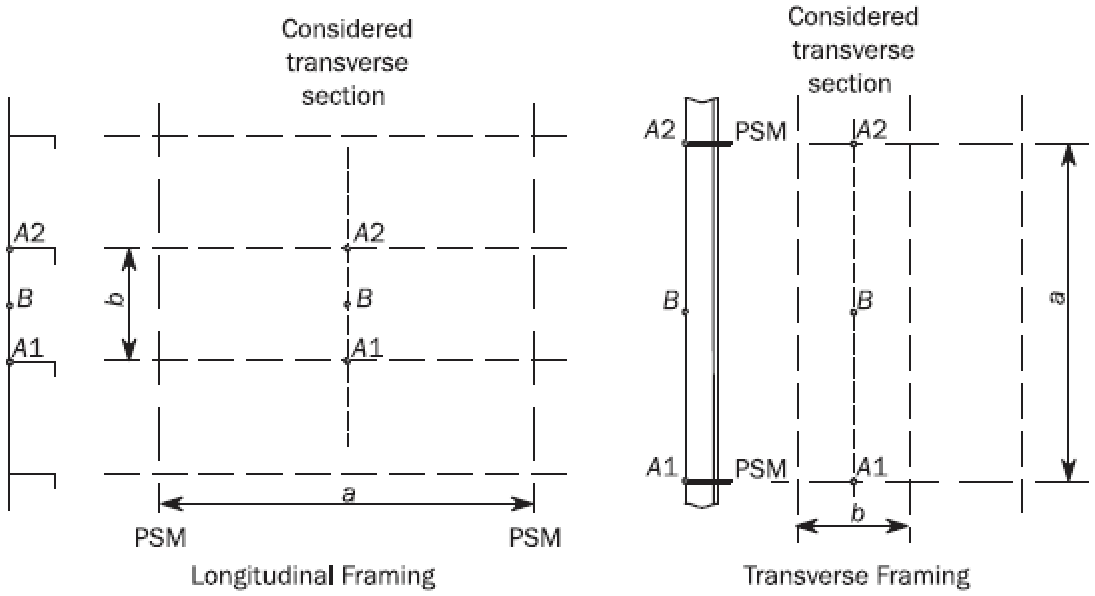

Figure 10: LCP for plate buckling – assessment, PSM stands for primary supporting members

The hull girder stresses for longitudinal stiffeners are to be calculated at the following load calculation point:

- at the mid length of the considered stiffener.
- at the intersection point between the stiffener and its attached plate.

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S11A.5 Hull girder ultimate strength

S11A.5.1 General

The hull girder ultimate strength is to be assessed for ships with length L equal or greater than 150m.

The acceptance criteria, given in 5.4 are applicable to intact ship structures.

The hull girder ultimate bending capacity is to be checked for the load cases “hogging” and “sagging” as defined in 2.4.

S11A.5.2 Hull girder ultimate bending moments

The vertical hull girder bending moment, M in hogging and sagging conditions, to be considered in the ultimate strength check is to be taken as:

$$M = \gamma_s M_s + \gamma_w M_w$$

where:

M_s = Permissible still water bending moment, in kNm, defined in 2.4

M_w = Vertical wave bending moment, in kNm, defined in 2.4.

γ_s = Partial safety factor for the still water bending moment, to be taken as:
$\gamma_s = 1.0$

γ_w = Partial safety factor for the vertical wave bending moment, to be taken as:
$\gamma_w = 1.2$

S11A.5.3 Hull girder ultimate bending capacity

S11A.5.3.1 General

The hull girder ultimate bending moment capacity, M_U is defined as the maximum bending moment capacity of the hull girder beyond which the hull structure collapses.

S11A.5.3.2 Determination of hull girder ultimate bending moment capacity

The ultimate bending moment capacities of a hull girder transverse section, in hogging and sagging conditions, are defined as the maximum values of the curve of bending moment M versus the curvature χ of the transverse section considered (M_{UH} for hogging condition and M_{US} for sagging condition, see Figure 11). The curvature χ is positive for hogging condition and negative for sagging condition.

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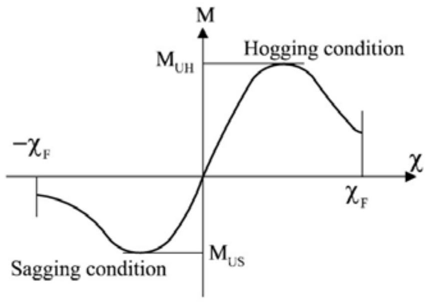

Figure 11: Bending moment *M* versus curvature *χ*

The hull girder ultimate bending moment capacity M_U is to be calculated using the incremental-iterative method as given in 2 of Annex 3 or using an alternative method as indicated in 3 of Annex 3.

S11A.5.4 Acceptance criteria

The hull girder ultimate bending capacity at any hull transverse section is to satisfy the following criteria:

$$M \leq \frac{M_U}{\gamma_M \gamma_{DB}}$$

where:

M = Vertical bending moment, in kNm, to be obtained as specified in 5.2.

M_U = Hull girder ultimate bending moment capacity, in kNm, to be obtained as specified in 5.3.

γ_M = Partial safety factor for the hull girder ultimate bending capacity, covering material, geometric and strength prediction uncertainties, to be taken as:
γ_M = 1.05

γ_{DB} = Partial safety factor for the hull girder ultimate bending moment capacity, covering the effect of double bottom bending, to be taken as:

- For hogging condition: γ_{DB} = 1.15
- For sagging condition: γ_{DB} = 1.0

For cross sections where the double bottom breadth of the inner bottom is less than that at amidships or where the double bottom structure differs from that at amidships (e.g. engine room sections), the factor γ_{DB} for hogging condition may be reduced based upon agreement with the Classification Society.

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S11A.6 Additional requirements for large container ships

S11A.6.1 General

The requirements in S11A.6.2 and S11A.6.3 are applicable, in addition to requirements in S11A.3 to S11A.5, to container ships with a breadth B greater than 32.26 m.

S11A.6.2 Yielding and buckling assessment

Yielding and buckling assessments are to be carried out in accordance with the Rules of the Classification Society, taking into consideration additional hull girder loads (wave torsion, wave horizontal bending and static cargo torque), as well as local loads. All in-plane stress components (i.e. bi-axial and shear stresses) induced by hull girder loads and local loads are to be considered.

S11A.6.3 Whipping

Hull girder ultimate strength assessment is to take into consideration the whipping contribution to the vertical bending moment according to the Classification Society procedures.

S11A (cont) Annex 1 – Calculation of shear flow

1. General

This annex describes the procedures of direct calculation of shear flow around a ship's cross section due to hull girder vertical shear force. The shear flow q_v at each location in the cross section, is calculated by considering the cross section is subjected to a unit vertical shear force of 1 N.

The unit shear flow per mm, q_v, in N/mm, is to be taken as:

$$q_v = q_D + q_I$$

where:

q_D : Determinate shear flow, as defined in 2.

q_I : Indeterminate shear flow which circulates around the closed cells, as defined in 3.

In the calculation of the unit shear flow, q_v, the longitudinal stiffeners are to be taken into account.

2. Determinate shear flow

The determinate shear flow, q_D, in N/mm at each location in the cross section is to be obtained from the following line integration:

$$q_D(s) = -\frac{1}{10^6 I_{y-net}} \int_0^s (z - z_n) t_{net} d_s$$

where:

s : Coordinate value of running coordinate along the cross section, in m.

I_{y-net} : Net moment of inertia of the cross section, in m^4.

t_{net} : Net thickness of plating, in mm.

z_n : Z coordinate of horizontal neutral axis from baseline, in m.

It is assumed that the cross section is composed of line segments as shown in Figure 1: where each line segment has a constant plate net thickness. The determinate shear flow is obtained by the following equation.

$$q_{Dk} = -\frac{t_{net}\ell}{2 \cdot 10^6 I_{Y-net}} (z_k + z_i - 2z_n) + q_{Di}$$

where:

q_{Dk}, q_{Di} : Determinate shear flow at node k and node i respectively , in N/mm.

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ℓ : Length of line segments, in m.

y_k, y_i : *Y* coordinate of the end points *k* and *i* of line segment, in m, as defined in Figure 1.

z_k, z_i : *Z* coordinate of the end points *k* and *i* of line segment, in m, as defined in Figure 1 .

Where the cross section includes closed cells, the closed cells are to be cut with virtual slits, as shown in Figure 2: in order to obtain the determinate shear flow.
These virtual slits must not be located in walls which form part of another closed cell.

Determinate shear flow at bifurcation points is to be calculated by water flow calculations, or similar, as shown in Figure 2.

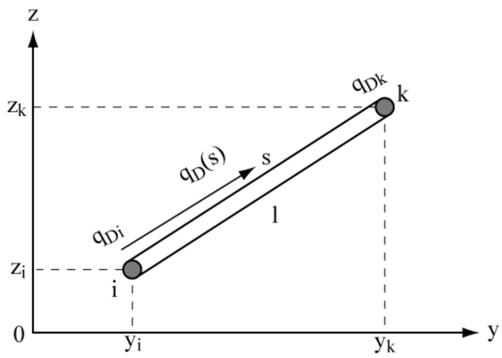

Figure 1: Definition of line segment

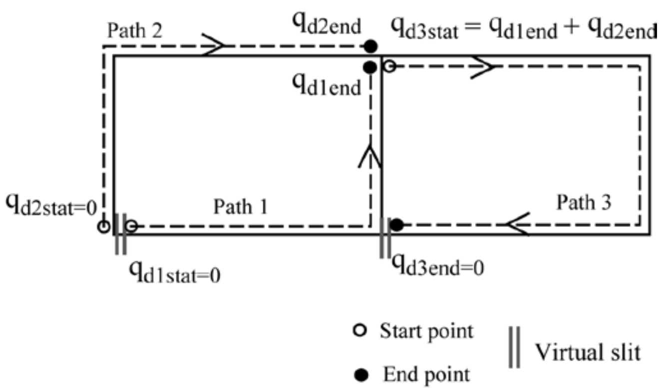

Figure 2: Placement of virtual slits and calculation of determinate shear flow at bifurcation points

3. Indeterminate shear flow

The indeterminate shear flow around closed cells of a cross section is considered as a constant value within the same closed cell. The following system of equation for determination of indeterminate shear flows can be developed. In the equations, contour integrations of several parameters around all closed cells are performed.

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$$q_{Ic}\oint_{C}\frac{1}{t_{net}}ds-\sum_{m=1}^{N_w}\left(q_{\mathrm{Im}}\oint_{c\&m}\frac{1}{t_{net}}ds\right)=-\oint_{c}\frac{q_D}{t_{net}}ds$$

where:

N_w : Number of common walls shared by cell c and all other cells.

c&m : Common wall shared by cells *c* and *m*

q_{Ic}, q_{Im} : Indeterminate shear flow around the closed cell *c* and *m* respectively, in N/mm.

Under the assumption of the assembly of line segments shown in Figure 1 and constant plate thickness of each line segment, the above equation can be expressed as follows:

$$q_{Ic}\sum_{j=1}^{N_c}\left(\frac{\ell}{t_{net}}\right)_j-\sum_{m=1}^{N_w}\left\{q_{\mathrm{Im}}\left[\sum_{j=1}^{N_m}\left(\frac{\ell}{t_{net}}\right)_j\right]_m\right\}=-\sum_{j=1}^{N_c}\phi_j$$

$$\phi_j=\left[-\frac{\ell^2}{6\cdot10^3 I_{Y-net}}(z_k+2z_i-3z_n)+\frac{\ell}{t_{net}}q_{Di}\right]_j$$

where:

N_c : Number of line segments in cell *c*.

N_m : Number of line segments on the common wall shared by cells *c* and *m*.

q_{Di} : Determinate shear flow, in N/mm, calculated according to Annex 1, 2.

The difference in the directions of running coordinates specified in Annex 1, 2 and in this section has to be considered.

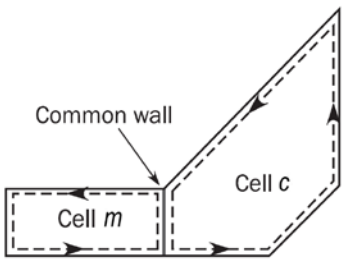

Figure 3: Closed cells and common wall

4. Computation of sectional properties

Properties of the cross section are to be obtained by the following formulae where the cross section is assumed as the assembly of line segments:

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$$\ell = \sqrt{(y_k - y_i)^2 + (z_k - z_i)^2}$$

$$a_{net} = 10^{-3} \ell t_{net} \qquad A_{net} = \sum a_{net}$$

$$s_{y-net} = \frac{a_{net}}{2}(z_k + z_i) \qquad s_{y-net} = \sum s_{y-net}$$

$$i_{y0-net} = \frac{a_{net}}{3}(z_k^2 + z_k z_i + z_i^2) \qquad I_{y0-net} = \sum i_{y0-net}$$

where:

a_{net}, A_{net}: Area of the line segment and the cross section respectively, in m^2.

s_{y-net}, s_{y-net}: First moment of the line segment and the cross section about the baseline, in m^3.

i_{y0-net}, I_{y0-net}: Moment of inertia of the line segment and the cross section about the baseline, in m^4.

The height of horizontal neutral axis, z_n, in m, is to be obtained as follows:

$$z_n = \frac{s_{y-net}}{A_{net}}$$

Inertia moment about the horizontal neutral axis, in m^4, is to be obtained as follows:

$$I_{y-net} = I_{y0-net} - z_n^2 A_{net}$$

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Annex 2 – Buckling Capacity

Symbols

x axis	: Local axis of a rectangular buckling panel parallel to its long edge.
y axis	: Local axis of a rectangular buckling panel perpendicular to its long edge.
σ_x	: Membrane stress applied in *x* direction, in N/mm^2.
σ_y	: Membrane stress applied in *y* direction, in N/mm^2.
τ	: Membrane shear stress applied in *xy* plane, in N/mm^2.
σ_a	: Axial stress in the stiffener, in N/mm²
σ_b	: Bending stress in the stiffener, in N/mm²
σ_w	: Warping stress in the stiffener, in N/mm²
$\sigma_{cx}, \sigma_{cy}, \tau_c$	: Critical stress, in N/mm^2, defined in [2.1.1] for plates.
R_{eH_S}	: Specified minimum yield stress of the stiffener, in N/mm²
R_{eH_P}	: Specified minimum yield stress of the plate, in N/mm²
a	: Length of the longer side of the plate panel as shown in Table 2, in mm.
b	: Length of the shorter side of the plate panel as shown in Table 2, in mm.
d	: Length of the side parallel to the axis of the cylinder corresponding to the curved plate panel as shown in Table 3, in mm.
σ_E	: Elastic buckling reference stress, in N/mm^2 to be taken as: • For the application of plate limit state according to [2.1.2]: $\sigma_E = \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t_p}{b}\right)^2$ • For the application of curved plate panels according to [2.2]: $\sigma_E = \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t_p}{d}\right)^2$
ν	: Poisson's ratio to be taken equal to 0.3
t_p	: Net thickness of plate panel, in mm
t_w	: Net stiffener web thickness, in mm
t_f	: Net flange thickness, in mm
b_f	: Breadth of the stiffener flange, in mm
h_w	: Stiffener web height, in mm
e_f	: Distance from attached plating to centre of flange, in mm, to be taken as: $e_f = h_w$ for flat bar profile. $e_f = h_w - 0.5\, t_f$ for bulb profile. $e_f = h_w + 0.5\, t_f$ for angle and Tee profiles.
α	: Aspect ratio of the plate panel, to be taken as $\alpha = \frac{a}{b}$
β	: Coefficient taken as $\beta = \frac{1-\psi}{\alpha}$
ψ	: Edge stress ratio to be taken as $\psi = \frac{\sigma_2}{\sigma_1}$
σ_1	: Maximum stress, in N/mm²
σ_2	: Minimum stress, in N/mm²
R	: Radius of curved plate panel, in mm
ℓ	: Span, in mm, of stiffener equal to the spacing between primary supporting members
s	: Spacing of stiffener, in mm, to be taken as the mean spacing between the stiffeners of the considered stiffened panel.

1. Elementary Plate Panel (EPP)

1.1 Definition

An Elementary Plate Panel (EPP) is the unstiffened part of the plating between stiffeners and/or primary supporting members.
All the edges of the elementary plate panel are forced to remain straight (but free to move in the in-plane directions) due to the surrounding structure/neighbouring plates (usually longitudinal stiffened panels in deck, bottom and inner-bottom plating, shell and longitudinal bulkheads).

1.2 EPP with different thicknesses

1.2.1 Longitudinally stiffened EPP with different thicknesses

In longitudinal stiffening arrangement, when the plate thickness varies over the width, b, in mm, of a plate panel, the buckling capacity is calculated on an equivalent plate panel width, having a thickness equal to the smaller plate thickness, t_1. The width of this equivalent plate panel, b_{eq}, in mm, is defined by the following formula:

$$b_{eq} = \ell_1 + \ell_2 \left(\frac{t_1}{t_2}\right)^{1.5}$$

where:

ℓ_1 : Width of the part of the plate panel with the smaller plate thickness, t_1, in mm, as defined in Figure 1.

ℓ_2 : Width of the part of the plate panel with the greater plate thickness, t_2, in mm, as defined in Figure 1.

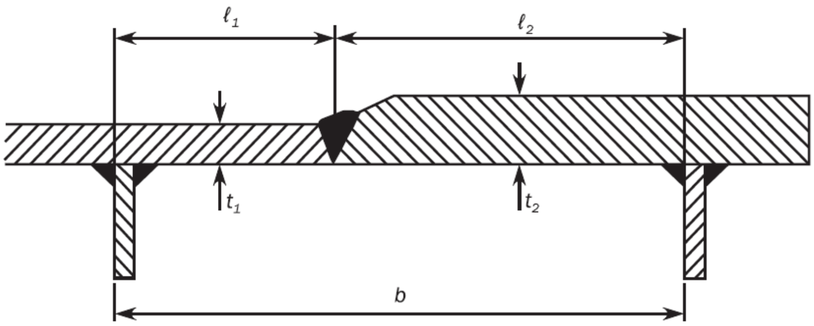

Figure 1: Plate thickness change over the width

1.2.2 Transversally stiffened EPP with different thicknesses

In transverse stiffening arrangement, when an EPP is made of different thicknesses, the buckling check of the plate and stiffeners is to be made for each thickness considered constant on the EPP.

2. Buckling capacity of plates

2.1 Plate panel

2.1.1 Plate limit state

The plate limit state is based on the following interaction formulae:

a) Longitudinal stiffening arrangement:

$$\left(\frac{\gamma_C \sigma_x}{\sigma_{cx}}\right)^{2/\beta_p^{0.25}} + \left(\frac{\gamma_C |\tau|}{\tau_c}\right)^{2/\beta_p^{0.25}} = 1$$

b) Transverse stiffening arrangement:

$$\left(\frac{\gamma_C \sigma_y}{\sigma_{cy}}\right)^{2/\beta_p^{0.25}} + \left(\frac{\gamma_C |\tau|}{\tau_c}\right)^{2/\beta_p^{0.25}} = 1$$

where:

σ_x, σ_y : Applied normal stress to the plate panel in N/mm², as defined in S11A 4.4, at load calculation points of the considered elementary plate panel.

τ : Applied shear stress to the plate panel, in N/mm², as defined in S11A 4.4, at load calculation points of the considered elementary plate panel.

σ_{cx} : Ultimate buckling stress in N/mm² in direction parallel to the longer edge of the buckling panel as defined in 2.1.3

σ_{cy} : Ultimate buckling stress in N/mm² in direction parallel to the shorter edge of the buckling panel as defined in 2.1.3

τ_c :Ultimate buckling shear stress, in N/mm² as defined in 2.1.3

β_p : Plate slenderness parameter taken as:

$$\beta_p = \frac{b}{t_p}\sqrt{\frac{R_{eH\_P}}{E}}$$

2.1.2 Reference degree of slenderness

The reference degree of slenderness is to be taken as:

$$\lambda = \sqrt{\frac{R_{eH\_P}}{K\sigma_E}}$$

where:

K : Buckling factor, as defined in Table 2 and Table 3.

2.1.3 Ultimate buckling stresses

The ultimate buckling stress of plate panels, in N/mm², is to be taken as:

$$\sigma_{cx} = C_x R_{eH\_P}$$

$$\sigma_{cy} = C_y R_{eH\_P}$$

The ultimate buckling stress of plate panels subject to shear, in N/mm², is to be taken as:

$$\tau_c = C_\tau \frac{R_{eH\_P}}{\sqrt{3}}$$

where:

C_x, C_y, $C\tau$: Reduction factors, as defined in Table 2

The boundary conditions for plates are to be considered as simply supported (see cases 1, 2 and 15 of Table 2). If the boundary conditions differ significantly from simple support, a more appropriate boundary condition can be applied according to the different cases of Table 2 subject to the agreement of the Classification Society.

2.1.4 Correction Factor F_{long}

The correction factor F_{long} depending on the edge stiffener types on the longer side of the buckling panel is defined in Table 1. An average value of F_{long} is to be used for plate panels having different edge stiffeners. For stiffener types other than those mentioned in Table 1, the value of *c* is to be agreed by the Society. In such a case, value of *c* higher than those mentioned in Table 1 can be used, provided it is verified by buckling strength check of panel using non-linear FE analysis and deemed appropriate by the Classification Society.

Table 1: Correction Factor F_{long}

<table>
<tr><th colspan="3">Structural element types</th><th>F_{long}</th><th>c</th></tr>
<tr><td colspan="3">Unstiffened Panel</td><td>1.0</td><td>N/A</td></tr>
<tr><td rowspan="6">Stiffened Panel</td><td colspan="2">Stiffener not fixed at both ends</td><td>1.0</td><td>N/A</td></tr>
<tr><td rowspan="5">Stiffener fixed at both ends</td><td>Flat bar [(1)]</td><td rowspan="4">$F_{long} = c + 1 \quad for \quad \frac{t_w}{t_p} > 1$
$F_{long} = c\left(\frac{t_w}{t_p}\right)^3 + 1 \quad for \quad \frac{t_w}{t_p} \le 1$</td><td>0.10</td></tr>
<tr><td>Bulb profile</td><td>0.30</td></tr>
<tr><td>Angle profile</td><td>0.40</td></tr>
<tr><td>T profile</td><td>0.30</td></tr>
<tr><td>Girder of high rigidity (e.g. bottom transverse)</td><td>1.4</td><td>N/A</td></tr>
<tr><td colspan="5">(1) t_w is the net web thickness, in mm, without the correction defined in 4.3.5</td></tr>
</table>

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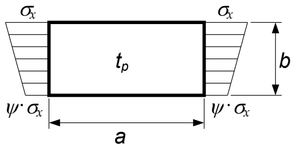
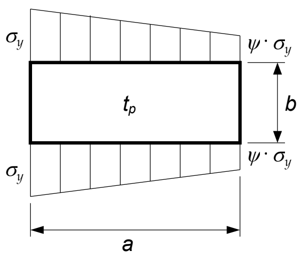
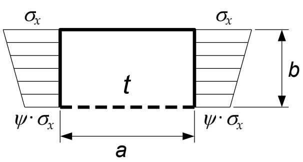
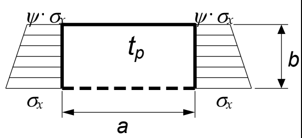
Table 2: Buckling Factor and reduction factor for plane plate panels

<table>
<tr><th>Case</th><th>Stress ratio ψ</th><th>Aspect ratio α</th><th>Buckling factor K</th><th>Reduction factor C</th></tr>
<tr><td rowspan="3">1
</td><td>$1 \geq \psi \geq 0$</td><td colspan="2">$K_x = F_{long} \frac{8.4}{\psi + 1.1}$</td><td rowspan="3">$C_x = 1$ for $\lambda \leq \lambda_c$
$C_x = c\left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right)$ for $\lambda > \lambda_c$
where:
$c = (1.25 - 0.12\psi) \leq 1.25$
$\lambda_c = \frac{c}{2}\left(1 + \sqrt{1 - \frac{0.88}{c}}\right)$</td></tr>
<tr><td>$0 > \psi > -1$</td><td colspan="2">$K_x = F_{long}\left[7.63 - \psi(6.26 - 10\psi)\right]$</td></tr>
<tr><td>$\psi \leq -1$</td><td colspan="2">$K_x = F_{long}\left[5.975(1-\psi)^2\right]$</td></tr>
<tr><td rowspan="7">2
</td><td rowspan="3">$1 \geq \psi \geq 0$</td><td colspan="2">$K_y = \frac{2\left(1 + \frac{1}{\alpha^2}\right)^2}{1 + \psi + \frac{(1-\psi)}{100}\left(\frac{2.4}{\alpha^2} + 6.9 f_1\right)}$</td><td rowspan="7">$C_y = c\left(\frac{1}{\lambda} - \frac{R + F^2(H - R)}{\lambda^2}\right)$
where:
$c = (1.25 - 0.12\psi) \leq 1.25$
$R = \lambda(1 - \lambda / c)$ for $\lambda < \lambda_c$
$R = 0.22$ for $\lambda \geq \lambda_c$
$\lambda_c = 0.5\, c\left(1 + \sqrt{1 - 0.88 / c}\right)$
$F = \left(1 - \left(\frac{K}{0.91} - 1\right) / \lambda_p^2\right) c_1 \geq 0$
$\lambda_p^2 = \lambda^2 - 0.5$ for $1 \leq \lambda_p^2 \leq 3$
$c_1 = \left(1 - \frac{1}{\alpha}\right) \geq 0$
$H = \lambda - \frac{2\lambda}{c(T + \sqrt{T^2 - 4})} \geq R$
$T = \lambda + \frac{14}{15\lambda} + \frac{1}{3}$</td></tr>
<tr><td>$\alpha \leq 6$</td><td>$f_1 = (1-\psi)(\alpha - 1)$</td></tr>
<tr><td>$\alpha > 6$</td><td>$f_1 = 0.6\left(1 - \frac{6\psi}{\alpha}\right)\left(\alpha + \frac{14}{\alpha}\right)$
But not greater than $14.5 - \frac{0.35}{\alpha^2}$</td></tr>
<tr><td rowspan="4">$0 > \psi \geq 1 - 4\alpha/3$</td><td colspan="2">$K_y = \frac{200(1 + \beta^2)^2}{(1 - f_3)(100 + 2.4\beta^2 + 6.9 f_1 + 23 f_2)}$</td></tr>
<tr><td>$\alpha > 6(1-\psi)$</td><td>$f_1 = 0.6\left(\frac{1}{\beta} + 14\beta\right)$
but not greater than $14.5 - 0.35\beta^2$
$f_2 = f_3 = 0$</td></tr>
<tr><td>$3(1-\psi) \leq \alpha \leq 6(1-\psi)$</td><td>$f_1 = \frac{1}{\beta} - 1$
$f_2 = f_3 = 0$</td></tr>
<tr><td>$1.5(1-\psi) \leq \alpha < 3(1-\psi)$</td><td>$f_1 = \frac{1}{\beta} - (2 - \omega\beta)^4 - 9(\omega\beta - 1)\left(\frac{2}{3} - \beta\right)$
$f_2 = f_3 = 0$</td></tr>
</table>

S11A
(cont)

Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
		$1-\psi \le \alpha < 1.5(1-\psi)$	For $\alpha > 1.5$: $f_1 = 2\left(\frac{1}{\beta} - 16\left(1 - \frac{\omega}{3}\right)^4\right)\left(\frac{1}{\beta} - 1\right)$ $f_2 = 3\beta - 2$ $f_3 = 0$ For $\alpha \le 1.5$: $f_1 = 2\left(\frac{1.5}{1-\psi} - 1\right)\left(\frac{1}{\beta} - 1\right)$ $f_2 = \frac{\psi(1 - 16 f_4^2)}{1-\alpha}$ $f_3 = 0$ $f_4 = (1.5\text{-}Min(1.5;\alpha))^2$	
		$0.75(1-\psi) \le \alpha < 1-\psi$	$f_1 = 0$ $f_2 = 1 + 2.31(\beta - 1) - 48\left(\frac{4}{3} - \beta\right) f_4^2$ $f_3 = 3 f_4 (\beta - 1)\left(\frac{f_4}{1.81} - \frac{\alpha - 1}{1.31}\right)$ $f_4 = (1.5\text{-}Min(1.5;\alpha))^2$	
	$\psi < 1-4\alpha/3$		$K_y = 5.972 \frac{\beta^2}{1-f_3}$ where: $f_3 = f_5\left(\frac{f_5}{1.81} + \frac{1+3\psi}{5.24}\right)$ $f_5 = \frac{9}{16}(1 + Max(-1;\psi))^2$	
3  	$1 \ge \psi \ge 0$		$K_x = \frac{4(0.425 + 1/\alpha^2)}{3\psi + 1}$	
	$0 > \psi \ge -1$		$K_x = 4(0.425 + 1/\alpha^2)(1+\psi)$ $-5\psi(1 - 3.42\psi)$	$C_x = 1$ for $\lambda \le 0.7$ $C_x = \frac{1}{\lambda^2 + 0.51}$ for $\lambda > 0.7$
4  	$1 \ge \psi \ge -1$		$K_x = \left(0.425 + \frac{1}{\alpha^2}\right)\frac{3-\psi}{2}$	

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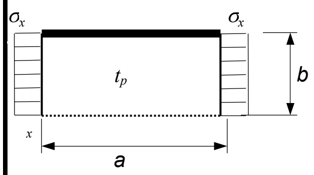
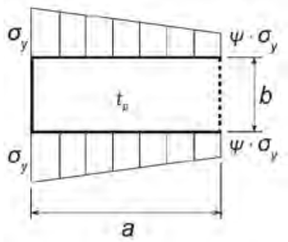
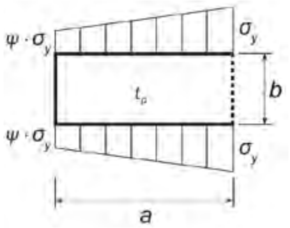
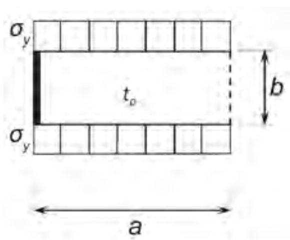
(cont)

Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
5 	—	$\alpha \geq 1.64$	$K_x = 1.28$	
		$\alpha < 1.64$	$K_x = \frac{1}{\alpha^2} + 0.56 + 0.13\alpha^2$	
6 	$1 \geq \psi \geq 0$		$K_y = \frac{4(0.425 + \alpha^2)}{(3\psi + 1)\alpha^2}$	$C_y = 1$ for $\lambda \leq 0.7$ $C_y = \frac{1}{\lambda^2 + 0.51}$ for $\lambda > 0.7$
	$0 > \psi \geq -1$		$K_y = 4(0.425 + \alpha^2)(1 + \psi)\frac{1}{\alpha^2}$ $-5\psi(1 - 3.42\psi)\frac{1}{\alpha^2}$	
7 	$1 \geq \psi \geq -1$		$K_y = (0.425 + \alpha^2)\frac{(3 - \psi)}{2\alpha^2}$	
8 	-		$K_y = 1 + \frac{0.56}{\alpha^2} + \frac{0.13}{\alpha^4}$	

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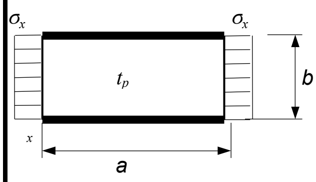
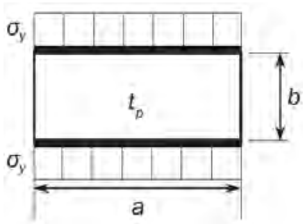
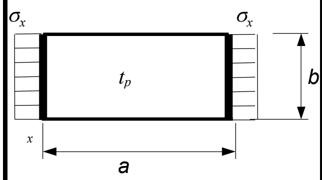
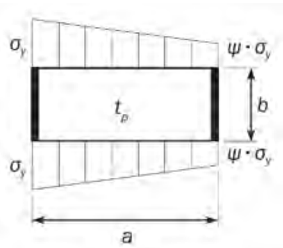
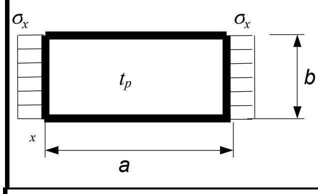
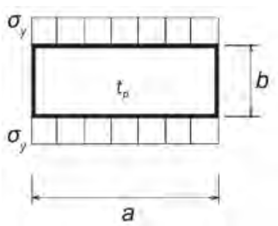
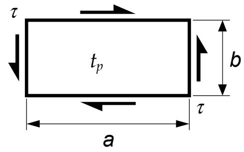
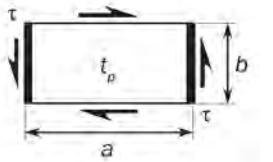
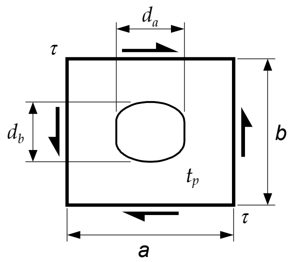
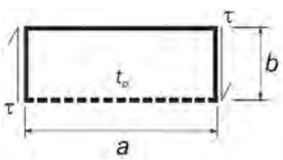
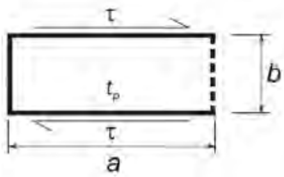
(cont)

Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
9 	-		$K_x = 6.97$	$C_x = 1$ for $\lambda \le 0.83$ $C_x = 1{,}13\left[\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right]$ for $\lambda > 0.83$
10 	-		$K_y = 4 + \frac{2.07}{\alpha^2} + \frac{0.67}{\alpha^4}$	
11 	-	$\alpha \ge 4$	$K_x = 4$	
		$\alpha < 4$	$K_x = 4 + 2.74\left(\frac{4-\alpha}{3}\right)^4$	
12 	-		$K_y = K_y$ determined as per case 2	• For $\alpha < 2$: $C_y = C_{y2}$ • For $\alpha \ge 2$: $C_y = \left(1.06 + \frac{1}{10\alpha}\right) C_{y2}$ where: C_{y2}= C_y determined as per case 2
13 	-	$\alpha \ge 4$	$K_x = 6.97$	$C_x = 1$ for $\lambda \le 0.83$ $C_x = 1{,}13\left[\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right]$ for $\lambda > 0.83$
		$\alpha < 4$	$K_x = 6.97 + 3.1\left(\frac{4-\alpha}{3}\right)^4$	
14 	-		$K_y = \frac{6.97}{\alpha^2} + \frac{3.1}{\alpha^2}\left[\frac{4 - 1/\alpha}{3}\right]^4$	$C_y = 1$ for $\lambda \le 0.83$ $C_y = 1.13\left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right)$ for $\lambda > 0.83$

S11A
(cont)

Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
15 	-		$K_\tau = \sqrt{3}\left[5.34 + \frac{4}{\alpha^2}\right]$	$C_\tau = 1$ for $\lambda \le 0.84$ $C_\tau = \frac{0.84}{\lambda}$ for $\lambda > 0.84$
16 	-		$K_\tau = \sqrt{3}\left\{5.34 + Max\left[\frac{4}{\alpha^2};\frac{7.15}{\alpha^{2.5}}\right]\right\}$	
17 	-		$K = K'r$ K' = K according to case 15. r = opening reduction factor taken as $r = \left(1 - \frac{d_a}{a}\right)\left(1 - \frac{d_b}{b}\right)$ with $\frac{d_a}{a} \le 0.7$ and $\frac{d_b}{b} \le 0.7$	
18 	-		$K_\tau = 3^{0.5}(0.6 + 4/\alpha^2)$	$C_\tau = 1$ for $\lambda \le 0.84$ $C_\tau = \frac{0.84}{\lambda}$ for $\lambda > 0.84$
19 	-		$K_\tau = 8$	

Edge boundary conditions:

- - - - - - - - - Plate edge free.

———— Plate edge simply supported.

———— Plate edge clamped.

Notes:

1) Cases listed are general cases. Each stress component (σx, σy) is to be understood in local coordinates.

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(cont)

2.2 Curved plate panels

This requirement for curved plate limit state is applicable when $R/t_p \le 2500$. Otherwise, the requirement for plate limit state given in 2.1.1 is applicable.

The curved plate limit state is based on the following interaction formula:

$$\left(\frac{\gamma_c \sigma_{ax}}{C_{ax} R_{eH\_P}}\right)^{1.25} + \left(\frac{\gamma_c \tau \sqrt{3}}{C_\tau R_{eH\_P}}\right)^{2} = 1.0$$

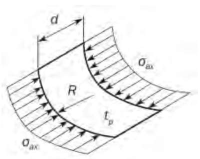
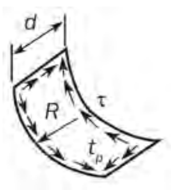
where:

σ_{ax} : Applied axial stress to the cylinder corresponding to the curved plate panel, in N/mm². In case of tensile axial stresses, σ_{ax}=0.

C_{ax}, C_τ : Buckling reduction factor of the curved plate panel, as defined in Table 3.

The stress multiplier factor γ_c of the curved plate panel needs not be taken less than the stress multiplier factor γ_c for the expanded plane panel according to 2.1.1.

Table 3: Buckling Factor and reduction factor for curved plate panel with $R/t_p \le 2500$

Case	Aspect ratio	Buckling factor K	Reduction factor C
1 	$\frac{d}{R} \le 0.5\sqrt{\frac{R}{t_p}}$	$K = 1 + \frac{2}{3}\frac{d^2}{Rt_p}$	For general application: $C_{ax} = 1$ for $\lambda \le 0.25$ $C_{ax} = 1.233 - 0.933\lambda$ for $0.25<\lambda\le 1$ $C_{ax} = 0.3/\lambda^3$ for $1<\lambda\le 1.5$ $C_{ax} = 0.2/\lambda^2$ for $\lambda>1.5$ For curved single fields, e.g. bilge strake, which are bounded by plane panels: $C_{ax} = 0.65/\lambda^2 \le 1.0$
	$\frac{d}{R} > 0.5\sqrt{\frac{R}{t_p}}$	$K = 0.267\frac{d^2}{Rt_p}\left[3 - \frac{d}{R}\sqrt{\frac{t_p}{R}}\right]$ $\ge 0.4\frac{d^2}{Rt_p}$	
2 	$\frac{d}{R} \le 8.7\sqrt{\frac{R}{t_p}}$	$K = \sqrt{3}\sqrt{28.3 + \frac{0.67d^3}{R^{1.5}t_p^{1.5}}}$	$C_\tau = 1$ for $\lambda \le 0.4$ $C_\tau = 1.274 - 0.686\lambda$ for $0.4 < \lambda \le 1.2$ $C_\tau = 0.65/\lambda^2$ for $\lambda > 1.2$
	$\frac{d}{R} > 8.7\sqrt{\frac{R}{t_p}}$	$K = \sqrt{3}\frac{0.28d^2}{R\sqrt{Rt_p}}$	
Explanations for boundary conditions: ——— Plate edge simply supported.			

3 Buckling capacity of overall stiffened panel

The elastic stiffened panel limit state is based on the following interaction formula:

$$\frac{P_z}{c_f} = 1$$

where P_z and c_f are defined in 4.4.3.

4 Buckling capacity of longitudinal stiffeners

4.1 Stiffeners limit states

The buckling capacity of longitudinal stiffeners is to be checked for the following limit states:

- Stiffener induced failure (*SI*).
- Associated plate induced failure (*PI*).

4.2 Lateral pressure

The lateral pressure is to be considered as constant in the buckling strength assessment of longitudinal stiffeners.

4.3 Stiffener idealization

4.3.1 Effective length of the stiffener ℓ_{eff}

The effective length of the stiffener ℓ_{eff}, in mm, is to be taken equal to:

$\ell_{eff} = \frac{\ell}{\sqrt{3}}$ for stiffener fixed at both ends.

$\ell_{eff} = 0.75\ell$ for stiffener simply supported at one end and fixed at the other.

$\ell_{eff} = \ell$ for stiffener simply supported at both ends.

4.3.2 Effective width of the attached plating b_{eff1}

The effective width of the attached plating of a stiffener b_{eff1}, in mm, without the shear lag effect is to be taken equal to:

$$b_{eff1} = \frac{C_{x1}b_1 + C_{x2}b_2}{2}$$

where:

C_{x1}, C_{x2} : Reduction factor defined in Table 2 calculated for the EPP1 and EPP2 on each side of the considered stiffener according to case 1.

b_1, b_2 : Width of plate panel on each side of the considered stiffener, in mm.

4.3.3 Effective width of attached plating b_{eff}

The effective width of attached plating of stiffeners, b_{eff}, in mm, is to be taken as:

$$b_{eff} = min\left(b_{eff1}, \chi_s s\right)$$

where:

χ_s : Effective width coefficient to be taken as:

- $\chi_s = min\left[\frac{1.12}{1+\frac{1.75}{\left(\frac{\ell_{eff}}{s}\right)^{1.6}}}; 1\right]$ for $\frac{\ell_{eff}}{s} \geq 1$
- $\chi_s = 0.407\frac{\ell_{eff}}{s}$ for $\frac{\ell_{eff}}{s} < 1$

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(cont)

4.3.4 Net thickness of attached plating t_p

The net thickness of plate $\boldsymbol{t_p}$, in mm, is to be taken as the mean thickness of the two attached plating panels.

4.3.5 Effective web thickness of flat bar

For accounting the decrease of stiffness due to local lateral deformation, the effective web thickness of flat bar stiffener, in mm, is to be used for the calculation of the net sectional area, A_s, the net section modulus, Z, and the moment of inertia, I, of the stiffener and is taken as:

$$t_{w\_red} = t_w\left(1 - \frac{2\pi^2}{3}\left(\frac{h_w}{s}\right)^2\left(1 - \frac{b_{eff1}}{s}\right)\right)$$

4.3.6 Net section modulus Z of a stiffener

The net section modulus Z of a stiffener, in cm^3, including effective width of plating b_{eff} is to be taken equal to:

- the section modulus calculated at the top of stiffener flange for stiffener induced failure (*SI*).
- the section modulus calculated at the attached plating for plate induced failure (*PI*).

4.3.7 Net moment of inertia I of a stiffener

The net m*oment* of inertia I, in cm^4, of a stiffener including effective width of attached plating b_{eff} is to comply with the following requirement:

$$I \geq \frac{s\, t_p^3}{12 \cdot 10^4}$$

4.3.8 Idealisation of bulb profile

Bulb profiles may be considered as equivalent angle profiles. The net dimensions of the equivalent built-up section are to be obtained, in mm, from the following formulae.

$$h_w = h'_w - \frac{h'_w}{9.2} + 2$$

$$b_f = \alpha\left(t'_w + \frac{h'_w}{6.7} - 2\right)$$

$$t_f = \frac{h'_w}{9.2} - 2$$

$$t_w = t'_w$$

where:

h'_w, t'_w : Net height and thickness of a bulb section, in mm, as shown in Figure 2.

α : Coefficient equal to:

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(cont)

$\alpha = 1.1 + \frac{(120 - h'_w)^2}{3000}$ for $h'_w \le 120$

$\alpha = 1.0$ for $h'_w > 120$

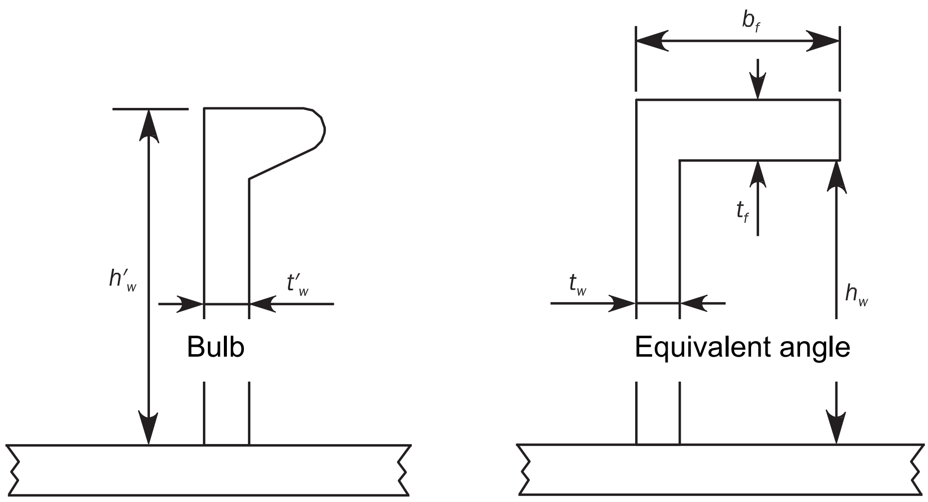

Figure 2: Idealisation of bulb stiffener

4.4 Ultimate buckling capacity

4.4.1 Longitudinal stiffener limit state

When $\sigma_a + \sigma_b + \sigma_w > 0$, the ultimate buckling capacity for stiffeners is to be checked according to the following interaction formula:

$$\frac{\gamma_c \, \sigma_a + \sigma_b + \sigma_w}{R_{eH}} = 1$$

where:

σ_a : Effective axial stress, in N/mm², at mid-span of the stiffener, defined in 4.4.2.

σ_b : Bending stress in the stiffener, in N/mm^2, defined in 4.4.3.

σ_w : Stress due to torsional deformation, in N/mm^2, defined in 4.4.4.

R_{eH} : Specified minimum yield stress of the material, in N/mm^2:

- $R_{eH} = R_{eH-S}$ for stiffener induced failure (*SI*).
- $R_{eH} = R_{eH-P}$ for plate induced failure (*PI*).

S11A
(cont)

4.4.2 Effective axial stress σ_a

The effective axial stress σ_a, in N/mm², at mid-span of the stiffener, acting on the stiffener with its attached plating is to be taken equal to:

$$\sigma_a = \sigma_x \frac{s\,t_p + A_s}{b_{eff1}\,t_p + A_s}$$

where:

σ_x : Nominal axial stress, in N/mm^2, acting on the stiffener with its attached plating, calculated according to S11A. 4.4.1 a) at load calculation point of the stiffener.

A_s : Net sectional area, in mm^2, of the considered stiffener.

4.4.3 Bending stress σ_b

The bending stress in the stiffener σ_b, in N/mm², is to be taken equal to:

$$\sigma_b = \frac{M_0 + M_1}{Z} 10^{-3}$$

where:

M_1 : Bending moment, in Nmm, due to the lateral load P:

$M_1 = C_i \frac{|P| s \ell^2}{24} 10^{-3}$ for continuous stiffener

$M_1 = C_i \frac{|P| s \ell^2}{8} 10^{-3}$ for sniped stiffener

P : Lateral load, in kN/m^2, to be taken equal to the static pressure at the load calculation point of the stiffener.

C_i : Pressure coefficient:

$C_i = C_{SI}$ for stiffener induced failure (*SI*).

$C_i = C_{PI}$ for plate induced failure (*PI*).

C_{PI} : Plate induced failure pressure coefficient:

C_{PI} = 1 if the lateral pressure is applied on the side opposite to the stiffener.

C_{PI} = -1 if the lateral pressure is applied on the same side as the stiffener.

C_{SI} : Stiffener induced failure pressure coefficient:

C_{SI} = -1 if the lateral pressure is applied on the side opposite to the stiffener.

C_{SI} = 1 if the lateral pressure is applied on the same side as the stiffener.

M_0 : Bending moment, in Nm, due to the lateral deformation *w* of stiffener:

$$M_0 = F_E \left(\frac{P_z w}{c_f - P_z} \right) \quad \text{with} \quad c_f - P_z > 0 .$$

F_E : Ideal elastic buckling force of the stiffener, in N.

$$F_E = \left(\frac{\pi}{\ell}\right)^2 EI\, 10^4$$

P_z : Nominal lateral load, in N/mm^2, acting on the stiffener due to stresses σ_x and τ, in the attached plating in way of the stiffener mid span:

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(cont)

$$P_z = \frac{t_p}{s}\left(\sigma_{x\ell}\left(\frac{\pi\, s}{\ell}\right)^2 + \sqrt{2}\,\tau_1\right)$$

$\sigma_{x\ell} = \gamma_c \sigma_x \left(1 + \frac{A_s}{s t_p}\right)$ but not but not less than 0

$\tau_1 = \left(\gamma_c |\tau| - t_p \sqrt{R_{eH-p}\, E\left(\frac{m_1}{a^2} + \frac{m_2}{s^2}\right)}\right) \geq 0$ but not less than 0

m₁, m₂: Coefficients taken equal to:

- m_1 = 1.47, m_2 = 0.49 for $\alpha \geq 2$.
- m_1 = 1.96, m_2 = 0.37 for $\alpha < 2$.

w : Deformation of stiffener, in mm, taken equal to:

$$w = w_0 + w_1$$

w_0 : Assumed imperfection, in mm, taken equal to:

- $w = \ell\, 10^{-3}$ in general
- $w_0 = -w_{na}$ for stiffeners sniped at both ends, considering stiffener induced failure (*SI*)
- $w_0 = w_{na}$ for stiffeners sniped at both ends, considering plate induced failure (*PI*)

w_{na} : Distance, in mm, from the mid-point of attached plating to the neutral axis of the stiffener calculated with the effective width of the attached plating b_{eff}.

w_1 : Deformation of stiffener at midpoint of stiffener span due to lateral load *P*, in mm. In case of uniformly distributed load, w_1 is to be taken as:

- $w_1 = C_i \frac{|P| s\, \ell^4}{384\, EI} 10^{-7}$ in general
- $w_1 = C_i \frac{5\, |P| s\, \ell^4}{384\, EI} 10^{-7}$ for stiffener sniped at both ends

c_f : Elastic support provided by the stiffener, in N/mm^2, to be taken equal to:

$$c_f = F_E \left(\frac{\pi}{\ell}\right)^2 (1 + c_p)$$

c_p : Coefficient to be taken as:

$$c_p = \frac{1}{1 + \frac{0.91}{c_{xa}}\left(\frac{12 I 10^4}{s t_p^3} - 1\right)}$$

c_{xa} : Coefficient to be taken as:

$c_{xa} = \left(\frac{\ell}{2s} + \frac{2s}{\ell}\right)^2$ for $\ell \geq 2s$

$c_{xa} = \left(1 + \left(\frac{\ell}{2s}\right)^2\right)^2$ for $\ell < 2s$

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(cont)

4.4.4 Stress due to torsional deformation σ_w

The stress due to torsional deformation σ_w, in N/mm^2, is to be taken equal to:

$$\sigma_w = E\, y_w \left(\frac{t_f}{2} + h_w\right) \Phi_0 \left(\frac{\pi}{\ell}\right)^2 \left(\frac{1}{1 - \frac{0.4\, R_{eH-S}}{\sigma_{ET}}} - 1\right)$$ for stiffener induced failure (*SI*).

$$\sigma_w = 0$$ for plate induced failure (*PI*).

where:

γ_w : Distance, in mm, from centroid of stiffener cross-section to the free edge of stiffener flange, to be taken as:

$$\gamma_w = \frac{t_w}{2}$$ for flat bar.

$$y_w = b_f - \frac{h_w t_w^2 + t_f b_f^2}{2 A_s}$$ for angle and bulb profiles.

$$y_w = \frac{b_f}{2}$$ for Tee profile.

$$\Phi_0 = \frac{\ell}{h_w} 10^{-3}$$

σ_{ET} : Reference stress for torsional buckling, in N/mm^2:

$$\sigma_{ET} = \frac{E}{I_P}\left(\frac{\varepsilon\, \pi^2\, I_\omega}{\ell^2} 10^2 + 0.385 I_T\right)$$

I_P : Net polar moment of inertia of the stiffener about point C as shown in Figure 3, as defined in Table 4, in cm^4.

I_T : Net St. Venant's moment of inertia of the stiffener, as defined in Table 4, in cm^4.

I_ω : Net sectional moment of inertia of the stiffener about point C as shown in Figure 3, as defined in Table 4, in cm^6.

ε : Degree of fixation.

$$\varepsilon = 1 + \frac{\left(\frac{\ell}{\pi}\right)^2 10^{-3}}{\sqrt{I_\omega \left(\frac{0.75\, s}{t_p^{\,3}} + \frac{e_f - 0.5 t_f}{t_w^{\,3}}\right)}}$$

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Table 4: Moments of inertia

	Flat bars	Bulb, angle and Tee profiles
I_P	$\dfrac{h_w^3\, t_w}{3 \cdot 10^4}$	$\left(\dfrac{A_w (e_f - 0.5 t_f)^2}{3} + A_f\, e_f^2\right) 10^{-4}$
I_T	$\dfrac{h_w t_w^3}{3 \cdot 10^4}\left(1 - 0.63 \dfrac{t_w}{h_w}\right)$	$\dfrac{(e_f - 0.5 t_f) t_w^3}{3 \cdot 10^4}\left(1 - 0.63 \dfrac{t_w}{e_f - 0.5 t_f}\right)$ + $\dfrac{b_f t_f^3}{3 \cdot 10^4}\left(1 - 0.63 \dfrac{t_f}{b_f}\right)$
I_ω	$\dfrac{h_w^3\, t_w^3}{36 \cdot 10^6}$	$\dfrac{A_f e_f^2 b_f^2}{12 \cdot 10^6}\left(\dfrac{A_f + 2.6 A_w}{A_f + A_w}\right)$ for bulb and angle profiles. $\dfrac{b_f^3 t_f e_f^2}{12 \cdot 10^6}$ for Tee profiles.

A_w : Net web area, in mm^2.
A_f : Net flange area, in mm^2.

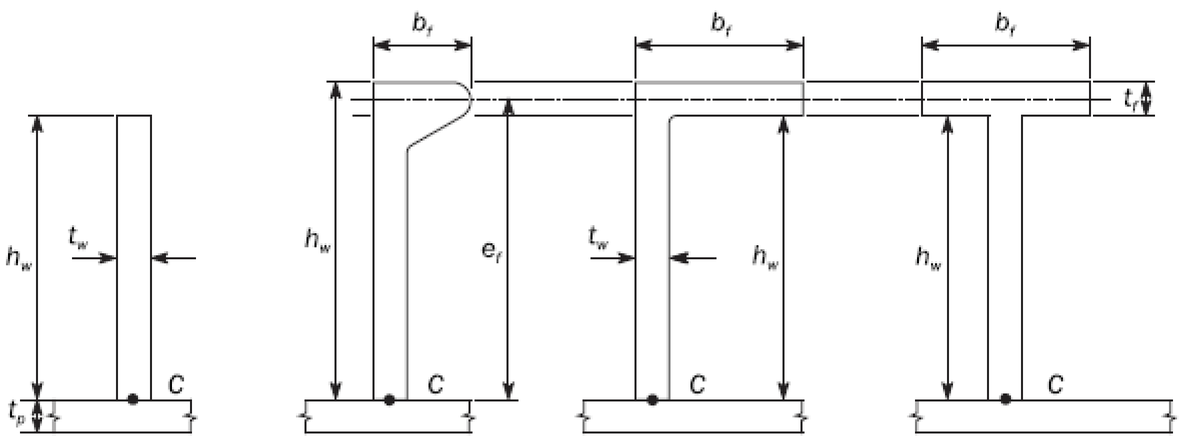

Figure 3: Stiffener cross sections

S11A Annex 3 - Hull girder ultimate bending capacity

(Cont)

Symbols

$I_{y\text{-}net}$: Net moment of inertia, in m^4, of the hull transverse section around its horizontal neutral axis

$Z_{B\text{-}net}$, $Z_{D\text{-}net}$: Section moduli, in m^3, at bottom and deck, respectively,

R_{eH_S}: Minimum yield stress, in N/mm^2, of the material of the considered stiffener.

R_{eH_P}: Minimum yield stress, in N/mm^2, of the material of the considered plate.

$A_{s\text{-}net}$: Net sectional area, in cm^2, of stiffener, without attached plating.

$A_{p\text{-}net}$: Net sectional area, in cm^2, of attached plating.

1. General Assumptions

1.1
The method for calculating the ultimate hull girder capacity is to identify the critical failure modes of all main longitudinal structural elements.

1.2
Structures compressed beyond their buckling limit have reduced load carrying capacity. All relevant failure modes for individual structural elements, such as plate buckling, torsional stiffener buckling, stiffener web buckling, lateral or global stiffener buckling and their interactions, are to be considered in order to identify the weakest inter-frame failure mode.

2. Incremental-iterative method

2.1 Assumptions

In applying the incremental-iterative method, the following assumptions are generally to be made:

- The ultimate strength is calculated at hull transverse sections between two adjacent transverse webs.
- The hull girder transverse section remains plane during each curvature increment.
- The hull material has an elasto-plastic behaviour.
- The hull girder transverse section is divided into a set of elements, see 2.2.2, which are considered to act independently.

According to the iterative procedure, the bending moment M_i acting on the transverse section at each curvature value χ_i is obtained by summing the contribution given by the stress σ acting on each element. The stress σ corresponding to the element strain, ε is to be obtained for each curvature increment from the non-linear load-end shortening curves σ-ε of the element.

These curves are to be calculated, for the failure mechanisms of the element, from the formulae specified in 2.3. The stress σ is selected as the lowest among the values obtained from each of the considered load-end shortening curves σ-ε.

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The procedure is to be repeated until the value of the imposed curvature reaches the value χ_F in m^{-1}, in hogging and sagging condition, obtained from the following formula:

$$X_F = \pm 0.003 \frac{M_y}{EI_{y-net}}$$

where:

M_y: Lesser of the values M_{Y1} and M_{Y2}, in kNm.

$M_{Y1} = 10^3 R_{eH} Z_{B\text{-}net}$.

$M_{Y2} = 10^3 R_{eH} Z_{D\text{-}net}$.

If the value χ_F is not sufficient to evaluate the peaks of the curve M-χ, the procedure is to be repeated until the value of the imposed curvature permits the calculation of the maximum bending moments of the curve.

2.2 Procedure

2.2.1 General

The curve M-χ is to be obtained by means of an incremental-iterative approach, summarised in the flow chart in Figure 1.

In this procedure, the ultimate hull girder bending moment capacity, M_U is defined as the peak value of the curve with vertical bending moment M versus the curvature χ of the ship cross section as shown in Figure 1. The curve is to be obtained through an incremental-iterative approach.

Each step of the incremental procedure is represented by the calculation of the bending moment M_i which acts on the hull transverse section as the effect of an imposed curvature χ_i.

For each step, the value χ_i is to be obtained by summing an increment of curvature, $\Delta\chi$ to the value relevant to the previous step χ_{i-1}. This increment of curvature corresponds to an increment of the rotation angle of the hull girder transverse section around its horizontal neutral axis.

This rotation increment induces axial strains ε in each hull structural element, whose value depends on the position of the element. In hogging condition, the structural elements above the neutral axis are lengthened, while the elements below the neutral axis are shortened, and vice-versa in sagging condition.

The stress σ induced in each structural element by the strain ε is to be obtained from the load-end shortening curve σ-ε of the element, which takes into account the behaviour of the element in the non-linear elasto-plastic domain.

The distribution of the stresses induced in all the elements composing the hull transverse section determines, for each step, a variation of the neutral axis position due to the nonlinear σ-ε, relationship. The new position of the neutral axis relevant to the step considered is to be obtained by means of an iterative process, imposing the equilibrium among the stresses acting in all the hull elements on the transverse section.

Once the position of the neutral axis is known and the relevant element stress distribution in the section is obtained, the bending moment of the section M_i around the new position of the

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neutral axis, which corresponds to the curvature χ_i imposed in the step considered, is to be obtained by summing the contribution given by each element stress.

The main steps of the incremental-iterative approach described above are summarised as follows (see also Figure 1):

a) Step 1: Divide the transverse section of hull into stiffened plate elements.

b) Step 2: Define stress-strain relationships for all elements as shown in Table 1.

c) Step 3: Initialise curvature χ_1 and neutral axis for the first incremental step with the value of incremental curvature (i.e. curvature that induces a stress equal to 1% of yield strength in strength deck) as:

$$\chi_{1.} = \Delta\chi = 0.01 \frac{R_{eH}}{E} \frac{1}{z_D - z_n}$$

where:

z_D: Z coordinate, in m, of strength deck at side.

z_n: Z coordinate, in m, of horizontal neutral axis of the hull transverse section with respect to the reference coordinate system defined in S11A.1.2.3

d) Step 4: Calculate for each element the corresponding strain, $\varepsilon_i = \chi(z_i - z_n)$ and the corresponding stress σ_i

e) Step 5: Determine the neutral axis z_{NA_cur} at each incremental step by establishing force equilibrium over the whole transverse section as:

$\Sigma A_{i\text{-}net}\ \sigma_i = \Sigma A_{j\text{-}net}\ \sigma_j$ (*i*-th element is under compression, *j*-th element under tension).

f) Step 6: Calculate the corresponding moment by summing the contributions of all elements as:

$$M_U = \sum \sigma_{Ui} A_{i-net} \left|(z_i - z_{NA\_cur})\right|$$

g) Step 7: Compare the moment in the current incremental step with the moment in the previous incremental step. If the slope in M-χ relationship is less than a negative fixed value, terminate the process and define the peak value M_U. Otherwise, increase the curvature by the amount of $\Delta\chi$ and go to Step 4.

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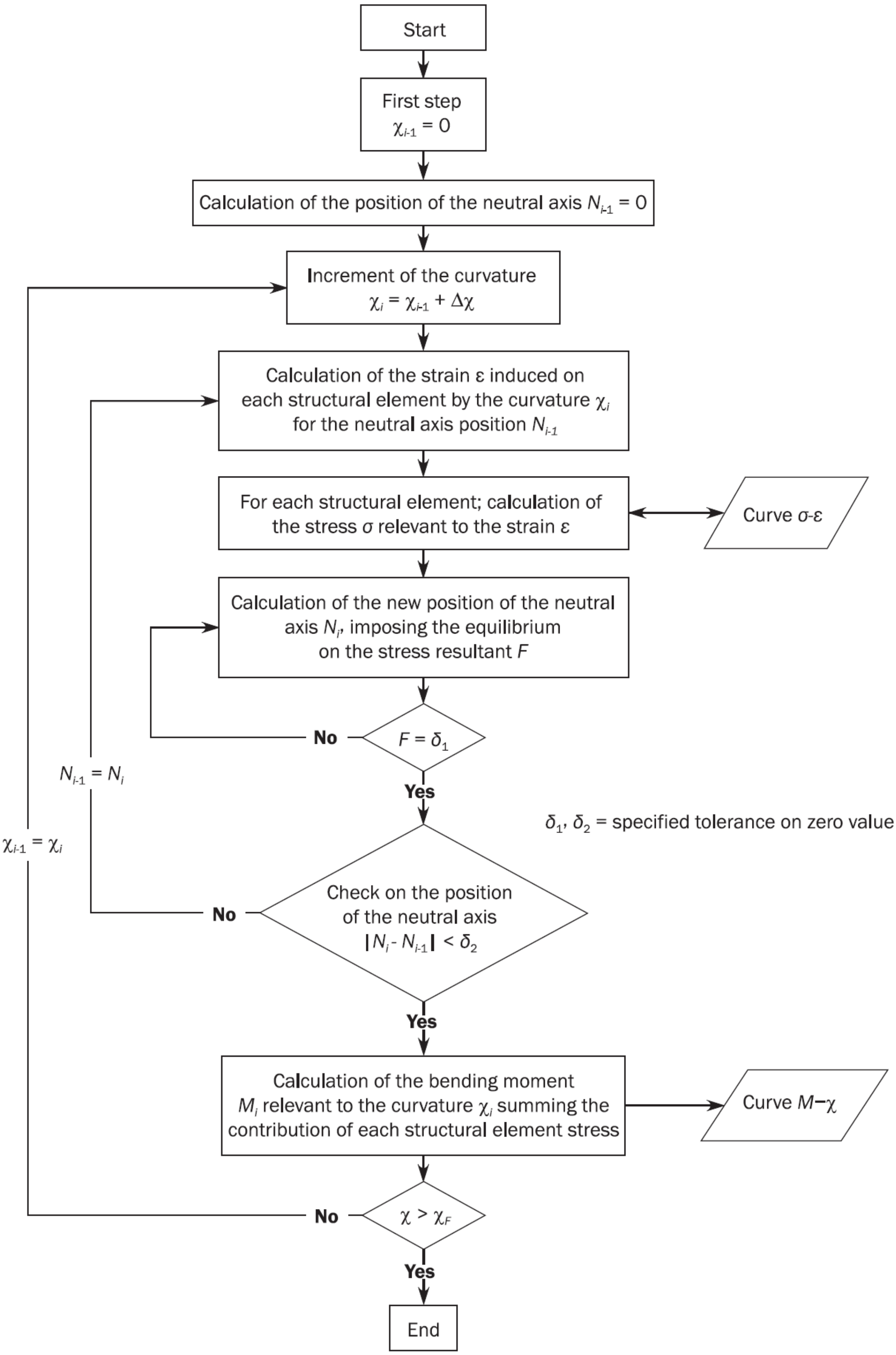

Figure 1: Flow chart of the procedure for the evaluation of the curve $M_{-\chi}$

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2.2.2 Modelling of the hull girder cross section

Hull girder transverse sections are to be considered as being constituted by the members contributing to the hull girder ultimate strength.

Sniped stiffeners are also to be modelled, taking account that they do not contribute to the hull girder strength.

The structural members are categorised into a stiffener element, a stiffened plate element or a hard corner element.

The plate panel including web plate of girder or side stringer is idealised into a stiffened plate element, an attached plate of a stiffener element or a hard corner element.

The plate panel is categorised into the following two kinds:

- Longitudinally stiffened panel of which the longer side is in ship's longitudinal direction, and
- Transversely stiffened panel of which the longer side is in the perpendicular direction to ship's longitudinal direction.

a) Hard corner element:

Hard corner elements are sturdier elements composing the hull girder transverse section, which collapse mainly according to an elasto-plastic mode of failure (material yielding); they are generally constituted by two plates not lying in the same plane.

The extent of a hard corner element from the point of intersection of the plates is taken equal to 20 t_{net} on a transversely stiffened panel and to 0.5 s on a longitudinally stiffened panel, see Figure 2.

where:

t_{net} : Net thickness of the plate, in mm.

s: Spacing of the adjacent longitudinal stiffener, in m.

Bilge, sheer strake-deck stringer elements, girder-deck connections and face plate-web connections on large girders are typical hard corners.

b) Stiffener element:

The stiffener constitutes a stiffener element together with the attached plate.

The attached plate width is in principle:

- Equal to the mean spacing of the stiffener when the panels on both sides of the stiffener are longitudinally stiffened, or
- Equal to the width of the longitudinally stiffened panel when the panel on one side of the stiffener is longitudinally stiffened and the other panel is of the transversely stiffened, see Figure 2.

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c) Stiffened plate element:

The plate between stiffener elements, between a stiffener element and a hard corner element or between hard corner elements is to be treated as a stiffened plate element, see Figure 2.

The typical examples of modelling of hull girder section are illustrated in Figure 3. Notwithstanding the foregoing principle, these figures are to be applied to the modelling in the vicinity of upper deck, sheer strake and hatch coaming.

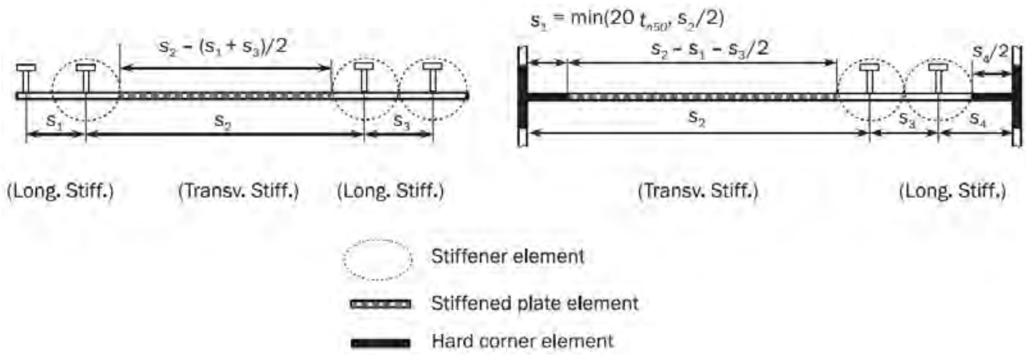

Figure 2: Extension of the breadth of the attached plating and hard corner element

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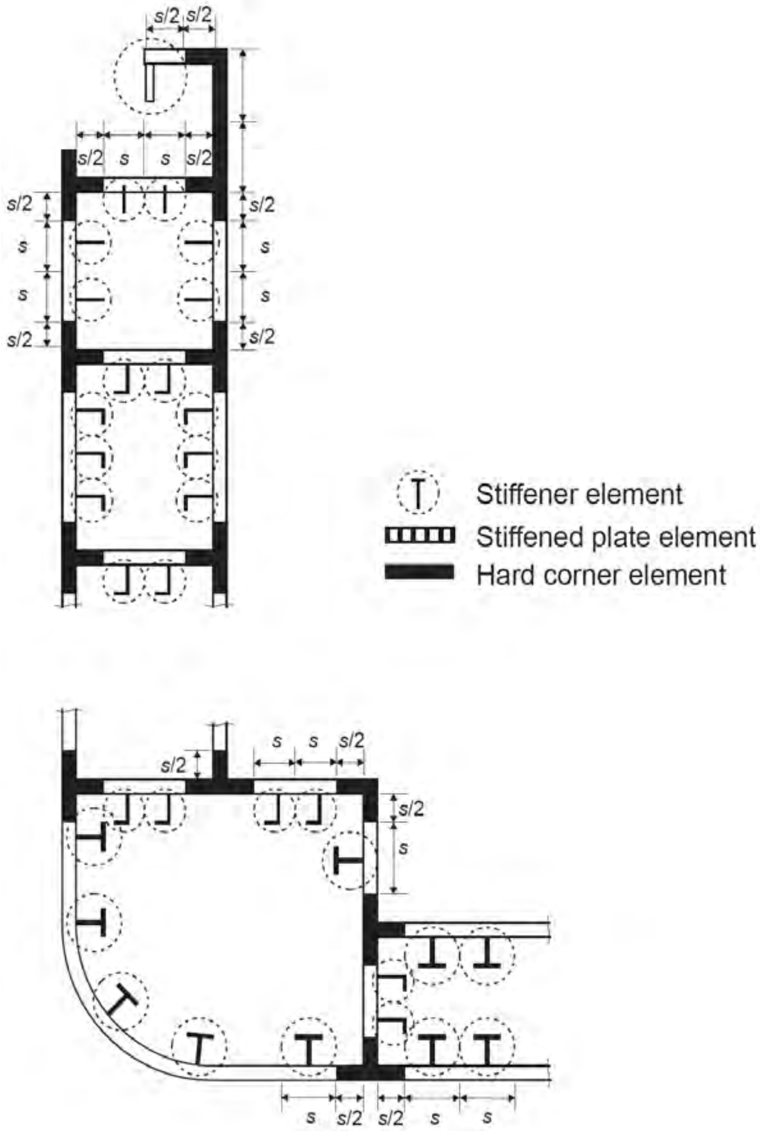

Figure 3: Examples of the configuration of stiffened plate elements, stiffener elements and hard corner elements on a hull section

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- In case of the knuckle point as shown in Figure 4, the plating area adjacent to knuckles in the plating with an angle greater than 30 degrees is defined as a hard corner. The extent of one side of the corner is taken equal to 20 t_{net} on transversely framed panels and to 0.5 s on longitudinally framed panels from the knuckle point.
- Where the plate members are stiffened by non-continuous longitudinal stiffeners, the non- continuous stiffeners are considered only as dividing a plate into various elementary plate panels.
- Where the opening is provided in the stiffened plate element, the openings are to be considered in accordance with the requirements of the Classification Society.
- Where attached plating is made of steels having different thicknesses and/or yield stresses, an average thickness and/or average yield stress obtained from the following formula are to be used for the calculation.

$$t_{net} = \frac{t_{1-net}s_1 + t_{2-net}s_2}{s} \qquad R_{eH\_P} = \frac{R_{eH\_P1}t_{1-net}s_1 + R_{eH\_P2}t_{2-net}s_2}{t_{net}s}$$

where R_{eH_P1}, R_{eH_P2}, t_{1-net}, t_{2-net}, s_1, s_2 and s are shown in Figure 5

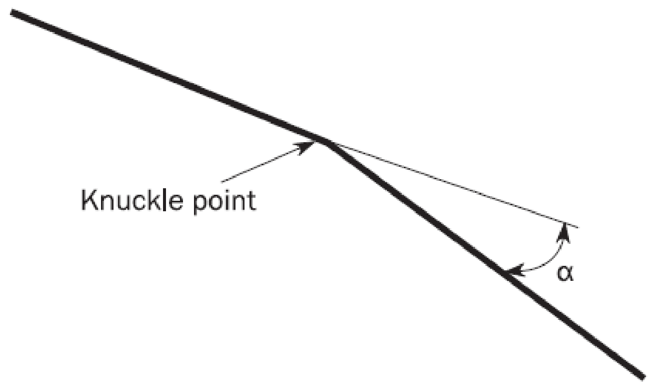

Figure 4: Plating with knuckle point

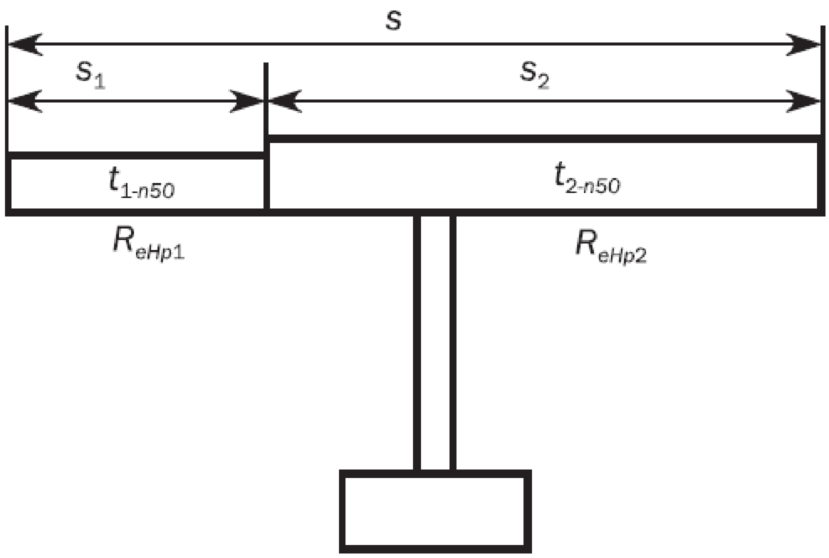

Figure 5: Element with different thickness and yield strength

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2.3 Load-end shortening curves

2.3.1 Stiffened plate element and stiffener element

Stiffened plate element and stiffener element composing the hull girder transverse sections may collapse following one of the modes of failure specified in Table 1.

- Where the plate members are stiffened by non-continuous longitudinal stiffeners, the stress of the element is to be obtained in accordance with 2.3.2 to 2.3.7, taking into account the non-continuous longitudinal stiffener.

In calculating the total forces for checking the hull girder ultimate strength, the area of non-continuous longitudinal stiffener is to be assumed as zero.

- Where the opening is provided in the stiffened plate element, the considered area of the stiffened plate element is to be obtained by deducting the opening area from the plating in calculating the total forces for checking the hull girder ultimate strength.

- For stiffened plate element, the effective width of plate for the load shortening portion of the stress-strain curve is to be taken as full plate width, i.e. to the intersection of other plate or longitudinal stiffener – neither from the end of the hard corner element nor from the attached plating of stiffener element, if any. In calculating the total forces for checking the hull girder ultimate strength, the area of the stiffened plate element is to be taken between the hard corner element and the stiffener element or between the hard corner elements, as applicable.

Table 1: Modes of failure of stiffened plate element and stiffener element

Element	**Mode of failure**	**Curve σ-ε defined in**
Lengthened stiffened plate element or stiffener element	Elasto-plastic collapse	2.3.2
Shortened stiffener element	Beam column buckling Torsional buckling Web local buckling of flanged profiles Web local buckling of flat bars	2.3.3, 2.3.4, 2.3.5, 2.3.6
Shortened stiffened plate element	Plate buckling	2.3.7

2.3.2 Elasto-plastic collapse of structural elements (Hard corner element)

The equation describing the load-end shortening curve σ-ε for the elasto-plastic collapse of structural elements composing the hull girder transverse section is to be obtained from the following formula.

$$\sigma = \Phi R_{eHA}$$

where:

R_{eHA}: Equivalent minimum yield stress, in N/mm^2, of the considered element, obtained by the following formula:

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$$R_{eHA} = \frac{R_{eH\_P} A_{p-net} + R_{eH\_S} A_{s-net}}{A_{p-net} + A_{s-net}}$$

Φ: Edge function, equal to:

Φ = -1 for ε < -1
Φ = ε for -1 ≤$\varepsilon \leq 1$
Φ = 1 for ε > 1

ε: Relative strain, equal to:

$$\varepsilon = \frac{\varepsilon_E}{\varepsilon_Y}$$

ε_E : Element strain.

ε_Y : Strain at yield stress in the element, equal to:

$$\varepsilon_y = \frac{R_{eHA}}{E}$$

2.3.3 Beam column buckling

The positive strain portion of the average stress – average strain curve $\sigma_{CR1-\varepsilon}$ based on beam column buckling of plate-stiffener combinations is described according to the following:

$$\sigma_{CR1} = \phi \sigma_{C1} \frac{A_{s-net} + A_{pE-net}}{A_{s-net} + A_{p-net}}$$

where:

Φ: Edge function, as defined in 2.3.2.

σ_{C1}: Critical stress, in N/mm^2, equal to:

$$\sigma_{C1} = \frac{\sigma_{E1}}{\varepsilon} \quad \text{for} \quad \sigma_{E1} \leq \frac{R_{eHB}}{2}\varepsilon$$

$$\sigma_{C1} = R_{eHB}\left(1 - \frac{R_{eHB}\varepsilon}{4\sigma_{E1}}\right) \quad \text{for} \quad \sigma_{E1} > \frac{R_{eHB}}{2}\varepsilon$$

R_{eHB}: Equivalent minimum yield stress, in N/mm^2, of the considered element, obtained by the following formula:

$$R_{eHB} = \frac{R_{eH\_p} A_{pEI-net} \ell_{pE} + R_{eH\_S} A_{s-net} \ell_{sE}}{A_{pEI-net} \ell_{pE} + A_{s-net} \ell_{sE}}$$

$A_{pEI-net}$: Effective area, in cm^2, equal to:

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$$A_{pEI-net} = 10 b_{E1} t_{net}$$

ℓ_{pE}: Distance, in mm, measured from the neutral axis of the stiffener with attached plate of width b_{E1} to the bottom of the attached plate

ℓ_{sE}: Distance, in mm, measured from the neutral axis of the stiffener with attached plate of width b_{E1} to the top of the stiffener

ε: Relative strain, as defined in 2.3.2

σ_{E1}: Euler column buckling stress, in N/mm^2, equal to:

$$\sigma_{E1} = \pi^2 E \frac{I_{E-net}}{A_{E-net}\ell^2} 10^{-4}$$

I_{E-net}: Net moment of inertia of stiffeners, in cm^4, with attached plate of width b_{E1}

A_{E-net}: Net area, in cm^2, of stiffeners with attached plating of width b_E

b_{E1}: Effective width corrected for relative strain, in m, of the attached plating, equal to:

$$b_{E1} = \frac{s}{\beta_E} \quad \text{for } \beta_E > 1.0$$

$$b_{E1} = s \quad \text{for } \beta_E \le 1.0$$

β_E: $$\beta_E = 10^3 \frac{s}{t_{net}} \sqrt{\frac{\varepsilon R_{eH\_P}}{E}}$$

A_{pE-net}: Net area, in cm^2, of attached plating of width $b_{E,}$ equal to:

$$A_{pE-net} = 10 b_E t_{net}$$

b_E: Effective width, in m, of the attached plating, equal to:

$$b_E = \left(\frac{2.25}{\beta_E} - \frac{1.25}{\beta_E^2}\right) s \quad \text{for } \beta_E > 1.25$$

$$b_E = s \quad \text{for } \beta_E \le 1.25$$

2.3.4 Torsional buckling

The load-end shortening curve $\sigma_{CR2-\varepsilon}$ for the flexural-torsional buckling of stiffeners composing the hull girder transverse section is to be obtained according to the following formula:

$$\sigma_{CR2} = \phi \frac{A_{s-net}\sigma_{C2} + A_{p-net}\sigma_{CP}}{A_{s-net} + A_{p-net}}$$

where:

Φ: Edge function, as defined in 2.3.2

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(cont)

σ_{C2}: Critical stress, in N/mm^2, equal to:

$$\sigma_{C2} = \frac{\sigma_{E2}}{\varepsilon} \quad \text{for } \sigma_{E2} \le \frac{R_{eH\_S}}{2}\varepsilon$$

$$\sigma_{C2} = R_{eH\_S}\left(1 - \frac{R_{eH\_S}\varepsilon}{4\sigma_{E2}}\right) \quad \text{for } \sigma_{E2} > \frac{R_{eH\_S}}{2}\varepsilon$$

ε: Relative strain, as defined in 2.3.2

σ_{E2}: Euler column buckling stress, in N/mm^2, taken as σ_{ET} defined in Annex 2 4.4.4

σ_{CP}: Buckling stress of the attached plating, in N/mm^2, equal to:

$$\sigma_{CP} = \left(\frac{2.25}{\beta_E} - \frac{1.25}{\beta_E^2}\right) R_{eH\_P} \quad \text{for } \beta_E > 1.25$$

$$\sigma_{CP} = R_{eH\_P} \quad \text{for } \beta_E \le 1.25$$

β_E: Coefficient, as defined in 2.3.3

2.3.5 Web local buckling of stiffeners made of flanged profiles

The load-end shortening curve $\sigma_{CR3-\varepsilon}$ for the web local buckling of flanged stiffeners composing the hull girder transverse section is to be obtained from the following formula:

$$\sigma_{CR3} = \phi \frac{10^3 b_E t_{net} R_{eH\_P} + (h_{we} t_{w-net} + b_f t_{f-net}) R_{eH\_s}}{10^3 s t_{net} + h_w t_{w-net} + b_f t_{f-net}}$$

where:

Φ: Edge function, as defined in 2.3.2

b_E: Effective width, in m, of the attached plating, as defined in 2.3.3

h_{we}: Effective height, in mm, of the web, equal to:

$$h_{we} = \left(\frac{2.25}{\beta_w} - \frac{1.25}{\beta_w^2}\right) h_w \quad \text{for } \beta_w \ge 1.25$$

$$h_{we} = h_w \quad \text{for } \beta_w < 1.25$$

β_w: $$\beta_w = \frac{h_w}{t_{w-net}} \sqrt{\frac{\varepsilon R_{eH\_s}}{E}}$$

ε: Relative strain, as defined in 2.3.2

2.3.6 Web local buckling of stiffeners made of flat bars

The load-end shortening curve $\sigma_{CR4-\varepsilon}$ for the web local buckling of flat bar stiffeners composing the hull girder transverse section is to be obtained from the following formula:

S11A (cont)

$$\sigma_{CR4} = \phi \frac{A_{p-net}\sigma_{CP} + A_{s-net}\sigma_{C4}}{A_{p-net} + A_{s-net}}$$

where:

Φ: Edge function, as defined in 2.3.2.

σ_{CP}: Buckling stress of the attached plating, in N/mm^2, as defined in 2.3.4.

σ_{C4}: Critical stress, in N/mm^2, equal to:

$$\sigma_{C4} = \frac{\sigma_{E4}}{\varepsilon} \quad \text{for } \sigma_{E4} \le \frac{R_{eH\_S}}{2}\varepsilon$$

$$\sigma_{C4} = R_{eH\_S}\left(1 - \frac{R_{eH\_S}\varepsilon}{4\sigma_{E4}}\right) \quad \text{for } \sigma_{E4} > \frac{R_{eH\_S}}{2}\varepsilon$$

σ_{E4}: Local Euler buckling stress, in N/mm^2, equal to:

$$\sigma_{E4} = 160000\left(\frac{t_{w-net}}{h_w}\right)^2$$

ε: Relative strain, as defined in 2.3.2.

2.3.7 Plate buckling

The load-end shortening curve $\sigma_{CR5-\varepsilon}$ for the buckling of transversely stiffened panels composing the hull girder transverse section is to be obtained from the following formula:

$$\sigma_{CR5} = \min\left\{\Phi R_{eH\_P}\left[\frac{s}{\ell}\left(\frac{2.25}{\beta_E} - \frac{1.25}{\beta_E^2}\right)^{R_{eH\_P}\Phi} + 0.1\left(1 - \frac{s}{\ell}\right)\left(1 + \frac{1}{\beta_E^2}\right)^2\right]\right\}$$

where:

Φ: Edge function, as defined in 2.3.2.

β_E: Coefficient as defined in 2.3.3.

s: Plate breadth, in m, taken as the spacing between the stiffeners.

ℓ: Longer side of the plate, in m.

3. Alternative methods

3.1 General

3.1.1
Application of alternative methods is to be agreed by the Society prior to commencement. Documentation of the analysis methodology and detailed comparison of its results are to be

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submitted for review and acceptance. The use of such methods may require the partial safety factors to be recalibrated.

3.1.2
The bending moment-curvature relationship, M-χ, may be established by alternative methods. Such models are to consider all the relevant effects important to the non-linear response with due considerations of:

a) Non-linear geometrical behaviour.

b) Inelastic material behaviour.

c) Geometrical imperfections and residual stresses (geometrical out-of-flatness of plate and stiffeners).

d) Simultaneously acting loads:

- Bi-axial compression.
- Bi-axial tension.
- Shear and lateral pressure.

e) Boundary conditions.

f) Interactions between buckling modes.

g) Interactions between structural elements such as plates, stiffeners, girders, etc.

h) Post-buckling capacity.

i) Overstressed elements on the compression side of hull girder cross section possibly leading to local permanent sets/buckle damages in plating, stiffeners etc. (double bottom effects or similar).

3.2 Non-linear finite element analysis

3.2.1
Advanced non-linear finite element analyses models may be used for the assessment of the hull girder ultimate capacity. Such models are to consider the relevant effects important to the non-linear responses with due consideration of the items listed in 3.1.2.

3.2.2
Particular attention is to be given to modelling the shape and size of geometrical imperfections. It is to be ensured that the shape and size of geometrical imperfections trigger the most critical failure modes.

End of Document

S11 Longitudinal Strength Standard

(1989)
(Rev.1 1993)
(Rev.2 Nov 2001)
(Rev.3 June 2003)
(Rev.4 July 2004)
(Rev.5 Jan 2006)
(Rev.6 May 2010)
(Rev.7 Nov 2010)
(Rev.8 June 2015)

S11.1 Application

This requirement applies only to steel ships of length 90 m and greater in unrestricted service. For ships having one or more of the following characteristics, special additional considerations may be applied by each Classification Society.

(i)	Proportion	$L/B \le 5$	$B/D \ge 2.5$
(ii)	Length	$L \ge 500$ m	
(iii)	Block coefficient	$Cb < 0.6$	
(iv)	Large deck opening		
(v)	Ships with large flare		
(vi)	Carriage of heated cargoes		
(vii)	Unusual type or design		

For bulk carriers with notation BC-A, BC-B or BC-C, as defined in UR S25, this UR is to be complied with by ships contracted for construction on or after 1 July 2003. For other ships, this revision of this UR is to be complied with by ships contracted for construction on or after 1 July 2004.

This UR does not apply to CSR Bulk Carriers and Oil Tankers or to container ships to which UR S11A is applicable.

S11.2 Loads

S11.2.1 Still water bending moment and shear force

S11.2.1.1 General

Still water bending moments, *Ms* (kN-m), and still water shear forces, *Fs* (kN), are to be calculated at each section along the ship length for design cargo and ballast loading conditions as specified in S11.2.1.2.

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

Notes:

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

2. Changes introduced in Rev.5 of this UR are to be uniformly applied by IACS Societies on ships contracted for construction on or after 1 July 2006.

3. Changes introduced in Rev.7 of this UR are to be uniformly implemented by IACS Members on ships contracted for construction on or after 1 July 2011.

4. Changes introduced in Rev.8 of this UR are to be uniformly implemented by IACS Members on ships contracted for construction on or after 1 July 2016.

S11
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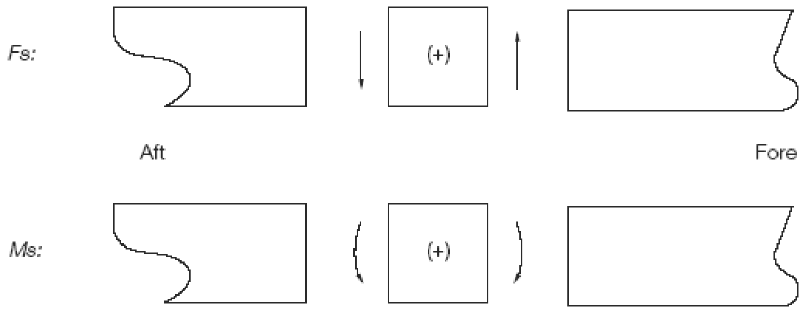


Fig.1 Sign Conventions of *Ms* and *Fs*

S11.2.1.2 Design loading conditions

In general, the following design cargo and ballast loading conditions, based on amount of bunker, fresh water and stores at departure and arrival, are to be considered for the *Ms* and *Fs* calculations. Where the amount and disposition of consumables at any intermediate stage of the voyage are considered more severe, calculations for such intermediate conditions are to 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 are to be submitted and where approved included in the loading manual for guidance.

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

- Homogeneous 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-homogeneous cargo conditions, deck cargo conditions, etc., where applicable;
- All loading conditions specified in UR S25 Section 4 for bulk carriers with notation BC-A, BC-B or BC-C, as applicable.

Oil tankers:

- Homogeneous 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.

Chemical tankers:

- Conditions as specified for oil tankers;
- Conditions for high density or segregated cargo.

Liquefied gas carriers:

- Homogeneous loading conditions for all approved cargoes;
- Ballast conditions;
- Cargo conditions where one or more tanks are empty or partially filled or where more than one type of cargo having significantly different densities are carried.

S11
(cont)

Combination Carriers:

- Conditions as specified for oil tankers and cargo ships.

S11.2.1.3 Partially filled ballast tanks in ballast loading conditions

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

- design stress limits are satisfied for all filling levels between empty and full, and
- for bulk carriers, UR S17, as applicable, is complied with for all filling levels between empty and full.

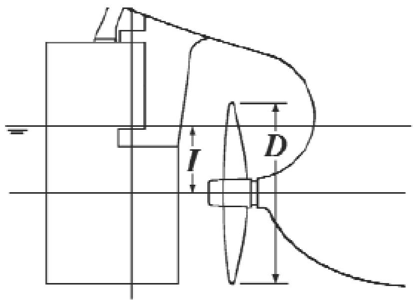
To demonstrate compliance with all filling levels between empty and full, it will be acceptable if, in each condition at departure, arrival and where required by S11.2.1.2 any intermediate condition, the tanks intended to be partially filled are assumed to be:

- empty
- full
- partially filled at intended level

Where multiple tanks are intended to be partially filled, all combinations of empty, 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 are to be considered between empty and full. The trim conditions mentioned above are:

- trim by stern of 3% of the ship's length, or
- trim by bow of 1.5% of ship's length, or
- any trim that cannot maintain propeller immersion *(I/D)* not less than 25%,
  where,
  I = the distance from propeller centreline to the waterline
  D = propeller diameter
  (see the following figure)



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

S11 (cont)

S11.2.1.4 Partially filled ballast tanks in cargo loading conditions

In cargo loading conditions, the requirement in S11.2.1.3 applies to the peak tanks only.

S11.2.1.5 Sequential ballast water exchange

Requirements of S11.2.1.3 and S11.2.1.4 are not applicable to ballast water exchange using the sequential method. However, bending moment and shear force calculations for each de-ballasting or ballasting stage in the ballast water exchange sequence are to be included in the loading manual or ballast water management plan of any vessel that intends to employ the sequential ballast water exchange method.

S11.2.2 Wave loads

S11.2.2.1 Wave bending moment

The wave bending moments, *Mw*, at each section along the ship length are given by the following formulae:

$M_W(+) = +190MCL^2BC_b \times 10^{-3}$ (kN - m) For positive moment

$M_W(+) = -110MCL^2B(C_b + 0.7) \times 10^{-3}$ (kN - m) For negative moment

where,

M = Distribution factor given in Fig. 2

C = $10.75 - \left[\frac{300 - L}{100}\right]^{1.5}$ for $90 \le L \le 300$

or 10.75 for $300 \le L \le 350$

or $10.75 - \left[\frac{L - 350}{150}\right]^{1.5}$ for $350 \le L \le 500$

L = Length of the ships in metres, defined by S2

B = Greatest moulded breadth in metres

C_b = Block coefficient, defined by S2, but not to be taken less than 0.6

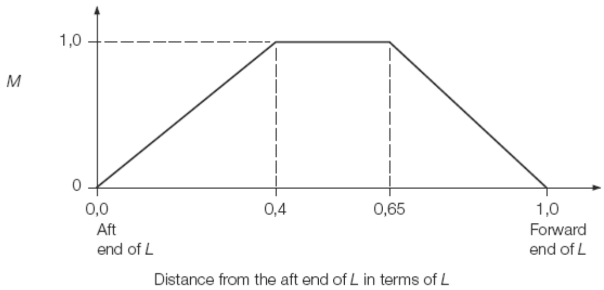


Fig.2 Distribution factor *M*

S11.2.2.2 Wave shear force

The wave shear forces, *Fw*, at each section along the length of the ship are given by the following formulae:

$F_W(+) = +30F1CLB(C_b + 0.7) \times 10^{-2}$ (kN) For positive shear force

S11
(cont)

$$F_W(-) = -30F2CLB(C_b + 0.7) \times 10^{-2}$$ (kN) For negative shear force

where,

$F1$, $F2$ = Distribution factors given in Figs. 3 and 4
C, L, B, C_b = As specified in S11.2.2.1

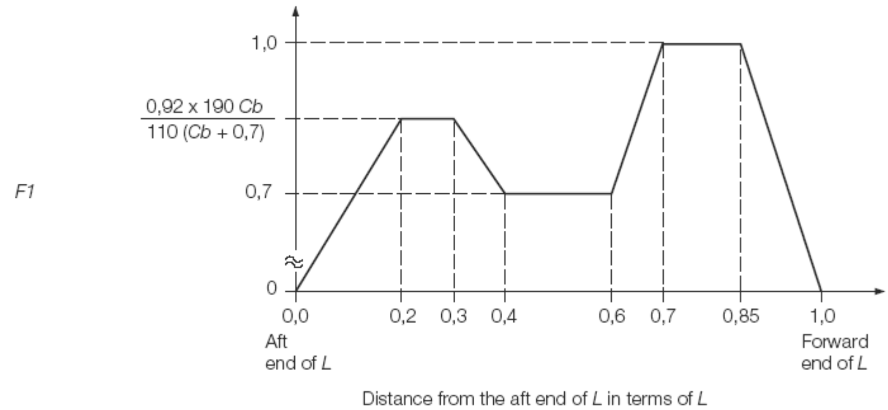


Fig.3 Distribution factor $F1$

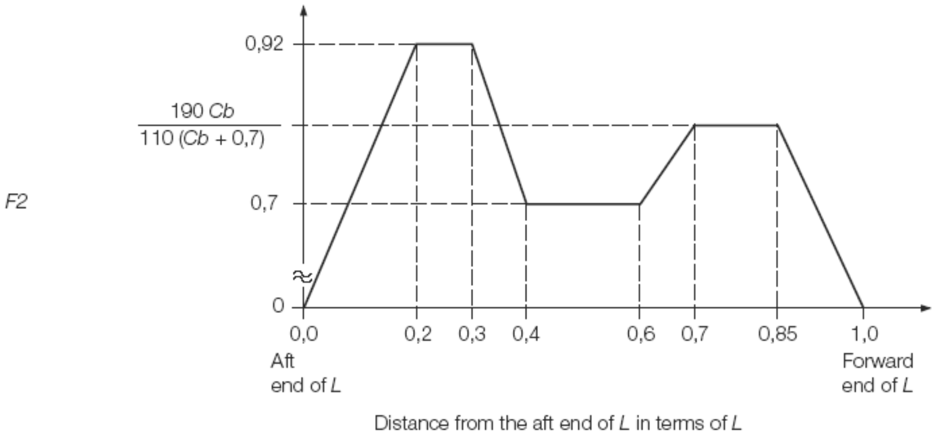


Fig.4 Distribution factor $F2$

S11.3 Bending strength

S11.3.1 Bending strength amidships

S11.3.1.1 Section modulus

(i) Hull section modulus, Z, calculated in accordance with S5, is not to be less than the values given by the following formula in way of 0.4 L midships for the still water bending moments Ms given in S11.2.1.1 and the wave bending moments Mw given in S11.2.2.1, respectively:

$$\frac{|Ms + Mw|}{\sigma} \times 10^3 \ (\text{cm}^3)$$

where,

S11 (cont)

σ = permissible bending stress = 175/*k* (N/mm^2)
k = 1.0 for ordinary hull structural steel
k < 1.0 for higher tensile steel according to S4.

(ii) In any case, the longitudinal strength of the ship is to be in compliance with S7.

S11.3.1.2 Moment of inertia

Moment of inertia of hull section at the midship point is not to be less than

$$I_{\min} = 3CL^3B(C_b + 0.7) \qquad (\text{cm}^4)$$

where,

C, L, B, C_b = As specified in S11.2.2.1.

S11.3.2 Bending strength outside amidships

The required bending strength outside 0.4*L* amidships is to be determined at the discretion of each Classification Society.

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

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

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

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

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

S11.4 Shearing strength

S11.4.1 General

The thickness requirements given in S11.4.2 or S11.4.3 apply unless smaller values are proved satisfactory by a method of direct stress calculation approved by each Classification Society, where the calculated shear stress is not to exceed 110/*k* (N/mm^2).

S11
(cont)

S11.4.2 Shearing strength for ships without effective longitudinal bulkheads

(i) The thickness of side shell is not to be less than the values given by the following formula for the still water shear forces *Fs* given in S11.2.1.1 and the wave shear forces *Fw* given in S11.2.2.2, respectively:

$$t = \frac{0.5|Fs + Fw|}{\tau}\frac{S}{I} \times 10^2 \qquad \text{(mm)}$$

where,

I = Moment of inertia in cm^4 about the horizontal neutral axis at the section under consideration
S = First moment in cm^3, about the neutral axis, of the area of the effective longitudinal members between the vertical level at which the shear stress is being determined and the vertical extremity of effective longitudinal members, taken at the section under consideration
τ = permissible shear stress = 110/*k* (N/mm^2)
k = As specified in S11.3.1.1 (i)

(ii) The value of *Fs* may be corrected for the direct transmission of forces to the transverse bulkheads at the discretion of each Classification Society.

S11.4.3 Shearing strength for ships with two effective longitudinal bulkheads

The thickness of side shell and longitudinal bulkheads are not to be less than the values given by the following formulae:

For side shell:

$$t = \frac{|(0.5 - \phi)(F_s + F_w) + \Delta F_{sh}|}{\tau}\frac{S}{I} \times 10^2 \qquad \text{(mm)}$$

For longitudinal bulkheads:

$$t = \frac{|\phi(F_s + F_w) + \Delta F_{bl}|}{\tau}\frac{S}{I} \times 10^2 \qquad \text{(mm)}$$

where,

Φ = ratio of shear force shared by the longitudinal bulkhead to the total shear force, and given by each Classification Society.
ΔF_{sh}, ΔF_{bl} = shear force acting upon the side shell plating and longitudinal bulkhead plating, respectively, due to local loads, and given by each Classification Society, subject to the sign convention specified in S11.2.1.1
S, I, τ = As specified in S11.4.2 (i)

S11.5 Buckling strength

S11.5.1 Application

These requirements apply to plate panels and longitudinals subject to hull girder bending and shear stresses.

S11
(cont)

S11.5.2 Elastic buckling stresses

S11.5.2.1 Elastic buckling of plates

1. Compression

The ideal elastic buckling stress is given by:

$$\sigma_E = 0.9mE\left(\frac{t_b}{1000s}\right) \qquad (\text{N/mm}^2)$$

For plating with longitudinal stiffeners (parallel to compressive stress):

$$m = \frac{8.4}{\psi + 1.1} \qquad \text{for } 0 \le \psi \le 1$$

For plating with transverse stiffeners (perpendicular to compressive stress)

$$m = c\left[1 + \left(\frac{s}{\ell}\right)^2\right]^2 \frac{2.1}{\psi + 1.1} \qquad \text{for } 0 \le \psi \le 1$$

where,

E = modulus of elasticity of material
= 2.06×10^5 N/mm^2 for steel
t_b = net thickness, in mm, of plating, considering standard deductions equal to the values given in the table here after:

Structure	Standard deduction (mm)	Limit values min-max (mm)
- Compartments carrying dry bulk cargoes - One side exposure to ballast and/or liquid cargo Vertical surfaces and surfaces sloped at an angle greater than 25^0 to the horizontal line	0.05 t	0.5 - 1
- One side exposure to ballast and/or liquid cargo Horizontal surfaces and surfaces sloped at an angle less than 25^0 to the horizontal line - Two side exposure to ballast and/or liquid cargo Vertical surfaces and surfaces sloped at an angle greater than 25^0 to the horizontal line	0.10 t	2 - 3

S11
(cont)

- Two side exposure to ballast and/or liquid cargo Horizontal surfaces and surfaces sloped at an angle less than 25^0 to the horizontal line	0.15 t	2 - 4

s = shorter side of plate panel, in m
ℓ = longer side of plate panel, in m
c = 1.3 when plating stiffened by floors or deep girders
= 1.21 when stiffeners are angles or T-sections
= 1.10 when stiffeners are bulb flats
= 1.05 when stiffeners are flat bars
ψ = ratio between smallest and largest compressive σ_a stress when linear variation across panel.

2. Shear

The ideal elastic buckling stress is given by:

$$\tau_E = 0.9 k_t E \left(\frac{t_b}{1000s} \right)^2 \qquad (\text{N/mm}^2)$$

$$k_t = 5.34 + 4 \left(\frac{s}{\ell} \right)^2$$

E, t_b, s and ℓ are given in 1.

S11.5.2.2 Elastic buckling of longitudinals

1. Column buckling without rotation of the cross section

For the column buckling mode (perpendicular to plane of plating) the ideal elastic buckling stress is given by:

$$\sigma_E = 0.001 E \frac{I_a}{A \ell^2} \qquad (\text{N/mm}^2)$$

I_a = moment of inertia, in cm^4, of longitudinal, including plate flange and calculated with thickness as specified in S11.5.2.1.1
A = cross-sectional area, in cm^2, of longitudinal, including plate flange and calculated with thickness as specified in S11.5.2.1.1
ℓ = span, in m, of longitudinal

A plate flange equal to the frame spacing may be included.

2. Torsional buckling mode

The ideal elastic buckling stress for the torsional mode is given by:

$$\sigma_E = \frac{\pi^2 E I_w}{10^4 I_p \ell^2} \left(m^2 + \frac{K}{m^2} \right) + 0.385 E \frac{I_t}{I_p} \qquad (\text{N/mm}^2)$$

S11
(cont)

$$K = \frac{C\ell^4}{\pi^4 E I_w} 10^6$$

m = number of half waves, given by the following table:

	0 < K < 4	4 < K < 36	36 < K < 144	$(m-1)^2 m^2 < K \le m^2(m+1)^2$
m	1	2	3	m

I_t = St Venant's moment of inertia, in cm^4, of profile (without plate flange)

$= \frac{h_w t_w^{\ 3}}{3} 10^{-4}$ for flat bars (slabs)

$= \frac{1}{3}\left[h_w t_w^{\ 3} + b_f t_f^{\ 3}\left(1 - 0.63\frac{t_f}{b_f}\right)\right] 10^{-4}$ for flanged profiles

I_p = polar moment of inertia, in cm^4, of profile about connection of stiffener to plate

$= \frac{h_w^{\ 3} t_w}{3} 10^{-4}$ for flat bars (slabs)

$= \left(\frac{h_w^{\ 3} t_w}{3} + h_w^{\ 2} b_f t_f\right) 10^{-4}$ for flanged profiles

I_w = sectorial moment of inertia, in cm^6, of profile about connection of stiffener to plate

$= \frac{h_w^{\ 3} t_w^{\ 3}}{36} 10^{-6}$ for flat bars (slabs)

$= \frac{t_f b_f^{\ 3} h_w^{\ 2}}{12} 10^{-6}$ for "Tee" 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, considering standard deductions as specified in S11.5.2.1.1
b_f = flange width, in mm
t_f = flange thickness, in mm, considering standard deductions as specified in S11.5.2.1.1. For bulb profiles the mean thickness of the bulb may be used.
ℓ = span of profile, in m
s = spacing of profiles, in m
C = spring stiffness exerted by supporting plate p

$$= \frac{k_p E t_p^{\ 3}}{3s\left(1 + \frac{1.33 k_p h_w t_p^{\ 3}}{1000 s t_w^{\ 3}}\right)} 10^{-3}$$

$k_p = 1 - \eta_p$ not to be taken less than zero

t_p = plate thickness, in mm, considering standard deductions as specified in S11.5.2.1.1

$$\eta_p = \frac{\sigma_a}{\sigma_{Ep}}$$

S11
(cont)

σ_a = calculated compressive stress. For longitudinals, see S11.5.4.1
σ_{Ep} = elastic buckling stress of supporting plate as calculated in S11.5.2.1

For flanged profiles, k_p need not be taken less than 0.1.

3. Web and flange buckling

For web plate of longitudinals the ideal elastic buckling stress is given by:

$$\sigma_E = 3.8E\left(\frac{t_w}{h_w}\right)^2 \qquad (\text{N/mm}^2)$$

For flanges on angles and T-sections of longitudinals, buckling is taken care of by the following requirement:

$$\frac{b_f}{t_f} \leq 15$$

b_f = flange width, in mm, for angles, half the flange width for T-sections.
t_f = as built flange thickness.

S11.5.3 Critical buckling stresses

S11.5.3.1 Compression

The critical buckling stress in compression σ_c is determined as follows:

$$\sigma_c = \sigma_E \qquad \text{when} \quad \sigma_E \leq \frac{\sigma_F}{2}$$

$$= \sigma_F\left(1 - \frac{\sigma_F}{4\sigma_E}\right) \qquad \text{when} \quad \sigma_E > \frac{\sigma_F}{2}$$

σ_F = yield stress of material, in N/mm^2. σ_F may be taken as 235 N/mm^2 for mild steel.
σ_E = ideal elastic buckling stress calculated according to S11.5.2.

S11.5.3.2 Shear

The critical buckling stress in shear τ_c is determined as follows:

$$\tau_c = \tau_E \qquad \text{when} \quad \tau_E \leq \frac{\tau_F}{2}$$

$$= \tau_F\left(1 - \frac{\tau_F}{4\tau_E}\right) \qquad \text{when} \quad \tau_E > \frac{\tau_F}{2}$$

$$\tau_F = \frac{\sigma_F}{\sqrt{3}}$$

σ_F = as given in S11.5.3.1.
τ_E = ideal elastic buckling stress in shear calculated according to S11.5.2.1.2.

S11 (cont)

S11.5.4 Working stress

S11.5.4.1 Longitudinal compressive stresses

The compressive stresses are given in the following formula:

$$\sigma_a = \frac{M_s + M_w}{I_n} y \times 10^5 \qquad \text{N/mm}^2$$

$$= \text{minimum } \frac{30}{k}$$

M_s = still water bending moment (kN.m), as given in S11.2.1
M_w = wave bending moment (kN.m) as given in S11.2.2.1
I_n = moment of inertia, in cm^4, of the hull girder
y = vertical distance, in m, from neutral axis to considered point
k = as specified in S11.3.1.1 (i)

M_s and M_w are to be taken as sagging or hogging bending moments, respectively, for members above or below the neutral axis.

Where the ship is always in hogging condition in still water, the sagging bending moment (M_s + M_w) is to be specially considered.

S11.5.4.2 Shear stresses

1. Ships without effective longitudinal bulkheads

For side shell

$$\tau_a = \frac{0.5\left|F_s + F_w\right|}{t} \frac{S}{I} 10^2 \qquad \text{N/mm}^2$$

F_s, F_w, t, S, I as specified in S11.4.2.

2. Ships with two effective longitudinal bulkheads

For side shell

$$\tau_a = \frac{\left|(0.5 - \phi)(F_s + F_w) + \Delta F_{sh}\right|}{t} \frac{S}{I} 10^2 \qquad \text{N/mm}^2$$

For longitudinal bulkheads

$$\tau_a = \frac{\left|\phi(F_s + F_w) + \Delta F_{bl}\right|}{t} \frac{S}{I} 10^2 \qquad \text{N/mm}^2$$

F_s, F_w, ΔF_{sh}, ΔF_{bl}, t, S, I as specified in S11.4.3.

S11
(cont)

S11.5.5 Scantling criteria

S11.5.5.1 Buckling Stress

The design buckling stress σ_c of plate panels and longitudinals (as calculated in S11.5.3.1) is not to be less than:

$$\sigma_c \geq \beta\sigma_a$$

where,

β = 1 for plating and for web plating of stiffeners (local buckling)
β = 1.1 for stiffeners

The critical buckling stress τ_c of plate panels (as calculated in S11.5.3.2) is not to be less than:

$$\tau_c \geq \tau_a$$

End of Document

S12
(1992)
(Rev.1 1997)
(Rev.2.1 1997)
(Rev.3 Sept 2000)
(Rev.4 July 2004)
(Rev.5 May 2010)

Side Structures in Single Side Skin Bulk Carriers

S12.1 Application and definitions

These requirements apply to side structures of cargo holds bounded by the side shell only of bulk carriers constructed with single deck, topside tanks and hopper tanks in cargo spaces intended primarily to carry dry cargo in bulk, which are contracted for construction on or after 1st July 1998.

This UR does not apply to CSR Bulk Carriers.

S12.2 Scantlings of side structures

The thickness of the side shell plating and the section modulus and shear area of side frames are to be determined according to the Society's criteria.

The scantlings of side hold frames immediately adjacent to the collision bulkhead are to be increased in order to prevent excessive imposed deformation on the shell plating. As an alternative, supporting structures are to be fitted which maintain the continuity of forepeak stringers within the foremost hold.

S12.3 Minimum thickness of frame webs

The thickness of frame webs within the cargo area is not to be less than $t_{w,min}$, in mm, given by:

$$t_{w,\min} = C(7.0 + 0.03L)$$

C = 1.15 for the frame webs in way of the foremost hold;
1.0 for the frame webs in way of other holds.

where L is the Rule length, in m, as defined in UR S2 but need not be taken greater than 200 m.

S12.4 Lower and upper brackets

The thickness of the frame lower brackets is not to be less than the greater of t_w and $t_{w,min}$ + 2 mm, where t_w is the fitted thickness of the side frame web. The thickness of the frame upper bracket is not to be less than the greater of t_w and $t_{w,min}$.

Note:

1. Changes introduced in Rev.3 are to be uniformly implemented by IACS Members and Associates from 1 July 2001.

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

S12 (cont)

The section modulus SM of the frame and bracket or integral bracket, and associated shell plating, at the locations shown in Figure 1, is not to be less than twice the section modulus SM_F required for the frame midspan area.

The dimensions of the lower and upper brackets are not to be less than those shown in Figure 2.

Structural continuity with the upper and lower end connections of side frames is to be ensured within topsides and hopper tanks by connecting brackets as shown in Figure 3. The brackets are to be stiffened against buckling according to the Society's criteria.

The section moduli of the side longitudinals and sloping bulkhead longitudinals which support the connecting brackets are to be determined according to the Society's criteria with the span taken between transverses. Other arrangements may be adopted at the Society's discretion. In these cases, the section moduli of the side longitudinals and sloping bulkhead longitudinals are to be determined according to the Society's criteria for the purpose of effectively supporting the brackets.

S12.5 Side frame sections

Frames are to be fabricated symmetrical sections with integral upper and lower brackets and are to be arranged with soft toes.

The side frame flange is to be curved (not knuckled) at the connection with the end brackets. The radius of curvature is not to be less than r, in mm, given by:

$$r = \frac{0.4 b_f^2}{t_f}$$

where b_f and t_f are the flange width and thickness of the brackets, respectively, in mm. The end of the flange is to be sniped.

In ships less than 190 m in length, mild steel frames may be asymmetric and fitted with separate brackets. The face plate or flange of the bracket is to be sniped at both ends. Brackets are to be arranged with soft toes.

The web depth to thickness ratio of frames is not to exceed the following values:

- 60 $k^{0.5}$ for symmetrically flanged frames
- 50 $k^{0.5}$ for asymmetrically flanged frames

where k = 1.0 for ordinary hull structural steel and k < 1 for higher tensile steel according to UR S4.

The outstanding flange is not to exceed 10 $k^{0.5}$ times the flange thickness.

S12.6 Tripping brackets

In way of the foremost hold, side frames of asymmetrical section are to be fitted with tripping brackets at every two frames, as shown in Figure 4.

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(cont)

S12.7 Weld connections of frames and end brackets

Double continuous welding is to be adopted for the connections of frames and brackets to side shell, hopper and upper wing tank plating and web to face plates.

For this purpose, the weld throat is to be (see Figure 1):

- 0.44 t in zone “a”
- 0.4 t in zone “b”

where t is the thinner of the two connected members.

Where the hull form is such to prohibit an effective fillet weld, edge preparation of the web of frame and bracket may be required, in order to ensure the same efficiency as the weld connection stated above.

S12.8 Minimum thickness of side shell plating

The thickness of side shell plating located between hopper and upper wing tanks is not to be less than $t_{p,min}$ in mm, given by:

$$t_{p,\min} = \sqrt{L}$$

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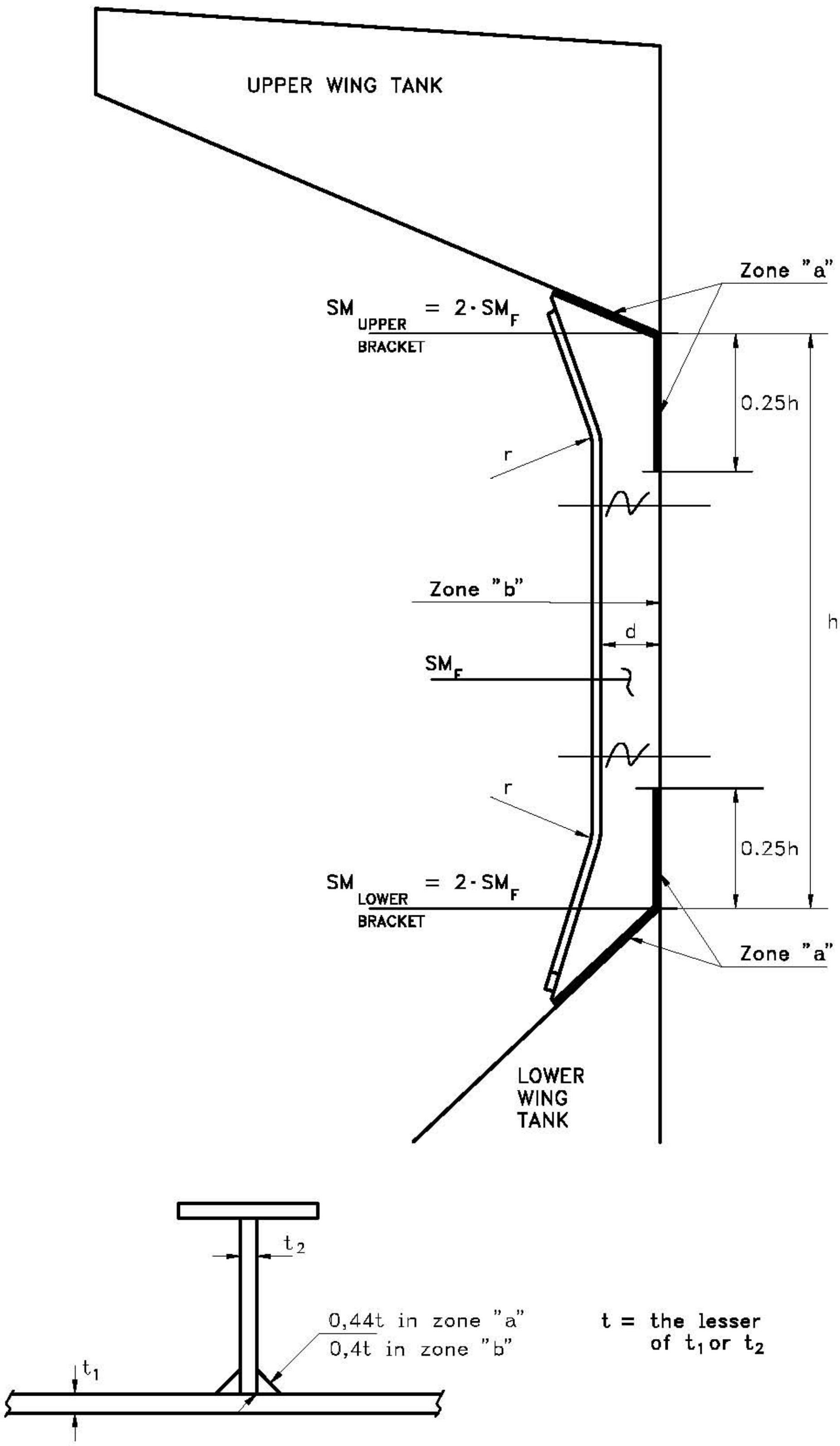
(cont)

Figure 1



S12
(cont)

Figure 2

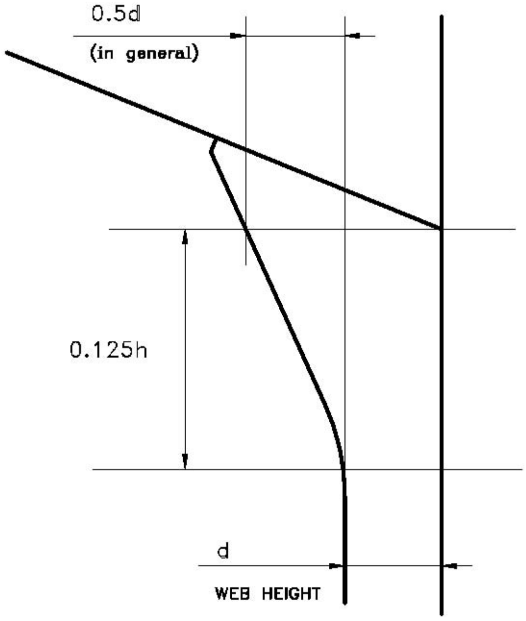
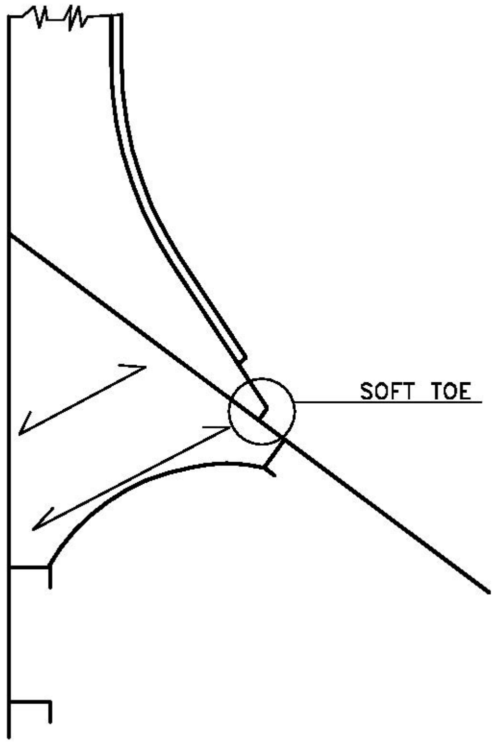


Figure 3



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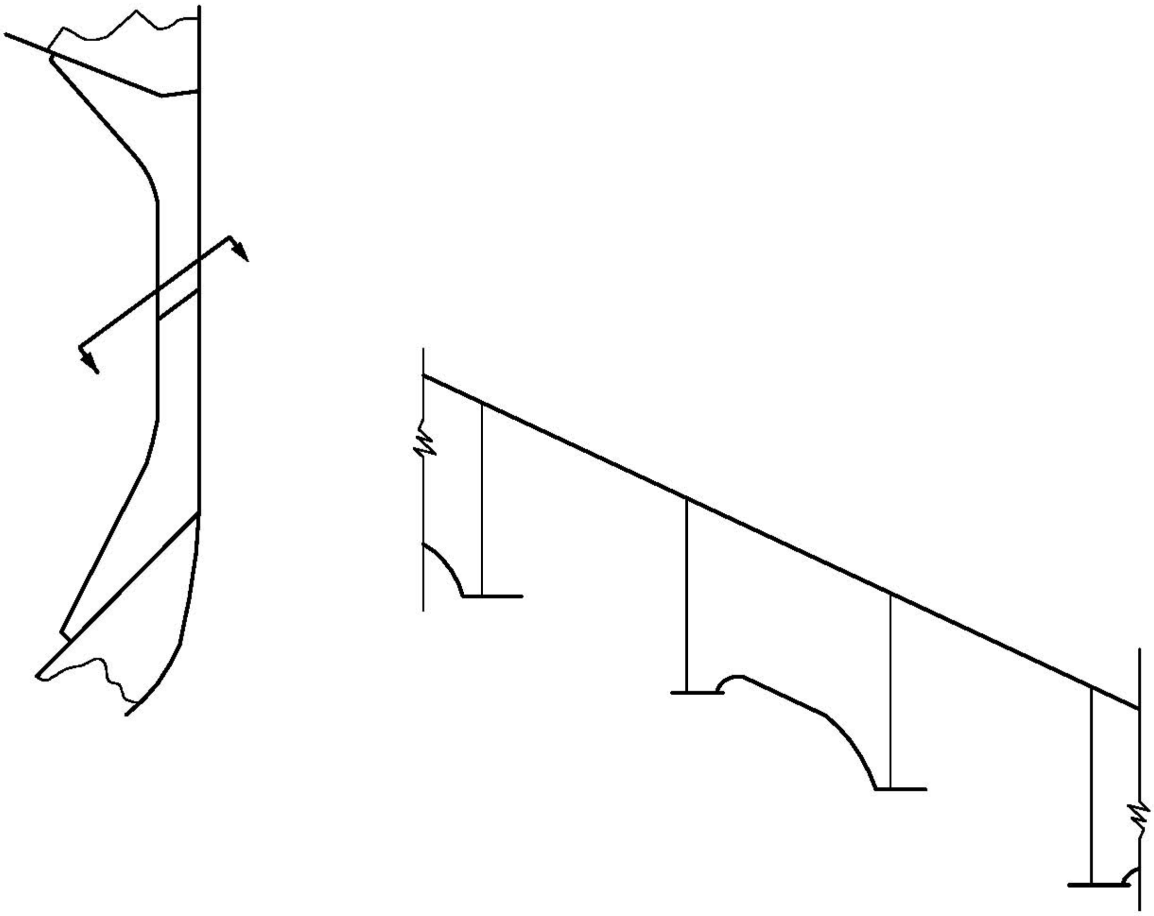
(cont)

Figure 4

Tripping brackets to be fitted in way of foremost hold



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S13 Strength of Bottom Forward in Oil Tankers

(1993)
(Rev.1 1993)
(Rev.2 May 2010)
(Corr.1 May 2014)

S13.1 General

For every oil tanker subject to Regulation 18 of MARPOL 73/78 Annex I, the strengthening of bottom forward is to be based on the draught obtained by using segregated ballast tanks only.

This UR does not apply to CSR Oil Tankers.

S13.2 Scantlings

Determination of scantlings to comply with the above requirement should be based on the Rules of individual Societies.

Note:

Mandatory implementation date of the unified requirement is the 1st July 1994.
(This note was adopted by IACS Council on 2nd December 1993).

End of Document

S14 Testing Procedures of Watertight Compartments

(1996)
(Rev.1 Feb 2001)
(Rev.2 May 2001)
(Rev.3 May 2010)
(Rev.4 Aug 2012)
(Rev.5 Jan 2015)
(Rev.6 Sept 2016)

S14.1 Application

Revision 6 of this UR is to be complied with in respect of the testing of watertight compartments in accordance with Notes 1, 2, 3 and 4.

S14.2 General

S14.2.1 The testing procedures of watertight compartments are to be carried out in accordance with ANNEX I, the "Procedures for Testing Tanks and Tight Boundaries". The requirements of ANNEX I are divided into two parts, PART A and PART B as follows:

- PART A - SOLAS Ships (including CSR BC & OT)
- PART B - Non-SOLAS Ships and SOLAS Exempt/Equivalent Ships

S14.2.2 Testing procedures of watertight compartments for SOLAS Ships (including CSR BC & OT) are to be carried out in accordance with PART A, unless:

a) the shipyard provides documentary evidence of the shipowner's agreement to a request to the Flag Administration for an exemption from the application of SOLAS Chapter II-1, Regulation 11, or for an equivalency agreeing that the content of PART B is equivalent to SOLAS Chapter II-1, Regulation 11; and

b) the above-mentioned exemption/equivalency has been granted by the responsible Flag Administration.

Notes:

1. Revision 4 of this UR is to be applied by IACS Societies to ships contracted for construction on or after 1 July 2013.

2. Revision 5 of this UR is to be applied by IACS Societies to ships contracted for construction on or after 1 January 2016.

3. Revision 6 of this UR is to be applied by IACS Societies to ships contracted for construction on or after 1 January 2018.

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

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(cont)

S14.2.3 Testing procedures of watertight compartments are to be carried out in accordance with PART B for non-SOLAS ships and those SOLAS ships (including CSR BC & OT) for which:

a) the shipyard provides documentary evidence of the shipowner’s agreement to a request to the Flag Administration for an exemption from the application of SOLAS Chapter II-1, Regulation 11, or for an equivalency agreeing that the content of PART B is equivalent to SOLAS Chapter II-1, Regulation 11; and

b) the above-mentioned exemption/equivalency has been granted by the responsible Flag Administration.

ANNEX I

PROCEDURES FOR TESTING TANKS AND TIGHT BOUNDARIES

PART A - SOLAS Ships

1 GENERAL

1.1 These test procedures are to confirm the watertightness of tanks and watertight boundaries and the structural adequacy of tanks which consist of the watertight subdivisions[1] of ships. These procedures may also be applied to verify the weathertightness of structures and shipboard outfitting. The tightness of all tanks and watertight boundaries of ships during new construction and those relevant to major conversions or major repairs[2] is to be confirmed by these test procedures prior to the delivery of the ship.

1.2 Testing procedures of watertight compartments for SOLAS Ships (including CSR BC & OT) are to be carried out in accordance with PART A, unless:

a) the shipyard provides documentary evidence of the shipowner's agreement to a request to the Flag Administration for an exemption from the application of SOLAS Chapter II-1, Regulation 11, or for an equivalency agreeing that the content of PART B is equivalent to SOLAS Chapter II-1, Regulation 11; and

b) the above-mentioned exemption/equivalency has been granted by the responsible Flag Administration.

2 APPLICATION

2.1 All gravity tanks[3] and other boundaries required to be watertight or weathertight are to be tested in accordance with this Procedure and proven to be tight and structurally adequate as follows:

1. Gravity Tanks for their tightness and structural adequacy,

2. Watertight Boundaries Other Than Tank Boundaries for their watertightness, and

3. Weathertight Boundaries for their weathertightness.

2.2 The testing of cargo containment systems of liquefied gas carriers is to be in accordance with the testing requirements in 4.21 to 4.26 of the IGC Code and standards deemed appropriate by the Classification Society.

2.3 The testing of structures not listed in Table 1 or 2 is to be specially considered.

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[1] Watertight subdivision means the transverse and longitudinal subdivisions of the ship required to satisfy the subdivision requirements of SOLAS Chapter II-1.
[2] Major repair means a repair affecting structural integrity.
[3] Gravity tank means a tank that is subject to vapour pressure not greater than 70 kPa.

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(cont)

3 TEST TYPES AND DEFINITIONS

3.1 The following two types of tests are specified in this requirement:

Structural Test:

A test to verify the structural adequacy of tank construction. This may be a hydrostatic test or, where the situation warrants, a hydropneumatic test.

Leak Test:

A test to verify the tightness of a boundary. Unless a specific test is indicated, this may be a hydrostatic/hydropneumatic test or an air test. A hose test may be considered an acceptable form of leak test for certain boundaries, as indicated by Footnote 3 of Table 1.

3.2 The definition of each test type is as follows:

Hydrostatic Test: *(Leak and Structural)*	A test wherein a space is filled with a liquid to a specified head.
Hydropneumatic Test: *(Leak and Structural)*	A test combining a hydrostatic test and an air test, wherein a space is partially filled with a liquid and pressurized with air.
Hose Test: *(Leak)*	A test to verify the tightness of a joint by a jet of water with the joint visible from the opposite side.
Air Test: *(Leak)*	A test to verify tightness by means of air pressure differential and leak indicating solution. It includes tank air test and joint air tests, such as *compressed air fillet weld tests* and *vacuum box tests*.
Compressed Air Fillet Weld Test: *(Leak)*	An air test of fillet welded tee joints wherein leak indicating solution is applied on fillet welds.
Vacuum Box Test: *(Leak)*	A box over a joint with leak indicating solution applied on the welds. A vacuum is created inside the box to detect any leaks.
Ultrasonic Test: *(Leak)*	A test to verify the tightness of the sealing of closing devices such as hatch covers by means of ultrasonic detection techniques.
Penetration Test: *(Leak)*	A test to verify that no visual dye penetrant indications of potential continuous leakages exist in the boundaries of a compartment by means of low surface tension liquids (i.e. dye penetrant test).

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(cont)

4 TEST PROCEDURES

4.1 General

Tests are to be carried out in the presence of a Surveyor at a stage sufficiently close to the completion of work with all hatches, doors, windows, etc. installed and all penetrations including pipe connections fitted, and before any ceiling and cement work is applied over the joints. Specific test requirements are given in 4.4 and Table 1. For the timing of the application of coating and the provision of safe access to joints, see 4.5, 4.6 and Table 3.

4.2 Structural test procedures

4.2.1 Type and time of test

Where a structural test is specified in Table 1 or Table 2, a hydrostatic test in accordance with 4.4.1 will be acceptable. Where practical limitations (strength of building berth, light density of liquid, etc.) prevent the performance of a hydrostatic test, a hydropneumatic test in accordance with 4.4.2 may be accepted instead.

A hydrostatic test or hydropneumatic test for the confirmation of structural adequacy may be carried out while the vessel is afloat, provided the results of a leak test are confirmed to be satisfactory before the vessel is afloat.

4.2.2 Testing Schedule for New Construction or Major Structural Conversion

4.2.2.1 Tanks which are intended to hold liquids, and which form part of the watertight subdivision of the ship[1], shall be tested for tightness and structural strength as indicated in Table 1 and Table 2.

4.2.2.2 The tank boundaries are to be tested from at least one side. The tanks for structural test are to be selected so that all representative structural members are tested for the expected tension and compression.

4.2.2.3 The watertight boundaries of spaces other than tanks for structural testing may be exempted, provided that the water-tightness of boundaries of exempted spaces is verified by leak tests and inspections. Structural testing may not be exempted and the requirements for structural testing of tanks in 4.2.2.1 to 4.2.2.2 shall apply, for ballast holds, chain lockers and a representative cargo hold if intended for in-port ballasting.

4.2.2.4 Tanks which do not form part of the watertight subdivision of the ship[1], may be exempted from structural testing provided that the water-tightness of boundaries of exempted spaces is verified by leak tests and inspections.

4.3 Leak test procedures

For the leak tests specified in Table 1, tank air tests, compressed air fillet weld tests, vacuum box tests in accordance with 4.4.4 through 4.4.6, or their combination, will be acceptable. Hydrostatic or hydropneumatic tests may also be accepted as leak tests provided that 4.5, 4.6 and 4.7 are complied with. Hose tests will also be acceptable for such locations as specified in Table 1, Footnote 3, in accordance with 4.4.3.

[1] Watertight subdivision means the main transverse and longitudinal subdivisions of the ship required to satisfy the subdivision requirements of SOLAS Chapter II-1.

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(cont)

The application of the leak test for each type of welded joint is specified in Table 3.

Air tests of joints may be carried out in the block stage provided that all work on the block that may affect the tightness of a joint is completed before the test. See also 4.5.1 for the application of final coatings and 4.6 for the safe access to joints and the summary in Table 3.

4.4 Test Methods

4.4.1 Hydrostatic test

Unless another liquid is approved, hydrostatic tests are to consist of filling the space with fresh water or sea water, whichever is appropriate for testing, to the level specified in Table 1 or Table 2. See also 4.7.

In cases where a tank is designed for cargo densities greater than sea water and testing is with fresh water or sea water, the testing pressure height is to simulate the actual loading for those greater cargo densities as far as practicable.

All external surfaces of the tested space are to be examined for structural distortion, bulging and buckling, other related damage and leaks.

4.4.2 Hydropneumatic test

Hydropneumatic tests, where approved, are to be such that the test condition, in conjunction with the approved liquid level and supplemental air pressure, will simulate the actual loading as far as practicable. The requirements and recommendations for tank air tests in 4.4.4 will also apply to hydropneumatic tests. See also 4.7.

All external surfaces of the tested space are to be examined for structural distortion, bulging and buckling, other related damage and leaks.

4.4.3 Hose test

Hose tests are to be carried out with the pressure in the hose nozzle maintained at least at $2 \cdot 10^5$ Pa during the test. The nozzle is to have a minimum inside diameter of 12 mm and be at a perpendicular distance from the joint not exceeding 1.5 m. The water jet is to impinge directly upon the weld.

Where a hose test is not practical because of possible damage to machinery, electrical equipment insulation or outfitting items, it may be replaced by a careful visual examination of welded connections, supported where necessary by means such as a dye penetrant test or ultrasonic leak test or the equivalent.

4.4.4 Tank air test

All boundary welds, erection joints and penetrations, including pipe connections, are to be examined in accordance with approved procedure and under a stabilized pressure differential above atmospheric pressure not less than $0.15 \cdot 10^5$ Pa, with a leak indicating solution such as soapy water/detergent or a proprietary brand applied.

A U-tube with a height sufficient to hold a head of water corresponding to the required test pressure is to be arranged. The cross sectional area of the U-tube is not to be less than that of the pipe supplying air to the tank. Arrangements involving the use of two calibrated pressure gauges to verify the required test pressure may be accepted taking into account the

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(cont)

provisions in F5.1 and F7.4 of IACS Recommendation 140, "Recommendation for Safe Precautions during Survey and Testing of Pressurized Systems".

A double inspection is to be made of tested welds. The first is to be immediately upon applying the leak indication solution; the second is to be after approximately four or five minutes in order to detect those smaller leaks which may take time to appear.

4.4.5 Compressed air fillet weld test

In this air test, compressed air is injected from one end of a fillet welded joint and the pressure verified at the other end of the joint by a pressure gauge. Pressure gauges are to be arranged so that an air pressure of at least $0.15 \cdot 10^5$ Pa can be verified at each end of all passages within the portion being tested.

Note: Where a leak test is required for fabrication involving partial penetration welds, a compressed air test is also to be applied in the same manner as to fillet weld where the root face is large, i.e., 6-8 mm.

4.4.6 Vacuum box test

A box (vacuum testing box) with air connections, gauges and an inspection window is placed over the joint with a leak indicating solution applied to the weld cap vicinity. The air within the box is removed by an ejector to create a vacuum of $0.20 \cdot 10^5$ – $0.26 \cdot 10^5$ Pa inside the box.

4.4.7 Ultrasonic test

An ultrasonic echo transmitter is to be arranged inside of a compartment and a receiver is to be arranged on the outside. The watertight/weathertight boundaries of the compartment are scanned with the receiver in order to detect an ultrasonic leak indication. A location where sound is detectable by the receiver indicates a leakage in the sealing of the compartment.

4.4.8 Penetration test

A test of butt welds or other weld joints uses the application of a low surface tension liquid at one side of a compartment boundary or structural arrangement. If no liquid is detected on the opposite sides of the boundaries after the expiration of a defined period of time, this indicates tightness of the boundaries. In certain cases, a developer solution may be painted or sprayed on the other side of the weld to aid leak detection.

4.4.9 Other test

Other methods of testing may be considered by each Classification Society upon submission of full particulars prior to the commencement of testing.

4.5 Application of coating

4.5.1 Final coating

For butt joints welded by an automatic process, the final coating may be applied any time before the completion of a leak test of spaces bounded by the joints, provided that the welds have been carefully inspected visually to the satisfaction of the Surveyor.

Surveyors reserve the right to require a leak test prior to the application of final coating over automatic erection butt welds.

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(cont)

For all other joints, the final coating is to be applied after the completion of the leak test of the joint. See also Table 3.

4.5.2 Temporary coating

Any temporary coating which may conceal defects or leaks is to be applied at the time as specified for the final coating (see 4.5.1). This requirement does not apply to shop primer.

4.6 Safe access to joints

For leak tests, safe access to all joints under examination is to be provided. See also Table 3.

4.7 Hydrostatic or hydropneumatic tightness test

In cases where the hydrostatic or hydropneumatic tests are applied instead of a specific leak test, examined boundaries must be dew-free, otherwise small leaks are not visible.

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(cont)

Table 1
Test Requirements for Tanks and Boundaries

	Tank or boundary to be tested	Test type	Test head or pressure	Remarks
1	Double bottom tanks[4]	Leak and structural[1]	The greater of - top of the overflow, - to 2.4m above top of tank[2], or - to bulkhead deck	
2	Double bottom voids[5]	Leak	See 4.4.4 through 4.4.6, as applicable	including pump room double bottom and bunker tank protection double hull required by MARPOL Annex I
3	Double side tanks	Leak and structural[1]	The greater of - top of the overflow, - to 2.4m above top of tank[2], or - to bulkhead deck	
4	Double side voids	Leak	See 4.4.4 through 4.4.6, as applicable	
5	Deep tanks other than those listed elsewhere in this table	Leak and structural[1]	The greater of - top of the overflow, or - to 2.4m above top of tank[2]	
6	Cargo oil tanks	Leak and structural[1]	The greater of - top of the overflow, - to 2.4m above top of tank[2], or - to top of tank[2] plus setting of any pressure relief valve	
7	Ballast hold of bulk carriers	Leak and structural[1]	Top of cargo hatch coaming	
8	Peak tanks	Leak and structural[1]	The greater of - top of the overflow, or - to 2.4m above top of tank[2]	After peak to be tested after installation of stern tube
9	.1 Fore peak spaces with equipment	Leak	See 4.4.3 through 4.4.6, as applicable	
	.2 Fore peak voids	Leak	See 4.4.4 through 4.4.6, as applicable	
	.3 Aft peak spaces with equipment	Leak	See 4.4.3 through 4.4.6, as applicable	
	.4 Aft peak voids	Leak	See 4.4.4 through 4.4.6, as applicable	After peak to be tested after installation of stern tube
10	Cofferdams	Leak	See 4.4.4 through 4.4.6, as applicable	

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(cont)

	Tank or boundary to be tested	Test type	Test head or pressure	Remarks
11	.1 Watertight bulkheads	Leak[8]	See 4.4.3 through 4.4.6, as applicable[7]	
	.2 Superstructure end bulkheads	Leak	See 4.4.3 through 4.4.6, as applicable	
12	Watertight doors below freeboard or bulkhead deck	Leak[6, 7]	See 4.4.3 through 4.4.6, as applicable	
13	Double plate rudder blades	Leak	See 4.4.4 through 4.4.6, as applicable	
14	Shaft tunnels clear of deep tanks	Leak[3]	See 4.4.3 through 4.4.6, as applicable	
15	Shell doors	Leak[3]	See 4.4.3 through 4.4.6, as applicable	
16	Weathertight hatch covers and closing appliances	Leak[3, 7]	See 4.4.3 through 4.4.6, as applicable	Hatch covers closed by tarpaulins and battens excluded
17	Dual purpose tanks/dry cargo hatch covers	Leak[3, 7]	See 4.4.3 through 4.4.6, as applicable	In addition to structural test in item 6 or 7
18	Chain lockers	Leak and structural[1]	Top of chain pipe	
19	L.O. sump. tanks and other similar tanks/spaces under main engines	Leak[9]	See 4.4.3 through 4.4.6, as applicable	
20	Ballast ducts	Leak and structural[1]	The greater of - ballast pump maximum pressure, or - setting of any pressure relief valve	
21	Fuel Oil Tanks	Leak and structural[1]	The greater of - top of the overflow, - to 2.4m above top of tank[2], or - to top of tank[2] plus setting of any pressure relief valves, or - to bulkhead deck	

Notes:

1 Refer to section 4.2.2

2 The top of a tank is the deck forming the top of the tank, excluding any hatchways.

3 *Hose Test* may also be considered as a medium of the test. See 3.2.

4 Including tanks arranged in accordance with the provisions of SOLAS regulation II-1/9.4.

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(cont)

5 Including duct keels and dry compartments arranged in accordance with the provisions of SOLAS regulation II-1/11.2 and II-1/9.4 respectively, and/or oil fuel tank protection and pump room bottom protection arranged in accordance with the provisions of MARPOL Annex I, Chapter 3, Part A regulation 12A and Chapter 4, Part A, regulation 22 respectively.

6 Where water tightness of a watertight door has not been confirmed by prototype test, testing by filling watertight spaces with water is to be carried out. See SOLAS regulation II-1/16.2 and MSC/Circ.1176.

7 As an alternative to the hose testing, other testing methods listed in 4.4.7 through 4.4.9 may be applicable subject to adequacy of such testing methods being verified. See SOLAS regulation II-1/11.1. For watertight bulkheads (item 11.1) alternatives to the hose testing may only be used where a hose test is not practicable.

8 A "Leak and structural test", see 4.2.2 is to be carried out for a representative cargo hold if intended for in-port ballasting. The filling level requirement for testing cargo holds intended for in-port ballasting is to be the maximum loading that will occur in-port as indicated in the loading manual.

9 Where L.O. sump tanks and other similar spaces under main engines intended to hold liquid form part of the watertight subdivision of the ship, they are to be tested as per the requirements of Item 5, Deep tanks other than those listed elsewhere in this table.

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(cont)

Table 2
Additional Test Requirements for Special Service Ships/Tanks

	Type of Ship/Tank	Structures to be tested	Type of Test	Test Head or Pressure	Remarks
1	Liquefied gas carriers	Integral tanks	Leak and structural	Refer to UR G1	
		Hull structure supporting membrane or semi-membrane tanks	Refer to UR G1	Refer to UR G1	
		Independent tanks type A	Refer to UR G1	Refer to UR G1	
		Independent tanks type B	Refer to UR G1	Refer to UR G1	
		Independent tanks type C	Refer to UR G2	Refer to UR G2	
2	Edible liquid tanks	Independent tanks	Leak and structural[1]	The greater of - top of the overflow, or - to 0.9m above top of tank[2]	
3	Chemical carriers	Integral or independent cargo tanks	Leak and structural[1]	The greater of - to 2.4m above top of tank[2], or - to top of tank[2] plus setting of any pressure relief valve	Where a cargo tank is designed for the carriage of cargoes with specific gravities larger than 1.0, an appropriate additional head is to be considered

Note:

1 Refer to section 4.2.2
2 Top of tank is deck forming the top of the tank excluding any hatchways.

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(cont)

Table 3
Application of Leak Test, Coating and Provision of Safe Access
For Type of Welded Joints

Type of welded joints		Leak test	Coating[1]		Safe Access[2]	
			Before leak test	After leak test but before structural test	Leak test	Structural test
Butt	Automatic	Not required	Allowed[3]	N/A	Not required	Not required
	Manual or Semi-automatic[4]	Required	Not allowed	Allowed	Required	Not required
Fillet	Boundary including penetrations	Required	Not allowed	Allowed	Required	Not required

Notes:

1 Coating refers to internal (tank/hold coating), where applied, and external (shell/deck) painting. It does not refer to shop primer.

2 Temporary means of access for verification of the leak test.

3 The condition applies provided that the welds have been carefully inspected visually to the satisfaction of the Surveyor.

4 Flux Core Arc Welding (FCAW) semiautomatic butt welds need not be tested provided that careful visual inspections show continuous uniform weld profile shape, free from repairs, and the results of NDE testing show no significant defects.

ANNEX I

PROCEDURES FOR TESTING TANKS AND TIGHT BOUNDARIES

PART B - Non-SOLAS Ships and SOLAS Exemption/Equivalent Ships

1 GENERAL

1.1 These test procedures are to confirm the watertightness of tanks and watertight boundaries and the structural adequacy of tanks which consist of the watertight subdivisions[1] of ships. These procedures may also be applied to verify the weathertightness of structures and shipboard outfitting. The tightness of all tanks and watertight boundaries of ships during new construction and those relevant to major conversions or major repairs[2] is to be confirmed by these test procedures prior to the delivery of the ship.

1.2 Testing procedures of watertight compartments are to be carried out in accordance with PART B for non-SOLAS ships and those SOLAS ships (including CSR BC & OT) for which:

a) the shipyard provides documentary evidence of the shipowner's agreement to a request to the Flag Administration for an exemption from the application of SOLAS Chapter II-1, Regulation 11, or for an equivalency agreeing that the content of PART B is equivalent to SOLAS Chapter II-1, Regulation 11; and

b) the above-mentioned exemption/equivalency has been granted by the responsible Flag Administration.

2 APPLICATION

2.1 Testing procedures are to be carried out in accordance with the requirements of PART A in association with the following alternative procedures for 4.2.2 of PART A "Testing Schedule for New Construction or Major Structural Conversion" and alternative test requirements for PART A Table 1.

2.2 The tank boundaries are to be tested from at least one side. The tanks for structural test are to be selected so that all representative structural members are tested for the expected tension and compression.

2.3 Structural tests are to be carried out for at least one tank of a group of tanks having structural similarity (i.e. same design conditions, alike structural configurations with only minor localised differences determined to be acceptable by the attending Surveyor) on each vessel provided all other tanks are tested for leaks by an air test. The acceptance of leak testing using an air test instead of a structural test does not apply to cargo space boundaries adjacent to other compartments in tankers and combination carriers or to the boundaries of tanks for segregated cargoes or pollutant cargoes in other types of ships.

2.4 Additional tanks may require structural testing if found necessary after the structural testing of the first tank.

[1] Watertight subdivision means the main transverse and longitudinal subdivisions of the ship required to satisfy the subdivision requirements of SOLAS Chapter II-1.

[2] Major repair means a repair affecting structural integrity.

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(cont)

2.5 Where the structural adequacy of the tanks of a vessel were verified by the structural testing required in PART A, Table 1, subsequent vessels in the series (i.e. sister ships built from the same plans at the same shipyard) may be exempted from structural testing of tanks, provided that:

1. water-tightness of boundaries of all tanks is verified by leak tests and thorough inspections are carried out.

2. structural testing is carried out for at least one tank of each type among all tanks of each sister vessel.

3. additional tanks may require structural testing if found necessary after the structural testing of the first tank or if deemed necessary by the attending Surveyor.

For cargo space boundaries adjacent to other compartments in tankers and combination carriers or boundaries of tanks for segregated cargoes or pollutant cargoes in other types of ships, the provisions of paragraph PART B 2.3 shall apply in lieu of paragraph PART B 2.5.2.

2.6 Sister ships built (i.e. keel laid) two years or more after the delivery of the last ship of the series, may be tested in accordance with PART B 2.5 at the discretion of the Classification Society, provided that:

1. general workmanship has been maintained (i.e. there has been no discontinuity of shipbuilding or significant changes in the construction methodology or technology at the yard, shipyard personnel are appropriately qualified and demonstrate an adequate level of workmanship as determined by the Classification Society); and

2. an NDT plan is implemented and evaluated by the Classification Society for the tanks not subject to structural tests. Shipbuilding quality standards for the hull structure during new construction are to be reviewed and agreed during the kick-off meeting. Structural fabrication is to be carried out in accordance with IACS Recommendation 47, “Shipbuilding and Repair Quality Standard”, or a recognised fabrication standard which has been accepted by the Classification Society prior to the commencement of fabrication/construction. The work is to be carried out in accordance with the Rules and under survey of the Classification Society.

End of Document

S15 Side Shell Doors and Stern Doors

(1996)
(Rev.1
Nov. 2003)

Retrospective application of UR-S9 to existing ro-ro passenger ships

1. The structural condition of side shell doors and stern doors, especially the primary structure, the securing and supporting arrangements and the hull structure alongside and above the doors, are to be specially examined and any defects rectified.

2. The following measures are to be complied with by all existing ro-ropassenger ships with the date of building before the 30th June 1996, including, when not differently deliberated by the competent flag Administrations, ships only engaged on domestic sea voyages.

a) The structural arrangement of securing devices and supporting devices of inwards opening doors in way of these securing devices and, where applicable, of the surrounding hull structure is to be re-assessed in accordance with the applicable requirements of S9.5 and modified accordingly.

b) The securing and locking arrangements for side shell doors and stern doors which may lead to the flooding of a special category space or ro-ro spaces as defined in S9.1.3, are to comply with the following requirements :

-Separate indicator lights and audible alarms are to be provided on the navigation bridge and on each operating panel to indicate that the doors are closed and that their securing and locking devices are properly positioned.

The indication panel is to be provided with a lamp test function. It shall not be possible to turn off the indicator light.

-The indication panel on the navigation bridge is to be equipped with a mode selection function "harbour/sea voyage", so arranged that audible alarm is given if the vessel leaves harbour with side shell or stern doors not closed or with any of the securing devices not in the correct position.

-A water leakage detection system with audible alarm and television surveillance is to be arranged to provide an indication to the navigation bridge and to the engine control room of any leakage through the doors.

3. Documented operating procedures for closing and securing side shell and stern doors are to be kept on board and posted at the appropriate places.

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S16
(1995)
(Rev.1
Nov 2003)
(Corr.1
Aug 2004)

Bow Doors and Inner Doors - Retrospective Application of UR-S8, as amended 1995, to existing Ro-Ro Passenger Ships

1. The structural condition of bow doors and inner doors, especially the primary structure, the securing and supporting arrangements and the hull structure alongside and above the doors, are to be specially examined and any defects rectified.

2. The requirements of S8.8 concerning operating procedures of the bow door and inner door are to be complied with.

3. The following measures are to be complied with by all existing ro-ro passenger ships with the date of building before the 30th June 1996, including, when not differently deliberated by the competent flag Administrations, ships only engaged on domestic sea voyages.

a) The location and arrangement of inner doors are to comply with the applicable requirements of the SOLAS Convention and with S8.1.2d.

b) Ships with visor door are to comply with S8.6.2g requiring redundant provision of securing devices preventing the upward opening of the bow door. In addition, where the visor door is not self closing under external loads (i.e. the closing moment M_y calculated in accordance with S8.3.1c is less than zero) then the opening moment M_o is not to be taken less than $-M_y$. If drainage arrangements in the space between the inner and bow doors are not fitted, the value of M_o is to be specially considered.

Where available space above the tanktop does not enable the full application of S.8.6.2g, equivalent measures are to be taken to ensure that the door has positive means for being kept closed during seagoing operation.

c) Ships with visor door are to comply with S8.6.2h requiring securing and supporting devices excluding hinges to be capable of bearing the vertical design force (F_z - 10W) without exceeding the permissable stresses given in S8.2.1a.

d) For side-opening doors, the structural arrangements for supporting vertical loads, including securing devices, supporting devices and, where applicable, hull structure above the door, are to be re-assessed in accordance with the applicable requirements of S8.6 and modified accordingly.

e) The securing and locking arrangements for bow doors and inner doors which may lead to the flooding of a special category space or ro-ro space as defined in the S8.1.3 are to comply with the following requirements:

- Separate indicator lights and audible alarms are to be provided on the navigation bridge and on each panel to indicate that the doors are closed and that their securing and locking devices are properly positioned.

- The indication panel is to be provided with a lamp test function. It is not to be possible to turn off the indicator light.

- The indication panel on the navigation bridge is to be equipped with a mode selection function “harbour/sea voyage”, so arranged that audible alarm is given if the vessel leaves harbour with the bow doors or inner doors not closed or with any of the securing devices not in the correct position.

- A water leakage detection system with audible alarm and television surveillance are to be arranged to provide an indication to the navigation bridge and to the engine control station of any leakage through the doors.

END

S17
(1997)
(Rev.1 1997)
(Rev.2 1998)
(Rev.3 Sep 2000)
(Rev.4 June 2002)
(Rev.5 June 2003)
(Rev.6 July 2004)
(Rev.7 Feb 2006)
(Corr.1 Oct 2009)
(Rev.8 May 2010)
(Rev.9 Apr 2014)

Longitudinal Strength of Hull Girder in Flooded Condition for Non-CSR Bulk Carriers

S17.1 General

Revision 7 or subsequent revisions or corrigenda as applicable of this UR is to be applied to non-CSR bulk carriers of 150 m in length and upwards, intending to carry solid bulk cargoes having a density of 1,0 t/m^3 or above, and with,

a) Single side skin construction, or

b) Double side skin construction in which any part of longitudinal bulkhead is located within B/5 or 11.5 m, whichever is less, inboard from the ship's side at right angle to the centreline at the assigned summer load line

in accordance with Note 2.

Such ships are to have their hull girder strength checked for specified flooded conditions, in each of the cargo and ballast loading conditions defined in UR S11.2.1.2 to S11.2.1.4. and in every other condition considered in the intact longitudinal strength calculations, including those according to UR S1 and S1A, except that harbour conditions, docking condition afloat, loading and unloading transitory conditions in port and loading conditions encountered during ballast water exchange need not be considered.

This UR does not apply to CSR Bulk Carriers.

S17.2 Flooding conditions

S17.2.1 Floodable holds

Each cargo hold is to be considered individually flooded up to the equilibrium waterline.

S17.2.2 Loads

The still water loads in flooded conditions are to be calculated for the above cargo and ballast loading conditions.

The wave loads in the flooded conditions are assumed to be equal to 80% of those given in UR S11.

Note:

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

2. Revision 7 or subsequent revisions or corrigenda as applicable of this UR is to be applied by IACS Societies to ships contracted for construction on or after 1 July 2006.

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(cont)

S17.3 Flooding criteria

To calculate the weight of ingressed water, the following assumptions are to be made:

a) The permeability of empty cargo spaces and volume left in loaded cargo spaces above any cargo is to be taken as 0.95.

b) Appropriate permeabilities and bulk densities are to be used for any cargo carried. For iron ore, a minimum permeability of 0.3 with a corresponding bulk density of 3.0 t/m^3 is to be used. For cement, a minimum permeability of 0.3 with a corresponding bulk density of 1.3 t/m^3 is to be used. In this respect, "permeability" for solid bulk cargo means the ratio of the floodable volume between the particles, granules or any larger pieces of the cargo, to the gross volume of the bulk cargo.

For packed cargo conditions (such as steel mill products), the actual density of the cargo should be used with a permeability of zero.

S17.4 Stress assessment

The actual hull girder bending stress σ_{fld}, in N/mm^2, at any location is given by:

$$\sigma_{fld} = \frac{M_{sf} + 0.8M_W}{W_Z} \cdot 10^3$$

where:

M_{sf} = still water bending moment, in kNm, in the flooded conditions for the section under consideration

M_W = wave bending moment, in kNm, as given in UR S11.2.2.1 for the section under consideration

W_Z = section modulus, in cm^3, for the corresponding location in the hull girder.

The shear strength of the side shell and the inner hull (longitudinal bulkhead) if any, at any location of the ship, is to be checked according to the requirements specified in UR S11.4 in which F_S and F_W are to be replaced respectively by F_{SF} and F_{WF}, where:

F_{SF} = still water shear force, in kN, in the flooded conditions for the section under consideration

F_{WF} = 0.8 F_W

F_W = wave shear force, in kN, as given in UR S11.2.2.2 for the section under consideration

S17.5 Strength criteria

The damaged structure is assumed to remain fully effective in resisting the applied loading.

Permissible stress and axial stress buckling strength are to be in accordance with UR S11.

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S18
(1997)
(Rev.1 1997)
(Rev.1.1 Mar 1998 /Corr.1)
(Rev.2 Sept 2000)
(Rev.3 Feb 2001)
(Rev.4 Nov 2001)
(Rev.5 July 2003)
(Rev.6 July 2004)
(Rev.7 Feb 2006)
(Corr.1 Oct 2009)
(Rev.8 May 2010)
(Rev.9 Apr 2014)

Evaluation of Scantlings of Corrugated Transverse Watertight Bulkheads in Non-CSR Bulk Carriers Considering Hold Flooding

S18.1 - Application and definitions

Revision 7 or subsequent revisions or corrigenda as applicable of this UR is to be applied to non-CSR bulk carriers of 150 m in length and upwards, intending to carry solid bulk cargoes having a density of 1.0 t/m^3 or above, with vertically corrugated transverse watertight bulkheads, and with,

a) Single side skin construction, or

b) Double side skin construction in which any part of longitudinal bulkhead is located within B/5 or 11.5 m, whichever is less, inboard from the ship's side at right angle to the centreline at the assigned summer load line

in accordance with Note 2.

The net thickness t_{net} is the thickness obtained by applying the strength criteria given in S18.4.

The required thickness is obtained by adding the corrosion addition t_s, given in S18.6, to the net thickness t_{net}.

In this requirement, homogeneous loading condition means a loading condition in which the ratio between the highest and the lowest filling ratio, evaluated for each hold, does not exceed 1.20, to be corrected for different cargo densities.

This UR does not apply to CSR Bulk Carriers.

S18.2 - Load model

S18.2.1 - General

The loads to be considered as acting on the bulkheads are those given by the combination of the cargo loads with those induced by the flooding of one hold adjacent to the bulkhead under examination. In any case, the pressure due to the flooding water alone is to be considered.

Notes:

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

2. Revision 7 or subsequent revisions or corrigenda as applicable of this UR is to be applied by IACS Societies to ships contracted for construction on or after 1 July 2006.

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The most severe combinations of cargo induced loads and flooding loads are to be used for the check of the scantlings of each bulkhead, depending on the loading conditions included in the loading manual:

- homogeneous loading conditions;
- non homogeneous loading conditions;

considering the individual flooding of both loaded and empty holds.

The specified design load limits for the cargo holds are to be represented by loading conditions defined by the Designer in the loading manual.

Non homogeneous part loading conditions associated with multiport loading and unloading operations for homogeneous loading conditions need not to be considered according to these requirements.

Holds carrying packed cargoes are to be considered as empty holds for this application.

Unless the ship is intended to carry, in non homogeneous conditions, only iron ore or cargo having bulk density equal or greater than 1.78 t/m^3, the maximum mass of cargo which may be carried in the hold shall also be considered to fill that hold up to the upper deck level ***at centreline***.

S18.2.2 - Bulkhead corrugation flooding head

The flooding head h_f (see Figure 1) is the distance, in m, measured vertically with the ship in the upright position, from the calculation point to a level located at a distance d_f, in m, from the baseline equal to:

a) in general:

- D for the foremost transverse corrugated bulkhead
- 0.9D for the other bulkheads

Where the ship is to carry cargoes having bulk density less than 1.78 t/m^3 in non homogeneous loading conditions, the following values can be assumed:

- 0.95D for the foremost transverse corrugated bulkhead
- 0.85D for the other bulkheads

b) for ships less than 50,000 tonnes deadweight with Type B freeboard:

- 0.95D for the foremost transverse corrugated bulkhead
- 0.85D for the other bulkheads

Where the ship is to carry cargoes having bulk density less than 1.78 t/m^3 in non homogeneous loading conditions, the following values can be assumed:

- 0.9D for the foremost transverse corrugated bulkhead
- 0.8D for the other bulkheads

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(cont)

D being the distance, in m, from the baseline to the freeboard deck at side amidship (see Figure 1).

S18.2.3 - Pressure in the non-flooded bulk cargo loaded holds

At each point of the bulkhead, the pressure p_c, in kN/m^2, is given by:

$$p_c = \rho_c g h_1 \tan^2 \gamma$$

where:

ρ_c = bulk cargo density, in t/m^3

g = 9.81 m/s^2, gravity acceleration

h_1 = vertical distance, in m, from the calculation point to horizontal plane corresponding to the level height of the cargo (see Figure 1), located at a distance d_1, in m, from the baseline.

γ = 45° - (φ/2)

φ = angle of repose of the cargo, in degrees, that may generally be taken as 35° for iron ore and 25° for cement

The force F_c, in kN, acting on a corrugation is given by:

$$F_c = \rho_c g s_1 \frac{(d_1 - h_{DB} - h_{LS})^2}{2} \tan^2 \gamma$$

where:

ρ_c, g, d_1, γ = as given above

s_1 = spacing of corrugations, in m (see Figure 2a)

h_{LS} = mean height of the lower stool, in m, from the inner bottom

h_{DB} = height of the double bottom, in m

S18.2.4 - Pressure in the flooded holds

S18.2.4.1 - Bulk cargo holds

Two cases are to be considered, depending on the values of d_1 and d_f.

a) $d_f \geq d_1$

At each point of the bulkhead located at a distance between d_1 and d_f from the baseline, the pressure $p_{c,f}$, in kN/m^2, is given by:

$$p_{c,f} = \rho g h_f$$

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where:

ρ = sea water density, in t/m^3

g = as given in S18.2.3

h_f = flooding head as defined in S18.2.2

At each point of the bulkhead located at a distance lower than d_1 from the baseline, the pressure $p_{c,f}$, in kN/m^2, is given by:

$$p_{c,f} = \rho g h_f + [\rho_c - \rho(1 - perm)] g h_1 \tan^2 \gamma$$

where:

ρ, h_f = as given above

ρ_c, g, h_1, γ = as given in S18.2.3

perm = permeability of cargo, to be taken as 0.3 for ore (corresponding bulk cargo density for iron ore may generally be taken as 3.0 t/m^3), coal cargoes and for cement (corresponding bulk cargo density for cement may generally be taken as 1.3 t/m^3)

The force $F_{c,f}$, in kN, acting on a corrugation is given by:

$$F_{c,f} = s_1 \left[\rho g \frac{(d_f - d_1)^2}{2} + \frac{\rho g (d_f - d_1) + (p_{c,f})_{le}}{2} (d_1 - h_{DB} - h_{LS}) \right]$$

where:

ρ = as given above

s_1, g, d_1, h_{DB}, h_{LS} = as given in S18.2.3

d_f = as given in S18.2.2

$(p_{c,f})_{le}$ = pressure, in kN/m^2, at the lower end of the corrugation

b) $d_f < d_1$

At each point of the bulkhead located at a distance between d_f and d_1 from the baseline, the pressure $p_{c,f}$, in kN/m^2, is given by:

$$p_{c,f} = \rho_c g h_1 \tan^2 \gamma$$

where:

ρ_c, g, h_1, γ = as given in S18.2.3

At each point of the bulkhead located at a distance lower than d_f from the baseline, the pressure $p_{c,f}$, in kN/m^2, is given by:

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$$p_{c,f} = \rho g h_f + \left[\rho_c h_1 - \rho(1-perm)h_f\right]g\tan^2\gamma$$

where:

ρ, h_f, perm = as given in a) above

ρ_c, g, h_1, γ = as given in S18.2.3

The force $F_{c,f}$, in kN, acting on a corrugation is given by:

$$F_{c,f} = s_1\left[\rho_c g\frac{(d_1-d_f)^2}{2}\tan^2\gamma + \frac{\rho_c g(d_1-d_f)\tan^2\gamma + (p_{c,f})_{le}}{2}(d_f - h_{DB} - h_{LS})\right]$$

where:

s_1, ρ_c, g, d_1, γ, h_{DB}, h_{LS} = as given in S18.2.3

d_f = as given in S18.2.2

$(p_{c,f})_{le}$ = pressure, in kN/m^2, at the lower end of the corrugation

S18.2.4.2 - Pressure in empty holds due to flooding water alone

At each point of the bulkhead, the hydrostatic pressure p_f induced by the flooding head h_f is to be considered.

The force F_f, in kN, acting on a corrugation is given by:

$$F_f = s_1\rho g\frac{(d_f - h_{DB} - h_{LS})^2}{2}$$

where:

s_1, g, h_{DB}, h_{LS} = as given in S18.2.3

ρ = as given in S18.2.4.1 a)

d_f = as given in S18.2.2

S18.2.5 - Resultant pressure and force

S18.2.5.1 - Homogeneous loading conditions

At each point of the bulkhead structures, the resultant pressure p, in kN/m^2, to be considered for the scantlings of the bulkhead is given by:

$$p = p_{c,f} - 0.8p_c$$

The resultant force F, in kN, acting on a corrugation is given by:

$$F = F_{c,f} - 0.8F_c$$

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S18.2.5.2 - Non homogeneous loading conditions

At each point of the bulkhead structures, the resultant pressure p, in kN/m^2, to be considered for the scantlings of the bulkhead is given by:

$p = p_{c,f}$

The resultant force F, in kN, acting on a corrugation is given by:

$F = F_{c,f}$

S18.3 - Bending moment and shear force in the bulkhead corrugations

The bending moment M and the shear force Q in the bulkhead corrugations are obtained using the formulae given in S18.3.1 and S18.3.2. The M and Q values are to be used for the checks in S18.4.5.

S18.3.1 - Bending moment

The design bending moment M, in kNm, for the bulkhead corrugations is given by:

$$M = \frac{F\ell}{8}$$

where:

F = resultant force, in kN, as given in S18.2.5

ℓ = span of the corrugation, in m, to be taken according to Figures 2a and 2b

S18.3.2 - Shear force

The shear force Q, in kN, at the lower end of the bulkhead corrugations is given by:

$$Q = 0.8F$$

where:

F = as given in S18.2.5

S18.4 - Strength criteria

S18.4.1 - General

The following criteria are applicable to transverse bulkheads with vertical corrugations (see Figure 2). For ships of 190 m of length and above, these bulkheads are to be fitted with a lower stool, and generally with an upper stool below deck. For smaller ships, corrugations may extend from inner bottom to deck; if the stool is fitted, it is to comply with the requirements in S18.4.1.

The corrugation angle φ shown in Figure 2a is not to be less than 55°.

Requirements for local net plate thickness are given in S18.4.7.

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In addition, the criteria as given in S18.4.2 and S18.4.5 are to be complied with.

The thicknesses of the lower part of corrugations considered in the application of S18.4.2 and S18.4.3 are to be maintained for a distance from the inner bottom (if no lower stool is fitted) or the top of the lower stool not less than 0.15l.

The thicknesses of the middle part of corrugations as considered in the application of S18.4.2 and S18.4.4 are to be maintained to a distance from the deck (if no upper stool is fitted) or the bottom of the upper stool not greater than 0.3l.

The section modulus of the corrugation in the remaining upper part of the bulkhead is not to be less than 75% of that required for the middle part, corrected for different yield stresses.

(a) - Lower stool

The height of the lower stool is generally to be not less than 3 times the depth of the corrugations. The thickness and material of the stool top plate is not to be less than those required for the bulkhead plating above. The thickness and material of the upper portion of vertical or sloping stool side plating within the depth equal to the corrugation flange width from the stool top is not to be less than the required flange plate thickness and material to meet the bulkhead stiffness requirement at lower end of corrugation. The thickness of the stool side plating and the section modulus of the stool side stiffeners is not to be less than those required by each Society on the basis of the load model in S18.2. The ends of stool side vertical stiffeners are to be attached to brackets at the upper and lower ends of the stool.

The distance from the edge of the stool top plate to the surface of the corrugation flange is to be in accordance with Figure 5. The stool bottom is to be installed in line with double bottom floors and is to have a width not less than 2.5 times the mean depth of the corrugation. The stool is to be fitted with diaphragms in line with the longitudinal double bottom girders for effective support of the corrugated bulkhead. Scallops in the brackets and diaphragms in way of the connections to the stool top plate are to be avoided.

Where corrugations are cut at the lower stool, corrugated bulkhead plating is to be connected to the stool top plate by full penetration welds. The stool side plating is to be connected to the stool top plate and the inner bottom plating by either full penetration or deep penetration welds (see Figure 6). The supporting floors are to be connected to the inner bottom by either full penetration or deep penetration welds (see Figure 6).

(b) - Upper stool

The upper stool, where fitted, is to have a height generally between 2 and 3 times the depth of corrugations. Rectangular stools are to have a height generally equal to 2 times the depth of corrugations, measured from the deck level and at hatch side girder. The upper stool is to be properly supported by girders or deep brackets between the adjacent hatch-end beams.

The width of the stool bottom plate is generally to be the same as that of the lower stool top plate. The stool top of non rectangular stools is to have a width not less then 2 times the depth of corrugations. The thickness and material of the stool bottom plate are to be the same as those of the bulkhead plating below. The thickness of the lower portion of stool side plating is not to be less than 80% of that required for the upper part of the bulkhead plating where the same material is used. The thickness of the stool side plating and the section modulus of the stool side stiffeners is not to be less than those required by each Society on the basis of the load model in S18.2. The ends of stool side stiffeners are to be attached to brackets at upper and lower end of the stool. Diaphragms are to be fitted inside the stool in line with and effectively attached to longitudinal deck girders extending to the hatch end

S18 (cont)

coaming girders for effective support of the corrugated bulkhead. Scallops in the brackets and diaphragms in way of the connection to the stool bottom plate are to be avoided.

(c) - Alignment

At deck, if no stool is fitted, two transverse reinforced beams are to be fitted in line with the corrugation flanges.

At bottom, if no stool is fitted, the corrugation flanges are to be in line with the supporting floors.

Corrugated bulkhead plating is to be connected to the inner bottom plating by full penetration welds. The plating of supporting floors is to be connected to the inner bottom by either full penetration or deep penetration welds (see Figure 6).

The thickness and material properties of the supporting floors are to be at least equal to those provided for the corrugation flanges. Moreover, the cut-outs for connections of the inner bottom longitudinals to double bottom floors are to be closed by collar plates. The supporting floors are to be connected to each other by suitably designed shear plates, as deemed appropriate by the Classification Society.

Stool side plating is to align with the corrugation flanges and stool side vertical stiffeners and their brackets in lower stool are to align with the inner bottom longitudinals to provide appropriate load transmission between these stiffening members. Stool side plating is not to be knuckled anywhere between the inner bottom plating and the stool top.

S18.4.2 - Bending capacity and shear stress τ

The bending capacity is to comply with the following relationship:

$$10^3 \cdot \frac{M}{0.5 Z_{le} \sigma_{a,le} + Z_m \sigma_{a,m}} \leq 0.95$$

where:

M = bending moment, in kNm, as given in S18.3.1

Z_{le} = section modulus of one half pitch corrugation, in cm^3, at the lower end of corrugations, to be calculated according to S18.4.3.

Z_m = section modulus of one half pitch corrugation, in cm^3, at the mid-span of corrugations, to be calculated according to S18.4.4.

$\sigma_{a,le}$ = allowable stress, in N/mm^2, as given in S18.4.5, for the lower end of corrugations

$\sigma_{a,m}$ = allowable stress, in N/mm^2, as given in S18.4.5, for the mid-span of corrugations

In no case Z_m is to be taken greater than the lesser of $1.15Z_{le}$ and $1.15Z'_{le}$ for calculation of the bending capacity, Z'_{le} being defined below.

In case shedders plates are fitted which:

- are not knuckled;

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- are welded to the corrugations and the top of the lower stool by one side penetration welds or equivalent;
- are fitted with a minimum slope of 45° and their lower edge is in line with the stool side plating;
- have thicknesses not less than 75% of that provided by the corrugation flange;
- and material properties at least equal to those provided by the flanges.

or gusset plates are fitted which:

- are in combination with shedder plates having thickness, material properties and welded connections in accordance with the above requirements;
- have a height not less than half of the flange width;
- are fitted in line with the stool side plating;
- are generally welded to the top of the lower stool by full penetration welds, and to the corrugations and shedder plates by one side penetration welds or equivalent.
- have thickness and material properties at least equal to those provided for the flanges.

the section modulus Z_{le}, in cm^3, is to be taken not larger than the value Z'_{le}, in cm^3, given by:

$$Z'_{le} = Z_g + 10^3 \cdot \frac{Qh_g - 0.5h_g{}^2 s_1 p_g}{\sigma_a}$$

where:

Z_g = section modulus of one half pitch corrugation, in cm^3, of the corrugations calculated, according to S18.4.4, in way of the upper end of shedder or gusset plates, as applicable

Q = shear force, in kN, as given in S18.3.2

h_g = height, in m, of shedders or gusset plates, as applicable (see Figures 3a, 3b, 4a and 4b)

s_1 = as given in S18.2.3

p_g = resultant pressure, in kN/m^2, as defined in S18.2.5, calculated in way of the middle of the shedders or gusset plates, as applicable

σ_a = allowable stress, in N/mm^2, as given in S18.4.5.

Stresses τ are obtained by dividing the shear force Q by the shear area. The shear area is to be reduced in order to account for possible non-perpendicularity between the corrugation webs and flanges. In general, the reduced shear area may be obtained by multiplying the web sectional area by (sin φ), φ being the angle between the web and the flange.

When calculating the section modulus and the shear area, the net plate thicknesses are to be used.

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The section modulus of corrugations are to be calculated on the basis of the following requirements given in S18.4.3 and S18.4.4.

S18.4.3 - Section modulus at the lower end of corrugations

The section modulus is to be calculated with the compression flange having an effective flange width, b_{ef}, not larger than as given in S18.4.6.

If the corrugation webs are not supported by local brackets below the stool top (or below the inner bottom) in the lower part, the section modulus of the corrugations is to be calculated considering the corrugation webs 30% effective.

a) Provided that effective shedder plates, as defined in S18.4.2, are fitted (see Figures 3a and 3b), when calculating the section modulus of corrugations at the lower end (cross-section ① in Figures 3a and 3b), the area of flange plates, in cm^2, may be increased by:

$\left(2.5a\sqrt{t_f t_{sh}}\right)$ (not to be taken greater than $2.5at_f$)

where:

a = width, in m, of the corrugation flange (see Figure 2a)

t_{sh} = net shedder plate thickness, in mm

t_f = net flange thickness, in mm

b) Provided that effective gusset plates, as defined in S18.4.2, are fitted (see Figures 4a and 4b), when calculating the section modulus of corrugations at the lower end (cross-section ① in Figures 4a and 4b), the area of flange plates, in cm^2, may be increased by $(7h_g t_f)$ where:

h_g = height of gusset plate in m, see Figures 4a and 4b, not to be taken greater than $\left(\frac{10}{7}s_{gu}\right)$

s_{gu} = width of the gusset plates, in m

t_f = net flange thickness, in mm, based on the as built condition.

c) If the corrugation webs are welded to a sloping stool top plate which have an angle not less than 45º with the horizontal plane, the section modulus of the corrugations may be calculated considering the corrugation webs fully effective. In case effective gusset plates are fitted, when calculating the section modulus of corrugations the area of flange plates may be increased as specified in b) above. No credit can be given to shedder plates only.

For angles less than 45º, the effectiveness of the web may be obtained by linear interporation between 30% for 0º and 100% for 45º.

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S18.4.4 - Section modulus of corrugations at cross-sections other than the lower end

The section modulus is to be calculated with the corrugation webs considered effective and the compression flange having an effective flange width, b_{ef}, not larger than as given in S18.4.6.1.

S18.4.5 - Allowable stress check

The normal and shear stresses σ and τ are not to exceed the allowable values σ_a and τ_a, in N/mm^2, given by:

$\sigma_a = \sigma_F$

$\tau_a = 0.5\ \sigma_F$

σ_F = the minimum upper yield stress, in N/mm^2, of the material.

S18.4.6 - Effective compression flange width and shear buckling check

S18.4.6.1 - Effective width of the compression flange of corrugations

The effective width b_{ef}, in m, of the corrugation flange is given by:

$b_{ef} = C_e a$

where:

$C_e = \dfrac{2.25}{\beta} - \dfrac{1.25}{\beta^2}$ for β > 1.25

$C_e = 1.0$ for β ≤ 1.25

$\beta = 10^3 \dfrac{a}{t_f}\sqrt{\dfrac{\sigma_f}{E}}$

t_f = net flange thickness, in mm

a = width, in m, of the corrugation flange (see Figure 2a)

σ_F = minimum upper yield stress, in N/mm^2, of the material

E = modulus of elasticity of the material, in N/mm^2, to be assumed equal to 2.06×10^5 for steel

S18.4.6.2 - Shear

The buckling check is to be performed for the web plates at the corrugation ends.

The shear stress τ is not to exceed the critical value τ_c, in N/mm^2 obtained by the following:

$\tau_c = \tau_E$ when $\tau_E \le \dfrac{\tau_F}{2}$

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(cont)

$$= \tau_F \left(1 - \frac{\tau_F}{4\tau_E}\right) \qquad \text{when } \tau_E > \frac{\tau_F}{2}$$

where:

$$\tau_F = \frac{\sigma_F}{\sqrt{3}}$$

σ_F = minimum upper yield stress, in N/mm^2, of the material

$$\tau_E = 0.9 k_t E \left(\frac{t}{1000c}\right)^2 \qquad (\text{N/mm}^2)$$

k_t, E, t and c are given by:

k_t = 6.34

E = modulus of elasticity of material as given in S18.4.6.1

t = net thickness, in mm, of corrugation web

c = width, in m, of corrugation web (See Figure 2a)

S18.4.7 - Local net plate thickness

The bulkhead local net plate thickness t, in mm, is given by:

$$t = 14.9 s_w \sqrt{\frac{1.05p}{\sigma_F}}$$

where:

s_w = plate width, in m, to be taken equal to the width of the corrugation flange or web, whichever is the greater (see Figure 2a)

p = resultant pressure, in kN/m^2, as defined in S18.2.5, at the bottom of each strake of plating; in all cases, the net thickness of the lowest strake is to be determined using the resultant pressure at the top of the lower stool, or at the inner bottom, if no lower stool is fitted or at the top of shedders, if shedder or gusset/shedder plates are fitted.

σ_F = minimum upper yield stress, in N/mm^2, of the material.

For built-up corrugation bulkheads, when the thicknesses of the flange and web are different, the net thickness of the narrower plating is to be not less than t_n, in mm, given by:

$$t_n = 14.9 s_n \sqrt{\frac{1.05p}{\sigma_F}}$$

s_n being the width, in m, of the narrower plating.

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The net thickness of the wider plating, in mm, is not to be taken less than the maximum of the following

$$t_w = 14.9 s_w \sqrt{\frac{1.05p}{\sigma_F}}$$

and

$$t_w = \sqrt{\frac{440 s_w^2 1.05p}{\sigma_F} - t_{np}^2}$$

where t_{np} ≤ actual net thickness of the narrower plating and not to be greater than

$$14.9 s_w \sqrt{\frac{1.05p}{\sigma_F}}$$

S18.5 - Local details

As applicable, the design of local details is to comply with the Society requirements for the purpose of transferring the corrugated bulkhead forces and moments to the boundary structures, in particular to the double bottom and cross-deck structures.

In particular, the thickness and stiffening of effective gusset and shedder plates, as defined in S18.4.3, is to comply with the Society requirements, on the basis of the load model in S18.2.

Unless otherwise stated, weld connections and materials are to be dimensioned and selected in accordance with the Society requirements.

S18.6 - Corrosion addition and steel renewal

The corrosion addition t_s is to be taken equal to 3.5 mm.

Steel renewal is required where the gauged thickness is less than t_{net} + 0.5 mm.

Where the gauged thickness is within the range t_{net} + 0.5 mm and t_{net} + 1.0 mm, coating (applied in accordance with the coating manufacturer’s requirements) or annual gauging may be adopted as an alternative to steel renewal.

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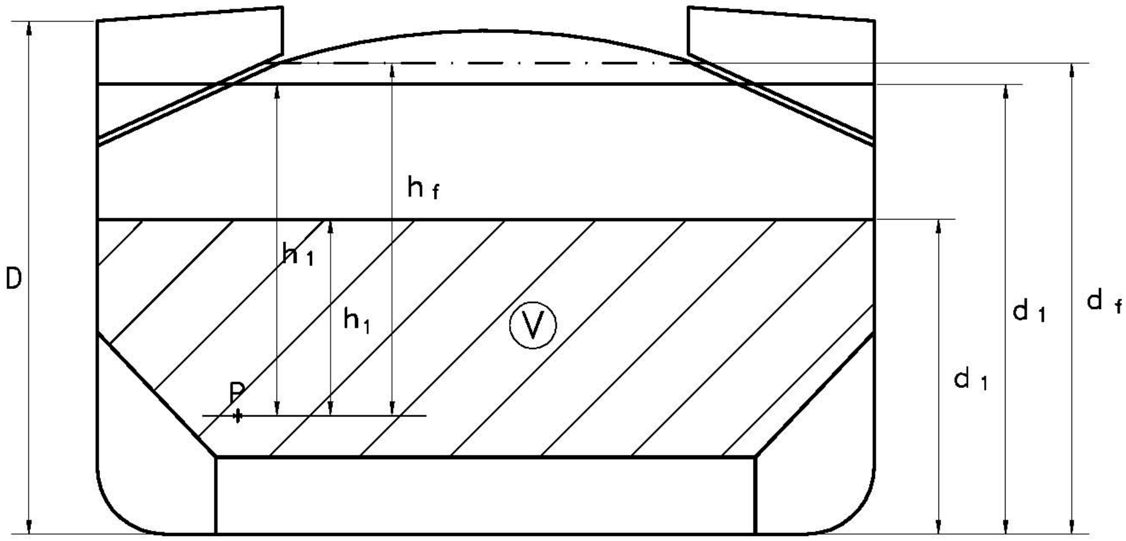
Figure 1



V = Volume of cargo

P = Calculation point

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Figure 2a

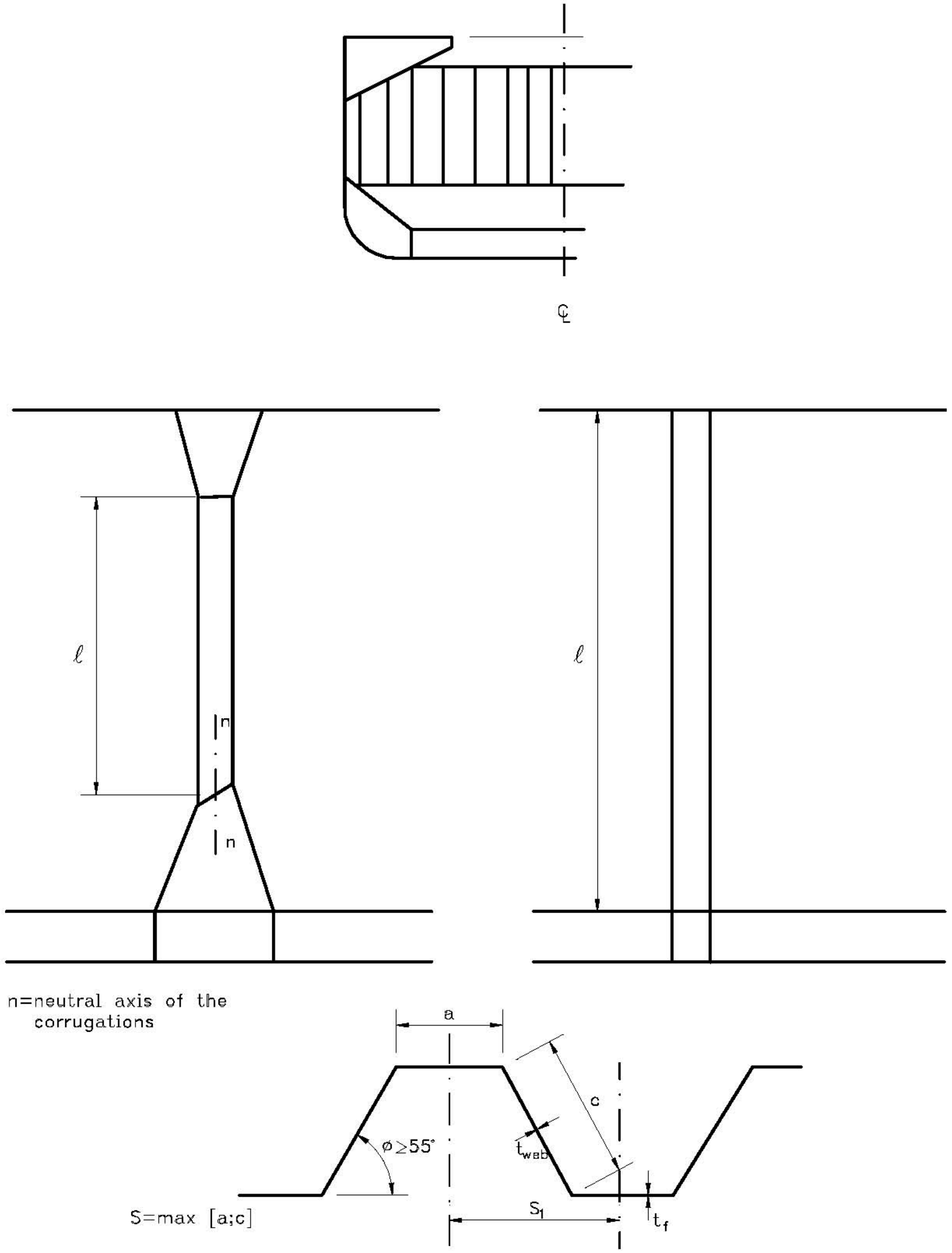

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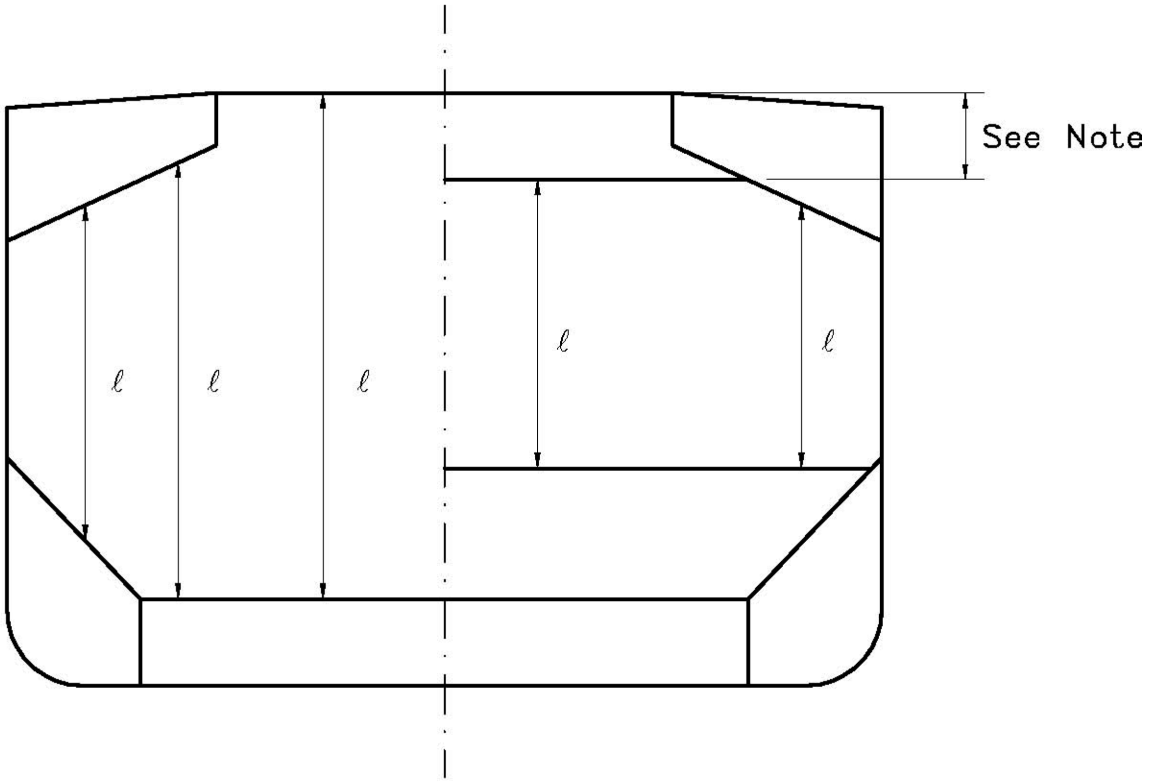
Figure 2b



Note For the definition of ℓ, the internal end of the upper stool is not to be taken more than a distance from the deck at the centre line equal to:

- 3 times the depth of corrugations, in general
- 2 times the depth of corrugations, for rectangular stool

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Figure 3a
Symmetric shedder plates

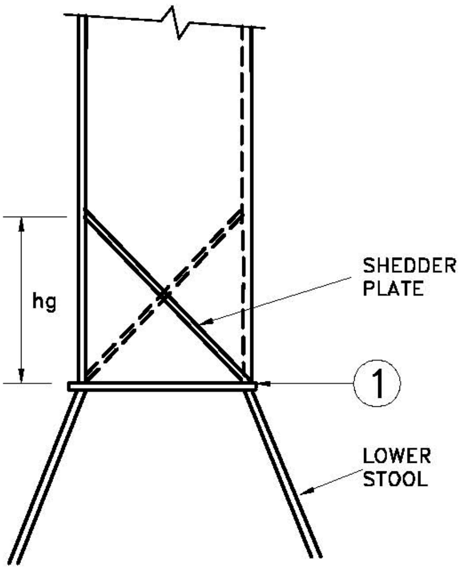

Figure 3b
Asymmetric shedder plates

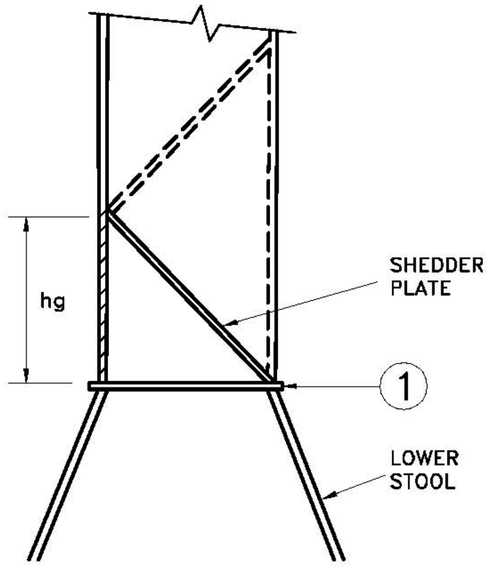

Figure 4a
Symmetric gusset / shedder plates

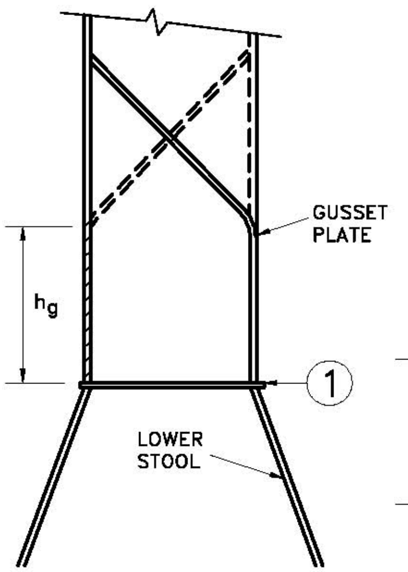

Figure 4b
Asymmetric gusset / shedder plates

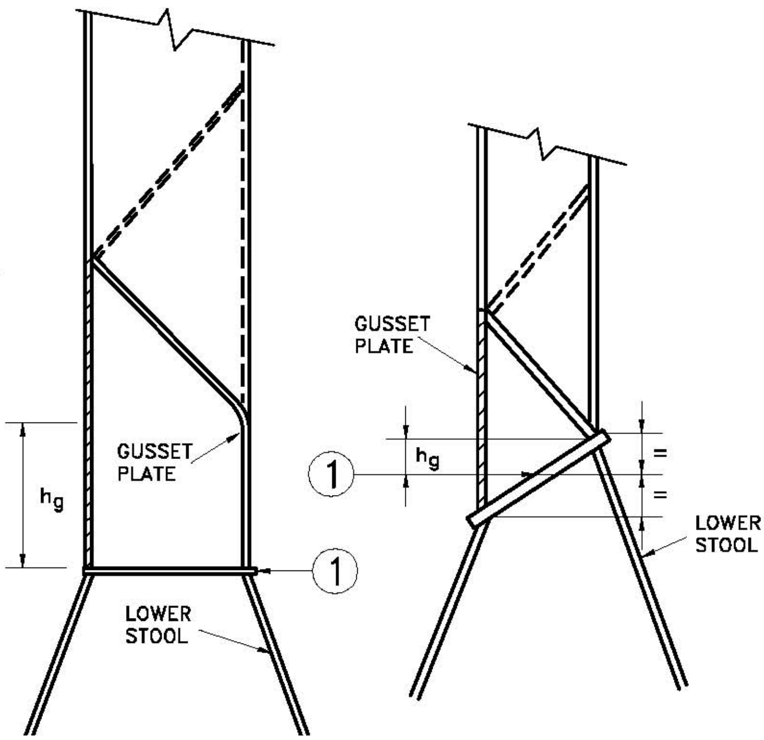

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Figure 5
Permitted distance, d, from edge of stool top plate to surface of corrugation flange

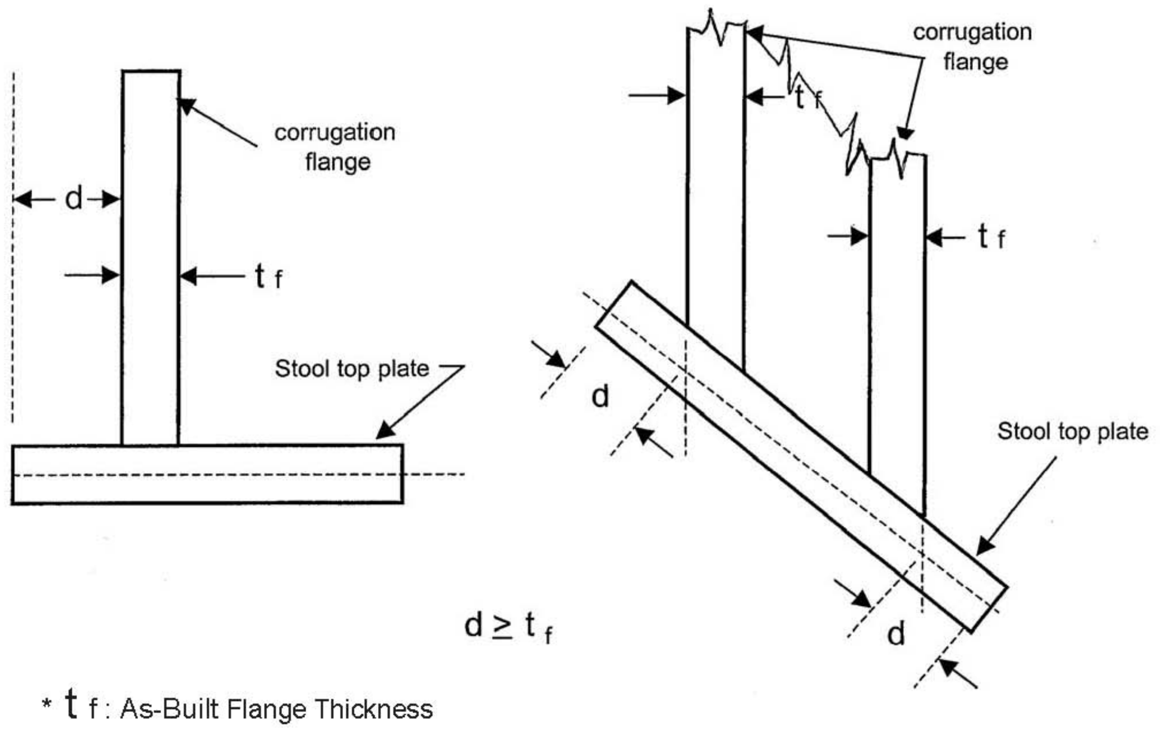
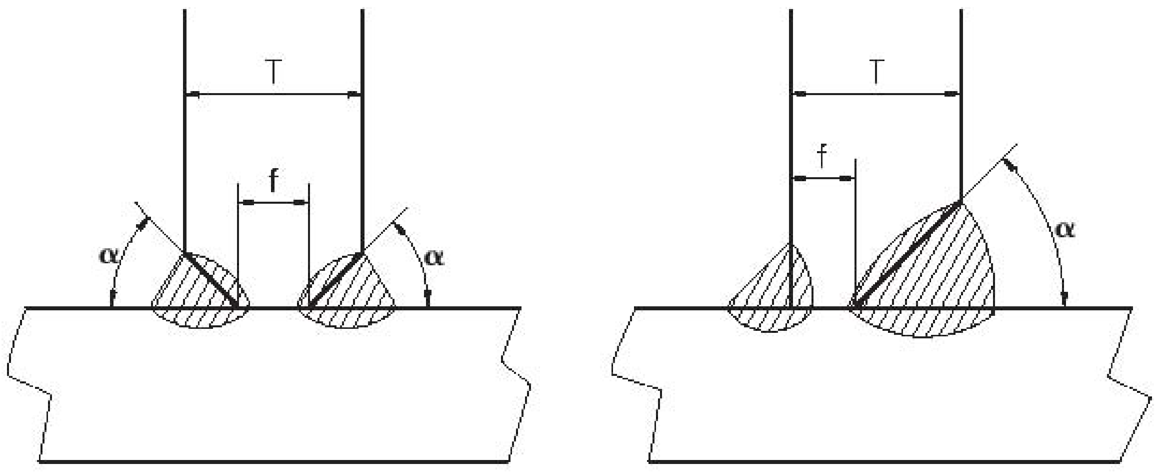


Figure 6



Root Face (f) : 3 mm to T/3 mm
Groove Angle (α) : 40° to 60°

End of Document

S19

(1997)
(Rev. 1
1997)
(Rev. 2
Feb. 1998)
(Rev.3
Jun. 1998)
(Rev.4
Sept. 2000)
(Rev.5
July 2004)

Evaluation of Scantlings of the Transverse Watertight Corrugated Bulkhead between Cargo Holds Nos. 1 and 2, with Cargo Hold No. 1 Flooded, for Existing Bulk Carriers

S19.1 - Application and definitions

These requirements apply to all bulk carriers of 150 m in length and above, in the foremost hold, intending to carry solid bulk cargoes having a density of 1,78 t/m^3, or above, with single deck, topside tanks and hopper tanks, fitted with vertically corrugated transverse watertight bulkheads between cargo holds No. 1 and 2 where:

(i) the foremost hold is bounded by the side shell only for ships which were contracted for construction prior to 1 July 1998, and have not been constructed in compliance with IACS Unified Requirement S18,

(ii) the foremost hold is double side skin construction of less than 760 mm breadth measured perpendicular to the side shell in ships, the keels of which were laid, or which were at a similar stage of construction, before 1 July 1999 and have not been constructed in compliance with IACS Unified Requirement S18 (Rev. 2, Sept. 2000).

The net scantlings of the transverse bulkhead between cargo holds Nos. 1 and 2 are to be calculated using the loads given in S19.2, the bending moment and shear force given in S19.3 and the strength criteria given in S19.4.

Where necessary, steel renewal and/or reinforcements are required as per S19.6.

In these requirements, homogeneous loading condition means a loading condition in which the ratio between the highest and the lowest filling ratio, evaluated for the two foremost cargo holds, does not exceed 1,20, to be corrected for different cargo densities.

S19.2 - Load model

S19.2.1 - General

The loads to be considered as acting on the bulkhead are those given by the combination of the cargo loads with those induced by the flooding of cargo hold No.1.

The most severe combinations of cargo induced loads and flooding loads are to be used for the check of the scantlings of the bulkhead, depending on the loading conditions included in the loading manual:

- homogeneous loading conditions;
- non homogeneous loading conditions.

Non homogeneous part loading conditions associated with multiport loading and unloading operations for homogeneous loading conditions need not to be considered according to these requirements.

Notes:

1. Changes introduced in Revision 2 to UR S19, i.e. the introduction of the first sentence of S19.6 as well as the Annex are to be applied by all Member societies and Associates not later than 1 July 1998.
2. Annex 2 contains, for guidance only, a flow chart entitled “Guidance to assess capability of Carriage of High Density Cargoes on Existing Bulk Carriers according to the Strength of Transverse Bulkhead between Cargo Holds Nos. 1 and 2”.
3. Changes introduced in Rev.4 are to be uniformly implemented by IACS Members and Associates from 1 July 2001.
4. The “contracted for construction” date means the date on which the contract to build the vessel is signed between the prospective owner and the shipbuilder. For further details regarding the date of “contract for construction”, refer to IACS Procedural Requirement (PR) No. 29.

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S19.2.2 - Bulkhead corrugation flooding head

The flooding head h_f (see Figure 1) is the distance, in m, measured vertically with the ship in the upright position, from the calculation point to a level located at a distance d_f, in m, from the baseline equal to:

a) in general:

- D

b) for ships less than 50,000 tonnes deadweight with Type B freeboard:

- $0,95 \cdot D$

D being the distance, in m, from the baseline to the freeboard deck at side amidship (see Figure 1).

c) for ships to be operated at an assigned load line draught T_r less than the permissible load line draught T, the flooding head defined in a) and b) above may be reduced by $T - T_r$.

S19.2.3 - Pressure in the flooded hold

S19.2.3.1 - Bulk cargo loaded hold

Two cases are to be considered, depending on the values of d1 and df, d1 (see Figure 1) being a distance from the baseline given, in m, by:

$$d_1 = \frac{M_c}{\rho_c \cdot l_c \cdot B} + \frac{V_{LS}}{l_c \cdot B} + \left(h_{HT} - h_{DB}\right) \cdot \frac{b_{HT}}{B} + h_{DB}$$

where:

M_c = mass of cargo, in tonnes, in hold No. 1

ρ_c = bulk cargo density, in t/m^3

l_c = length of hold No. 1, in m

B = ship's breadth amidship, in m

v_{LS} = volume, in m^3, of the bottom stool above the inner bottom

h_{HT} = height of the hopper tanks amidship, in m, from the baseline

h_{DB} = height of the double bottom, in m

b_{HT} = breadth of the hopper tanks amidship, in m.

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a) $d_f \geq d_1$

At each point of the bulkhead located at a distance between d_1 and d_f from the baseline, the pressure $p_{c,f}$, in kN/m^2, is given by:

$$p_{c,f} = \rho \cdot g \cdot h_f$$

where:

ρ = sea water density, in t/m^3

g = 9,81 m/s^2, gravity acceleration

h_f = flooding head as defined in S19.2.2.

At each point of the bulkhead located at a distance lower than d_1 from the baseline, the pressure $p_{c,f}$, in kN/m^2, is given by:

$$p_{c,f} = \rho \cdot g \cdot h_f + [\rho_c - \rho \cdot (1 - perm)] \cdot g \cdot h_1 \cdot \tan^2 \gamma$$

where:

ρ, g, h_f = as given above

ρ_c = bulk cargo density, in t/m^3

perm = permeability of cargo, to be taken as 0,3 for ore (corresponding bulk cargo density for iron ore may generally be taken as 3,0 t/m^3),

h_1 = vertical distance, in m, from the calculation point to a level located at a distance d_1, as defined above, from the base line (see Figure 1)

γ = 45° -(ϕ/2)

ϕ = angle of repose of the cargo, in degrees, and may generally be taken as 35° for iron ore.

The force $F_{c,f}$, in kN, acting on a corrugation is given by:

$$F_{c,f} = s_1 \cdot \left(\rho \cdot g \cdot \frac{(d_f - d_1)^2}{2} + \frac{\rho \cdot g \cdot (d_f - d_1) + (p_{c,f})_{le}}{2} \cdot (d_1 - h_{DB} - h_{LS}) \right)$$

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where:

s_1 = spacing of corrugations, in m (see Figure 2a)

ρ, g, d_1, h_{DB} = as given above

d_f = as given in S19.2.2

$(p_{c,f})_{le}$ = pressure, in kN/m^2, at the lower end of the corrugation

h_{LS} = height of the lower stool, in m, from the inner bottom.

b) $d_f < d_1$

At each point of the bulkhead located at a distance between d_f and d_1 from the baseline, the pressure $p_{c,f}$, in kN/m^2, is given by:

$$p_{c,f} = \rho_c \cdot g \cdot h_1 \cdot \tan^2 \gamma$$

where:

ρ_c, g, h_1, γ = as given in a) above

At each point of the bulkhead located at a distance lower than d_f from the baseline, the pressure $p_{c,f}$, in kN/m^2, is given by:

$$p_{c,f} = \rho \cdot g \cdot h_f + \left[\rho_c \cdot h_1 - \rho \cdot (1 - perm) \cdot h_f\right] \cdot g \cdot \tan^2 \gamma$$

where:

ρ, g, h_f, ρ_c, h_1, perm, γ = as given in a) above

The force $F_{c,f}$, in kN, acting on a corrugation is given by:

$$F_{c,f} = s_1 \cdot \left(\rho_c \cdot g \cdot \frac{(d_1 - d_f)^2}{2} \cdot \tan^2 \gamma + \frac{\rho_c \cdot g \cdot (d_1 - d_f) \cdot \tan^2 \gamma + (p_{c,f})_{le}}{2} \cdot (d_f - h_{DB} - h_{LS}) \right)$$

where:

s_1, ρ_c, g, γ, $(p_{c,f})_{le}$, h_{LS} = as given in a) above

d_1, h_{DB} = as given in S19.2.3.1

d_f = as given in S19.2.2.

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S19.2.3.2 - Empty hold

At each point of the bulkhead, the hydrostatic pressure p_f induced by the flooding head h_f is to be considered.

The force F_f, in kN, acting on a corrugation is given by:

$$F_f = s_1 \cdot \rho \cdot g \cdot \frac{(d_f - h_{DB} - h_{LS})^2}{2}$$

where:

s_1, ρ, g, h_{LS} = as given in S19.2.3.1 a)

h_{DB} = as given in S19.2.3.1

d_f = as given in S19.2.2.

S19.2.4 - Pressure in the non-flooded bulk cargo loaded hold

At each point of the bulkhead, the pressure p_c, in kN/m^2, is given by:

$$p_c = \rho_c \cdot g \cdot h_1 \cdot \tan^2 \gamma$$

where:

ρ_c, g, h_1, γ = as given in S19.2.3.1 a)

The force F_c, in kN, acting on a corrugation is given by:

$$F_c = \rho_c \cdot g \cdot s_1 \cdot \frac{(d_1 - h_{DB} - h_{LS})^2}{2} \cdot \tan^2 \gamma$$

where:

ρ_c, g, s_1, h_{LS}, γ = as given in S19.2.3.1 a)

d_1, h_{DB} = as given in S19.2.3.1

S19.2.5 - Resultant pressure

S19.2.5.1 - Homogeneous loading conditions

At each point of the bulkhead structures, the resultant pressure p, in kN/m^2, to be considered for the scantlings of the bulkhead is given by:

$$p = \rho_{c,f} - 0{,}8 \cdot \rho_c$$

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The resultant force F, in kN, acting on a corrugation is given by:

$$F = F_{c,f} - 0,8 \cdot F_c$$

S19.2.5.2 - Non homogeneous loading conditions

At each point of the bulkhead structures, the resultant pressure p, in kN/m^2, to be considered for the scantlings of the bulkhead is given by:

$$p = \rho_{c,f}$$

The resultant force F, in kN, acting on a corrugation is given by:

$$F = F_{c,f}$$

In case hold No.1, in non homogeneous loading conditions, is not allowed to be loaded, the resultant pressure p, in kN/m^2, to be considered for the scantlings of the bulkhead is given by:

$$p = p_f$$

and the resultant force F, in kN, acting on a corrugation is given by:

$$F = F_f$$

S19.3 - Bending moment and shear force in the bulkhead corrugations

The bending moment M and the shear force Q in the bulkhead corrugations are obtained using the formulae given in S19.3.1 and S19.3.2. The M and Q values are to be used for the checks in S19.4.

S19.3.1 - Bending moment

The design bending moment M, in kN·m, for the bulkhead corrugations is given by:

$$M = \frac{F \cdot l}{8}$$

where:

F = resultant force, in kN, as given in S19.2.5

l = span of the corrugation, in m, to be taken according to Figures 2a and 2b

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S19.3.2 - Shear force

The shear force Q, in kN, at the lower end of the bulkhead corrugations is given by:

$$Q = 0{,}8 \cdot F$$

where:

F = as given in S19.2.5

S19.4 - Strength criteria

S19.4.1 - General

The following criteria are applicable to transverse bulkheads with vertical corrugations (see Figure 2a).

Requirements for local net plate thickness are given in S19.4.7.

In addition, the criteria given in S19.4.2 and S19.4.5 are to be complied with.

Where the corrugation angle ϕ shown in Figure 2a if less than 50°, an horizontal row of staggered shedder plates is to be fitted at approximately mid depth of the corrugations (see Figure 2a) to help preserve dimensional stability of the bulkhead under flooding loads. The shedder plates are to be welded to the corrugations by double continuous welding, but they are not to be welded to the side shell.

The thicknesses of the lower part of corrugations considered in the application of S19.4.2 and S19.4.3 are to be maintained for a distance from the inner bottom (if no lower stool is fitted) or the top of the lower stool not less than 0,15·l.

The thicknesses of the middle part of corrugations considered in the application of S19.4.2 and S19.4.4 are to be maintained to a distance from the deck (if no upper stool is fitted) or the bottom of the upper stool not greater than 0,3·l.

S19.4.2 - Bending capacity and shear stress τ

The bending capacity is to comply with the following relationship:

$$10^3 \cdot \frac{M}{0{,}5 \cdot Z_{le} \cdot \sigma_{a,le} + Z_m \cdot \sigma_{a,m}} \le 1{,}0$$

where:

M = bending moment, in kN·m, as given in S19.3.1.

Z_{le} = section modulus of one half pitch corrugation, in cm^3, at the lower end of corrugations, to be calculated according to S19.4.3.

Z_m = section modulus of one half pitch corrugation, in cm^3, at the mid-span of corrugations, to be calculated according to S19.4.4.

$\sigma_{a,le}$ = allowable stress, in N/mm^2, as given in S19.4.5, for the lower end of corrugations

$\sigma_{a,m}$ = allowable stress, in N/mm^2, as given in S19.4.5, for the mid-span of corrugations.

In no case Z_m is to be taken greater than the lesser of $1{,}15 \cdot Z_{le}$.and $1{,}15 \cdot Z'_{le}$ for calculation of the

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bending capacity, Z'_{le} being defined below.

In case effective shedders plates are fitted which:

- are not knuckled;
- are welded to the corrugations and the top of the lower stool by one side penetration welds or equivalent;
- are fitted with a minimum slope of 45° and their lower edge is in line with the stool side plating;

or effective gusset plates are fitted which:

- are fitted in line with the stool side plating;
- have material properties at least equal to those provided for the flanges,

the section modulus Z_{le}, in cm^3, is to be taken not larger than the value Z'_{le}, in cm^3, given by:

$$Z'_{le} = Z_g + 10^3 \cdot \frac{Q \cdot h_g - 0{,}5 \cdot h_g^2 \cdot s_1 \cdot p_g}{\sigma_a}$$

where:

Z_g = section modulus of one half pitch corrugation, in cm^3, according to S19.4.4, in way of the upper end of shedder or gusset plates, as applicable

Q = shear force, in kN, as given in S19.3.2

h_g = height, in m, of shedders or gusset plates, as applicable (see Figures 3a, 3b, 4a and 4b)

s_1 = as given in S19.2.3.1 a)

p_g = resultant pressure, in kN/m^2, as defined in S19.2.5, calculated in way of the middle of the shedders or gusset plates, as applicable

σ_a = allowable stress, in N/mm^2, as given in S19.4.5.

Stresses τ are obtained by dividing the shear force Q by the shear area. The shear area is to be reduced in order to account for possible non-perpendicularity between the corrugation webs and flanges. In general, the reduced shear area may be obtained by multiplying the web sectional area by ($\sin \phi$), ϕ being the angle between the web and the flange.

When calculating the section moduli and the shear area, the net plate thicknesses are to be used.

The section moduli of corrugations are to be calculated on the basis of the requirements given in S19.4.3 and S19.4.4.

S19.4.3 - Section modulus at the lower end of corrugations

The section modulus is to be calculated with the compression flange having an effective flange width, b_{ef}, not larger than as given in S19.4.6.1.

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If the corrugation webs are not supported by local brackets below the stool top (or below the inner bottom) in the lower part, the section modulus of the corrugations is to be calculated considering the corrugation webs 30% effective.

a) Provided that effective shedder plates, as defined in S19.4.2, are fitted (see Figures 3a and 3b), when calculating the section modulus of corrugations at the lower end (cross-section ① in Figures 3a and 3b), the area of flange plates, in cm^2, may be increased by

$$\left(2{,}5 \cdot a \cdot \sqrt{t_f \cdot t_{sh}} \cdot \sqrt{\frac{\sigma_{Fsh}}{\sigma_{Ffl}}}\right)$$

(not to be taken greater than $2{,}5 \cdot a \cdot t_f$) where:

a = width, in m, of the corrugation flange (see Figure 2a)

t_{sh} = net shedder plate thickness, in mm

t_f = net flange thickness, in mm

σ_{Fsh} = minimum upper yield stress, in N/mm^2, of the material used for the shedder plates

σ_{Ffl} = minimum upper yield stress, in N/mm^2, of the material used for the corrugation flanges.

b) Provided that effective gusset plates, as defined in S19.4.2, are fitted (see Figures 4a and 4b), when calculating the section modulus of corrugations at the lower end (cross-section ① in Figures 4a and 4b), the area of flange plates, in cm^2, may be increased by (7•hg•tgu) where:

h_g = height of gusset plate in m, see Figures 4a and 4b, not to be taken greater than :

$$\left(\frac{10}{7} \cdot s_{gu}\right)$$

s_{gu} = width of the gusset plates, in m

t_{gu} = net gusset plate thickness, in mm, not to be taken greater than t_f

t_f = net flange thickness, in mm, based on the as built condition.

c) If the corrugation webs are welded to a sloping stool top plate, which is at an angle not less than 45º with the horizontal plane, the section modulus of the corrugations may be calculated considering the corrugation webs fully effective. In case effective gusset plates are fitted, when calculating the section modulus of corrugations the area of flange plates may be increased as specified in b) above. No credit can be given to shedder plates only.

For angles less than 45º, the effectiveness of the web may be obtained by linear interporation between 30% for 0º and 100% for 45º.

S19.4.4 - Section modulus of corrugations at cross-sections other than the lower end

The section modulus is to be calculated with the corrugation webs considered effective and the compression flange having an effective flange width, b_{ef}, not larger than as given in S19.4.6.1.

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S19.4.5 - Allowable stress check

The normal and shear stresses σ and τ are not to exceed the allowable values σ_a and τ_a, in N/mm^2, given by:

$$\sigma_a = \sigma F$$

$$\tau_a = 0{,}5 \cdot \sigma F$$

σ_F = minimum upper yield stress, in N/mm^2, of the material.

S19.4.6 - Effective compression flange width and shear buckling check

S19.4.6.1 - Effective width of the compression flange of corrugations

The effective width b_{ef}, in m, of the corrugation flange is given by:

$$b_{ef} = C_e \cdot a$$

where:

$C_e = \dfrac{2{,}25}{\beta} - \dfrac{1{,}25}{\beta^2}$ for $\beta > 1{,}25$

$C_e = 1{,}0$ for $\beta \le 1{,}25$

$\beta = 10^3 \cdot \dfrac{a}{t_f} \cdot \sqrt{\dfrac{\sigma_F}{E}}$

t_f = net flange thickness, in mm

a = width, in m, of the corrugation flange (see Figure 2a)

σ_F = minimum upper yield stress, in N/mm^2, of the material

E = modulus of elasticity, in N/mm^2, to be assumed equal to $2{,}06 \cdot 10^5$ N/mm^2 for steel

S19.4.6.2 - Shear

The buckling check is to be performed for the web plates at the corrugation ends.

The shear stress τ is not to exceed the critical value τ_c, in N/mm^2 obtained by the following:

$$\tau_C = \tau_E \qquad \text{when } \tau_E \le \frac{\tau_F}{2}$$

$$= \tau_F\left(1 - \frac{\tau_F}{4\tau_E}\right) \qquad \text{when } \tau_E > \frac{\tau_F}{2}$$

S19
cont'd

$$\tau_F = \frac{\sigma_F}{\sqrt{3}}$$

where:

σ_F = minimum upper yield stress, in N/mm^2, of the material

$$\tau_E = 0.9 k_t E \left(\frac{t}{1000c} \right)^2 \qquad (\mathrm{N/mm^2})$$

k_t, E, t and c are given by:

k_t = 6.34

E = modulus of elasticity of material as given in S19.4.6.1

t = net thickness, in mm, of corrugation web

c = width, in m, of corrugation web (See Figure 2a)

S19.4.7 - Local net plate thickness

The bulkhead local net plate thickness t, in mm, is given by:

$$t = 14{,}9 \cdot s_w \cdot \sqrt{\frac{p}{\sigma_F}}$$

where:

s_w = plate width, in m, to be taken equal to the width of the corrugation flange or web, whichever is the greater (see Figure 2a)

p = resultant pressure, in kN/m^2, as defined in S19.2.5, at the bottom of each strake of plating; in all cases, the net thickness of the lowest strake is to be determined using the resultant pressure at the top of the lower stool, or at the inner bottom, if no lower stool is fitted or at the top of shedders, if shedder or gusset/shedder plates are fitted.

σ_F = minimum upper yield stress, in N/mm^2, of the material.

For built-up corrugation bulkheads, when the thicknesses of the flange and web are different, the net thickness of the narrower plating is to be not less than t_n, in mm, given by:

$$t_n = 14{,}9 \cdot s_n \cdot \sqrt{\frac{p}{\sigma_F}}$$

s_n being the width, in m, of the narrower plating.

S19
cont'd

The net thickness of the wider plating, in mm, is not to be taken less than the maximum of the following values:

$$t_w = 14{,}9 \cdot s_w \cdot \sqrt{\frac{p}{\sigma_F}}$$

$$t_w = \sqrt{\frac{440 \cdot s_w^2 \cdot p}{\sigma_F} - t_{np}^2}$$

where $t_{np} \le$ actual net thickness of the narrower plating and not to be greater than:

$$14{,}9 \cdot s_w \cdot \sqrt{\frac{p}{\sigma_F}}$$

S19.5 - Local details

As applicable, the design of local details is to comply with the Society's requirements for the purpose of transferring the corrugated bulkhead forces and moments to the boundary structures, in particular to the double bottom and cross-deck structures.

In particular, the thickness and stiffening of gusset and shedder plates, installed for strengthening purposes, is to comply with the Society's requirements, on the basis of the load model in S19.2.

Unless otherwise stated, weld connections and materials are to be dimensioned and selected in accordance with the Society's requirements.

S19.6 - Corrosion addition and steel renewal

Renewal/reinforcement shall be done in accordance with the following requirements and the guidelines contained in the Annex.

a) Steel renewal is required where the gauged thickness is less than t_{net} + 0,5 mm, t_{net} being the thickness used for the calculation of bending capacity and shear stresses as given in S19.4.2. or the local net plate thickness as given in S19.4.7. Alternatively, reinforcing doubling strips may be used providing the net thickness is not dictated by shear strength requirements for web plates (see S19.4.5 and S19.4.6.2) or by local pressure requirements for web and flange plates (see S19.4.7).

   Where the gauged thickness is within the range t_{net} + 0,5 mm and t_{net} + 1,0 mm, coating (applied in accordance with the coating manufacturer's requirements) or annual gauging may be adopted as an alternative to steel renewal.

b) Where steel renewal or reinforcement is required, a minimum thickness of t_{net} + 2,5 mm is to be replenished for the renewed or reinforced parts.

c) When:

$$0{,}8 \cdot \left(\sigma_{Ffl} \cdot t_{fl}\right) \ge \sigma_{Fs} \cdot t_{st}$$

S19
cont'd

where:

σ_{Ffl} = minimum upper yield stress, in N/mm^2, of the material used for the corrugation flanges

σ_{Fs} = minimum upper yield stress, in N/mm^2, of the material used for the lower stool side plating or floors (if no stool is fitted)

t_{fl} = flange thickness, in mm, which is found to be acceptable on the basis of the criteria specified in a) above or, when steel renewal is required, the replenished thickness according to the criteria specified in b) above. The above flange thickness dictated by local pressure requirements (see S19.4.7) need not be considered for this purpose

t_{st} = as built thickness, in mm, of the lower stool side plating or floors (if no stool is fitted)

gussets with shedder plates, extending from the lower end of corrugations up to 0,1·l, or reinforcing doubling strips (on bulkhead corrugations and stool side plating) are to be fitted.

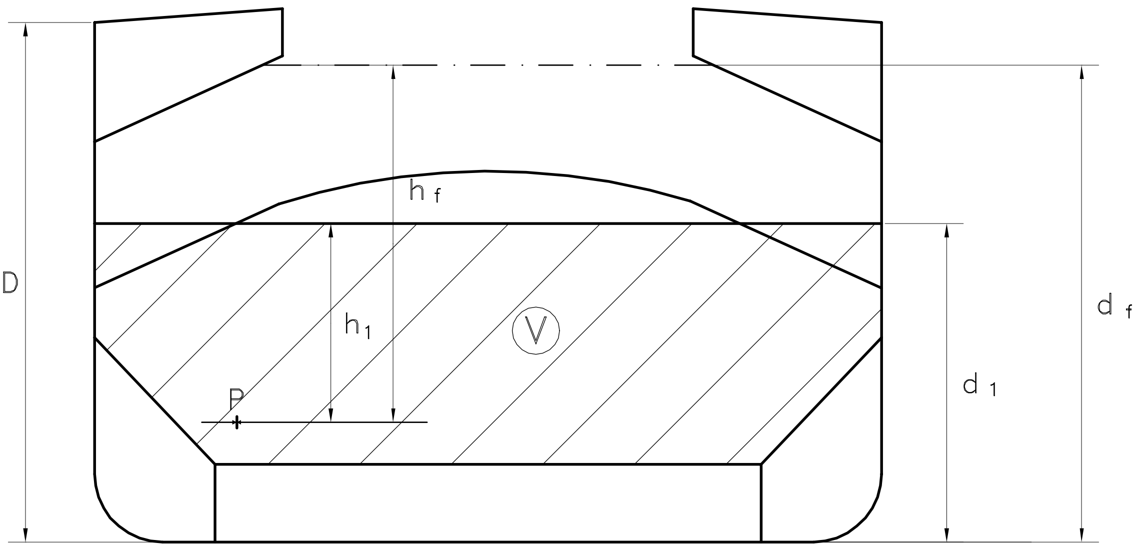
If gusset plates are fitted, the material of such gusset plates is to be the same as that of the corrugation flanges. The gusset plates are to be connected to the lower stool shelf plate or inner bottom (if no lower stool is fitted) by deep penetration welds (see Figure 5).

d) Where steel renewal is required, the bulkhead connections to the lower stool shelf plate or inner bottom (if no stool is fitted) are to be at least made by deep penetration welds (see Figure 5).

e) Where gusset plates are to be fitted or renewed, their connections with the corrugations and the lower stool shelf plate or inner bottom (if no stool is fitted) are to be at least made by deep penetration welds (see Figure 5).

S19
cont'd

Figure 1

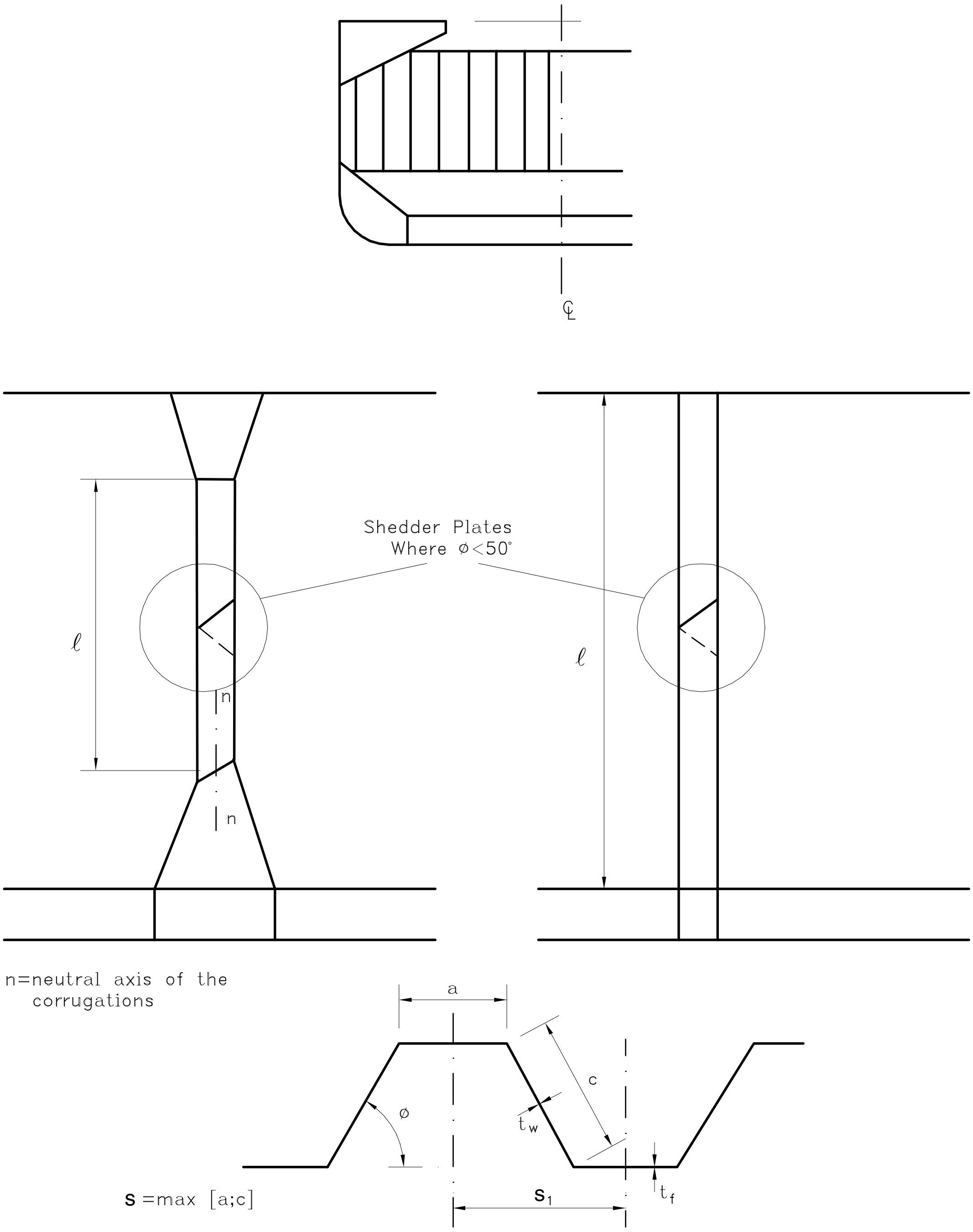


V = Volume of cargo

P = Calculation point

S19
cont'd

Figure 2a



S19
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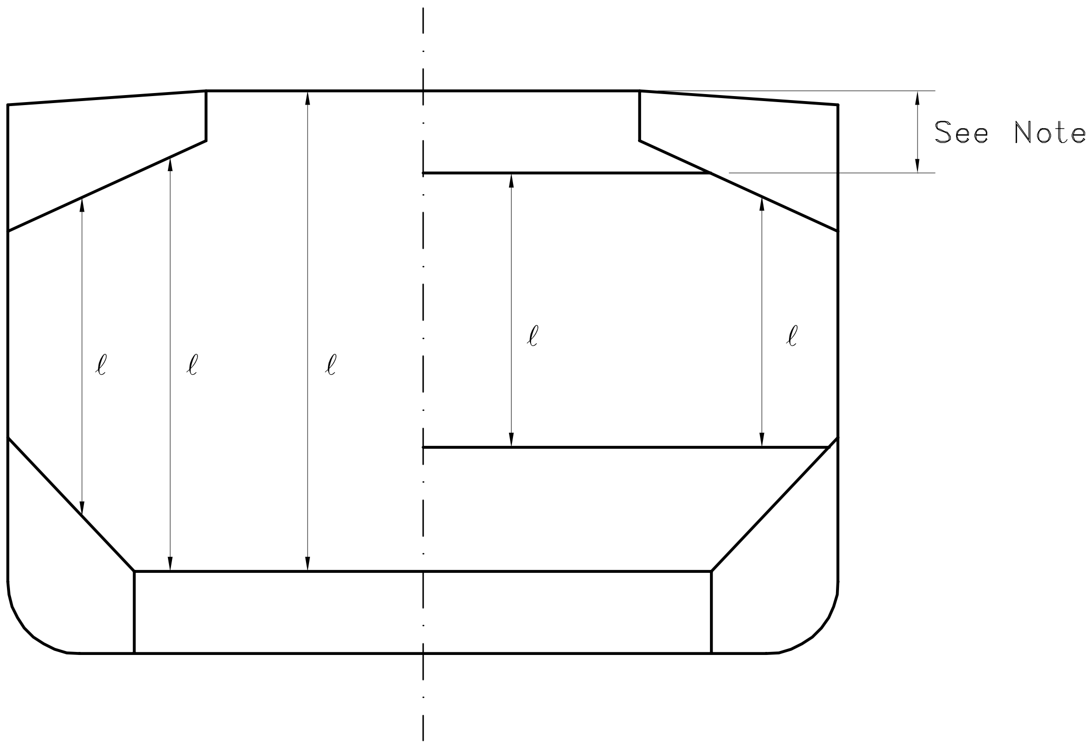
Figure 2b



Note: For the definition of ℓ, the internal end of the upper stool is not to be taken more than a distance from the deck at the centre line equal to:
- 3 times the depth of corrugations, in general
- 2 times the depth of corrugations, for rectangular stool

S19
cont'd

Figure 3a
Symmetric shedder plates

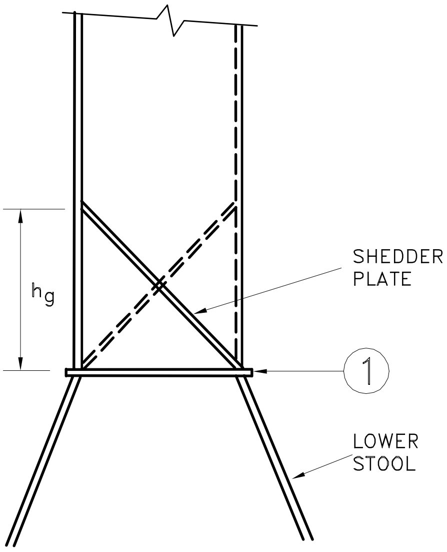
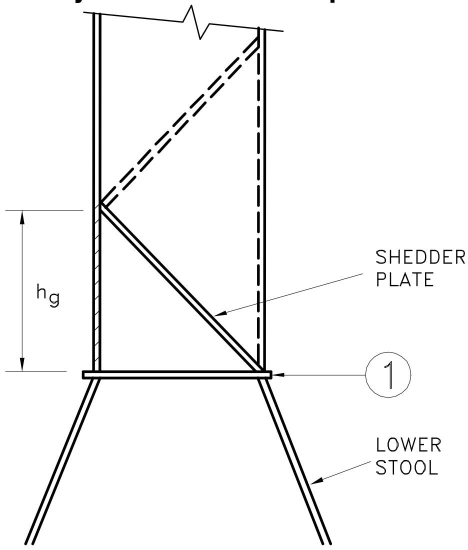


Figure 3b
Asymmetric shedder plates



S19
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Figure 4a
Symmetric gusset / shedder plates

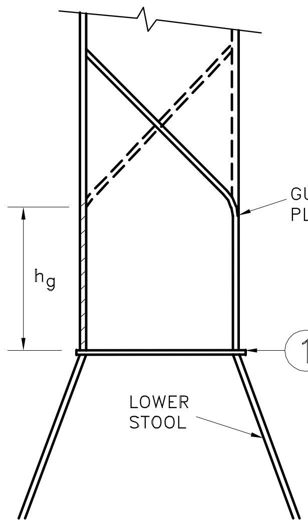
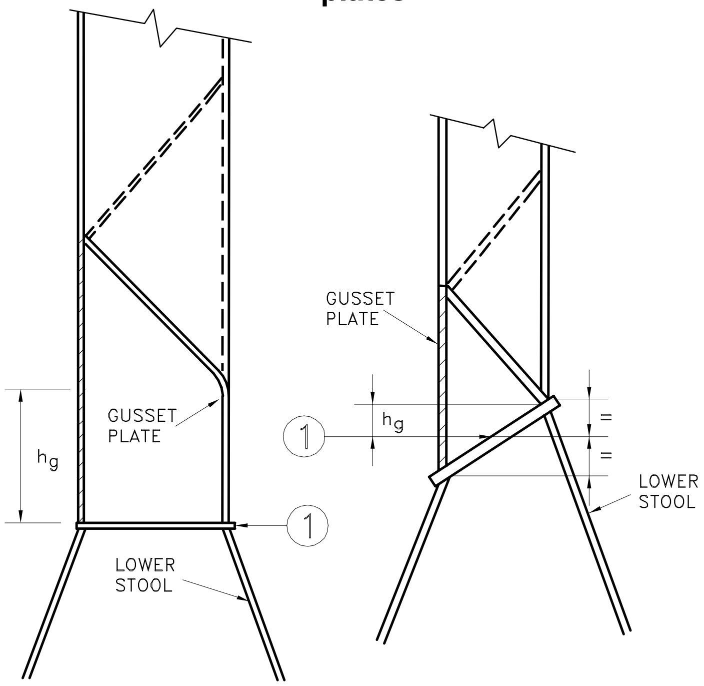


Figure 4b
Asymmetric gusset / shedder plates



S19
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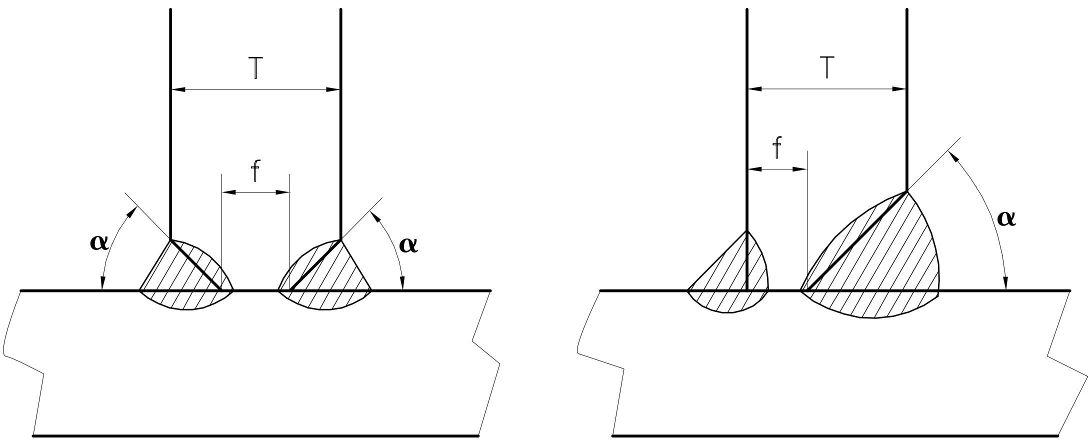
Figure 5



Root Face (f) : 3 mm to T/3 mm
Groove Angle (**α**) : 40° to 60°

S19
cont'd

ANNEX 1

Guidance on renewal/reinforcement of vertically corrugated transverse watertight bulkhead between cargo holds Nos. 1 and 2

1. The need for renewal or reinforcement of the vertically corrugated transverse watertight bulkhead between cargo holds Nos. 1 and 2 will be determined by the classification society on a case by case basis using the criteria given in S19 in association with the most recent gaugings and findings from survey.

2. In addition to class requirements, the S19 assessment of the transverse corrugated bulkhead will take into account the following:-

   (a) Scantlings of individual vertical corrugations will be assessed for reinforcement/renewal based on thickness measurements obtained in accordance with Annex III to UR Z10.2 at their lower end, at mid-depth and in way of plate thickness changes in the lower 70%. These considerations will take into account the provision of gussets and shedder plates and the benefits they offer, provided that they comply with S19.4.2 and S19.6.

   (b) Taking into account the scantlings and arrangements for each case, permissible levels of diminution will be determined and appropriate measures taken in accordance with S19.6.

3. Where renewal is required, the extent of renewal is to be shown clearly in plans. The vertical distance of each renewal zone is to be determined by considering S19 and in general is to be not less than 15% of the vertical distance between the upper and lower end of the corrugation - measured at the ship's centreline.

4. Where the reinforcement is accepted by adding strips, the length of the reinforcing strips is to be sufficient to allow it to extend over the whole depth of the diminished plating. In general, the width and thickness of strips should be sufficient to comply with the S19 requirements. The material of the strips is to be the same as that of the corrugation plating. The strips are to be attached to the existing bulkhead plating by continuous fillet welds. The strips are to be suitably tapered or connected at ends in accordance with Class Society practice.

5. Where reinforcing strips are connected to the inner bottom or lower stool shelf plates, one side full penetration welding is to be used. When reinforcing strips are fitted to the corrugation flange and are connected to the lower stool shelf plate, they are normally to be aligned with strips of the same scantlings welded to the stool side plating and having a minimum length equal to the breadth of the corrugation flange.

6. Figure 1 gives a general arrangement of structural reinforcement.

S19
cont'd

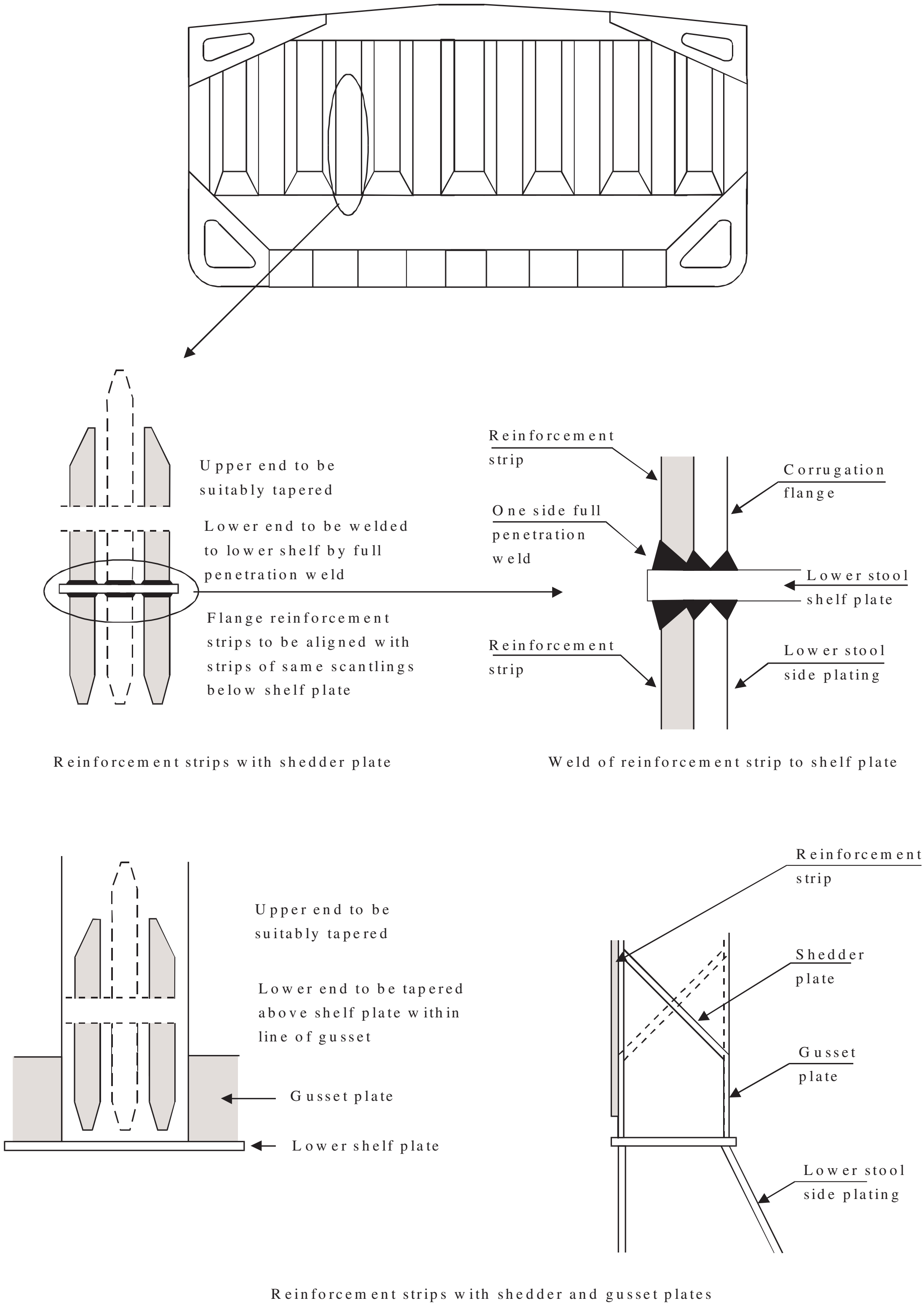


Figure 1

S19
cont'd

Notes to Figure 1 on reinforcement:-

1. Square or trapezoidal corrugations are to be reinforced with plate strips fitted to each corrugation flange sufficient to meet the requirements of S19.

2. The number of strips fitted to each corrugation flange is to be sufficient to meet the requirements of S19.

3. The shedder plate may be fitted in one piece or prefabricated with a welded knuckle (gusset plate).

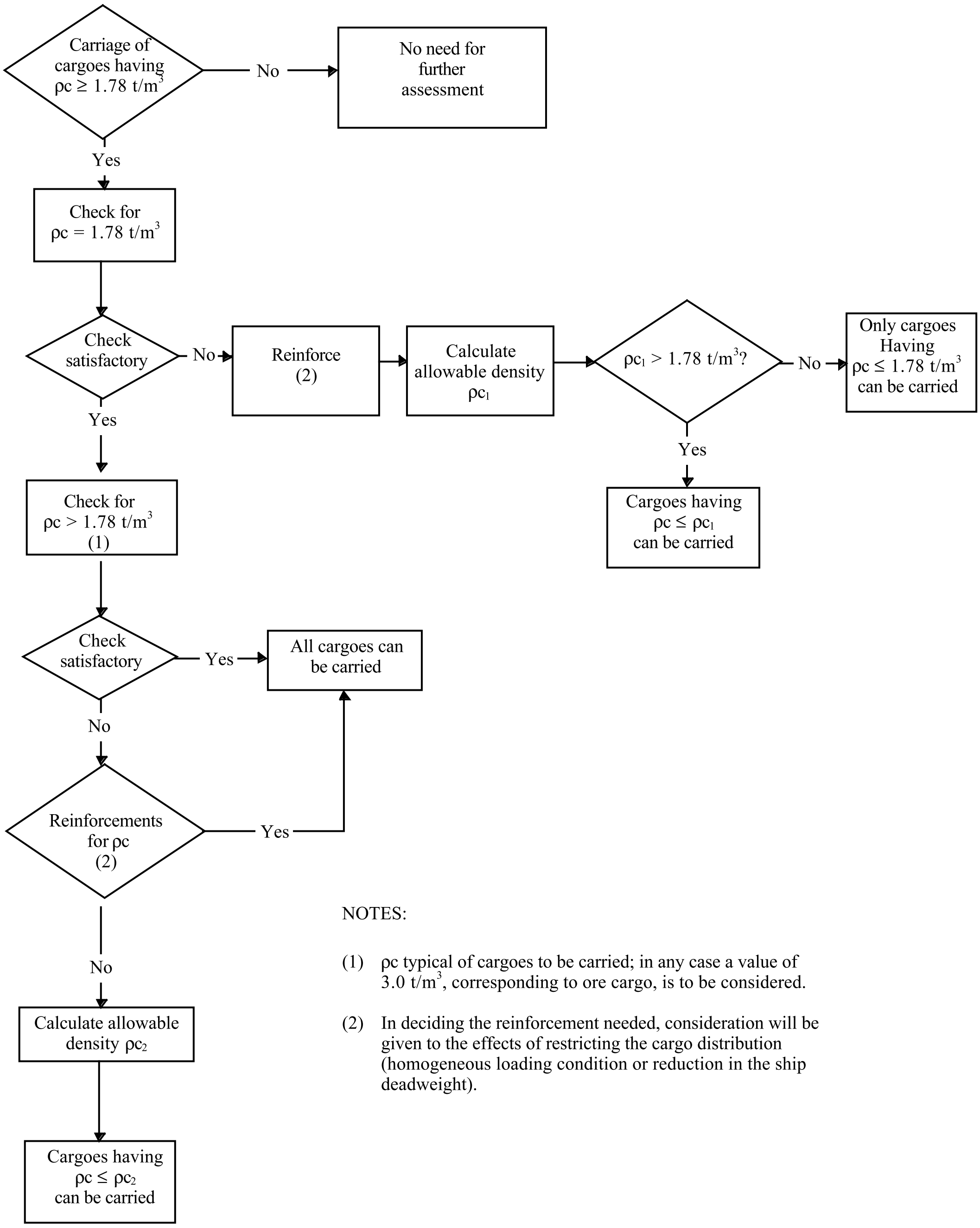
4. Gusset plates, where fitted, are to be welded to the shelf plate in line with the flange of the corrugation, to reduce the stress concentrations at the corrugation corners. Ensure good alignment between gusset plate, corrugation flange and lower stool sloping plate. Use deep penetration welding at all connections. Ensure start and stop of welding is as far away as practically possible from corners of corrugation.

5. Shedder plates are to be attached by one side full penetration welds onto backing bars.

6. Shedder and gusset plates are to have a thickness equal to or greater than the original bulkhead thickness. Gusset plate is to have a minimum height (on the vertical part) equal to half of the width of the corrugation flange. Shedders and gussets are to be same material as flange material.

ANNEX 2

Guidance to Assess Capability of Carriage of High Density Cargoes on Existing Bulk Carriers according to the Strength of Transverse Bulkhead between Cargo Holds Nos. 1 and 2



NOTES:

(1) ρc typical of cargoes to be carried; in any case a value of $3.0\ t/m^3$, corresponding to ore cargo, is to be considered.

(2) In deciding the reinforcement needed, consideration will be given to the effects of restricting the cargo distribution (homogeneous loading condition or reduction in the ship deadweight).

END

S20 Evaluation of Allowable Hold Loading for Non-CSR Bulk Carriers Considering Hold Flooding

(1997)
(Rev.1 1997)
(Rev.2 Sept 2000)
(Rev.3 July 2004)
(Rev.4 Feb 2006)
(Corr.1 Oct 2009)
(Rev.5 May 2010)
(Rev.6 Apr 2014)

S20.1 - Application and definitions

Revision 4 or subsequent revisions or corrigenda as applicable of this UR is to be applied to non-CSR bulk carriers of 150 m in length and upwards, intending to carry solid bulk cargoes having a density of 1.0 t/m^3 or above, and with,

a) Single side skin construction, or

b) Double side skin construction in which any part of longitudinal bulkhead is located within B/5 or 11.5 m, whichever is less, inboard from the ship's side at right angle to the centreline at the assigned summer load line

in accordance with Note 2.

The loading in each hold is not to exceed the allowable hold loading in flooded condition, calculated as per S20.4, using the loads given in S20.2 and the shear capacity of the double bottom given in S20.3.

In no case is the allowable hold loading, considering flooding, to be greater than the design hold loading in the intact condition.

This UR does not apply to CSR Bulk Carriers.

S20.2 - Loading model

S20.2.1 - General

The loads to be considered as acting on the double bottom are those given by the external sea pressures and the combination of the cargo loads with those induced by the flooding of the hold which the double bottom belongs to.

The most severe combinations of cargo induced loads and flooding loads are to be used, depending on the loading conditions included in the loading manual:

- homogeneous loading conditions;
- non homogeneous loading conditions;
- packed cargo conditions (such as steel mill products).

For each loading condition, the maximum bulk cargo density to be carried is to be considered in calculating the allowable hold loading limit.

Note:

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

2. Revision 4 or subsequent revisions or corrigenda as applicable of this UR is to be applied by IACS Societies to ships contracted for construction on or after 1 July 2006.

S20
(cont)

S20.2.2 - Inner bottom flooding head

The flooding head h_f (see Figure 1) is the distance, in m, measured vertically with the ship in the upright position, from the inner bottom to a level located at a distance d_f, in m, from the baseline equal to:

a) in general:

- D for the foremost hold
- 0.9D for the other holds

b) for ships less than 50,000 tonnes deadweight with Type B freeboard:

- 0.95D for the foremost hold
- 0.85D for the other holds

D being the distance, in m, from the baseline to the freeboard deck at side amidship (see Figure 1).

S20.3 - Shear capacity of the double bottom

The shear capacity C of the double bottom is defined as the sum of the shear strength at each end of:

- all floors adjacent to both hoppers, less one half of the strength of the two floors adjacent to each stool, or transverse bulkhead if no stool is fitted (see Figure 2).

- all double bottom girders adjacent to both stools, or transverse bulkheads if no stool is fitted.

Where in the end holds, girders or floors run out and are not directly attached to the boundary stool or hopper girder, their strength is to be evaluated for the one end only.

Note that the floors and girders to be considered are those inside the hold boundaries formed by the hoppers and stools (or transverse bulkheads if no stool is fitted). The hopper side girders and the floors directly below the connection of the bulkhead stools (or transverse bulkheads if no stool is fitted) to the inner bottom are not to be included.

When the geometry and/or the structural arrangement of the double bottom are such to make the above assumptions inadequate, to the Society's discretion, the shear capacity C of double bottom is to be calculated according to the Society's criteria.

In calculating the shear strength, the net thickness of floors and girders is to be used. The net thickness t_{net}, in mm, is given by:

$$t_{net} = t - 2.5$$

where:

t = thickness, in mm, of floors and girders.

S20 (cont)

S20.3.1 - Floor shear strength

The floor shear strength in way of the floor panel adjacent to hoppers S_{f1}, in kN, and the floor shear strength in way of the openings in the outmost bay (i.e. that bay which is closer to hopper) S_{f2}, in kN, are given by the following expressions:

$$S_{f1} = 10^{-3} A_f \frac{\tau_a}{\eta_1}$$

$$S_{f2} = 10^{-3} A_{f,h} \frac{\tau_a}{\eta_2}$$

where:

A_f = sectional area, in mm^2, of the floor panel adjacent to hoppers

$A_{f,h}$ = net sectional area, in mm^2, of the floor panels in way of the openings in the outmost bay (i.e. that bay which is closer to hopper)

τ_a = allowable shear stress, in N/mm^2, to be taken equal to the lesser of

$$\tau_a = \frac{162\sigma_F^{0.6}}{(s/t_{net})^{0.8}} \quad \text{and} \quad \frac{\sigma_F}{\sqrt{3}}$$

For floors adjacent to the stools or transverse bulkheads, as identified in S20.3 τ_a may be taken $\sigma_F/\sqrt{3}$

σ_F = minimum upper yield stress, in N/mm^2, of the material

s = spacing of stiffening members, in mm, of panel under consideration

η_1 = 1.10

η_2 = 1.20

η_2 may be reduced, to the Society's discretion, down to 1.10 where appropriate reinforcements are fitted to the Society's satisfaction

S20.3.2 - Girder shear strength

The girder shear strength in way of the girder panel adjacent to stools (or transverse bulkheads, if no stool is fitted) S_{g1}, in kN, and the girder shear strength in way of the largest opening in the outmost bay (i.e. that bay which is closer to stool, or transverse bulkhead, if no stool is fitted) S_{g2}, in kN, are given by the following expressions:

$$S_{g1} = 10^{-3} A_g \frac{\tau_a}{\eta_1}$$

$$S_{g2} = 10^{-3} A_{g,h} \frac{\tau_a}{\eta_2}$$

S20
(cont)

where:

A_g = minimum sectional area, in mm^2, of the girder panel adjacent to stools (or transverse bulkheads, if no stool is fitted)

$A_{g,h}$ = net sectional area, in mm^2, of the girder panel in way of the largest opening in the outmost bay (i.e. that bay which is closer to stool, or transverse bulkhead, if no stool is fitted)

τ_a = allowable shear stress, in N/mm^2, as given in S20.3.1

η_1 = 1.10

η_2 = 1.15

η_2 may be reduced, to the Society's discretion, down to 1.10 where appropriate reinforcements are fitted to the Society's satisfaction

S20.4 - Allowable hold loading

The allowable hold loading W, in tonnes, is given by:

$$W = \rho_c V \frac{1}{F}$$

where:

F = 1.1 in general
1.05 for steel mill products

ρ_c = cargo density, in t/m^3; for bulk cargoes see S20.2.1; for steel products, ρ_c is to be taken as the density of steel

V = volume, in m^3, occupied by cargo at a level h_1

$$h_1 = \frac{X}{\rho_c g}$$

X = *for bulk cargoes* the lesser of X_1 and X_2 given by:

$$X_1 = \frac{Z + \rho g (E - h_f)}{1 + \frac{\rho}{\rho_c}(perm - 1)}$$

$$X_2 = Z + \rho g (E - h_f\, perm)$$

X = for steel products, X may be taken as X_1, using perm = 0

ρ = sea water density, in t/m^3

g = 9.81 m/s^2, gravity acceleration

S20
(cont)

E = ship immersion in m for flooded hold condition = d_f – 0.1D

d_f,D = as given in S20.2.2

h_f = flooding head, in m, as defined in S20.2.2

perm = cargo permeability, (i.e. the ratio between the voids within the cargo mass and the volume occupied by the cargo); it needs not be taken greater than 0.3.

Z = the lesser of Z_1 and Z_2 given by:

$$Z_1 = \frac{C_h}{A_{DB,h}}$$

$$Z_2 = \frac{C_e}{A_{DB,e}}$$

C_h = shear capacity of the double bottom, in kN, as defined in S20.3, considering, for each floor, the lesser of the shear strengths S_{f1} and S_{f2} (see S20.3.1) and, for each girder, the lesser of the shear strengths S_{g1} and S_{g2} (see S20.3.2)

C_e = shear capacity of the double bottom, in kN, as defined in S20.3, considering, for each floor, the shear strength S_{f1} (see S20.3.1) and, for each girder, the lesser of the shear strengths S_{g1} and S_{g2} (see S20.3.2)

$$A_{DB,h} = \sum_{i=1}^{i=n} S_i B_{DB,i}$$

$$A_{DB,e} = \sum_{i=1}^{i=n} S_i \left(B_{DB} - s_1\right)$$

n = number of floors between stools (or transverse bulkheads, if no stool is fitted)

S_i = space of ith-floor, in m

$B_{DB,i}$ = B_{DB} – s_1 for floors whose shear strength is given by S_{f1} (see S20.3.1)

$B_{DB,i}$ = $B_{DB,h}$ for floors whose shear strength is given by S_{f2} (see S20.3.1)

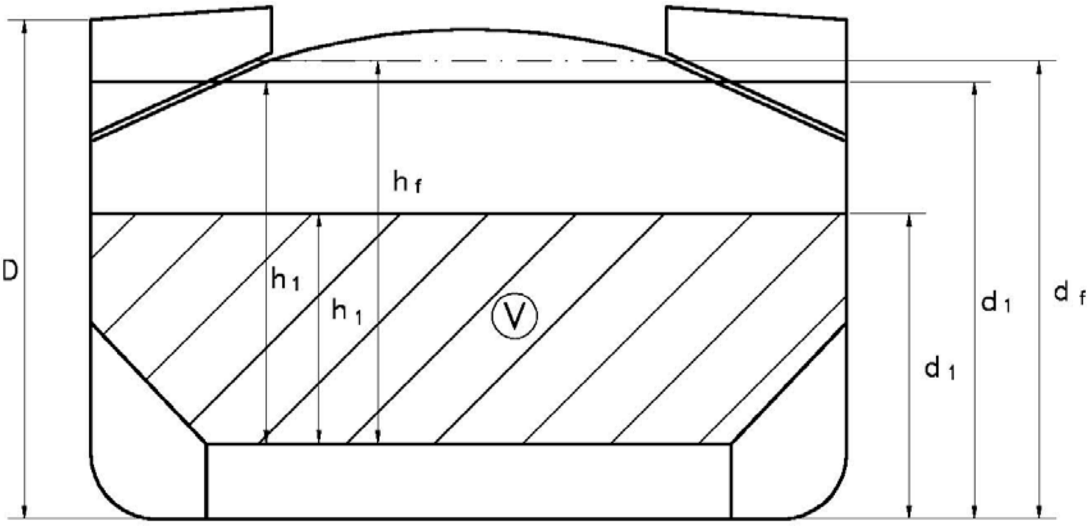
B_{DB} = breadth of double bottom, in m, between hoppers (see Figure 3)

$B_{DB,h}$ = distance, in m, between the two considered opening (see Figure 3)

s_1 = spacing, in m, of double bottom longitudinals adjacent to hoppers

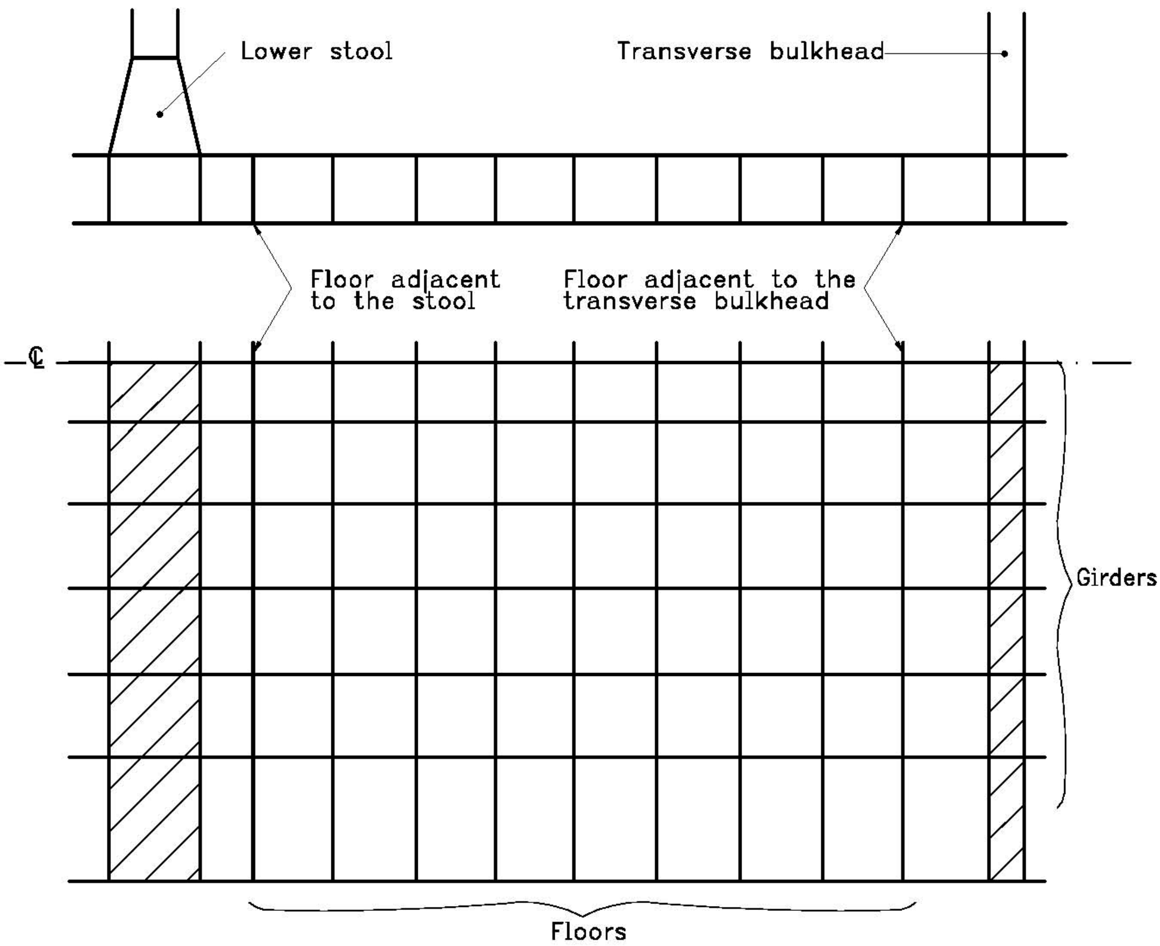
S20
(cont)

Figure 1



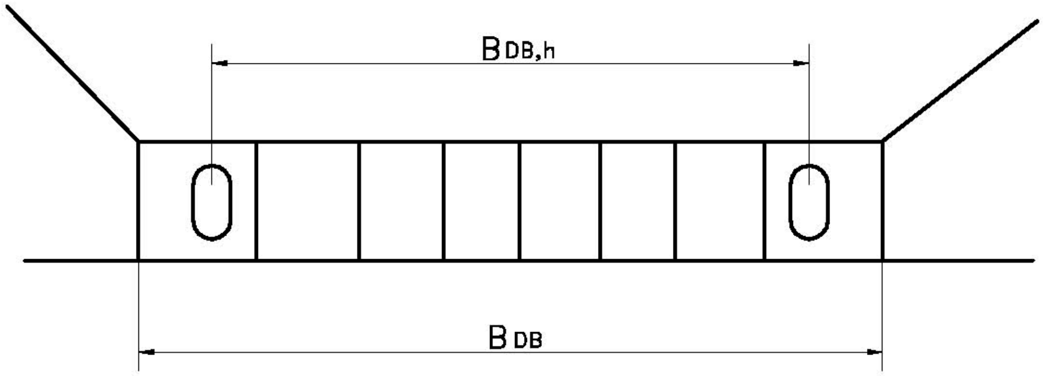
V = Volume of cargo

Figure 2



S20
(cont)

Figure 3



End of Document

S21A
(May 2011)
(Corr.1
Oct 2011)
(Rev.1
May 2015)
(Corr.1
Feb 2018)
(Corr.2
Mar 2019)

Requirements concerning STRENGTH OF SHIPS

S21A

Evaluation of Scantlings of Hatch Covers and Hatch Coamings and Closing Arrangements of Cargo Holds of Ships

Notes:

1. This UR applies for ships contracted for construction on or after 1 July 2012.
2. Rev.1 of this UR applies for ships contracted for construction on or after 1 July 2016.
3. The "contracted for construction" date means the date on which the contract to build the vessel is signed between the prospective owner and the shipbuilder. For further details regarding the date of "contract for construction", refer to IACS Procedural Requirement (PR) No. 29.

1 Application and definitions

1.1 Application

These requirements apply to all ships except bulk carriers, self-unloading bulk carriers, ore carriers and combination carriers, as defined in UR Z11, and are for all cargo hatch covers and coamings on exposed decks.

The strength requirements are applicable to hatch covers and hatch coamings of stiffened plate construction and its closing arrangements.

This UR is applicable to hatch covers and coamings made of steel. In case of alternative materials and innovative designs the approval is subject to the individual class society.

This UR does not apply to portable covers secured weathertight by tarpaulins and battening devices, or pontoon covers, as defined in ICLL Regulation 15.

These requirements are in addition to the requirements of the ICLL.

1.2 Definitions

ICLL Where ICLL is referred to in the text, this is to be taken as the International Convention on Load Lines, 1966 as amended by the 1988 protocol, as amended in 2003.

1.2.1 Hatch cover types

- **Single skin cover**

  A hatch cover made of steel or equivalent material that is designed to comply with ICLL Regulation 16. The cover has continuous top and side plating, but is open underneath with the stiffening structure exposed. The cover is weathertight and fitted with gaskets and clamping devices unless such fittings are specifically excluded.

- **Double skin cover**

  A hatch cover as above but with continuous bottom plating such that all the stiffening structure and internals are protected from the environment.

- **Pontoon type cover**

  A special type of portable cover, secured weathertight by tarpaulins and battening devices. Such covers are to be designed in accordance with ICLL Regulation 15 and are not covered by this UR.

Clarification note:

Modern hatch cover designs of lift-away-covers are in many cases called pontoon covers. This definition does not fit to the definition above. Modern lift-away hatch cover designs should belong to one of the two categories-single skin covers or double skin cover.

1.2.2 Positions

The hatchways are classified according to their position as follows:

Position 1 Upon exposed freeboard and raised quarterdecks, and upon exposed superstructure decks situated forward of a point located a quarter of ship's length from forward perpendicular.

Position 2 Upon exposed superstructure decks situated abaft a quarter of the ship's length from the forward perpendicular and located at least one standard height of the superstructure above the freeboard deck.

Upon exposed superstructure decks situated forward of a point located a quarter of the ship's length from the forward perpendicular and located at least two standard height of the superstructure above the freeboard deck.

1.3 Material

Hatch covers and coamings are to be made of material in accordance with the definitions of UR S6. Material class I is to be applied for top plate, bottom plate and primary supporting members.

1.4 General requirements

Primary supporting members and secondary stiffeners of hatch covers are to be continuous over the breadth and length of hatch covers, as far as practical. When this is impractical, sniped end connections are not to be used and appropriate arrangements are to be adopted to provide sufficient load carrying capacity.

The spacing of primary supporting members parallel to the direction of secondary stiffeners is not to exceed 1/3 of the span of primary supporting members. When strength calculation is carried out by FE analysis using plane strain or shell elements, this requirement can be waived.

Secondary stiffeners of hatch coamings are to be continuous over the breadth and length of hatch coamings.

1.5 Net scantling approach

Unless otherwise quoted, the thicknesses t of the following sections are net thicknesses.

The net thicknesses are the member thicknesses necessary to obtain the minimum net scantlings required by 3 and 5.

The required gross thicknesses are obtained by adding corrosion additions, t_s, given in Tab.10 in 7.1.

Strength calculations using grillage analysis or FEM are to be performed with net scantlings.

S21A
(cont)

2 Hatch cover and coaming load model

Structural assessment of hatch covers and hatch coamings is to be carried out using the design loads, defined in this chapter.

Definitions

L = length of ship, in m, as defined in UR S2
L_{LL} = length of ship, in m, as defined in ICLL Regulation 3
x = longitudinal co-ordinate of mid point of assessed structural member measured from aft end of length L or L_{LL}, as applicable
D_{min} = the least moulded depth, in m, as defined in ICLL Regulation 3

h_N = standard superstructure height in m

= $1{,}05 + 0{,}01 L_{LL}$, $1{,}8 \le h_N \le 2{,}3$

2.1 Vertical weather design load

The pressure p_H , in kN/m², on the hatch cover panels is given by ICLL. This may be taken from Tab.1. The vertical weather design load needs not to be combined with cargo loads according to 2.3 and 2.4.

In Fig.1 the positions 1 and 2 are illustrated for an example ship.

Where an increased freeboard is assigned, the design load for hatch covers according to Tab.1 on the actual freeboard deck may be as required for a superstructure deck, provided the summer freeboard is such that the resulting draught will not be greater than that corresponding to the minimum freeboard calculated from an assumed freeboard deck situated at a distance at least equal to the standard superstructure height h_N below the actual freeboard deck, see Fig.2.

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(cont)

Tab. 1.Design load p_H of weather deck hatches

<table>
<tr><th rowspan="2">Position</th><th colspan="2">Design load p_H [kN/m^2]</th></tr>
<tr><th>$\frac{x}{L_{LL}} \le 0,75$</th><th>$0,75 < \frac{x}{L_{LL}} \le 1,0$</th></tr>
<tr><td rowspan="8">1</td><td colspan="2">for 24 m ≤ L_{LL} ≤ 100 m</td></tr>
<tr><td rowspan="2">$\frac{9,81}{76} \cdot (1,5 \cdot L_{LL} + 116)$</td><td>on freeboard deck
$\frac{9,81}{76} \cdot \left[(4,28 \cdot L_{LL} + 28) \cdot \frac{x}{L_{LL}} - 1,71 \cdot L_{LL} + 95 \right]$</td></tr>
<tr><td>upon exposed superstructure decks located at least one superstructure standard height above the freeboard deck
$\frac{9,81}{76} \cdot (1,5 \cdot L_{LL} + 116)$</td></tr>
<tr><td colspan="2">for L_{LL} > 100 m</td></tr>
<tr><td rowspan="3">$9,81 \cdot 3,5$</td><td>on freeboard deck for type B ships according to ICLL
$9,81 \cdot \left[(0,0296 \cdot L_1 + 3,04) \cdot \frac{x}{L_{LL}} - 0,0222 \cdot L_1 + 1,22 \right]$</td></tr>
<tr><td>on freeboard deck for ships with less freeboard than type B according to ICLL
$9,81 \cdot \left[(0,1452 \cdot L_1 - 8,52) \cdot \frac{x}{L_{LL}} - 0,1089 \cdot L_1 + 9,89 \right]$
$L_1 = L_{LL}$ but not more than 340 m</td></tr>
<tr><td>upon exposed superstructure decks located at least one superstructure standard height above the freeboard deck
$9,81 \cdot 3,5$</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td rowspan="5">2</td><td colspan="2">for 24 m ≤ L_{LL} ≤ 100 m</td></tr>
<tr><td colspan="2">$\frac{9,81}{76} \cdot (1,1 \cdot L_{LL} + 87,6)$</td></tr>
<tr><td colspan="2">for L_{LL} > 100 m</td></tr>
<tr><td colspan="2">$9,81 \cdot 2,6$</td></tr>
<tr><td colspan="2">upon exposed superstructure decks located at least one superstructure standard height above the lowest Position 2 deck
$9,81 \cdot 2,1$</td></tr>
</table>

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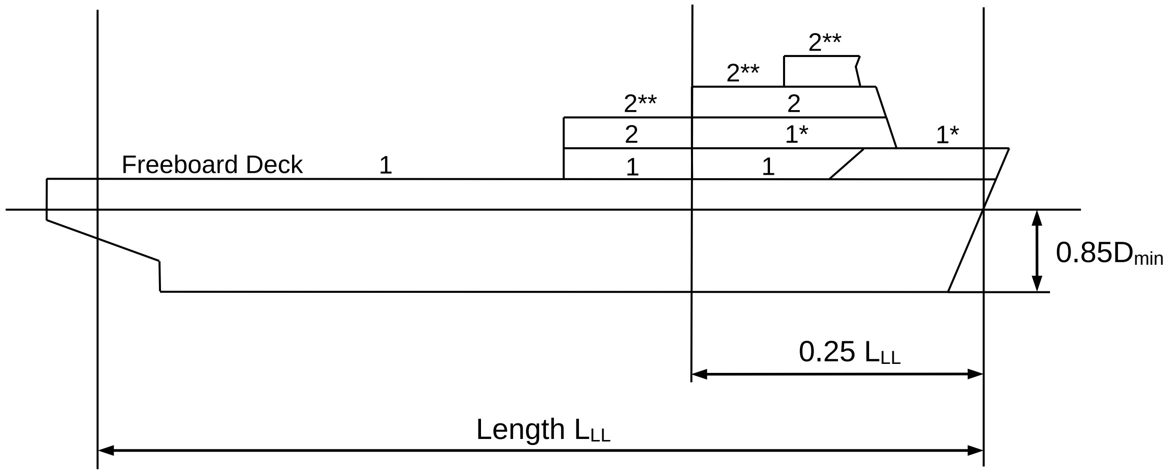
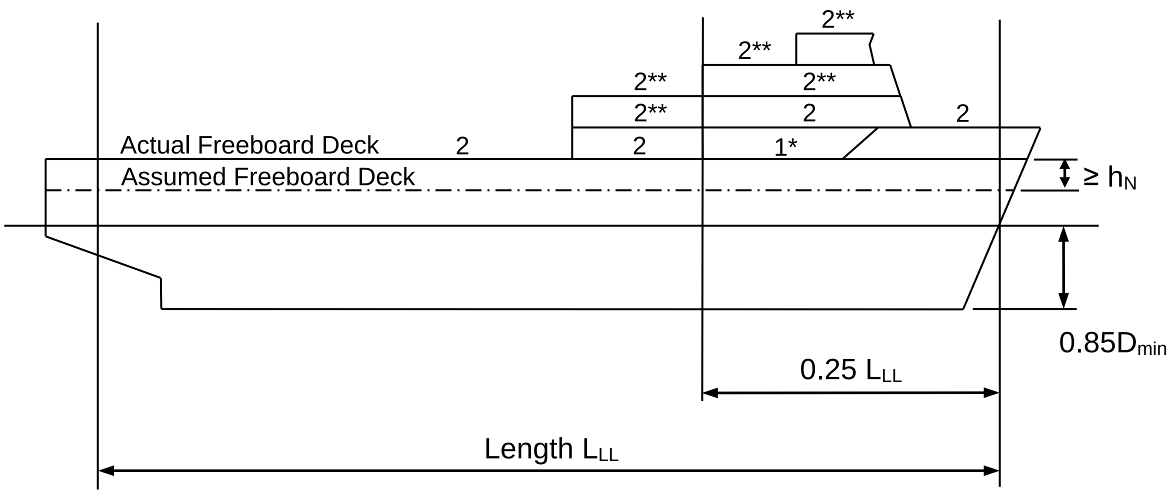
(cont)



* reduced load upon exposed superstructure decks located at least one superstructure standard height above the freeboard deck

** reduced load upon exposed superstructure decks of vessels with L_{LL} > 100 m located at least one superstructure standard height above the lowest Position 2 deck

Fig. 1.Positions 1 and 2



* reduced load upon exposed superstructure decks located at least one superstructure standard height above the freeboard deck

** reduced load upon exposed superstructure decks of vessels with L_{LL} > 100 m located at least one superstructure standard height above the lowest Position 2 deck

Fig. 2.Positions 1 and 2 for an increased freeboard

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(cont)

2.2 Horizontal weather design load

The horizontal weather design load, in kN/m², for determining the scantlings of outer edge girders (skirt plates) of weather deck hatch covers and of hatch coamings is:

$$p_A = a \cdot c \cdot \left(b \cdot c_L \cdot f - z\right)$$

f $= \frac{L}{25} + 4{,}1$ for L < 90 m

$= 10{,}75 - \left(\frac{300 - L}{100}\right)^{1{,}5}$ for $90\,\text{m} \le \text{L} < 300\,\text{m}$

$= 10{,}75$ for $300\,\text{m} \le \text{L} < 350\,\text{m}$

$= 10{,}75 - \left(\frac{L - 350}{150}\right)^{1{,}5}$ for $350\,\text{m} \le \text{L} \le 500\,\text{m}$

c_L $= \sqrt{\frac{L}{90}}$ for L < 90 m

$= 1$ for $L \ge 90\,m$

a $= 20 + \frac{L_1}{12}$ for unprotected front coamings and hatch cover skirt plates

a $= 10 + \frac{L_1}{12}$ for unprotected front coamings and hatch cover skirt plates, where the distance from the actual freeboard deck to the summer load line exceeds the minimum non-corrected tabular freeboard according to ICLL by at least one standard superstructure height h_N

a $= 5 + \frac{L_1}{15}$ for side and protected front coamings and hatch cover skirt plates

a $= 7 + \frac{L_1}{100} - 8 \cdot \frac{x'}{L}$ for aft ends of coamings and aft hatch cover skirt plates abaft amidships

a $= 5 + \frac{L_1}{100} - 4 \cdot \frac{x'}{L}$ for aft ends of coamings and aft hatch cover skirt plates forward of amidships

L_1 = L, need not be taken greater than 300 m

b $= 1{,}0 + \left(\frac{\frac{x'}{L} - 0{,}45}{C_B + 0{,}2}\right)^2$ for $\frac{x'}{L} < 0{,}45$

$= 1{,}0 + 1{,}5 \cdot \left(\frac{\frac{x'}{L} - 0{,}45}{C_B + 0{,}2}\right)^2$ for $\frac{x'}{L} \ge 0{,}45$

$0{,}6 \le C_B \le 0{,}8$, when determining scantlings of aft ends of coamings and aft hatch cover skirt plates forward of amidships, C_B need not be taken less than 0,8.

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(cont)

x' = distance in m between the transverse coaming or hatch cover skirt plate considered and aft end of the length L. When determining side coamings or side hatch cover skirt plates, the side is to be subdivided into parts of approximately equal length, not exceeding 0,15 L each, and x' is to be taken as the distance between aft end of the length L and the centre of each part considered.

z = vertical distance in m from the summer load line to the midpoint of stiffener span, or to the middle of the plate field

c = $0{,}3 + 0{,}7 \cdot \frac{b'}{B'}$

b' = breadth of coaming in m at the position considered

B' = actual maximum breadth of ship in m on the exposed weather deck at the position considered.

b'/B' is not to be taken less than 0,25.

The design load p_A is not to be taken less than the minimum values given in Tab.2.

Tab.2 Minimum design load p_{Amin}

L	P_{Amin} in kN/m² for	
	unprotected fronts	elsewhere
≤ 50	30	15
> 50 < 250	$25 + \frac{L}{10}$	$12{,}5 + \frac{L}{20}$
≥ 250	50	25

Note:
The horizontal weather design load need not be included in the direct strength calculation of the hatch cover, unless it is utilized for the design of substructures of horizontal support according to 6.2.3.

2.3 Cargo loads

2.3.1 Distributed loads

The load on hatch covers due to distributed cargo loads P_L , in kN/m², resulting from heave and pitch (i.e. ship in upright condition) is to be determined according to the following formula:

$$p_L = p_C (1 + a_V)$$

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(cont)

where:

p_C = uniform cargo load in kN/m²

a_v = vertical acceleration addition as follows:

$$a_V = F \cdot m$$

$$F = 0{,}11 \cdot \frac{v_0}{\sqrt{L}}$$

m $= m_0 - 5(m_0 - 1)\frac{x}{L}$ for $0 \le \frac{x}{L} \le 0{,}2$

$= 1.0$ for $0{,}2 < \frac{x}{L} \le 0{,}7$

$= 1 + \frac{m_0 + 1}{0{,}3}\left[\frac{x}{L} - 0{,}7\right]$ for $0{,}7 < \frac{x}{L} \le 1{,}0$

m_0 $= 1{,}5 + F$

v_0 = maximum speed at summer load line draught, v_0 is not to be taken less than $\sqrt{L}$ in knots

2.3.2 Point loads

The load *P*, in kN, due to a concentrated force P_s, in kN, except for container load, resulting from heave and pitch (i.e. ship in upright condition) is to be determined as follows:

$$P = P_S(1 + a_V)$$

2.4 Container loads

2.4.1

The loads defined in 2.4.2 and 2.4.4 are to be applied where containers are stowed on the hatch cover.

2.4.2

The load *P* in kN, applied at each corner of a container stack, and resulting from heave and pitch (i.e. ship in upright condition) is to be determined as follows:

$$P = 9{,}81\frac{M}{4}(1 + a_V)$$

where:
a_v = acceleration addition according to 2.3.1
M = maximum designed mass of container stack in t

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(cont)

2.4.3

The loads, in kN, applied at each corner of a container stack, and resulting from heave, pitch, and the ship's rolling motion (i.e. ship in heel condition) are to be determined as follows, (see also Fig.3):

$$A_z = 9{,}81\frac{M}{2}\cdot(1+a_V)\cdot\left(0{,}45-0{,}42\frac{h_m}{b}\right)$$

$$B_z = 9{,}81\frac{M}{2}\cdot(1+a_V)\cdot\left(0{,}45+0{,}42\frac{h_m}{b}\right)$$

$$B_y = 2{,}4\cdot M$$

where:

a_v = acceleration addition according to 2.3.1

M = maximum designed mass of container stack in t

= $\sum W_i$

h_m = designed height of centre of gravity of stack above hatch cover top in m, may be calculated as weighted mean value of the stack, where the centre of gravity of each tier is assumed to be located at the centre of each container,

$= \sum (z_i \cdot W_i) / M$

z_i = distance from hatch cover top to the centre of *i*th container in m

W_i = weight of *i*th container in t

b = distance between midpoints of foot points in m

A_z, B_z = support forces in z-direction at the forward and aft stack corners

B_y = support force in y-direction at the forward and aft stack corners

When strength of the hatch cover structure is assessed by grillage analysis according to 3.5, h_m and z_i need to be taken above the hatch cover supports. Forces By does not need to be considered in this case.

Values of A_Z and B_Z applied for the assessment of hatch cover strength are to be shown in the drawings of the hatch covers.

Note:

It is recommended that container loads as calculated above are considered as limit for foot point loads of container stacks in the calculations of cargo securing (container lashing).

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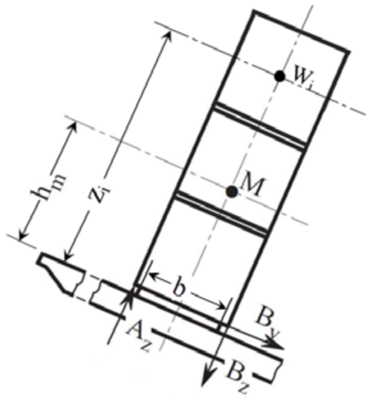

Fig. 3 Forces due to container loads

2.4.4 Load cases with partial loading

The load cases defined in 2.4.2 and 2.4.3 are also to be considered for partial non homogeneous loading which may occur in practice, e.g. where specified container stack places are empty. For each hatch cover, the heel directions, as shown in Tab. 3, are to be considered.

The load case *partial loading of container hatch covers* can be evaluated using a simplified approach, where the hatch cover is loaded without the outermost stacks that are located completely on the hatch cover. If there are additional stacks that are supported partially by the hatch cover and partially by container stanchions then the loads from these stacks are also to be neglected, refer to Tab.3. Partial loading of container hatch covers.

In addition, the case where only the stack places supported partially by the hatch cover and partially by container stanchions are left empty is to be assessed in order to consider the maximum loads in the vertical hatch cover supports.

It may be necessary to also consider partial load cases where more or different container stack places are left empty. Therefore, a classification society may require that additional partial load cases be considered.

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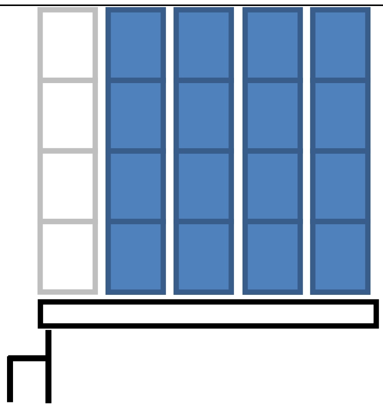
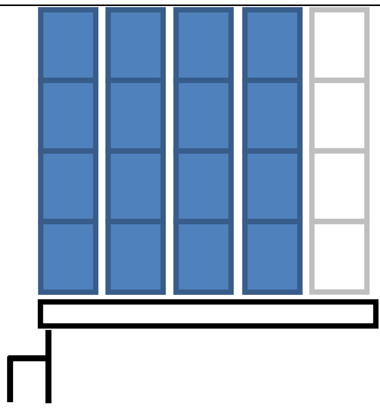
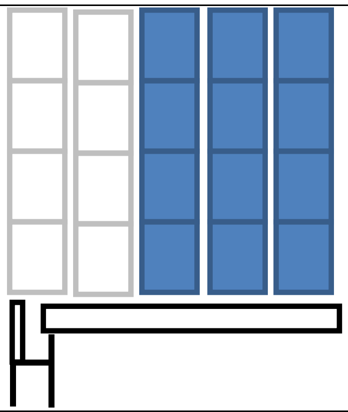
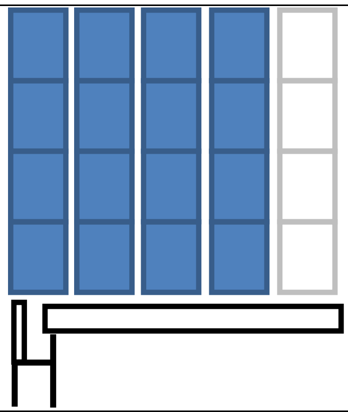
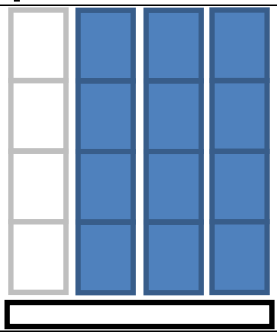
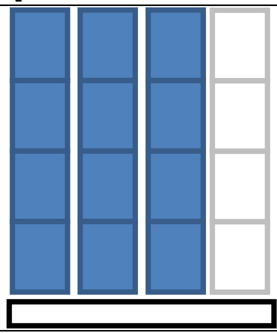
(cont)

Tab.3 Partial loading of container hatch covers

Heel direction		
Hatch covers supported by the longitudinal hatch coaming with all container stacks located completely on the hatch cover		
Hatch covers supported by the longitudinal hatch coaming with the outermost container stack supported partially by the hatch cover and partially by container stanchions		
Hatch covers not supported by the longitudinal hatch coaming (center hatch covers)		

2.4.5 Mixed stowage of 20’ and 40’ containers on hatch cover

In the case of mixed stowage (20'+40' container combined stack), the foot point forces at the fore and aft end of the hatch cover are not to be higher than resulting from the design stack weight for 40’ containers, and the foot point forces at the middle of the cover are not to be higher than resulting from the design stack weight for 20’ containers.

2.5 Loads due to elastic deformations of the ship's hull

Hatch covers, which in addition to the loads according to 2.1 to 2.4 are loaded in the ship's transverse direction by forces due to elastic deformations of the ship's hull, are to be designed such that the sum of stresses does not exceed the permissible values given in 3.1.1.

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(cont)

3 Hatch cover strength criteria

3.1 Permissible stresses and deflections

3.1.1 Stresses

The equivalent stress σ_v in steel hatch cover structures related to the net thickness shall not exceed $0{,}8 \cdot \sigma_F$, where σ_F is the minimum yield stress, in N/mm^2, of the material. For design loads according to 2.2 to 2.5, the equivalent stress σ_v related to the net thickness shall not exceed $0{,}9 \cdot \sigma_F$ when the stresses are assessed by means of FEM.

For steels with a minimum yield stress of more than 355 N/mm^2, the value of σ_F to be applied throughout this requirement is subject to the individual classification society but is not to be more than the minimum yield stress of the material.

For grillage analysis, the equivalent stress may be taken as follows:

$$\sigma_V = \sqrt{\sigma^2 + 3\tau^2} \text{ in N/mm}^2$$

where:

σ = normal stress in N/mm²

τ = shear stress in N/mm²

For FEM calculations, the equivalent stress may be taken as follows:

$$\sigma_V = \sqrt{\sigma_x^2 - \sigma_x \cdot \sigma_y + \sigma_y^2 + 3\tau^2} \text{ in N/mm}^2$$

where:

σ_x = normal stress, in N/mm^2, in x-direction

σ_y = normal stress, in N/mm^2, in y-direction

τ = shear stress, in N/mm^2, in the x-y plane

Indices x and y are coordinates of a two-dimensional Cartesian system in the plane of the considered structural element.

In case of FEM calculations using shell or plane strain elements, the stresses are to be read from the centre of the individual element. It is to be observed that, in particular, at flanges of unsymmetrical girders, the evaluation of stress from element centre may lead to non-conservative results. Thus, a sufficiently fine mesh is to be applied in these cases or, the stress at the element edges shall not exceed the allowable stress. Where shell elements are used, the stresses are to be evaluated at the mid plane of the element.

Stress concentrations are to be assessed to the satisfaction of the individual classification society.

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(cont)

3.1.2 Deflection

The vertical deflection of primary supporting members due to the vertical weather design load according to 2.1 is to be not more than $0.0056 \cdot l_g$ where l_g is the greatest span of primary supporting members.

Note:
Where hatch covers are arranged for carrying containers and mixed stowage is allowed, i.e., a 40'-container stowed on top of two 20'-containers, particular attention should be paid to the deflections of hatch covers. Further the possible contact of deflected hatch covers with in hold cargo has to be observed.

3.2 Local net plate thickness

The local net plate thickness t, in mm, of the hatch cover top plating is not to be less than:

$$t = F_p \cdot 15{,}8 \cdot s \sqrt{\frac{p}{0{,}95 \cdot \sigma_F}}$$

and to be not less than 1% of the spacing of the stiffener or 6 mm if that be greater.

F_p = factor for combined membrane and bending response
= 1,5 in general
= $1{,}9 \cdot \frac{\sigma}{\sigma_a}$, for $\frac{\sigma}{\sigma_a} \geq 0{,}8$ for the attached plate flange of primary supporting members

where:
s = stiffener spacing in m
p = pressure p_H and p_L, in kN/m^2, as defined in 2.
σ = maximum normal stress, in N/mm^2, of hatch cover top plating, determined according to Fig.4
σ_a = $0{,}8 \cdot \sigma_F$ in N/mm^2

For flange plates under compression sufficient buckling strength according to 3.6 is to be demonstrated.

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(cont)

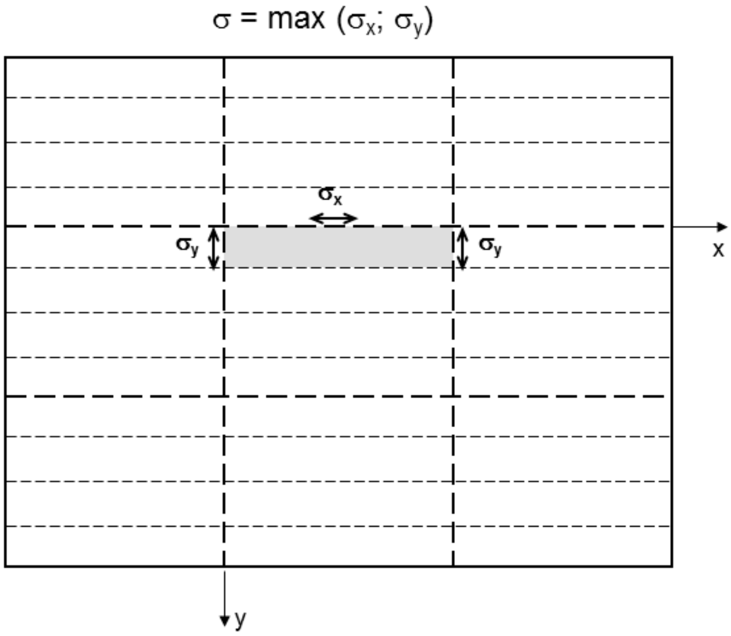

Fig.4 Determination of normal stress of the hatch cover plating

3.2.1 Local net plate thickness of hatch covers for wheel loading

The local net plate thickness of hatch covers for wheel loading have to be derived from the individual classification society's rules.

3.2.2 Lower plating of double skin hatch covers and box girders

The thickness to fulfill the strength requirements is to be obtained from the calculation according to 3.5 under consideration of permissible stresses according to 3.1.1. When the lower plating is taken into account as a strength member of the hatch cover, the net thickness, in mm, of lower plating is to be taken not less than 5 mm. When project cargo is intended to be carried on a hatch cover, the net thickness must not be less than:

$t = 6{,}5 \cdot s$ in mm

where:
s = stiffener spacing in m

Note:
Project cargo means especially large or bulky cargo lashed to the hatch cover. Examples are parts of cranes or wind power stations, turbines, etc. Cargoes that can be considered as uniformly distributed over the hatch cover, e.g., timber, pipes or steel coils need not to be considered as project cargo.

When the lower plating is not considered as a strength member of the hatch cover, the thickness of the lower plating should be determined according to the individual class society's rules.

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(cont)

3.3 Net scantling of secondary stiffeners

The net section modulus Z and net shear area A_s of uniformly loaded hatch cover stiffeners constraint at both ends must not be less than:

$$Z = \frac{104 psl^2}{\sigma_F}$$, in cm³, for design load according to 2.1

$$Z = \frac{93 psl^2}{\sigma_F}$$, in cm³, for design loads according to 2.3.1

$$A_s = \frac{10.8 psl}{\sigma_F}$$, in cm², for design load according to 2.1

$$A_s = \frac{9.6 psl}{\sigma_F}$$, in cm², for design loads according to 2.3.1

where:

l = secondary stiffener span, in m, to be taken as the spacing, in m, of primary supporting members or the distance between a primary supporting member and the edge support, as applicable.

s = secondary stiffener spacing in m

p = pressure p_H and p_L, in kN/m², as defined in 2.

For secondary stiffeners of lower plating of double skin hatch covers, requirements mentioned above are not applied due to the absence of lateral loads.

The net thickness, in mm, of the stiffener (except u-beams/trapeze stiffeners) web is to be taken not less than 4 mm.

The net section modulus of the secondary stiffeners is to be determined based on an attached plate width assumed equal to the stiffener spacing.

For flat bar secondary stiffeners and buckling stiffeners, the ratio h/t_w is to be not greater than $15 \cdot k^{0.5}$, where:

h = height of the stiffener
t_w = net thickness of the stiffener
k = $235/\sigma_F$

Stiffeners parallel to primary supporting members and arranged within the effective breadth according to 3.5.1 must be continuous at crossing primary supporting member and may be regarded for calculating the cross sectional properties of primary supporting members. It is to be verified that the combined stress of those stiffeners induced by the bending of primary supporting members and lateral pressures does not exceed the permissible stresses according to 3.1.1. The requirements of this paragraph are not applied to stiffeners of lower plating of double skin hatch covers if the lower plating is not considered as strength member.

S21A (cont)

For hatch cover stiffeners under compression sufficient safety against lateral and torsional buckling according 3.6.3 is to be verified.

For hatch covers subject to wheel loading or point loads stiffener scantlings are to be determined under consideration of the permissible stresses according to 3.1.1 or are to be determined according to the individual class society's rules.

3.4 Net scantling of primary supporting members

3.4.1 Primary supporting members

Scantlings of primary supporting members are obtained from calculations according to 3.5 under consideration of permissible stresses according to 3.1.1.

For all components of primary supporting members sufficient safety against buckling must be verified according to 3.6. For biaxial compressed flange plates this is to be verified within the effective widths according to 3.6.3.2.

The net thickness, in mm, of webs of primary supporting members shall not be less than:

$$t = 6{,}5 \cdot s \text{ in mm}$$
$$t_{\min} = 5 \text{ mm}$$

where:
s = stiffener spacing in m

3.4.2 Edge girders (Skirt plates)

Scantlings of edge girders are obtained from the calculations according to 3.5 under consideration of permissible stresses according to 3.1.1.

The net thickness, in mm, of the outer edge girders exposed to wash of sea shall not be less than the largest of the following values:

$$t = 15{,}8 \cdot s \cdot \sqrt{\frac{p_A}{0{,}95 \cdot \sigma_F}}$$

$$t = 8{,}5 \cdot s \text{ in mm}$$
$$t_{min} = 5 \text{ mm}$$

where:
p_A = horizontal pressure as defined in 2.2
s = stiffener spacing in m

The stiffness of edge girders is to be sufficient to maintain adequate sealing pressure between securing devices. The moment of inertia, in cm^4, of edge girders is not to be less than:

$$I = 6 \cdot q \cdot s_{SD}{}^4$$

S21A (cont)

where:
q = packing line pressure in N/mm, minimum 5 N/mm

s_{SD} = spacing, in m, of securing devices

3.5 Strength calculations

Strength calculation for hatch covers may be carried out by either grillage analysis or FEM. Double skin hatch covers or hatch covers with box girders are to be assessed using FEM, refer to 3.5.2.

3.5.1 Effective cross-sectional properties for calculation by grillage analysis

Cross-sectional properties are to be determined considering the effective breadth. Cross sectional areas of secondary stiffeners parallel to the primary supporting member under consideration within the effective breadth can be included, refer Fig.6.

The effective breadth of plating e_m of primary supporting members is to be determined according to Tab.4, considering the type of loading. Special calculations may be required for determining the effective breadth of one-sided or non-symmetrical flanges.

The effective cross sectional area of plates is not to be less than the cross sectional area of the face plate.

For flange plates under compression with secondary stiffeners perpendicular to the web of the primary supporting member, the effective width is to be determined according to 3.6.3.2.

Tab. 4 Effective breadth e_m of plating of primary supporting members

l/e	0	1	2	3	4	5	6	7	≥ 8
e_{m1}/e	0	0.36	0.64	0.82	0.91	0.96	0.98	1.00	1.00
e_{m2}/e	0	0.20	0.37	0.52	0.65	0.75	0.84	0.89	0.90

e_{m1} is to be applied where primary supporting members are loaded by uniformly distributed loads or else by not less than 6 equally spaced single loads

e_{m2} is to be applied where primary supporting members are loaded by 3 or less single loads

Intermediate values may be obtained by direct interpolation.

l length of zero-points of bending moment curve:

$l = l_0$ for simply supported primary supporting members

$l = 0,6 \cdot l_0$ for primary supporting members with both ends constraint,

where l_0 is the unsupported length of the primary supporting member

e width of plating supported, measured from centre to centre of the adjacent unsupported fields

3.5.2 General requirements for FEM calculations

For strength calculations of hatch covers by means of finite elements, the cover geometry shall be idealized as realistically as possible. Element size must be appropriate to account for

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(cont)

effective breadth. In no case element width shall be larger than stiffener spacing. In way of force transfer points and cutouts the mesh has to be refined where applicable. The ratio of element length to width shall not exceed 4.

The element height of webs of primary supporting member must not exceed one-third of the web height. Stiffeners, supporting plates against pressure loads, have to be included in the idealization. Stiffeners may be modelled by using shell elements, plane stress elements or beam elements. Buckling stiffeners may be disregarded for the stress calculation.

3.6 Buckling strength of hatch cover structures

For hatch cover structures sufficient buckling strength is to be demonstrated.

The buckling strength assessment of coaming parts is to be done according to the individual class society's rules.

Definitions

a = length of the longer side of a single plate field in mm (x-direction)

b = breadth of the shorter side of a single plate field in mm (y-direction)

α = aspect ratio of single plate field
= a / b

n = number of single plate field breadths within the partial or total plate field

t = net plate thickness in mm

σ_x = membrane stress, in N/mm², in x-direction

σ_y = membrane stress, in N/mm², in y-direction

τ = shear stress, in N/mm², in the x-y plane

E = modulus of elasticity, in N/mm², of the material
= $2{,}06 \cdot 10^5$ N/mm^2 for steel

σ_F = minimum yield stress, in N/mm², of the material

Compressive and shear stresses are to be taken positive, tension stresses are to be taken negative.

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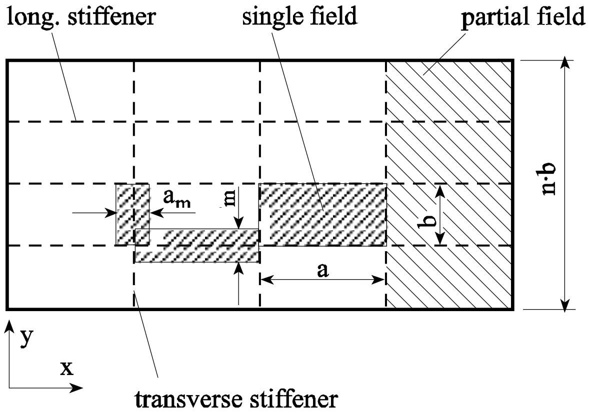
(cont)



longitudinal : stiffener in the direction of the length a
transverse : stiffener in the direction of the breath b

Fig. 5 General arrangement of panel

Note:
If stresses in the x- and y-direction already contain the Poisson-effect (calculated using FEM), the following modified stress values may be used. Both stresses σ_x^* and σ_y^* are to be compressive stresses, in order to apply the stress reduction according to the following formulae:

$$\sigma_x = \left(\sigma_x^* - 0{,}3 \cdot \sigma_y^*\right) / 0{,}91$$

$$\sigma_y = \left(\sigma_y^* - 0{,}3 \cdot \sigma_x^*\right) / 0{,}91$$

σ_x^*, σ_y^* = *stresses containing the Poisson-effect*

Where compressive stress fulfils the condition $\sigma_y^* < 0{,}3\sigma_x^*$, then $\sigma_y = 0$ and $\sigma_x = \sigma_x^*$

Where compressive stress fulfils the condition $\sigma_x^* < 0{,}3\sigma_y^*$, then $\sigma_x = 0$ and $\sigma_y = \sigma_y^*$

F_1 =correction factor for boundary condition at the longitudinal stiffeners according to Tab.5.

S21A
(cont)

Tab. 5 Correction factor F_1

Stiffeners sniped at both ends	1,00
Guidance values[1] where both ends are effectively connected to adjacent structures	1,05 for flat bars 1,10 for bulb sections 1,20 for angle and tee-sections 1,30 for u-type sections[2] and girders of high rigidity
An average value of F_1 is to be used for plate panels having different edge stiffeners	
[1] Exact values may be determined by direct calculations [2] Higher value may be taken if it is verified by a buckling strength check of the partial plate field using non-linear FEA and deemed appropriate by the individual class society but not greater than 2.0	

σ_e = reference stress, in N/mm², taken equal to

$$= 0{,}9 \cdot E\left(\frac{t}{b}\right)^2$$

Ψ = edge stress ratio taken equal to
= σ_2 / σ_1 where

σ_1 = maximum compressive stress

σ_2 = minimum compressive stress or tension stress

S = safety factor (based on net scantling approach), taken equal to
= 1.25 for hatch covers when subjected to the vertical weather design load according to 2.1
= 1.10 for hatch covers when subjected to loads according to 2.3 to 2.5

λ = reference degree of slenderness, taken equal to:

$$= \sqrt{\frac{\sigma_F}{K \cdot \sigma_e}}$$

K = buckling factor according to Tab.7.

3.6.1 Proof of top and lower hatch cover plating

Proof is to be provided that the following condition is complied with for the single plate field a · b:

$$\left(\frac{|\sigma_x| \cdot S}{\kappa_x \cdot \sigma_F}\right)^{e1} + \left(\frac{|\sigma_y| \cdot S}{\kappa_y \cdot \sigma_F}\right)^{e2} - B\left(\frac{\sigma_x \cdot \sigma_y \cdot S^2}{\sigma_F^2}\right) + \left(\frac{|\tau| \cdot S \cdot \sqrt{3}}{\kappa_\tau \cdot \sigma_F}\right)^{e3} \le 1{,}0$$

The first two terms and the last term of the above condition shall not exceed 1,0.

S21A
(cont)

The reduction factors κ_x, κ_y and κ_τ are given in Tab.7.
Where $\sigma_x \le 0$ (tension stress), $\kappa_x = 1{,}0$.
Where $\sigma_y \le 0$ (tension stress), $\kappa_y = 1{,}0$.

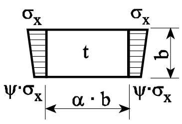
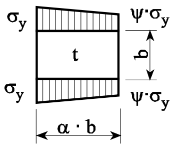
The exponents e_1, e_2 and e_3 as well as the factor B are to be taken as given by Tab. 6.

Tab. 6 Coefficients e_1, e_2, e_3 and factor B

Exponents e_1 - e_3 and factor B	Plate panel
e_1	$1+\kappa_x^4$
e_2	$1+\kappa_y^4$
e_3	$1+\kappa_x \cdot \kappa_y \cdot \kappa_\tau^2$
B σ_x and σ_y positive (compression stress)	$(\kappa_x \cdot \kappa_y)^5$
B σ_x or σ_y negative (tension stress)	1

S21A
(cont)

Tab. 7 Buckling and reduction factors for plane elementary plate panels

<table>
<tr><th>Buckling-Load Case</th><th>Edge stress ratio ψ</th><th>Asp. ratio $\alpha = a/b$</th><th>Buckling factor K</th><th>Reduction factor κ</th></tr>
<tr><td rowspan="3">1
</td><td>$1 \ge \psi \ge 0$</td><td rowspan="3">$\alpha \ge 1$</td><td>$K = \frac{8,4}{\psi + 1,1}$</td><td rowspan="3">$\kappa_x = 1$ for $\lambda \le \lambda_c$
$\kappa_x = c\left(\frac{1}{\lambda} - \frac{0,22}{\lambda^2}\right)$ for $\lambda > \lambda_c$
$c = (1,25 - 0,12\psi) \le 1,25$
$\lambda_c = \frac{c}{2}\left(1 + \sqrt{1 - \frac{0,88}{c}}\right)$</td></tr>
<tr><td>$0 > \psi > -1$</td><td>$K = 7,63 - \psi(6,26 - 10\psi)$</td></tr>
<tr><td>$\psi \le -1$</td><td>$K = (1-\psi)^2 \cdot 5,975$</td></tr>
<tr><td rowspan="5">2
</td><td>$1 \ge \psi \ge 0$</td><td>$\alpha \ge 1$</td><td>$K = F_1\left(1 + \frac{1}{\alpha^2}\right)^2 \cdot \frac{2,1}{(\psi + 1,1)}$</td><td rowspan="5">$\kappa_y = c\left(\frac{1}{\lambda} - \frac{R + F^2(H-R)}{\lambda^2}\right)$
$c = (1,25 - 0,12\psi) \le 1,25$
$R = \lambda\left(1 - \frac{\lambda}{c}\right)$ for $\lambda < \lambda_c$
$R = 0,22$ for $\lambda \ge \lambda_c$
$\lambda_c = \frac{c}{2}\left(1 + \sqrt{1 - \frac{0,88}{c}}\right)$
$F = \left(1 - \frac{\frac{K}{0,91} - 1}{\lambda_p{}^2}\right) \cdot c_1 \ge 0$
$\lambda_p{}^2 = \lambda^2 - 0,5$ for $1 \le \lambda_p{}^2 \le 3$
$c_1 = \left(1 - \frac{F_1}{\alpha}\right) \ge 0$
$H = \lambda - \frac{2\lambda}{c\left(T + \sqrt{T^2 - 4}\right)} \ge R$
$T = \lambda + \frac{14}{15\lambda} + \frac{1}{3}$</td></tr>
<tr><td rowspan="2">$0 > \psi > -1$</td><td>$1 \le \alpha \le 1,5$</td><td>$K = F_1\left[\left(1 + \frac{1}{\alpha^2}\right)^2 \cdot \frac{2,1(1+\psi)}{1,1} - \frac{\psi}{\alpha^2}(13,9 - 10\psi)\right]$</td></tr>
<tr><td>$\alpha > 1,5$</td><td>$K = F_1\left[\left(1 + \frac{1}{\alpha^2}\right)^2 \cdot \frac{2,1(1+\psi)}{1,1} - \frac{\psi}{\alpha^2} \cdot (5,87 + 1,87\alpha^2 + \frac{8,6}{\alpha^2} - 10\psi)\right]$</td></tr>
<tr><td rowspan="2">$\psi \le -1$</td><td>$1 \le \alpha \le \frac{3(1-\psi)}{4}$</td><td>$K = F_1\left(\frac{1-\psi}{\alpha}\right)^2 \cdot 5,975$</td></tr>
<tr><td>$\alpha > \frac{3(1-\psi)}{4}$</td><td>$K = F_1\left[\left(\frac{1-\psi}{\alpha}\right)^2 \cdot 3,9675 + 0,5375\left(\frac{1-\psi}{\alpha}\right)^4 + 1,87\right]$</td></tr>
<tr><td colspan="3">Explanations for boundary conditions</td><td colspan="2">- - - - - plate edge free
———— plate edge simply supported</td></tr>
</table>

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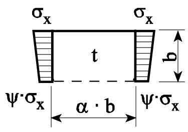
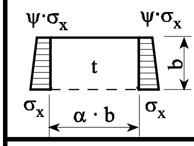
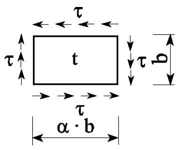
(cont)

3 	$1 \ge \psi \ge 0$	$\alpha > 0$	$K = \dfrac{4\left(0{,}425 + \dfrac{1}{\alpha^2}\right)}{3\psi + 1}$	$\kappa_x = 1$ for $\lambda \le 0{,}7$ $\kappa_x = \dfrac{1}{\lambda^2 + 0{,}51}$ for $\lambda > 0{,}7$
	$0 > \psi \ge -1$		$K = 4\left(0{,}425 + \dfrac{1}{\alpha^2}\right)(1+\psi) - 5\psi(1 - 3{,}42\psi)$	
4 	$1 \ge \psi \ge -1$	$\alpha > 0$	$K = \left(0{,}425 + \dfrac{1}{\alpha^2}\right)\dfrac{3-\psi}{2}$	
5 	===		$K = K_\tau \cdot \sqrt{3}$	
		$\alpha \ge 1$	$K_\tau = \left[5{,}34 + \dfrac{4}{\alpha^2}\right]$	$\kappa_\tau = 1$ for $\lambda \le 0{,}84$ $\kappa_\tau = \dfrac{0{,}84}{\lambda}$ for $\lambda > 0{,}84$
		$0 < \alpha < 1$	$K_\tau = \left[4 + \dfrac{5{,}34}{\alpha^2}\right]$	
Explanations for boundary conditions			- - - - - plate edge free ——— plate edge simply supported	

3.6.2 Webs and flanges of primary supporting members

For non-stiffened webs and flanges of primary supporting members sufficient buckling strength as for the hatch cover top and lower plating is to be demonstrated according to 3.6.1.

3.6.3 Proof of partial and total fields of hatch covers

3.6.3.1 Longitudinal and transverse secondary stiffeners

It is to be demonstrated that the continuous longitudinal and transverse stiffeners of partial and total plate fields comply with the conditions set out in 3.6.3.3 through 3.6.3.4.

For u-type stiffeners, the proof of torsional buckling strength according to 3.6.3.4 can be omitted.

Single-side welding is not permitted to use for secondary stiffeners except for u-stiffeners.

3.6.3.2 Effective width of top and lower hatch cover plating

For demonstration of buckling strength according to 3.6.3.3 through 3.6.3.4 the effective width of plating may be determined by the following formulae:

$b_m = \kappa_x \cdot b$ for longitudinal stiffeners

$a_m = \kappa_y \cdot a$ for transverse stiffeners

see also Fig.5.

The effective width of plating is not to be taken greater than the value obtained from 3.5.1.

The effective width e'_m of stiffened flange plates of primary supporting members may be determined as follows:

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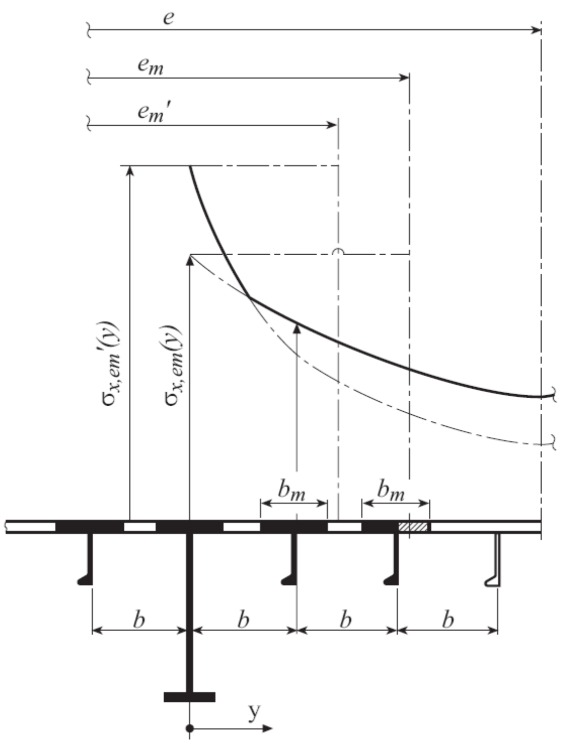

Fig. 6 Stiffening parallel to web of primary supporting member

b < e_m

e'_m = $n \cdot b_m$

n = integer number of stiffener spacings b inside the effective breadth e_m according to 3.5.1

= $\text{int}\left(\frac{e_m}{b}\right)$

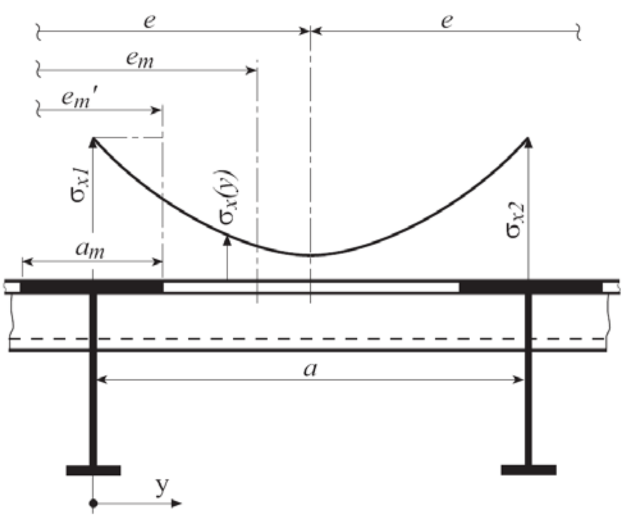

Fig. 7 Stiffening perpendicular to web of primary supporting member

a ≥ e_m

e'_m = $n \cdot a_m < e_m$

n = $2{,}7 \cdot \frac{e_m}{a} \leq 1$

e = width of plating supported according to 3.5.1

S21A
(cont)

For $b \geq e_m$ or $a < e_m$, respectively, b and a have to be exchanged.

a_m and b_m for flange plates are in general to be determined for $\psi = 1$.

Note:
Scantlings of plates and stiffeners are in general to be determined according to the maximum stresses $\sigma_x(y)$ at webs of primary supporting member and stiffeners, respectively. For stiffeners with spacing b under compression arranged parallel to primary supporting members no value less than $0{,}25 \cdot \sigma_F$ shall be inserted for $\sigma_x(y=b)$.

The stress distribution between two primary supporting members can be obtained by the following formula:

$$\sigma_x(y) = \sigma_{x1} \cdot \left\{1 - \frac{y}{e}\left[3 + c_1 - 4 \cdot c_2 - 2\frac{y}{e}\left(1 + c_1 - 2c_2\right)\right]\right\}$$

where:

$c_1 = \dfrac{\sigma_{x2}}{\sigma_{x1}} \qquad 0 \leq c_1 \leq 1$

$c_2 = \dfrac{1{,}5}{e} \cdot \left(e''_{m1} + e''_{m2}\right) - 0{,}5$

e''_{m1} = *proportionate effective breadth e_{m1} or proportionate effective width e'_{m1} of primary supporting member 1 within the distance e, as appropriate*

e''_{m2} = *proportionate effective breadth e_{m2} or proportionate effective width e'_{m2} of primary supporting member 2 within the distance e, as appropriate*

σ_{x1}, σ_{x2} = *normal stresses in flange plates of adjacent primary supporting member 1 and 2 with spacing e, based on cross-sectional properties considering the effective breadth or effective width, as appropriate*

y = *distance of considered location from primary supporting member 1*

Shear stress distribution in the flange plates may be assumed linearly.

3.6.3.3 Lateral buckling of secondary stiffeners

$$\frac{\sigma_a + \sigma_b}{\sigma_F} S \leq 1$$

where:

σ_a = uniformly distributed compressive stress, in N/mm^2 in the direction of the stiffeneraxis.

σ_a = σ_x for longitudinal stiffeners

σ_a = σ_y for transverse stiffeners

σ_b = bending stress, in N/mm^2, in the stiffener

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(cont)

$$= \frac{M_0 + M_1}{Z_{st} \cdot 10^3}$$

M_0 = bending moment, in Nmm, due to the deformation w of stiffener, taken equal to:

$$M_0 = F_{Ki} \frac{p_z \cdot w}{c_f - p_z} \quad \text{with } \left(c_f - p_z\right) > 0$$

M_1 = bending moment, in Nmm, due to the lateral load p equal to:

$$M_1 = \frac{p \cdot b \cdot a^2}{24 \cdot 10^3} \quad \text{for longitudinal stiffeners}$$

$$M_1 = \frac{p \cdot a (n \cdot b)^2}{c_s \cdot 8 \cdot 10^3} \quad \text{for transverse stiffeners}$$

n is to be taken equal to 1 for ordinary transverse stiffeners.

p = lateral load in kN/m²

F_{Ki} = ideal buckling force, in N, of the stiffener

$$F_{Kix} = \frac{\pi^2}{a^2} \cdot E \cdot I_x \cdot 10^4 \quad \text{for longitudinal stiffeners}$$

$$F_{Kiy} = \frac{\pi^2}{(n \cdot b)^2} \cdot E \cdot I_y \cdot 10^4 \quad \text{for transverse stiffeners}$$

I_x, I_y = net moments of inertia, in cm⁴, of the longitudinal or transverse stiffener including effective width of attached plating according to 3.6.3.2. I_x and I_y are to comply with the following criteria:

$$I_x \geq \frac{b \cdot t^3}{12 \cdot 10^4}$$

$$I_y \geq \frac{a \cdot t^3}{12 \cdot 10^4}$$

p_z = nominal lateral load, in N/mm², of the stiffener due to σ_x, σ_y and τ

$$p_{zx} = \frac{t}{b}\left(\sigma_{xl}\left(\frac{\pi \cdot b}{a}\right)^2 + 2 \cdot c_y \cdot \sigma_y + \sqrt{2}\tau_1\right) \quad \text{for longitudinal stiffeners}$$

$$p_{zy} = \frac{t}{a}\left(2 \cdot c_x \cdot \sigma_{xl} + \sigma_y\left(\frac{\pi \cdot a}{n \cdot b}\right)^2\left(1 + \frac{A_y}{a \cdot t}\right) + \sqrt{2}\tau_1\right) \quad \text{for transverse stiffeners}$$

$$\sigma_{xl} = \sigma_x\left(1 + \frac{A_x}{b \cdot t}\right)$$

c_x, c_y = factor taking into account the stresses perpendicular to the stiffener's axis and distributed variable along the stiffener's length

$= 0{,}5 \cdot (1 + \Psi) \quad \text{for } 0 \leq \Psi \leq 1$

S21A
(cont)

$$= \frac{0,5}{1-\Psi} \qquad \text{for } \Psi < 0$$

A_x, A_y = net sectional area, in mm², of the longitudinal or transverse stiffener, respectively, without attached plating

$$\tau_1 = \left[\tau - t\sqrt{\sigma_F \cdot E\left(\frac{m_1}{a^2} + \frac{m_2}{b^2}\right)}\right] \geq 0$$

for longitudinal stiffeners:

$$\frac{a}{b} \geq 2,0 \quad : \quad m_1 = 1,47 \quad m_2 = 0,49$$

$$\frac{a}{b} < 2,0 \quad : \quad m_1 = 1,96 \quad m_2 = 0,37$$

for transverse stiffeners:

$$\frac{a}{n \cdot b} \geq 0,5 \quad : \quad m_1 = 0,37 \quad m_2 = \frac{1,96}{n^2}$$

$$\frac{a}{n \cdot b} < 0,5 \quad : \quad m_1 = 0,49 \quad m_2 = \frac{1,47}{n^2}$$

$$w = w_0 + w_1$$

w_o = assumed imperfection in mm

$$w_{0x} \leq \min\left(\frac{a}{250}, \frac{b}{250}, 10\right) \text{ for longitudinal stiffeners}$$

$$w_{0y} \leq \min\left(\frac{a}{250}, \frac{n \cdot b}{250}, 10\right) \text{ for transverse stiffeners}$$

Note:

For stiffeners sniped at both ends w_O must not be taken less than the distance from the midpoint of plating to the neutral axis of the profile including effective width of plating.

w_1 = Deformation of stiffener, in mm, at midpoint of stiffener span due to lateral load *p*.
In case of uniformly distributed load the following values for w_1 may be used:

$$w_1 = \frac{p \cdot b \cdot a^4}{384 \cdot 10^7 \cdot E \cdot I_x} \text{ for longitudinal stiffeners}$$

$$w_1 = \frac{5 \cdot a \cdot p \cdot (n \cdot b)^4}{384 \cdot 10^7 \cdot E \cdot I_y \cdot c_s^2} \text{ for transverse stiffeners}$$

c_f = elastic support provided by the stiffener, in N/mm²

i. For longitudinal stiffeners:

$$c_{fx} = F_{Kix} \cdot \frac{\pi^2}{a^2} \cdot (1 + c_{px})$$

S21A
(cont)

$$c_{px} = \frac{1}{1 + \frac{0{,}91 \cdot \left(\frac{12 \cdot 10^4 \cdot I_x}{t^3 \cdot b} - 1 \right)}{c_{xa}}}$$

$$c_{xa} = \left[\frac{a}{2b} + \frac{2b}{a} \right]^2 \quad \text{for} \quad a \geq 2b$$

$$c_{xa} = \left[1 + \left(\frac{a}{2b} \right)^2 \right]^2 \quad \text{for} \quad a < 2b$$

ii. For transverse. stiffeners:

$$c_{fy} = c_S \cdot F_{Kiy} \cdot \frac{\pi^2}{(n \cdot b)^2} \cdot (1 + c_{py})$$

$$c_{py} = \frac{1}{1 + \frac{0{,}91 \cdot \left(\frac{12 \cdot 10^4 \cdot I_y}{t^3 \cdot a} - 1 \right)}{c_{ya}}}$$

$$c_{ya} = \left[\frac{n \cdot b}{2a} + \frac{2a}{n \cdot b} \right]^2 \quad \text{for} \quad n \cdot b \geq 2a$$

$$c_{ya} = \left[1 + \left(\frac{n \cdot b}{2a} \right)^2 \right]^2 \quad \text{for} \quad n \cdot b < 2a$$

c_s = factor accounting for the boundary conditions of the transverse stiffener
= 1,0 for simply supported stiffeners
= 2,0 for partially constraint stiffeners

Z_{st} = net section modulus of stiffener (long. or transverse) in cm³ including effective width of plating according to 3.6.3.2.

If no lateral load p is acting the bending stress σ_b is to be calculated at the midpoint of the stiffener span for that fibre which results in the largest stress value. If a lateral load p is acting, the stress calculation is to be carried out for both fibres of the stiffener's cross sectional area (if necessary for the biaxial stress field at the plating side).

3.6.3.4 Torsional buckling of secondary stiffeners

3.6.3.4.1 Longitudinal secondary stiffeners

The longitudinal ordinary stiffeners are to comply with the following criteria:

$$\frac{\sigma_x \cdot S}{\kappa_T \cdot \sigma_F} \leq 1{,}0$$

κ_T = coefficient taken equal to:

S21A
(cont)

$$\kappa_T = 1{,}0 \text{ for } \lambda_T \le 0{,}2$$

$$\kappa_T = \frac{1}{\Phi + \sqrt{\Phi^2 - \lambda_T^2}} \text{ for } \lambda_T > 0{,}2$$

$$\Phi = 0{,}5\left(1 + 0{,}21(\lambda_T - 0{,}2) + \lambda_T^2\right)$$

λ_T = reference degree of slenderness taken equal to:

$$\lambda_T = \sqrt{\frac{\sigma_F}{\sigma_{KiT}}}$$

$$\sigma_{KiT} = \frac{E}{I_P}\left(\frac{\pi^2 \cdot I_\omega \cdot 10^2}{a^2}\varepsilon + 0{,}385 \cdot I_T\right), \text{ in N/mm}^2$$

For I_P, I_T, I_ω see Fig.8 and Tab.8.

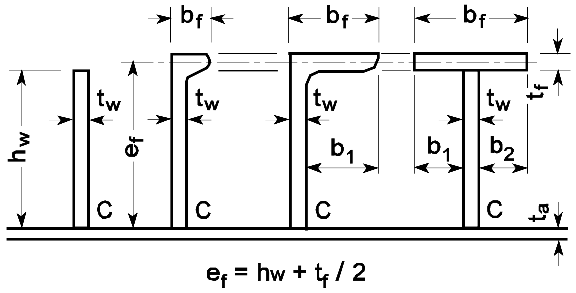

Fig. 8 Dimensions of stiffener

I_P = net polar moment of inertia of the stiffener, in cm^4, related to the point C

I_T = net St. Venant's moment of inertia of the stiffener, in cm^4

I_ω = net sectorial moment of inertia of the stiffener, in cm^6, related to the point C

ε = degree of fixation taken equal to:

$$\varepsilon = 1 + 10^{-3}\sqrt{\frac{a^4}{\frac{3}{4}\pi^4 \cdot I_\omega\left(\frac{b}{t^3} + \frac{4h_w}{3t_w^3}\right)}}$$

h_w = web height, in mm

t_w = net web thickness, in mm

b_f = flange breadth, in mm

t_f = net flange thickness, in mm

A_w = net web area equal to: $A_w = h_w \cdot t_w$

A_f = net flange area equal to: $A_f = b_f \cdot t_f$

$$e_f = h_w + \frac{t_f}{2} \text{ , in mm}$$

S21A
(cont)

Tab. 8 Moments of inertia

Section	I_P	I_T	I_ω
Flat bar	$\frac{h_w^3 \cdot t_w}{3 \cdot 10^4}$	$\frac{h_w \cdot t_w^3}{3 \cdot 10^4}\left(1-0{,}63\frac{t_w}{h_w}\right)$	$\frac{h_w^3 \cdot t_w^3}{36 \cdot 10^6}$
Sections with bulb or flange	$\left(\frac{A_w \cdot h_w^2}{3} + A_f \cdot e_f^2\right)10^{-4}$	$\frac{h_w \cdot t_w^3}{3 \cdot 10^4}\left(1-0{,}63\frac{t_w}{h_w}\right)$ + $\frac{b_f \cdot t_f^3}{3 \cdot 10^4}\left(1-0{,}63\frac{t_f}{b_f}\right)$	for bulb and angle sections: $\frac{A_f \cdot e_f^2 \cdot b_f^2}{12 \cdot 10^6}\left(\frac{A_f + 2.6A_W}{A_f + A_W}\right)$ for tee-sections: $\frac{b_f^3 \cdot t_f \cdot e_f^2}{12 \cdot 10^6}$

3.6.3.4.2 Transverse secondary stiffeners

For transverse secondary stiffeners loaded by compressive stresses and which are not supported by longitudinal stiffeners, sufficient torsional buckling strength is to be demonstrated analogously in accordance with 3.6.3.4.1.

4 Details of hatch covers

4.1 Container foundations on hatch covers

Container foundations are to be designed to the satisfaction of the individual class society. The substructures of container foundations are to be designed for cargo and container loads according to 2, applying the permissible stresses according to 3.1.1.

4.2 Weather tightness

Further to the following requirements IACS Rec. 14 is applicable to hatch covers.

4.2.1 Packing material (General)

The packing material is to be suitable for all expected service conditions of the ship and is to be compatible with the cargoes to be transported. The packing material is to be selected with regard to dimensions and elasticity in such a way that expected deformations can be carried. Forces are to be carried by the steel structure only.

The packings are to be compressed so as to give the necessary tightness effect for all expected operating conditions. Special consideration shall be given to the packing arrangement in ships with large relative movements between hatch covers and coamings or between hatch cover sections.

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(cont)

4.2.2 Dispensation of weather tight gaskets

For hatch covers of cargo holds solely for the transport of containers, upon request by the owners and subject to compliance with the following conditions the fitting of weather tight gaskets according to 4.2.1 may be dispensed with:

- The hatchway coamings shall be not less than 600 mm in height.
- The exposed deck on which the hatch covers are located is situated above a depth H(x). H(x) is to be shown to comply with the following criteria:

$H(x) \geq T_{fb} + f_b + h$ in m

T_{fb} = draught, in m, corresponding to the assigned summer load line

f_b = minimum required freeboard, in m, determined in accordance with ICLL Reg. 28 as modified by further regulations as applicable

h = 4,6 m for $\frac{x}{L_{LL}} \leq 0{,}75$

= 6,9 m for $\frac{x}{L_{LL}} > 0{,}75$

- Labyrinths, gutter bars or equivalents are to be fitted proximate to the edges of each panel in way of the coamings. The clear profile of these openings is to be kept as small as possible.
- Where a hatch is covered by several hatch cover panels the clear opening of the gap in between the panels shall be not wider than 50mm.
- The labyrinths and gaps between hatch cover panels shall be considered as unprotected openings with respect to the requirements of intact and damage stability calculations.
- With regard to drainage of cargo holds and the necessary fire-fighting system reference is made to the sections *Piping Systems, Valves and Pumps* and *Fire Protection and Fire Extinguishing Equipment* of the individual classification society’s rules.
- Bilge alarms should be provided in each hold fitted with non-weathertight covers.
- Furthermore, Chapter 3 of IMO MSC/Circ. 1087 is to be referred to concerning the stowage and segregation of containers containing dangerous goods.

4.2.3 Drainage arrangements

Cross-joints of multi-panel covers are to be provided with efficient drainage arrangements.

5 Hatch coaming strength criteria

5.1 Local net plate thickness of coamings

The net thickness of weather deck hatch coamings shall not be less than the larger of the following values:

S21A
(cont)

$$t = 14{,}2 \cdot s \sqrt{\frac{p_A}{0{,}95 \cdot \sigma_F}} \text{ in mm}$$

$$t_{min} = 6 + \frac{L_1}{100} \text{ in mm}$$

where:
s = stiffener spacing in m
L_1 = L, need not be taken greater than 300 m

Longitudinal strength aspects are to be observed.

5.2 Net scantling of secondary stiffeners of coamings

The stiffeners must be continuous at the coaming stays. For stiffeners with both ends constraint the elastic net section modulus Z in cm^3 and net shear area A_s in cm^2, calculated on the basis of net thickness, must not be less than:

$$Z = \frac{83}{\sigma_F} \cdot s \cdot l^2 \cdot p_A$$

$$A_s = \frac{10 \cdot s \cdot l \cdot p_A}{\sigma_F}$$

where:
l = secondary stiffener span, in m, to be taken as the spacing of coaming stays
s = stiffener spacing in m

For sniped stiffeners of coaming at hatch corners section modulus and shear area at the fixed support have to be increased by 35 %. The gross thickness of the coaming plate at the sniped stiffener end shall not be less than:

$$t = 19{,}6 \cdot \sqrt{\frac{p_A \cdot s \cdot (l - 0{,}5\, s)}{\sigma_F}} \text{ in mm}$$

Horizontal stiffeners on hatch coamings, which are part of the longitudinal hull structure, are to be designed according to the individual classification society’s rules.

5.3 Coaming stays

Coaming stays are to be designed for the loads transmitted through them and permissible stresses according to 3.1.1.

5.3.1 Coaming stay section modulus and web thickness

At the connection with deck, the net section modulus Z, in cm^3, and the gross thickness t_w, in mm, of the coaming stays designed as beams with flange (examples 1 and 2 are shown in Fig. 9) are to be taken not less than:

$$Z = \frac{526}{\sigma_F} \cdot e \cdot h_s^2 \cdot p_A \text{ in cm}^3$$

S21A (cont)

$$t_w = \frac{2}{\sigma_F} \cdot \frac{e \cdot h_S \cdot p_A}{h_W} + t_S \quad \text{in mm}$$

where:

e = spacing of coaming stays in m

h_s = height of coaming stays in m

h_w = web height of coaming stay at its lower end in m

t_s = corrosion addition, in mm, according to 7

For other designs of coaming stays, such as those shown in Fig. 9, examples 3 and 4, the stresses are to be determined through a grillage analysis or FEM. The calculated stresses are to comply with the permissible stresses according to 3.1.1.

Coaming stays are to be supported by appropriate substructures. Face plates may only be included in the calculation if an appropriate substructure is provided and welding provides an adequate joint.

Webs are to be connected to the deck by fillet welds on both sides with a throat thickness of $a = 0{,}44\,t_W$. The size of welding for toes of webs at the lower end of coaming stays should be according to the individual class society's rules.

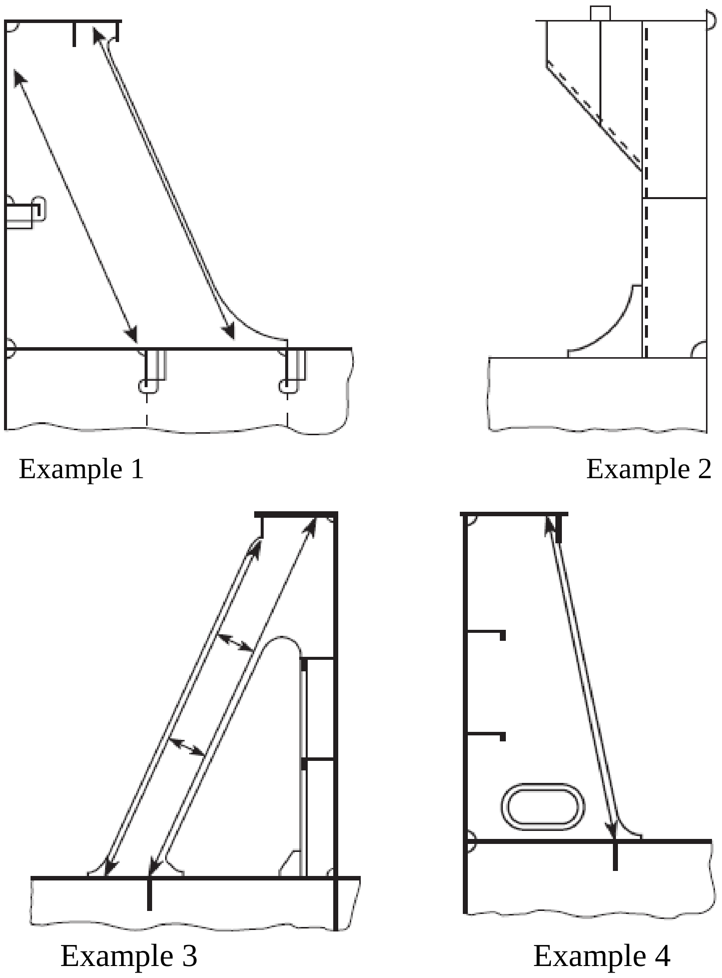

Fig. 9 Examples of coaming stays

5.3.2 Coaming stays under friction load

For coaming stays, which transfer friction forces at hatch cover supports, fatigue strength is to be considered according to individual class society's rules, refer to 6.2.2.

5.4 Further requirements for hatch coamings

5.4.1 Longitudinal strength

Hatch coamings which are part of the longitudinal hull structure are to be designed according to the requirements for longitudinal strength of the individual classification society.

For structural members welded to coamings and for cutouts in the top of coamings sufficient fatigue strength is to be verified.

Longitudinal hatch coamings with a length exceeding 0,1·L m are to be provided with tapered brackets or equivalent transitions and a corresponding substructure at both ends. At the end of the brackets they are to be connected to the deck by full penetration welds of minimum 300 mm in length.

5.4.2 Local details

If the design of local details is not regulated in 5, local details are to comply with the individual classification society's requirement for the purpose of transferring the loads on the hatch covers to the hatch coamings and, through them, to the deck structures below. Hatch coamings and supporting structures are to be adequately stiffened to accommodate the loading from hatch covers, in longitudinal, transverse and vertical directions.

Structures under deck are to be checked against the load transmitted by the stays.

Unless otherwise stated, weld connections and materials are to be dimensioned and selected in accordance with the individual classification society's requirements.

5.4.3 Stays

On ships carrying cargo on deck, such as timber, coal or coke, the stays are to be spaced not more than 1,5 m apart.

5.4.4 Extend of coaming plates

Coaming plates are to extend to the lower edge of the deck beams or hatch side girders are to be fitted that extend to the lower edge of the deck beams. Extended coaming plates and hatch side girders are to be flanged or fitted with face bars or half-round bars. Fig.10 gives an example.

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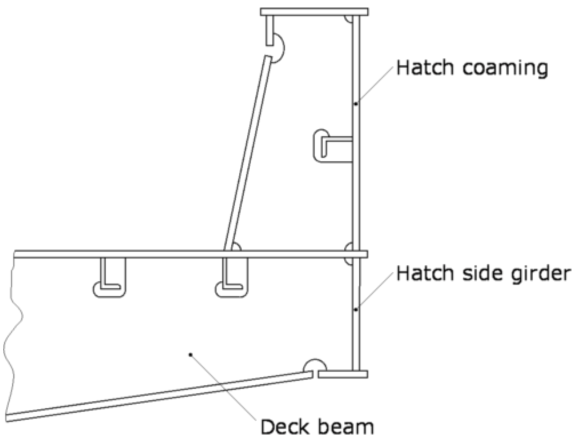

Fig.10 Example for a hatch side girder

5.4.5 Drainage arrangement at the coaming

If drain channels are provided inside the line of gasket by means of a gutter bar or vertical extension of the hatch side and end coaming, drain openings are to be provided at appropriate positions of the drain channels.

Drain openings in hatch coamings are to be arranged with sufficient distance to areas of stress concentration (e.g. hatch corners, transitions to crane posts).

Drain openings are to be arranged at the ends of drain channels and are to be provided with non-return valves to prevent ingress of water from outside. It is unacceptable to connect fire hoses to the drain openings for this purpose.

If a continuous outer steel contact between cover and ship structure is arranged, drainage from the space between the steel contact and the gasket is also to be provided for.

6 Closing arrangements

6.1 Securing devices

6.1.1 General

Securing devices between cover and coaming and at cross-joints are to be installed to provide weathertightness. Sufficient packing line pressure is to be maintained.

Securing devices must be appropriate to bridge displacements between cover and coaming due to hull deformations.

Securing devices are to be of reliable construction and effectively attached to the hatchway coamings, decks or covers. Individual securing devices on each cover are to have approximately the same stiffness characteristics.

Sufficient number of securing devices is to be provided at each side of the hatch cover considering the requirements of 3.4.2. This applies also to hatch covers consisting of several parts.

S21A (cont)

The materials of stoppers, securing devices and their weldings are to be to the satisfaction the individual class society. Specifications of the materials are to be shown in the drawings of the hatch covers.

6.1.2 Rod cleats

Where rod cleats are fitted, resilient washers or cushions are to be incorporated.

6.1.3 Hydraulic cleats

Where hydraulic cleating is adopted, a positive means is to be provided so that it remains mechanically locked in the closed position in the event of failure of the hydraulic system.

6.1.4 Cross-sectional area of the securing devices

The gross cross-sectional area in cm^2 of the securing devices is not to be less than:

$$A = 0{,}28 \cdot q \cdot s_{SD} \cdot k_l$$

where:
q = packing line pressure in N/mm, minimum 5 N/mm
s_{SD} = spacing between securing devices in m, not to be taken less than 2 m
$k_l = \left(\frac{235}{\sigma_F}\right)^e$, σ_F is the minimum yield strength of the material in N/mm^2, but is not to be taken greater than 0,7 · σ_m, where σ_m is the tensile strength of the material in N/mm^2.

e = 0,75 for $\sigma_F > 235$ N/mm²
= 1,00 for $\sigma_F \leq 235$ N/mm²

Rods or bolts are to have a gross diameter not less than 19 mm for hatchways exceeding 5 m² in area.

Securing devices of special design in which significant bending or shear stresses occur may be designed as anti-lifting devices according to 6.1.5. As load the packing line pressure q multiplied by the spacing between securing devices s_{SD} is to be applied.

6.1.5 Anti lifting devices

The securing devices of hatch covers, on which cargo is to be lashed, are to be designed for the lifting forces resulting from loads according to 2.4, refer Fig.11. Unsymmetrical loadings, which may occur in practice, are to be considered. Under these loadings the equivalent stress in the securing devices is not to exceed:

$$\sigma_V = \frac{150}{k_l} \text{ in N/mm}^2$$

Note:
The partial load cases given in Tab. 3 may not cover all unsymmetrical loadings, critical for hatch cover lifting.

Chapter 5.6 of IACS Rec. 14 should be referred to for the omission of anti lifting devices.

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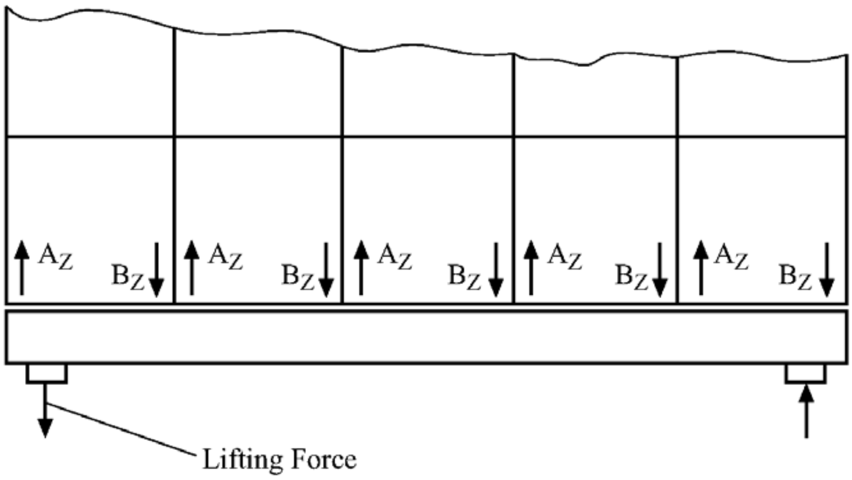

Fig. 11 Lifting forces at a hatch cover

6.2 Hatch cover supports, stoppers and supporting structures

6.2.1 Horizontal mass forces

For the design of hatch cover supports the horizontal mass forces $F_h = m \cdot a$ are to be calculated with the following accelerations:

$a_X = 0{,}2 \cdot g$ in longitudinal direction
$a_Y = 0{,}5 \cdot g$ in transverse direction
m = Sum of mass of cargo lashed on the hatch cover and mass of hatch cover

The accelerations in longitudinal direction and in transverse direction do not need to be considered as acting simultaneously.

6.2.2 Hatch cover supports

For the transmission of the support forces resulting from the load cases specified in 2 and of the horizontal mass forces specified in 6.2.1, supports are to be provided which are to be designed such that the nominal surface pressures in general do not exceed the following values:

$p_{n\max} = d \cdot p_n$ in N/mm²

$d = 3{,}75 - 0{,}015$ L

$d_{\max} = 3{,}0$

$d_{\min} = 1{,}0$ in general

$= 2{,}0$ for partial loading conditions, see 2.4.1

p_n = see Tab.9

For metallic supporting surfaces not subjected to relative displacements the nominal surface pressure applies:
$p_{n\max} = 3 \cdot p_n$ in N/mm²

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Note:
When the maker of vertical hatch cover support material can provide proof that the material is sufficient for the increased surface pressure, not only statically but under dynamic conditions including relative motion for adequate number of cycles, permissible nominal surface pressure may be relaxed at the discretion of the individual classification society. However, realistic long term distribution of spectra for vertical loads and relative horizontal motion should be assumed and agreed with the individual classification society.

Drawings of the supports must be submitted. In the drawings of supports the permitted maximum pressure given by the material manufacturer must be specified.

Tab. 9 Permissible nominal surface pressure p_n

Support material	p_n [N/mm²] when loaded by	
	Vertical force	Horizontal force (on stoppers)
Hull structural steel	25	40
Hardened steel	35	50
Lower friction materials	50	–

Where large relative displacements of the supporting surfaces are to be expected, the use of material having low wear and frictional properties is recommended.

The substructures of the supports must be of such a design, that a uniform pressure distribution is achieved.

Irrespective of the arrangement of stoppers, the supports must be able to transmit the following force P_h in the longitudinal and transverse direction:

$$P_h = \mu \cdot \frac{P_V}{\sqrt{d}}$$

where:

P_v = vertical supporting force
μ = frictional coefficient
= 0,5 in general

For non-metallic, low-friction support materials on steel, the friction coefficient may be reduced but not to be less than 0,35 and to the satisfaction of the individual class society.

Supports as well as the adjacent structures and substructures are to be designed such that the permissible stresses according to 3.1.1 are not exceeded.

For substructures and adjacent structures of supports subjected to horizontal forces P_h, fatigue strength is to be considered according to the individual classification society's rules.

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6.2.3 Hatch cover stoppers

Hatch covers shall be sufficiently secured against horizontal shifting. Stoppers are to be provided for hatch covers on which cargo is carried.

The greater of the loads resulting from 2.2 and 6.2.1 is to be applied for the dimensioning of the stoppers and their substructures.

The permissible stress in stoppers and their substructures, in the cover, and of the coamings is to be determined according to 3.1.1. In addition, the provisions in 6.2.2 are to be observed.

7 Corrosion addition and steel renewal

7.1 Corrosion addition for hatch covers and hatch coamings

The scantling requirements of the above sections imply the following general corrosion additions t_S:

Tab. 10 Corrosion additions t_S for hatch covers and hatch coamings

Application	Structure	t_S [mm]
Weather deck hatches of container ships, car carriers, paper carriers, passenger vessels	Hatch covers	1,0
	Hatch coamings	according to individual class society's rules
Weather deck hatches of all other ship types covered by this UR	Hatch covers in general	2,0
	Weather exposed plating and bottom plating of double skin hatch covers	1,5
	Internal structure of double skin hatch covers and closed box girders	1,0
	Hatch coamings not part of the longitudinal hull structure	1,5
	Hatch coamings part of the longitudinal hull structure	according to individual class society's rules
	Coaming stays and stiffeners	1,5

7.2 Steel renewal

Steel renewal is required where the gauged thickness is less than t_{net} + 0,5 mm for
- single skin hatch covers,
- the plating of double skin hatch covers, and
- coaming structures the corrosion additions t_S of which are provided in Tab. 10.

Where the gauged thickness is within the range t_{net} + 0,5 mm and t_{net} + 1,0 mm, coating (applied in accordance with the coating manufacturer's requirements) or annual gauging may be adopted as an alternative to steel renewal. Coating is to be maintained in GOOD condition, as defined in UR Z10.2.1.2.

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For the internal structure of double skin hatch covers, thickness gauging is required when hatch cover top or bottom plating renewal is to be carried out or when this is deemed necessary, at the discretion of the individual class society's surveyor, on the basis of the plating corrosion or deformation condition. In these cases, steel renewal for the internal structures is required where the gauged thickness is less than t_{net}.

For corrosion addition t_S = 1,0 mm the thickness for steel renewal is t_{net} and the thickness for coating or annual gauging is when gauged thickness is between t_{net} and t_{net} + 0,5 mm.

For coaming structures, the corrosion additions t_s of which are not provided in Tab. 10, steel renewal and coating or annual gauging are to be in accordance with the individual classification society's requirements.

End of Document

S21

(1997)
(Rev.1 2002)
(Rev.2 Nov 2002)
(Rev.3 April 2003)
(Rev.4 July 2004)
(Corr.1 Oct 2004)
(Rev.5 May 2010)

Evaluation of Scantlings of Hatch Covers and Hatch Coamings of Cargo Holds of Bulk Carriers, Ore Carriers and Combination Carriers

S21.1 Application and definitions

These requirements apply to all bulk carriers, ore carriers and combination carriers, as defined in UR Z11, and are for all cargo hatch covers and hatch forward and side coamings on exposed decks in position 1, as defined in ILLC.

Rev. 3 of this UR applies to ships contracted for construction on or after 1 January 2004.

This UR does not apply to CSR Bulk Carriers.

The strength requirements are applicable to hatch covers and hatch coamings of stiffened plate construction. The secondary stiffeners and primary supporting members of the hatch covers are to be continuous over the breadth and length of the hatch covers, as far as practical. When this is impractical, sniped end connections are not to be used and appropriate arrangements are to be adopted to provide sufficient load carrying capacity.

The spacing of primary supporting members parallel to the direction of secondary stiffeners is not to exceed 1/3 of the span of primary supporting members.

The secondary stiffeners of the hatch coamings are to be continuous over the breadth and length of the hatch coamings.

These requirements are in addition to the requirements of the ILLC.

The net minimum scantlings of hatch covers are to fulfil the strength criteria given in:

- S21.3.3, for plating,
- S21.3.4, for secondary stiffeners,
- S21.3.5 for primary supporting members,

the critical buckling stress check in S21.3.6 and the rigidity criteria given in S21.3.7, adopting the load model given in S21.2.

The net minimum scantlings of hatch coamings are to fulfil the strength criteria given in:

- S21.4.2, for plating,
- S21.4.3, for secondary stiffeners,
- S21.4.4, for coaming stays,

adopting the load model given in S21.4.1.

Note:

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

S21 (cont)

The net thicknesses, t_{net}, are the member thicknesses necessary to obtain the minimum net scantlings required by S21.3 and S21.4.

The required gross thicknesses are obtained by adding the corrosion additions, t_s, given in S21.6, to t_{net}.

Material for the hatch covers and coamings is to be steel according to the requirements for ship's hull.

S21.2 Hatch cover load model

The pressure p, in kN/m^2, on the hatch covers panels is given by:

For ships of 100 m in length and above

$$p = 34.3 + \frac{p_{FP} - 34.3}{0.25}\left(0.25 - \frac{x}{L}\right) \geq 34.3$$, for hatchways located at the freeboard deck

where:

p_{FP} = pressure at the forward perpendicular
= 49.1 + (L-100)a

a = 0.0726 for type B freeboard ships
0.356 for ships with reduced freeboard

L = Freeboard length, in m, as defined in Regulation 3 of Annex I to the 1966 Load Line Convention as modified by the Protocol of 1988, to be taken not greater than 340 m

x = distance, in m, of the mid length of the hatch cover under examination from the forward end of L

Where a position 1 hatchway is located at least one superstructure standard height higher than the freeboard deck, the pressure p may be 34.3kN/m^2.

For ships less than 100 m in length

$$p = 15.8 + \frac{L}{3}\left(1 - \frac{5}{3}\cdot\frac{x}{L}\right) - 3.6\frac{x}{L} \geq 0.195L + 14.9$$, for hatchways located at the freeboard deck

Where two or more panels are connected by hinges, each individual panel is to be considered separately.

S21.3 Hatch cover strength criteria

S21.3.1 Allowable stress checks

The normal and shear stresses σ and τ in the hatch cover structures are not to exceed the allowable values, σ_a and τ_a, in N/mm^2, given by:

$$\sigma_a = 0.8\sigma_F$$

S21 (cont)

$$\tau_a = 0.46\sigma_F$$

σ_F being the minimum upper yield stress, in N/mm^2, of the material.

The normal stress in compression of the attached flange of primary supporting members is not to exceed 0.8 times the critical buckling stress of the structure according to the buckling check as given in S21.3.6.

The stresses in hatch covers that are designed as a grillage of longitudinal and transverse primary supporting members are to be determined by a grillage or a FE analysis.

When a beam or a grillage analysis is used, the secondary stiffeners are not to be included in the attached flange area of the primary members.

When calculating the stresses σ and τ, the net scantlings are to be used.

S21.3.2 Effective cross-sectional area of panel flanges for primary supporting members

The effective flange area A_f, in cm^2, of the attached plating, to be considered for the yielding and buckling checks of primary supporting members, when calculated by means of a beam or grillage model, is obtained as the sum of the effective flange areas of each side of the girder web as appropriate:

$$A_F = \sum_{nf}\left(10 b_{ef} t\right)$$

where:

nf = 2 if attached plate flange extends on both sides of girder web
= 1 if attached plate flange extends on one side of girder web only

t = net thickness of considered attached plate, in mm

b_{ef} = effective breadth, in m, of attached plate flange on each side of girder web
= b_p, but not to be taken greater than 0.165ℓ

b_p = half distance, in m, between the considered primary supporting member and the adjacent one

ℓ = span, in m, of primary supporting members

S21.3.3 Local net plate thickness

The local net plate thickness t, in mm, of the hatch cover top plating is not to be less than:

$$t = F_p 15.8 s \sqrt{\frac{p}{0.95\sigma_F}}$$

but to be not less than 1% of the spacing of the stiffener or 6 mm if that be greater.

where:

S21
(cont)

F_p = factor for combined membrane and bending response
= 1.50 in general
= 1.90 σ/σ_a, for $\sigma/\sigma_a \geq 0.8$, for the attached plate flange of primary supporting members

s = stiffener spacing, in m

p = pressure, in kN/m^2, as defined in S21.2

σ = as defined in S21.3.5

σ_a = as defined in S21.3.1.

S21.3.4 Net scantlings of secondary stiffeners

The required minimum section modulus, Z, in cm^3, of secondary stiffeners of the hatch cover top plate, based on stiffener net member thickness, are given by:

$$Z = \frac{1000\ell^2 sp}{12\sigma_a}$$

where:

ℓ = secondary stiffener span, in m, to be taken as the spacing, in m, of primary supporting members or the distance between a primary supporting member and the edge support, as applicable. When brackets are fitted at both ends of all secondary stiffener spans, the secondary stiffener span may be reduced by an amount equal to 2/3 of the minimum brackets arm length, but not greater than 10% of the gross span, for each bracket.

s = secondary stiffener spacing, in m

p = pressure, in kN/m^2, as defined in S21.2

σ_a = as defined in S21.3.1.

The net section modulus of the secondary stiffeners is to be determined based on an attached plate width assumed equal to the stiffener spacing.

S21.3.5 Net scantlings of primary supporting members

The section modulus and web thickness of primary supporting members, based on member net thickness, are to be such that the normal stress σ in both flanges and the shear stress τ, in the web, do not exceed the allowable values σ_a and τ_a, respectively, defined in S21.3.1.

The breadth of the primary supporting member flange is to be not less than 40% of their depth for laterally unsupported spans greater than 3.0 m. Tripping brackets attached to the flange may be considered as a lateral support for primary supporting members.

The flange outstand is not to exceed 15 times the flange thickness.

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S21.3.6 Critical buckling stress check

S21.3.6.1 Hatch cover plating

The compressive stress σ in the hatch cover plate panels, induced by the bending of primary supporting members parallel to the direction of secondary stiffeners, is not to exceed 0.8 times the critical buckling stress σ_{C1}, to be evaluated as defined below:

$$\sigma_{C1} = \sigma_{E1} \qquad \text{when } \sigma_{E1} \le \frac{\sigma_F}{2}$$

$$= \sigma_F\left[1 - \sigma_F / \left(4\sigma_{E1}\right)\right] \qquad \text{when } \sigma_{E1} > \frac{\sigma_F}{2}$$

where:

σ_F = minimum upper yield stress, in N/mm^2, of the material

$$\sigma_{E1} = 3.6E\left(\frac{t}{1000s}\right)^2$$

E = modulus of elasticity, in N/mm^2
= 2.06×10^5 for steel

t = net thickness, in mm, of plate panel

s = spacing, in m, of secondary stiffeners

The mean compressive stress σ in each of the hatch cover plate panels, induced by the bending of primary supporting members perpendicular to the direction of secondary stiffeners, is not to exceed 0.8 times the critical buckling stress σ_{C2}, to be evaluated as defined below:

$$\sigma_{C2} = \sigma_{E2} \qquad \text{when } \sigma_{E2} \le \frac{\sigma_F}{2}$$

$$= \sigma_F\left[1 - \sigma_F / \left(4\sigma_{E2}\right)\right] \qquad \text{when } \sigma_{E2} > \frac{\sigma_F}{2}$$

where:

σ_F = minimum upper yield stress, in N/mm^2, of the material

$$\sigma_{E2} = 0.9mE\left(\frac{t}{1000s_s}\right)^2$$

$$m = c\left[1 + \left(\frac{s_s}{\ell_s}\right)^2\right]^2 \frac{2.1}{\psi + 1.1}$$

E = modulus of elasticity, in N/mm^2
= 2.06×10^5 for steel

S21
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t = net thickness, in mm, of plate panel

s_s = length, in m, of the shorter side of the plate panel

ℓ_s = length, in m, of the longer side of the plate panel

ψ = ratio between smallest and largest compressive stress

c = 1.3 when plating is stiffened by primary supporting members

c = 1.21 when plating is stiffened by secondary stiffeners of angle or T type

c = 1.1 when plating is stiffened by secondary stiffeners of bulb type

c = 1.05 when plating is stiffened by flat bar

The biaxial compressive stress in the hatch cover panels, when calculated by means of FEM shell element model, is to be in accordance with each classification society's rule as deemed equivalent to the above criteria.

S21.3.6.2 Hatch cover secondary stiffeners

The compressive stress σ in the top flange of secondary stiffeners, induced by the bending of primary supporting members parallel to the direction of secondary stiffeners, is not to exceed 0.8 times the critical buckling stress σ_{CS}, to be evaluated as defined below:

$$\sigma_{CS} = \sigma_{ES} \qquad \text{when } \sigma_{ES} \le \frac{\sigma_F}{2}$$

$$= \sigma_F \left[1 - \sigma_F / (4\sigma_{ES})\right] \qquad \text{when } \sigma_{ES} > \frac{\sigma_F}{2}$$

where:

σ_F = minimum upper yield stress, in N/mm^2, of the material

σ_{ES} = ideal elastic buckling stress, in N/mm^2, of the secondary stiffener,
= minimum between σ_{E3} and σ_{E4}

$$\sigma_{E3} = \frac{0.001 E I_a}{A \ell^2}$$

E = modulus of elasticity, in N/mm^2
= 2.06 x 10^5 for steel

I_a = moment of inertia, in cm^4, of the secondary stiffener, including a top flange equal to the spacing of secondary stiffeners

A = cross-sectional area, in cm^2, of the secondary stiffener, including a top flange equal to the spacing of secondary stiffeners

ℓ = span, in m, of the secondary stiffener

S21 (cont)

$$\sigma_{E4} = \frac{\pi^2 E I_w}{10^4 I_p \ell^2}\left(m^2 + \frac{K}{m^2}\right) + 0.385E\frac{I_t}{I_p}$$

$$K = \frac{C\ell^4}{\pi^4 E I_w}10^6$$

m = number of half waves, given by the following table:

	0 < K < 4	4 < K < 36	36 < K < 144	$(m-1)^2m^2 < K \le m^2(m+1)^2$
m	1	2	3	m

I_w = sectorial moment of inertia, in cm^6, of the secondary stiffener about its connection with the plating

$= \frac{h_w^3 t_w^3}{36}10^{-6}$ for flat bar secondary stiffeners

$= \frac{t_f b_f^3 h_w^2}{12}10^{-6}$ for "Tee" secondary stiffeners

$= \frac{b_f^3 h_w^2}{12(b_f + h_w)^2}\left[t_f\left(b_f^2 + 2b_f h_w + 4h_w^2\right) + 3t_w b_f h_w\right]10^{-6}$ for angles and bulb secondary stiffeners

I_p = polar moment of inertia, in cm^4, of the secondary stiffener about its connection with the plating

$= \frac{h_w^3 t_w}{3}10^{-4}$ for flat bar secondary stiffeners

$= \left(\frac{h_w^3 t_w}{3} + h_w^2 b_f t_f\right)10^{-4}$ for flanged secondary stiffeners

I_t = St Venant's moment of inertia, in cm^4, of the secondary stiffener without top flange

$= \frac{h_w t_w^3}{3}10^{-4}$ for flat bar secondary stiffeners

$= \frac{1}{3}\left[h_w t_w^3 + b_f t_f^3\left(1 - 0.63\frac{t_f}{b_f}\right)\right]10^{-4}$ for flanged secondary stiffeners

h_w, t_w = height and net thickness, in mm, of the secondary stiffener, respectively

b_f, t_f = width and net thickness, in mm, of the secondary stiffener bottom flange, respectively

s = spacing, in m, of secondary stiffeners

C = spring stiffness exerted by the hatch cover top plating $= \frac{k_p E t_p^3}{3s\left(1 + \frac{1.33 k_p h_w t_p^3}{1000 s t_w^3}\right)}10^{-3}$

S21 (cont)

$k_p = 1 - \eta_p$ to be taken not less than zero;
for flanged secondary sitffeners, k_p need not be taken less than 0.1

$$\eta_p = \frac{\sigma}{\sigma_{E1}}$$

σ = as defined in S21.3.5

σ_{E1} = as defined in S21.3.6.1

t_p = net thickness, in mm, of the hatch cover plate panel.

For flat bar secondary stiffeners and buckling stiffeners, the ratio h/t_W is to be not greater than $15k^{0.5}$, where:

h, t_W = height and net thickness of the stiffener, respectively

k = $235/\sigma_F$

σ_F = minimum upper yield stress, in N/mm^2, of the material.

S21.3.6.3 Web panels of hatch cover primary supporting members

This check is to be carried out for the web panels of primary supporting members, formed by web stiffeners or by the crossing with other primary supporting members, the face plate (or the bottom cover plate) or the attached top cover plate.

The shear stress τ in the hatch cover primary supporting members web panels is not to exceed 0.8 times the critical buckling stress τ_C , to be evaluated as defined below:

$$\tau_C = \tau_E \qquad \text{when } \tau_E \le \frac{\tau_F}{2}$$

$$= \tau_F \left[1 - \tau_F / (4\tau_E)\right] \qquad \text{when } \tau_E > \frac{\tau_F}{2}$$

where:

σ_F = minimum upper yield stress, in N/mm^2, of the material

$$\tau_F = \sigma_F / \sqrt{3}$$

$$\tau_E = 0.9 k_t E \left[\frac{t_{pr,n}}{1000d}\right]^2$$

E = modulus of elasticity, in N/mm^2
= 2.06×10^5 for steel

$t_{pr,n}$ = net thickness, in mm, of primary supporting member

k_t = $5.35 + 4.0 / (a / d)^2$

S21 (cont)

a = greater dimension, in m, of web panel of primary supporting member

d = smaller dimension, in m, of web panel of primary supporting member

For primary supporting members parallel to the direction of secondary stiffeners, the actual dimensions of the panels are to be considered.

For primary supporting members perpendicular to the direction of secondary stiffeners or for hatch covers built without secondary stiffeners, a presumed square panel of dimension d is to be taken for the determination of the stress τ_C. In such a case, the average shear stress τ between the values calculated at the ends of this panel is to be considered.

S21.3.7 Deflection limit and connections between hatch cover panels

Load bearing connections between the hatch cover panels are to be fitted with the purpose of restricting the relative vertical displacements.

The vertical deflection of primary supporting members is to be not more than 0.0056ℓ, where ℓ is the greatest span of primary supporting members.

S21.4 Hatch coamings and local details

S21.4.1 Load model

The pressure p_{coam}, in kN/m^2, on the No. 1 forward transverse hatch coaming is given by:

p_{coam} = 220, when a forecastle is fitted in accordance with UR S28
= 290 in the other cases

The pressure p_{coam}, in kN/m^2, on the other coamings is given by:

p_{coam} = 220

S21.4.2 Local net plate thickness

The local net plate thickness t, in mm, of the hatch coaming plating is given by:

$$t = 14.9s\sqrt{\frac{p_{coam}}{\sigma_{a,coam}}S_{coam}}$$

where:

s = secondary stiffener spacing, in m

p_{coam} = pressure, in kN/m^2, as defined in S21.4.1

S_{coam} = safety factor to be taken equal to 1.15

$\sigma_{a,coam}$ = 0.95 σ_F

The local net plate thickness is to be not less than 9.5 mm.

S21
(cont)

S21.4.3 Net scantlings of longitudinal and transverse secondary stiffeners

The required section modulus Z, in cm^3, of the longitudinal or transverse secondary stiffeners of the hatch coamings, based on net member thickness, is given by:

$$Z = \frac{1000 S_{coam} \ell^2 s p_{coam}}{m c_p \sigma_{a,coam}}$$

where:

m = 16 in general
= 12 for the end spans of stiffeners sniped at the coaming corners

S_{coam} = safety factor to be taken equal to 1.15

ℓ = span, in m, of secondary stiffeners

s = spacing, in m, of secondary stiffeners

p_{coam} = pressure in kN/m^2 as defined in S21.4.1

c_p = ratio of the plastic section modulus to the elastic section modulus of the secondary stiffeners with an attached plate breadth, in mm, equal to 40 t, where t is the plate net thickness
= 1.16 in the absence of more precise evaluation

$\sigma_{a,coam}$ = 0.95 σ_F

S21.4.4 Net scantlings of coaming stays

The required minimum section modulus, Z, in cm^3, and web thickness, t_w, in mm of coamings stays designed as beams with flange connected to the deck or sniped and fitted with a bracket (see Figures 1 and 2) at their connection with the deck, based on member net thickness,are given by:

$$Z = \frac{1000 H_C^2 s p_{coam}}{2 \sigma_{a,coam}}$$

$$t_w = \frac{1000 H_C s p_{coam}}{h \tau_{a,coam}}$$

H_C = stay height, in m

s = stay spacing, in m

h = stay depth, in mm, at the connection with the deck

p_{coam} = pressure, in kN/m^2, as defined in S21.4.1

$\sigma_{a,coam}$ = 0.95 σ_F

$\tau_{a,coam}$ = 0.5 σ_F

S21 (cont)

For calculating the section modulus of coaming stays, their face plate area is to be taken into account only when it is welded with full penetration welds to the deck plating and adequate underdeck structure is fitted to support the stresses transmitted by it.

For other designs of coaming stays, such as, for examples, those shown in Figures 3 and 4, the stress levels in S21.3.1 apply and are to be checked at the highest stressed locations.

S21.4.5 Local details

The design of local details is to comply with the Society requirement for the purpose of transferring the pressures on the hatch covers to the hatch coamings and, through them, to the deck structures below. Hatch coamings and supporting structures are to be adequately stiffened to accommodate the loading from hatch covers, in longitudinal, transverse and vertical directions.

Underdeck structures are to be checked against the load transmitted by the stays, adopting the same allowable stresses specified in S21.4.4.

Unless otherwise stated, weld connections and materials are to be dimensioned and selected in accordance with the Society requirements.

Double continuous welding is to be adopted for the connections of stay webs with deck plating and the weld throat is to be not less than 0.44 t_W, where t_W is the gross thickness of the stay web.

Toes of stay webs are to be connected to the deck plating with deep penetration double bevel welds extending over a distance not less than 15% of the stay width.

S21.5 Closing arrangements

S21.5.1 Securing devices

The strength of securing devices is to comply with the following requirements:

Panel hatch covers are to be secured by appropriate devices (bolts, wedges or similar) suitably spaced alongside the coamings and between cover elements.

Arrangement and spacing are to be determined with due attention to the effectiveness for weather-tightness, depending upon the type and the size of the hatch cover, as well as on the stiffness of the cover edges between the securing devices.

The net sectional area of each securing device is not to be less than:

$A = 1.4\, a / f\ (cm^2)$

where:

a = spacing in m of securing devices, not being taken less than 2 m

$f = (\sigma_Y / 235)^e$

σ_Y = specified minimum upper yield stress in N/mm^2 of the steel used for fabrication, not to be taken greater than 70% of the ultimate tensile strength.

S21
(cont)

e = 0.75 for $\sigma_Y > 235$
= 1.0 for $\sigma_Y \leq 235$

Rods or bolts are to have a net diameter not less than 19 mm for hatchways exceeding 5 m^2 in area.

Between cover and coaming and at cross-joints, a packing line pressure sufficient to obtain weathertightness is to be maintained by the securing devices.

For packing line pressures exceeding 5 N/mm, the cross section area is to be increased in direct proportion. The packing line pressure is to be specified.

The cover edge stiffness is to be sufficient to maintain adequate sealing pressure between securing devices. The moment of inertia, I, of edge elements is not to be less than:

I = $6pa^4$ (cm^4)

p = packing line pressure in N/mm, minimum 5 N/mm.

a = spacing in m of securing devices.

Securing devices are to be of reliable construction and securely attached to the hatchway coamings, decks or covers. Individual securing devices on each cover are to have approximately the same stiffness characteristics.

Where rod cleats are fitted, resilient washers or cushions are to be incorporated.

Where hydraulic cleating is adopted, a positive means is to be provided to ensure that it remains mechanically locked in the closed position in the event of failure of the hydraulic system.

S21.5.2 Stoppers

Hatch covers are to be effectively secured, by means of stoppers, against the transverse forces arising from a pressure of 175 kN/m^2.

With the exclusion of No.1 hatch cover, hatch covers are to be effectively secured, by means of stoppers, against the longitudinal forces acting on the forward end arising from a pressure of 175 kN/m^2.

No. 1 hatch cover is to be effectively secured, by means of stoppers, against the longitudinal forces acting on the forward end arising from a pressure of 230 kN/m^2.

This pressure may be reduced to 175 kN/m^2 when a forecastle is fitted in accordance with UR S28.

The equivalent stress:

i. in stoppers and their supporting structures, and

ii. calculated in the throat of the stopper welds

is not to exceed the allowable value of 0.8 σ_Y.

S21
(cont)

S21.5.3 Materials and welding

Stoppers or securing devices are to be manufactured of materials, including welding electrodes, meeting relevant IACS requirements.

S21.6 Corrosion addition and steel renewal

S21.6.1 Hatch covers

For all the structure (plating and secondary stiffeners) of single skin hatch covers, the corrosion addition t_s is to be 2.0 mm.

For double skin hatch covers, the corrosion addition is to be:

- 2.0 mm for the top and bottom plating
- 1.5 mm for the internal structures.

For single skin hatch covers and for the plating of double skin hatch covers, steel renewal is required where the gauged thickness is less than t_{net} + 0.5 mm. Where the gauged thickness is within the range t_{net} + 0.5 mm and t_{net} + 1.0 mm, coating (applied in accordance with the coating manufacturer's requirements) or annual gauging may be adopted as an alternative to steel renewal. Coating is to be maintained in GOOD condition, as defined in UR Z10.2.1.2.

For the internal structure of double skin hatch covers, thickness gauging is required when plating renewal is to be carried out or when this is deemed necessary, at the discretion of the Society Surveyor, on the basis of the plating corrosion or deformation condition. In these cases, steel renewal for the internal structures is required where the gauged thickness is less than t_{net}.

S21.6.2 Hatch coamings

For the structure of hatch coamings and coaming stays, the corrosion addition t_s is to be 1.5 mm.

Steel renewal is required where the gauged thickness is less than t_{net} + 0.5 mm. Where the gauged thickness is within the range t_{net} + 0.5 mm and t_{net} + 1.0 mm, coating (applied in accordance with the coating manufacturer's requirements) or annual gauging may be adopted as an alternative to steel renewal. Coating is to be maintained in GOOD condition, as defined in UR Z10.2.1.2.

S21
(cont)

Figure 1

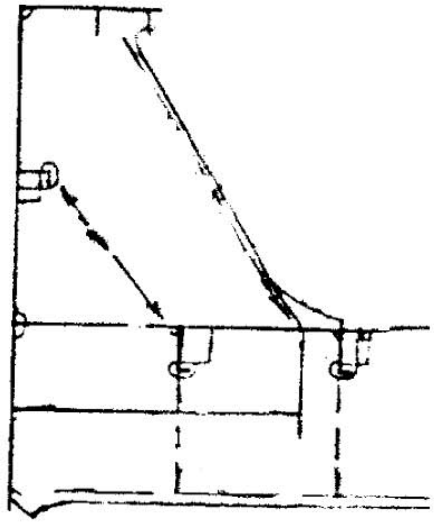


Figure 2

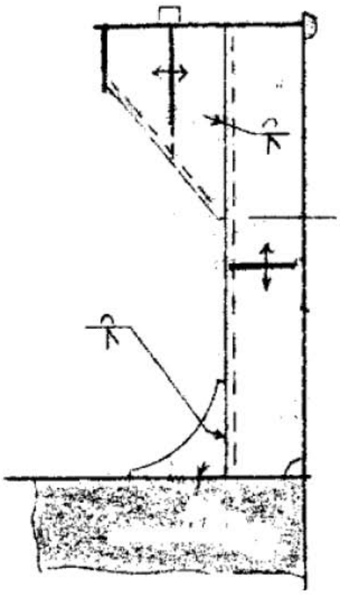


Figure 3

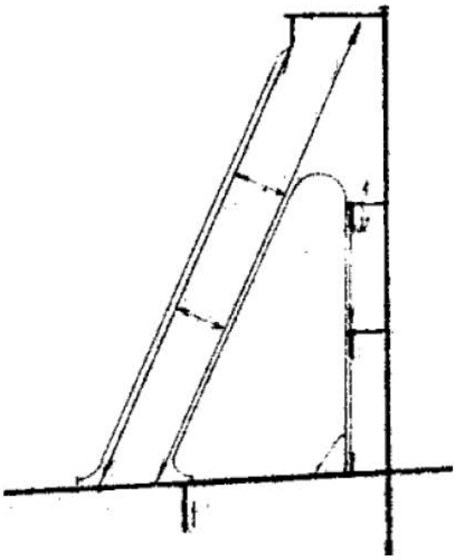
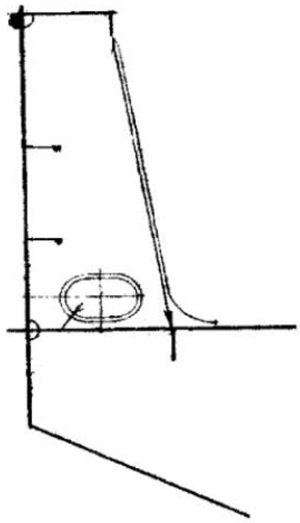


Figure 4



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