

Requirements concerning STRENGTH OF SHIPS

CONTENTS

S1	Requirements for Loading Conditions, Loading Manuals and Loading Instruments	Rev.7 May 2010
S1A	Additional Requirements for Loading Conditions, Loading Manuals and Loading Instruments for Bulk Carriers, Ore Carriers and Combination Carriers	Rev.6 May 2010
S2	Definition of Ship's Length L and of Block Coefficient C_b	Rev.2 June 2019
S3	Strength of End Bulkheads of Superstructures and Deckhouses	Rev.2 June 2023
S4	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	Rev.4 Apr 2017
S5	Calculation of Midship Section Moduli for Conventional Ship for Ship's Scantlings	Corr.1 June 2019
S6	Use of Steel Grades for Various Hull Members - Ships of 90m in Length and Above	Corr.2 Nov 2021
S7	Minimum Longitudinal Strength Standards†	Rev.4 May 2010
S8	Bow Doors and Inner Doors	Rev.4 Dec 2010
S9	Side Shell Doors and Stern Doors	Rev.6 Dec 2010
S10	Rudders, Sole Pieces and Rudder Horns	Rev.7 Corr.2 May 2024
S11	Longitudinal Strength Standard	Rev.10 Dec 2020
S11A	Longitudinal Strength Standard for Container Ships	June 2015
S12	Side Structures in Single Side Skin Bulk Carriers	Rev.5 May 2010
S13	Strength of Bottom Forward in Oil Tankers	Corr.1 May 2014

S14	Testing Procedures of Watertight Compartments	Rev.7 Dec 2022
S15	Side Shell Doors and Stern Doors - Retrospective Application of UR-S9 to Existing Ro-Ro Passenger Ships	Rev.1 Nov 2003
S16	Bow Doors and Inner Doors - Retrospective Application of UR-S8, as Amended 1995, to Existing Ro-Ro Passenger Ships	Corr.1 Aug 2004
S17	Longitudinal Strength of Hull Girder in Flooded Condition for Non-CSR Bulk Carriers	Rev.10 Mar 2019
S18	Evaluation of Scantlings of Corrugated Transverse Watertight Bulkheads in Non-CSR Bulk Carriers Considering Hold Flooding	Rev.10 Mar 2019
S19	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	Rev.5 July 2004
S20	Evaluation of Allowable Hold Loading for Non-CSR Bulk Carriers Considering Hold Flooding	Rev.6 Apr 2014
S21	Evaluation of Scantlings of Hatch Covers and Hatch Coamings of Cargo Holds of Bulk Carriers, Ore Carriers and Combination Carriers	Rev.6 Jan 2023
S21A	Evaluation of Scantlings of Hatch Covers and Hatch Coamings and Closing Arrangements of Cargo Holds of Ships	Del Jan 2023
S22	Evaluation of Allowable Hold Loading of Cargo Hold No.1 with Cargo Hold No.1 Flooded, for Existing Bulk Carriers	Rev.3 July 2004
S23	Implementation of IACS Unified Requirements S19 and S22 for Existing Single Side Skin Bulk Carriers	Rev.4 Aug 2007
S24	Deleted Jan 2004	
S25	Deleted May 2010	
S26	Strength and Securing of Small Hatches on the Exposed Fore Deck	Rev.5 May 2023

S27	Strength Requirements for Fore Deck Fittings and Equipment	Rev.6 Jun 2013
S28	Requirements for the Fitting of a Forecastle for Bulk Carriers, Ore Carriers and Combination Carriers	Rev.3 May 2010
S29	Unassigned	
S30	Cargo Hatch Cover Securing Arrangements for Bulk Carriers not Built in Accordance with UR S21 (Rev.3)	Corr.1 Mar 2019
S31	Renewal Criteria for Side Shell Frames and Brackets in Single Side Skin Bulk Carriers and Single Side Skin OBO Carriers not Built in Accordance with UR S12 Rev.1 or Subsequent Revisions	Rev.4 Apr 2007
S32	Deleted May 2010	
S33	Requirements for Use of Extremely Thick Steel Plates in Container Ships	Rev.3 Feb 2020
S34	Functional Requirements on Load Cases for Strength Assessment of Container Ships by Finite Element Analysis	May 2015
S35	Buckling Strength Assessment of Ship Structural Elements	Corr.1 Sep 2024

S1 Requirements for Loading Conditions, Loading Manuals and Loading Instruments

(1971)
(Rev.1
1981)
(Rev.2
1983)
(Rev.3
1995)
(Rev.4
1997)
(Rev.5
June
2001)
(Rev.6
July
2004)
(Rev.7
May
2010)

IACS considers that this Requirement satisfies Regulation 10(1) of the International Convention on Load Lines, 1966.

S1.1 General

S1.1.1 Application

These requirements* apply to all classed sea-going ships of 65m in length and above which are contracted for construction on or after 1st July 1998, and contain minimum requirements for loading guidance information.

For CSR Bulk Carriers and Oil Tankers, these requirements apply in addition to those of the Common Structural Rules.

S1.1.2 Definitions

Loading Manual:

A Loading Manual is a document which describes:

- the loading conditions on which the design of the ship has been based, including permissible limits of still water bending moment and shear force
- the results of the calculations of still water bending moments, shear forces and where applicable, limitations due to torsional and lateral loads
- the allowable local loading for the structure (hatch covers, decks, double bottom, etc.)

Notes

- * For ships which were contracted for construction before 1st July 1998, the relevant prior revisions of this Unified Requirement as well as Members' reservations to those revisions of this Unified Requirement apply. Certain additional requirements of Unified Requirement S1A also apply to bulk carriers, ore carriers and combination carriers (see UR Z11), of 150m length and above.
- * 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.

S1
(cont)**Loading Instrument**

A loading instrument is an instrument, which is either analogue or digital, by means of which it can be easily and quickly ascertained that, at specified read-out points, the still water bending moments, shear forces, and the still water torsional moments and lateral loads, where applicable, in any load or ballast condition will not exceed the specified permissible values.

An operational manual is always to be provided for the loading instrument.

Single point loading instruments are not acceptable.

Category I Ships

- Ships with large deck openings where combined stresses due to vertical and horizontal hull girder bending and torsional and lateral loads have to be considered;
- Ships liable to carry non-homogeneous loadings, where the cargo and/or ballast may be unevenly distributed. Ships less than 120 metres in length, when their design takes into account uneven distribution of cargo or ballast, belong to Category II;
- Chemical tankers and gas carriers.

Category II Ships

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

S1.1.3 Annual and Special Survey

At each Annual and Special Survey, it is to be checked that the approved loading guidance information is available on board.

The loading instrument is to be checked for accuracy at regular intervals by the ship's Master by applying test loading conditions.

At each Special Survey this checking is to be done in the presence of the Surveyor.

S1.2 Loading Conditions, Loading Manuals and Loading Instruments**S1.2.1 General**

An approved loading manual is to be supplied for all ships except those of Category II with length less than 90m in which the deadweight does not exceed 30% of the displacement at the summer loadline draft.

In addition, an approved loading instrument is to be supplied for all ships of Category I of 100m in length and above.

S1.2.2 Conditions of Approval of Loading Manuals

The approved Loading Manual is to be based on the final data of the ship. The Manual is to include the design loading and ballast conditions upon which the approval of the hull scantlings is based.

S1
(cont)

Annex 1 contains, as guidance only, a list of the loading conditions which normally should be included in the Loading Manual.

In case of modifications resulting in changes to the main data of the ship, a new approved Loading Manual is to be issued.

The Loading Manual must be prepared in a language understood by the users. If this language is not English, a translation into English is to be included.

S1.2.3 Condition of Approval of Loading Instruments

The loading instrument is subject to approval, which is to include:

- verification of type approval, if any
- verification that the final data of the ship has been used
- acceptance of number and position of read-out points
- acceptance of relevant limits for all read-out points
- checking of proper installation and operation of the instrument on board, in accordance with agreed test conditions, and that a copy of the operation manual is available.

Recommendations on the approval of Loading instruments are given in the IACS document "Recommendations on loading instruments".

In case of modifications implying changes in the main data of the ship, the loading instrument is to be modified accordingly and approved.

The operation manual and the instrument output must be prepared in a language understood by the users. If this language is not English, a translation into English is to be included.

The operation of the loading instrument is to be verified upon installation. It is to be checked that the agreed test conditions and the operation manual for the instrument is available on board.

S1
(cont)**ANNEX 1 TO REQUIREMENT S1****GUIDANCE ON CONDITIONS**

1. The Loading Manual should contain the design loading and ballast conditions, subdivided into departure and arrival conditions, and ballast exchange at sea conditions, where applicable, upon which the approval of the hull scantlings is based.

2. In particular the following loading conditions should be included:

2.1 Cargo Ships, Container Ships, Roll-on/Roll-off and Refrigerated Carriers, Ore Carriers and Bulk 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
- Short voyage or harbour conditions, where applicable
- Docking condition afloat
- Loading and unloading transitory conditions, where applicable

2.2 Oil Tankers:

- Homogeneous loading conditions (excluding dry and clean ballast tanks) and ballast or part-loaded conditions for both departure and arrival
- Any specified non-uniform distribution of loading
- Mid-voyage conditions relating to tank cleaning or other operations where these differ significantly from the ballast conditions
- Docking condition afloat
- Loading and unloading transitory conditions

2.3 Chemical Tankers:

- Conditions as specified for oil tankers
- Conditions for high density or heated cargo and segregated cargo where these are included in the approved cargo list

2.4 Liquefied Gas Carriers:

- Homogeneous loading conditions for all approved cargoes for both arrival and departure
- Ballast conditions for both arrival and departure
- Cargo condition where one or more tanks are empty or partially filled or where more than one type of cargo having significantly different densities is carried, for both arrival and departure
- Harbour condition for which an increased vapour pressure has been approved
- Docking condition afloat

2.5 Combination Carriers:

- Conditions as specified in 2.1 and 2.2, above.

End of Document

S1A

(1997)
(Rev.1
April
1998)
(Rev.2
May
1998)
(Rev.3
Sept
2000)
(Rev.4
Nov
2001)
(Rev.5
July
2004)
(Rev.6
May
2010)

Additional Requirements for Loading Conditions, Loading Manuals and Loading Instruments for Bulk Carriers, Ore Carriers and Combination Carriers

S1A.1 Application

Bulk Carriers, Ore Carriers and Combination Carriers (see UR Z11) of 150 m length and above, which are contracted for construction before 1st July 1998 are to be provided with an approved loading instrument of a type to the satisfaction of the Society not later than their entry into service or 1st January 1999, whichever occurs later.

In addition, Bulk Carriers of 150 m length and above where one or more cargo holds are bounded by the side shell only, which were contracted for construction before 1st July 1998, are to be provided, with an approved loading manual with typical loading sequences where the vessel is loaded from commencement of cargo loading to reaching full deadweight capacity for homogeneous conditions, relevant part load conditions and alternate conditions where applicable. Typical unloading sequences for these conditions shall also be included. Annex 1 contains, as guidance only, an example of a Loading Sequence Summary Form. Annex 2 contains guidance for loading and unloading sequences for existing bulk carriers.

Bulk Carriers, Ore Carriers and Combination Carriers of 150 m length and above, which are contracted for construction on or after 1st July 1998, are to be provided with an approved Loading Manual and approved computer-based Loading Instrument, in accordance with S1A.2, S1A.3 and S1A.4. Annex 3 contains guidance for loading and unloading sequences for new bulk carriers.

This UR does not apply to CSR Bulk Carriers.

Notes:

1. The latest date for implementation for requirements in S1A.2.1(f) is 1st July 1999.
2. The latest date for implementation for requirements in S1A.2.2(b) is 1st July 1999.
3. The latest date for implementation for requirements in S1A.4(d) is 1st July 1999.
4. Changes introduced in Rev.3 are to be uniformly implemented by IACS Members and Associates from 1 July 2001.
5. 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.

S1A
(cont)**S1A.2 Definitions****S1A.2.1 Loading Manual**

Loading Manual is a document which describes:

- a) the loading conditions on which the design of the ship has been based, including permissible limits of still water bending moments and shear forces;
- b) the results of the calculations of still water bending moments, shear forces and where applicable, limitations due to torsional loads;
- c) for bulk carriers, envelope results and permissible limits of still water bending moments and shear forces in the hold flooded condition according to S17 as applicable;
- d) the cargo hold(s) or combination of cargo holds that might be empty at full draught. If no cargo hold is allowed to be empty at full draught, this is to be clearly stated in the loading manual;
- e) maximum allowable and minimum required mass of cargo and double bottom contents of each hold as a function of the draught at mid-hold position;
- f) maximum allowable and minimum required mass of cargo and double bottom contents of any two adjacent holds as a function of the mean draught in way of these holds. This mean draught may be calculated by averaging the draught of the two mid-hold positions;
- g) maximum allowable tank top loading together with specification of the nature of the cargo for cargoes other than bulk cargoes;
- h) maximum allowable load on deck and hatch covers. If the vessel is not approved to carry load on deck or hatch covers, this is to be clearly stated in the loading manual;
- i) the maximum rate of ballast change together with the advice that a load plan is to be agreed with the terminal on the basis of the achievable rates of change of ballast.

S1A.2.2 Loading Instrument

A loading instrument is an approved digital system as defined in S1. In addition to the requirements in S1, it shall ascertain as applicable that:

- a) the mass of cargo and double bottom contents in way of each hold as a function of the draught at mid-hold position;
- b) the mass of cargo and double bottom contents of any two adjacent holds as a function of the mean draught in way of these holds;
- c) the still water bending moment and shear forces in the hold flooded conditions according to S17;

are within permissible values.

S1A
(cont)**S1A.3 Conditions of Approval of Loading Manuals**

In addition to the requirements given in S1.2.2, the following conditions, subdivided into departure and arrival conditions as appropriate, are to be included in the Loading Manual:

- a) alternate light and heavy cargo loading conditions at maximum draught, where applicable;
- b) homogeneous light and heavy cargo loading conditions at maximum draught;
- c) ballast conditions. For vessels having ballast holds adjacent to topside wing, hopper and double bottom tanks, it shall be strengthwise acceptable that the ballast holds are filled when the topside wing, hopper and double bottom tanks are empty;
- d) short voyage conditions where the vessel is to be loaded to maximum draught but with limited amount of bunkers;
- e) multiple port loading / unloading conditions;
- f) deck cargo conditions, where applicable;
- g) typical loading sequences where the vessel is loaded from commencement of cargo loading to reaching full deadweight capacity, for homogeneous conditions, relevant part load conditions and alternate conditions where applicable. Typical unloading sequences for these conditions shall also be included. The typical loading / unloading sequences shall also be developed to not exceed applicable strength limitations. The typical loading sequences shall also be developed paying due attention to loading rate and the deballasting capability. Annex 1 contains, as guidance only, an example of a Loading Sequence Summary Form;
- h) typical sequences for change of ballast at sea, where applicable.

S1A.4 Condition of Approval of Loading Instruments

The loading instrument is subject to approval. In addition to the requirements given in S1.2.3, the approval is to include as applicable:

- a) acceptance of hull girder bending moment limits for all read-out points;
- b) acceptance of hull girder shear force limits for all read-out points;
- c) acceptance of limits for mass of cargo and double bottom contents of each hold as a function of draught;
- d) acceptance of limits for mass of cargo and double bottom contents in any two adjacent holds as a function of draught.

ANNEX 1

GUIDANCE ON TYPICAL LOADING SEQUENCE SUMMARY FORM

[illegible]

S1A
(cont)**ANNEX 2****EXISTING BULK CARRIERS
GUIDANCE FOR LOADING / UNLOADING SEQUENCES**

1. UR S1A.1 requires that bulk carriers of 150 m length and above, where one or more cargo holds are bounded by the side shell only, which were contracted for construction before 1st July 1998, are to be provided, with an approved loading manual with typical loading sequences where the ship is loaded from commencement of cargo loading to reaching full deadweight capacity, for homogeneous conditions, relevant part loaded conditions and alternate conditions where applicable. Typical unloading sequences shall be included.
2. This requirement will necessitate shipowners and operators to prepare and submit for approval typical loading and unloading sequences.
3. The minimum acceptable number of typical sequences is:
 - one homogeneous full load condition,
 - one part load condition where relevant, such as block loading or two port unloading,
 - one full load alternate hold condition, if the ship is approved for alternate hold loading.
4. The shipowner / operator should select actual loading / unloading sequences, where possible, which may be port specific or typical.
5. The sequence may be prepared using the onboard loading instrument. The selected loading conditions should be built up step by step from commencement of cargo loading to reaching full deadweight capacity. Each time the loading equipment changes position to a new hold defines a step. Each step is to be documented and submitted to the class society. The printout from the loading instrument is generally acceptable. This allows the actual bending moments and shear forces to be verified and prevent the permissible values being exceeded. In addition, the local strength of each hold may need to be considered during the loading.
6. For each loading condition a summary of all steps is to be included. This summary is to highlight the essential information for each step such as:
 - How much cargo is filled in each hold during the different steps,
 - How much ballast is discharged from each ballast tank during the different steps,
 - The maximum still water bending moment and shear at the end of each step,
 - The ship's trim and draught at the end of each step.

Blank summary sheets are attached for reference for typical 5, 7 and 9 hold bulk carriers.
7. The approved typical loading / unloading sequences, may be included in the approved loading manual or take the form of an addendum prepared for purposes of complying with class society requirements. A copy of the approved typical loading / unloading sequences is to be placed onboard the ship.

S1A
(cont)**ANNEX 3****NEW BULK CARRIERS
GUIDANCE FOR LOADING / UNLOADING SEQUENCES**

1. UR S1A.1 requires that Bulk Carriers, Ore Carriers and Combination Carriers of 150 m length and above, which are contracted for construction on or after 1st July 1998, are to be provided with an approved loading manual with typical loading sequences where the ship is loaded from commencement of cargo loading to reaching full deadweight capacity, for homogeneous conditions, relevant part loaded conditions and alternate conditions where applicable. The typical unloading sequences shall be developed paying due attention to the loading rate, the deballasting capacity and the applicable strength limitations.
2. The shipbuilder will be required to prepare and submit for approval typical loading and unloading sequences.
3. The typical loading sequences as relevant should include:
 - alternate light and heavy cargo load condition,
 - homogeneous light and heavy cargo load condition,
 - short voyage condition where the ship is loaded to maximum draught but with limited bunkers,
 - multiple port loading / unloading condition,
 - deck cargo condition,
 - block loading.
4. The loading / unloading sequences may be port specific or typical.
5. The sequence is to be built up step by step from commencement of cargo loading to reaching full deadweight capacity. Each time the loading equipment changes position to a new hold defines a step. Each step is to be documented and submitted to the class society. In addition to longitudinal strength, the local strength of each hold is to be considered.
6. For each loading condition a summary of all steps is to be included. This summary is to highlight the essential information for each step such as:
 - How much cargo is filled in each hold during the different steps,
 - How much ballast is discharged from each ballast tank during the different steps,
 - The maximum still water bending moment and shear at the end of each step,
 - The ship's trim and draught at the end of each step.

End of Document

S2 Definition of Ship's Length L and of Block Coefficient C_b

(1973)
(Rev.1
May 2010)
(Rev.2
June 2019)

S2.0 Application

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

S2.1 Rule length L

The Rule length L is the distance, in metres, measured on the waterline at the scantling draught from the fore side of the stem to the after side of the rudder post, or the centre of the rudder stock if there is no rudder post. L is not to be less than 96%, and need not be greater than 97%, of the extreme length on the waterline at the scantling draught.

In ships without rudder stock (e.g. ships fitted with azimuth thrusters), the Rule length L is to be taken equal to 97% of the extreme length on the waterline at the scantling draught.

In ships with unusual stern and bow arrangement the Rule length L will be specially considered.

S2.2 Block coefficient C_b

The block coefficient C_b is the moulded block coefficient corresponding to the waterline at the scantling draught T_s , based on rule length L and moulded breadth B :

$$C_b = \frac{\text{Moulded displacement } [m^3] \text{ at scantling draught } T_s}{LBT_s}$$

Where:

B : Greatest moulded breadth, in m, measured amidships at the scantling draught, T_s .

T_s : Scantling draught, in m, at which the strength requirements for the scantlings of the ship are met and represents the full load condition. The scantling draught is to be not less than that corresponding to the assigned freeboard.

End of Document

Note:

1. Changes introduced in Rev.2 are to be uniformly implemented by IACS Members from 1 July 2020.

S3

Strength of End Bulkheads of Superstructures and Deckhouses

(1973)
(Rev.1
May 2010)
(Rev.2
June 2023)

S3.1 Scope

The following proposal applies to bulkheads forming the only protection for openings as per Regulation 18 of LLC 1966 and for accommodations. These requirements define minimum scantlings based upon local lateral loads and it may be required that they be increased in individual cases. Scantlings of tiers not specifically mentioned in this proposal are left to the discretion of individual Classification Societies.

This UR does not apply to CSR Bulk Carriers.

Note:

1. Changes introduced in Rev.2 are to be uniformly implemented by IACS Members for ships contracted for construction on or after 1 July 2024.
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.

S3

(cont)

S3.2 Design pressure head

$$p = \frac{a}{100}(bf - y)c$$

where

p = design pressure in N/mm² (MPa)

$$a = 2.0 + \frac{L_1}{120} \text{ for lowest tier of unprotected fronts}$$

The lowest tier is normally that tier which is directly situated above the uppermost continuous deck to which the rule depth D is to be measured. However, where the freeboard is excessive, it may be left to each individual Classification Society to define this tier as an upper tier. It is recommended that 'excessive freeboard' is that which exceeds the minimum tabular freeboard by more than one standard superstructure height.

$$a = 1.0 + \frac{L_1}{120} \quad \text{for 2nd tier of unprotected fronts}$$

$$a = 0.5 + \frac{L_1}{150} \quad \text{for 3rd tier of unprotected fronts and} \\ \text{for sides and protected fronts}$$

$$a = 0.7 + \frac{L_1}{1000} - 0.8 \frac{x}{L} \quad \text{for aft ends aft of amidships}$$

$$a = 0.5 + \frac{L_1}{1000} - 0.4 \frac{x}{L} \quad \text{for aft ends forward of amidships}$$

L, L_1 = length of ships in metres, L_1 need not be taken greater than 300 m

$$b = 1.0 + \left(\frac{x/L - 0.45}{C_b + 0.2} \right)^2 \quad \text{for } x/L \leq 0.45$$

$$b = 1.0 + 1.5 \left(\frac{x/L - 0.45}{C_b + 0.2} \right)^2 \quad \text{for } x/L > 0.45$$

C_b = block coefficient, $0.60 < C_b < 0.80$
when determining aft ends forward of amidships, C_b need not be taken less than 0.80

x = distance in metres between bulkhead considered and AP
When determining sides of a deckhouse, the deckhouse is to be subdivided into parts of approximately equal length, not exceeding $0.15L$ each and x is to be taken as the distance between AP and the centre of each part considered.

S3 (cont)

$$f = \frac{L}{10} e^{-L/300} - \left[1 - \left(\frac{L}{150} \right)^2 \right] \quad \text{for } L < 150 \text{ m}$$

$$f = \frac{L}{10} e^{-L/300} \quad \text{for } 150 \text{ m} < L < 300 \text{ m}$$

$$f = 11.03 \quad \text{for } L > 300 \text{ m}$$

y = vertical distance in metres from summer waterline to midpoint of stiffener span

$$c = \left(0.3 + 0.7 \frac{b'}{B'} \right)$$

b' = breadth of deckhouse at the position considered

B' = actual maximum breadth of ship on the exposed weather deck at the position considered

For exposed parts of machinery casings c is not to be taken less than 1.0

The design pressure p is not to be taken less than the minimum values given in Table 1.

Table 1

$L(\text{m})$	$p \text{ (N/mm}^2 \text{ or MPa)}$	
	Lowest tier of unprotected fronts	Elsewhere
$L \leq 50$	0.03	0.015
$50 < L < 250$	$0.025 + 10^{-4}L$	$0.0125 + 0.5 \times 10^{-4}L$
$L \geq 250$	0.05	0.025

S3.3 Stiffener modulus

$$W = 350sl^2p$$

where

W = stiffener modulus (cm^3)

s = spacing of stiffeners (m), measured along the plating

l = unsupported span (m), which is to be taken as the 'tween deck height $l_{\min} = 2.0 \text{ m}$

p = pressure in N/mm^2 (MPa) as defined above.

S3

(cont)

The section modulus of house side stiffeners need not be greater than that of side frames on the deck situated directly below, taking account of spacing and span.

These requirements assume the webs of lower tier stiffeners to be efficiently welded to the decks.

Scantlings for other types of end connections may be specially considered.

S3.4 Thickness of plating

$$t = 30s\sqrt{p}$$

where

t = thickness of plating (mm), not less than the minimum thickness as follows:

$$t_{\min} = \begin{array}{l} 5.0 + L_1/100 \text{ for lowest tier} \\ 4.0 + L_1/100 \text{ for upper tiers, but not less than 5.0 mm} \end{array}$$

For ships with $L_1 < 65\text{m}$, the minimum thickness of plating should be as follows:

$$t_{\min} = \begin{array}{l} 5\text{mm for the lowest unprotected front} \\ 4\text{mm for all other cases} \end{array}$$

s and p are as defined above.

When determining p , y is to be measured to middle of the plate field.

End of Document

S4 Criteria for the Use of High Tensile Steel with Minimum Yield Stress of 315 N/mm², 355 N/mm² and 390 N/mm²

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

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 $R_{eH} = 315 \text{ N/mm}^2$

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

$k = 0.66$ for steel with $R_{eH} = 390 \text{ N/mm}^2$ 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 $R_{eH} = 390 \text{ N/mm}^2$ in other cases.

Where:

R_{eH} : Minimum yield stress, in N/mm²

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 $0.4L$ 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 Use of Steel Grades for Various Hull Members - Ships of 90 m in Length and Above

(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)
(Corr.1
Mar 2021)
(Corr.2
Nov 2021)

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/6.4, |
| 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:

- Changes introduced in Rev.5 are to be uniformly implemented by IACS Members and Associates from 1 July 2008.
- Changes introduced in Rev.7 are to be uniformly implemented by IACS Members from 1 July 2014.
- Changes introduced in Rev.8 are to be uniformly implemented by IACS Members from 1 January 2017.
- 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:		- Class I within 0.4L amidships - Grade A/AH outside 0.4L amidships
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	
PRIMARY:		- Class II within 0.4L amidships - Grade A/AH outside 0.4L amidships
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	
SPECIAL:		- Class III within 0.4L amidships - Class II outside 0.4L amidships - Class I outside 0.6L amidships
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 - Min. Class III within cargo region
C4.	Strength deck plating at outboard corners of cargo hatch openings in container carriers and other ships with similar hatch opening configurations	
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	
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	

(*) 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 *

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

(*) Table 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)

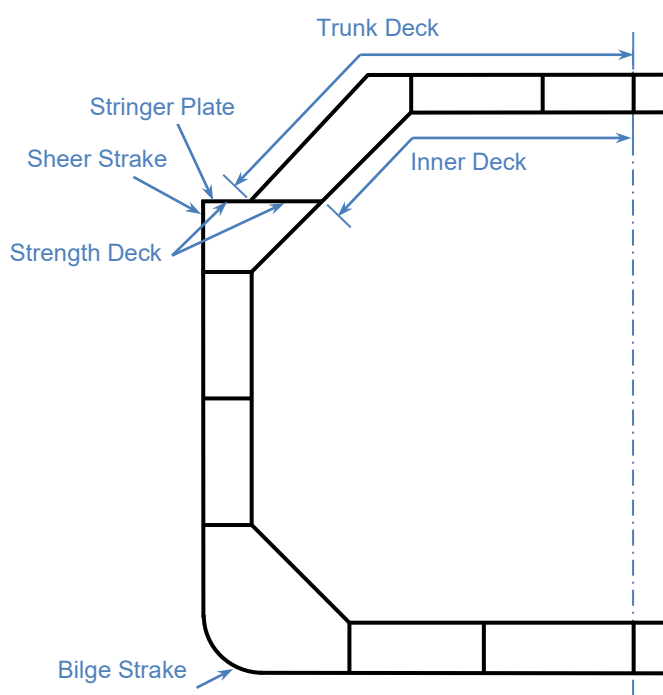


Fig. 1 Typical deck arrangement for membrane type Liquefied Natural Gas Carriers

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

Structural member category	Material grade
Sheer 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 D/DH or Grade E/EH as shown in the above table 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/6.4

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
$t \leq 15$	A	AH	A	AH	A	AH
$15 < t \leq 20$	A	AH	A	AH	B	AH
$20 < t \leq 25$	A	AH	B	AH	D	DH
$25 < t \leq 30$	A	AH	D	DH	D	DH
$30 < t \leq 35$	B	AH	D	DH	E	EH
$35 < t \leq 40$	B	AH	D	DH	E	EH
$40 < t \leq 50$	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 -10°C), 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	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 $t_D < -55^\circ\text{C}$, 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/-15°C		-16/-25°C		-26/-35°C		-36/-45°C		-46/-55°C	
	MS	HT	MS	HT	MS	HT	MS	HT	MS	HT
$t \leq 10$	A	AH	A	AH	B	AH	D	DH	D	DH
$10 < t \leq 15$	A	AH	B	AH	D	DH	D	DH	D	DH
$15 < t \leq 20$	A	AH	B	AH	D	DH	D	DH	E	EH
$20 < t \leq 25$	B	AH	D	DH	D	DH	D	DH	E	EH
$25 < t \leq 30$	B	AH	D	DH	D	DH	E	EH	E	EH
$30 < t \leq 35$	D	DH	D	DH	D	DH	E	EH	E	EH
$35 < t \leq 45$	D	DH	D	DH	E	EH	E	EH	Ø	FH
$45 < t \leq 50$	D	DH	E	EH	E	EH	Ø	FH	Ø	FH

Ø = Not applicable

Class II

Plate thickness, in mm	-11/-15°C		-16/-25°C		-26/-35°C		-36/-45°C		-46/-55°C	
	MS	HT	MS	HT	MS	HT	MS	HT	MS	HT
$t \leq 10$	A	AH	B	AH	D	DH	D	DH	E	EH
$10 < t \leq 20$	B	AH	D	DH	D	DH	E	EH	E	EH
$20 < t \leq 30$	D	DH	D	DH	E	EH	E	EH	Ø	FH
$30 < t \leq 40$	D	DH	E	EH	E	EH	Ø	FH	Ø	FH
$40 < t \leq 45$	E	EH	E	EH	Ø	FH	Ø	FH	Ø	Ø
$45 < t \leq 50$	E	EH	E	EH	Ø	FH	Ø	FH	Ø	Ø

Ø = Not applicable

Class III

Plate thickness, in mm	-11/-15°C		-16/-25°C		-26/-35°C		-36/-45°C		-46/-55°C	
	MS	HT	MS	HT	MS	HT	MS	HT	MS	HT
$t \leq 10$	B	AH	D	DH	D	DH	E	EH	E	EH
$10 < t \leq 20$	D	DH	D	DH	E	EH	E	EH	Ø	FH
$20 < t \leq 25$	D	DH	E	EH	E	EH	E	FH	Ø	FH
$25 < t \leq 30$	D	DH	E	EH	E	EH	Ø	FH	Ø	FH
$30 < t \leq 35$	E	EH	E	EH	Ø	FH	Ø	FH	Ø	Ø
$35 < t \leq 40$	E	EH	E	EH	Ø	FH	Ø	FH	Ø	Ø
$40 < t \leq 50$	E	EH	Ø	FH	Ø	FH	Ø	Ø	Ø	Ø

Ø = Not applicable

Single strokes 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.

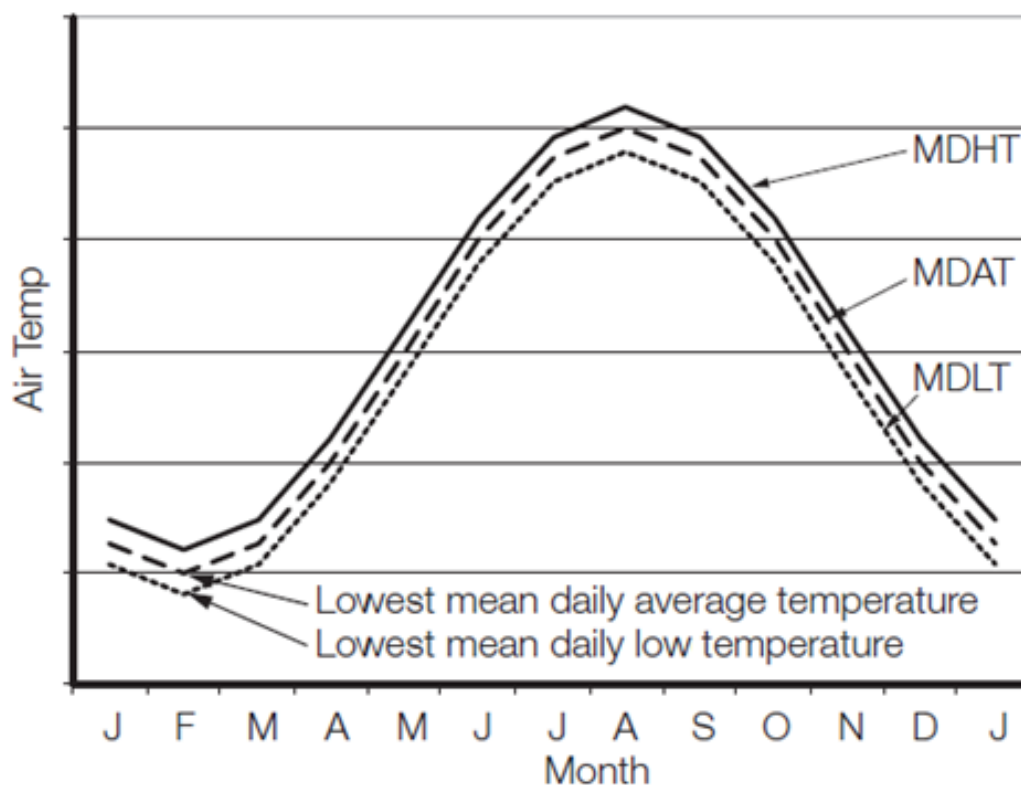


Fig. 2 Commonly used definitions of temperatures

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 $^{\circ}\text{C}$
- 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 $90 \text{ m} \leq L \leq 500 \text{ m}$ and made of hull structural steel is

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

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 = $0.9 c_n$

$$\begin{aligned} c_n &= 10.75 - \left(\frac{300 - L}{100} \right)^{3/2} && \text{for } 90 \text{ m} \leq L \leq 300 \text{ m} \\ &= 10.75 && \text{for } 300 \text{ m} < L < 350 \text{ m} \\ &= 10.75 - \left(\frac{L - 350}{150} \right)^{3/2} && \text{for } 350 \text{ m} \leq L \leq 500 \text{ m} \end{aligned}$$

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.

End of Document

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

- | | |
|--------------------------------|---|
| <i>Securing device</i> | - a device used to keep the door closed by preventing it from rotating about its hinges. |
| <i>Supporting device</i> | - 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. |
| <i>Locking device</i> | - a device that locks a securing device in the closed position. |
| <i>Ro-ro passenger ship</i> | - a passenger ship with ro-ro spaces or special category spaces. |
| <i>Ro-ro spaces</i> | - 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. |
| <i>Special category spaces</i> | - 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:

shear 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.

S8.2.1c 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:

$\lambda = 1$ for seagoing ships,

$\lambda = 0.8$ for ships operated in coastal waters,

$\lambda = 0.5$ 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 $L < 80\text{m}$
1 for $L \geq 80\text{m}$

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:

$$\begin{aligned} F_x &= P_e A_x \\ F_y &= P_e A_y \\ F_z &= P_e A_z \end{aligned}$$

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:

$$M_y = F_x a + 10 W c - F_z b$$

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:

$$p_i = 25$$

S8

(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.

S8.4.2c The stiffener webs are to have a net sectional area, in cm², 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.

S8
(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:

$$M_{y0} = 10Wc + 0.1(a^2 + b^2)^{0.5} (F_x^2 + F_z^2)^{0.5}$$

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.

S8

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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.

S8

(cont)

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

S8

(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.

S8**(cont)****S8.8 Operating and Maintenance Manual**

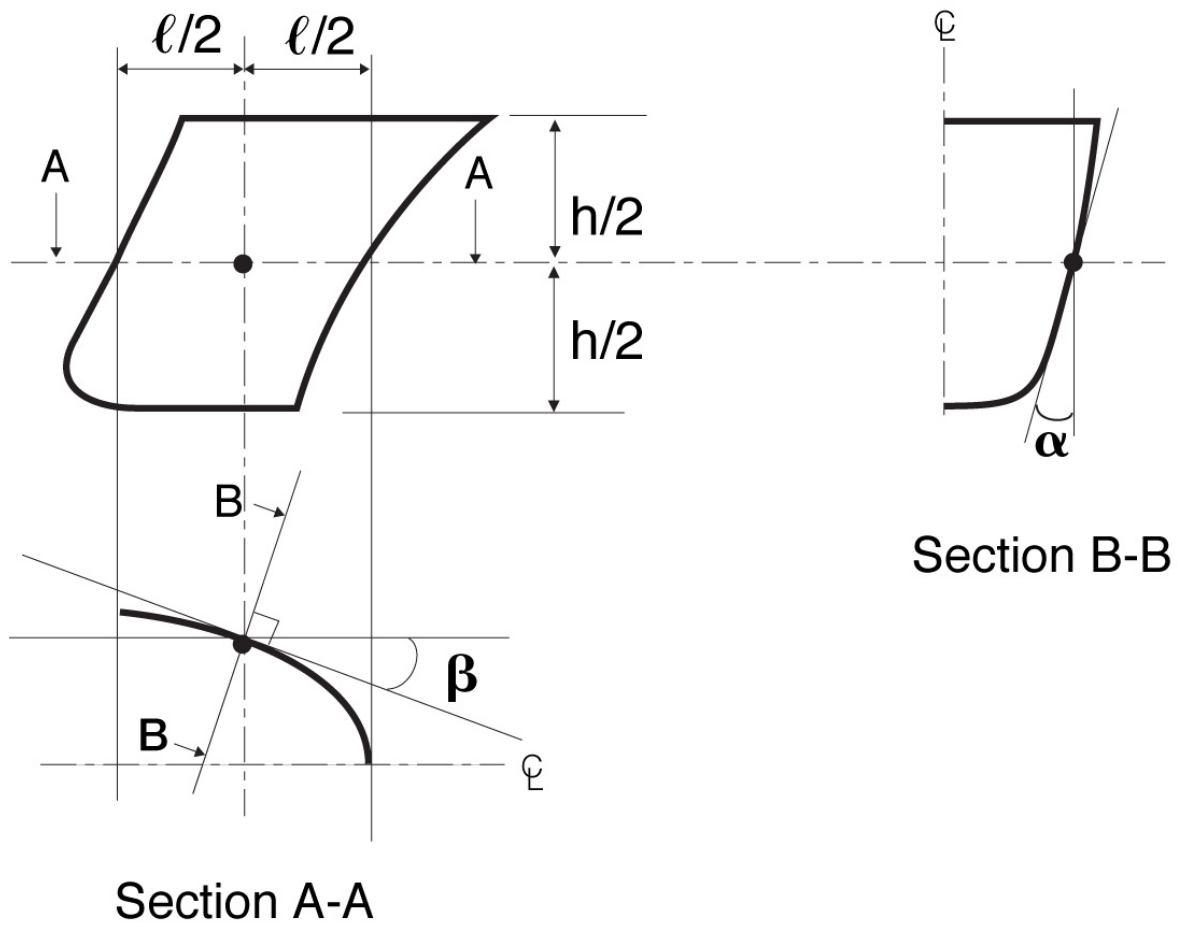
S8.8.1 An Operating and Maintenance Manual for the bow door and inner door is to be provided on board and is to contain necessary information on:

- 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.

S8
(cont)**Fig. 1** Definition of α and β 

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Fig. 2 Bow Door of Visor Type

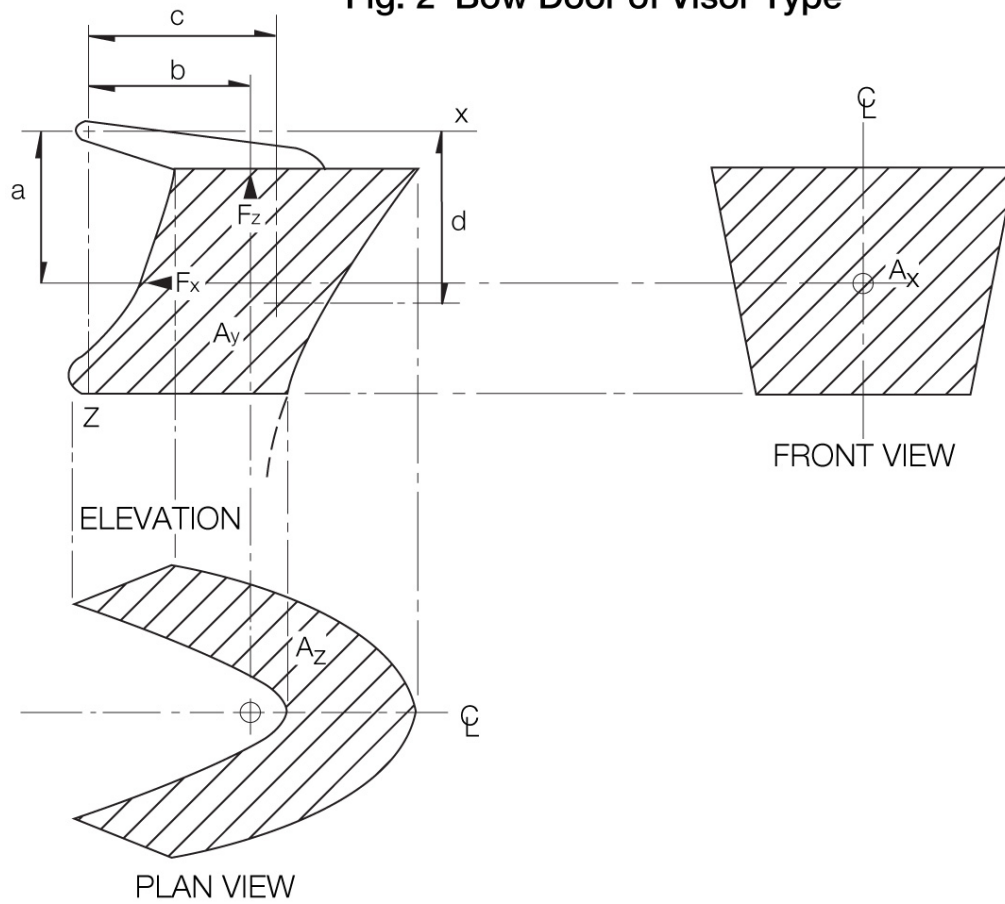
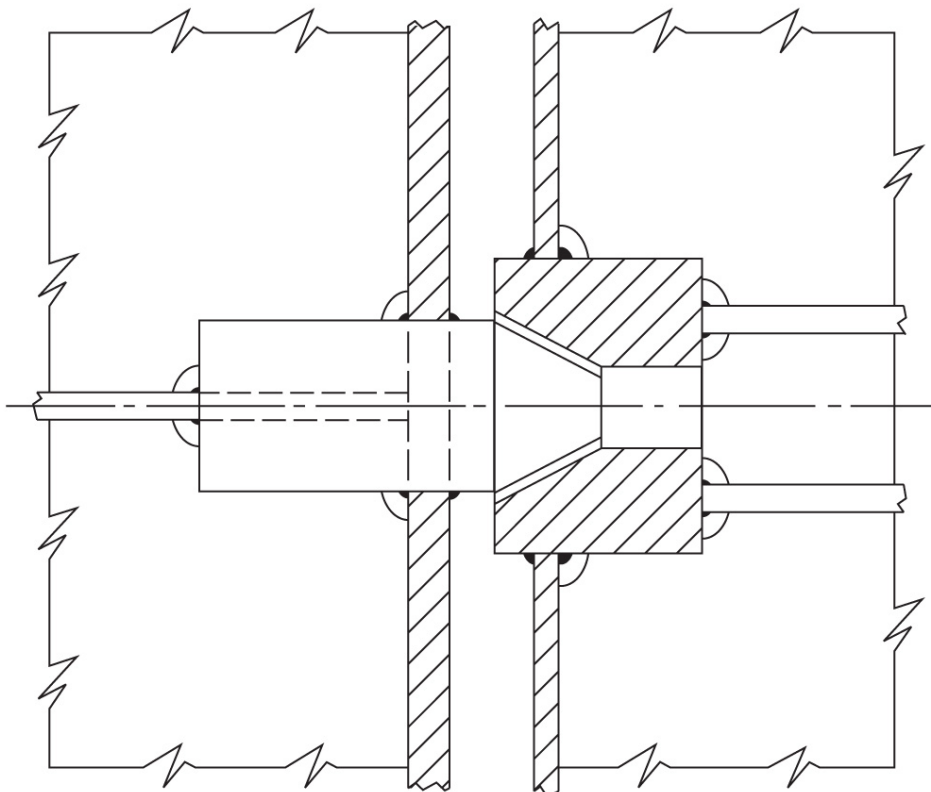


Fig. 3 Thrust Bearing



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Document

S9 Side Shell Doors and Stern Doors

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

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

- | | |
|--------------------------|---|
| <i>Securing device</i> | - a device used to keep the door closed by preventing it from rotating about its hinges or about pivotted attachments to the ship. |
| <i>Supporting device</i> | - 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. |
| <i>Locking device</i> | - a device that locks a securing device in the closed position. |

Notes:

- Revision 4 of the UR is applicable to new ships for which the request for classification is received on or after 1 July 1997.
- Changes introduced in Rev.6 are to be uniformly implemented by IACS Members from 1 January 2012.

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(cont)
- 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.

S9

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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:

shear 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:

$$\begin{array}{ll} 10 (T - Z_G) + 25 & \text{for } Z_G < T \\ 25 & \text{for } Z_G \geq T \end{array}$$

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

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

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

$\lambda = 1$ for sea going ships,

$\lambda = 0.8$ for ships operated in coastal waters,

$\lambda = 0.5$ 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

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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(cont)**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.

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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 6m² 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 6m², 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

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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.

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(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)
(Rev.6
Sep 2019)
(Rev.7
Feb 2023)
(Corr.1
June 2023)
(Corr.2
May 2024)

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 for ships with $L \geq 24\text{m}$.

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 waterline at scantling draught (without trim), two separate watertight seals / 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.

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.
5. Changes introduced in Rev.6 are to be uniformly implemented by IACS Members for ships contracted for construction on or after 1 January 2021.
6. Changes introduced in Rev.7 are to be uniformly implemented by IACS Members for ships contracted for construction on or after 1 July 2024.

S10

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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.

1.3.5 For rudder stocks, pintles, keys and bolts the specified minimum yield stress is not to be less than 200 N/mm². The requirements of this UR are based on a material's specified minimum yield stress of 235 N/mm². If material is used having a specified minimum yield stress differing from 235 N/mm² the material factor k is to be determined as follows:

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

with

$$e = 0.75 \text{ for } R_{eH} > 235 \text{ N/mm}^2$$

$$e = 1.00 \text{ for } R_{eH} \leq 235 \text{ N/mm}^2$$

R_{eH} = specified minimum yield stress, in N/mm², of material used, and is not to be taken greater than $0.7\sigma_T$ or 450 N/mm², whichever is the smaller value.

σ_T = tensile strength, in N/mm², 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 $2t$, 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 except in way of solid part in cast steel 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 in the rudder side plating subjected to significant stresses from rudder bending and 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

S10 (cont)

backing bars may be used and are to be fitted with continuous weld on one side to the bevelled edge, see Figure 1. The bevel angle is to be at least 15° for one sided welding.

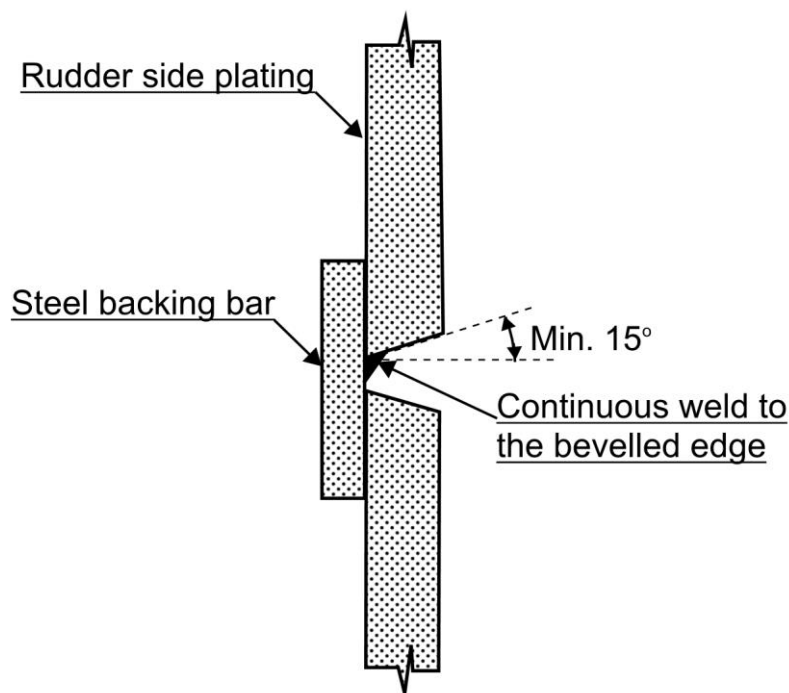


Figure 1: Use of steel backing bar in way of full penetration welding of rudder side plating

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.

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

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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:

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

where:

C_R = rudder force [N]

A = area of rudder blade [m²]

V = maximum service speed, in 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 as defined in SOLAS Regulation II-1/3.15 is to be used, however, in no case taken less than:

$$V_{astern} = 0.5 V$$

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

K_1 = $(\lambda + 2) / 3$, with λ not to be taken greater than 2.

λ = b^2 / A_t

b = mean height of the rudder area, in m. Mean breadth and mean height of rudder are calculated according to the coordinate system in Fig. 2.

A_t = sum of rudder blade area A and area of rudder post or rudder horn, if any, within the height b , in m².

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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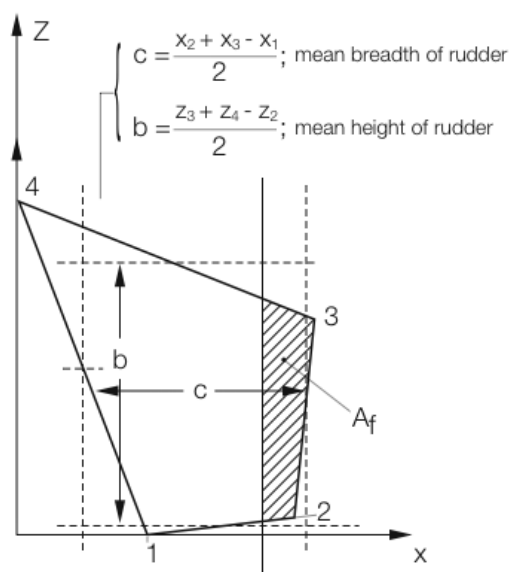
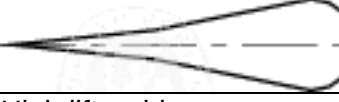
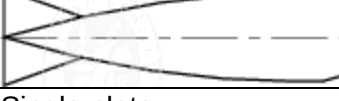
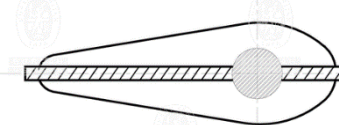


Figure 2

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	1.30
Fish tail 	1.40	0.80
Single plate 	1.00	1.00
Mixed profiles (e.g. HSVA)	1.21	0.90

S10

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

$$Q_R = C_R r \quad [\text{Nm}]$$

$$r = c (\alpha - k_1) \quad [\text{m}]$$

c = mean breadth of rudder area, in m, see Fig. 2.

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.

$$r_{min} = 0.1c \text{ for ahead condition, in m.}$$

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 3).

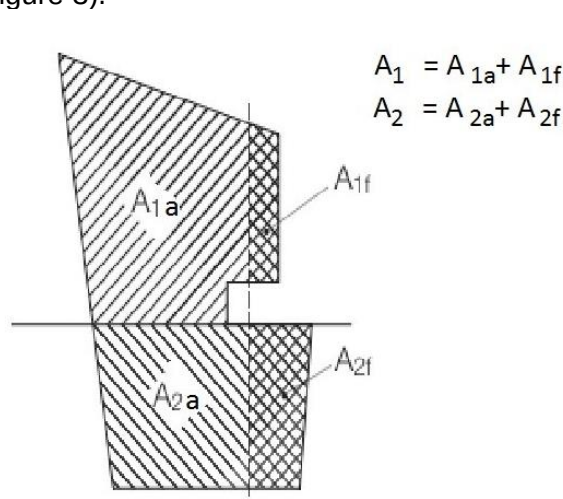


Figure 3

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

$$r_1 = c_1 (\alpha - k_1) \quad [\text{m}]$$

$$r_2 = c_2 (\alpha - k_2) \quad [\text{m}]$$

c_1, c_2 = mean breadth of partial areas A_1, A_2 determined, where applicable, in accordance with Figure 2.

S10

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$$k_1 = A_{1f} / A_1$$

$$k_2 = A_{2f} / A_2$$

A_{1a} = portion of A_1 situated aft of the centre line of the rudder stock.

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

A_{2a} = portion of A_2 situated aft 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:

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

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

The resulting torque of each part may be taken as:

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

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

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

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

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

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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:

$$\tau_T = 68 / k \quad [\text{N/mm}^2]$$

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, in 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 $118 / k$, in 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:

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

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

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

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

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

M = bending moment, in Nm, at the station of the rudder stock considered.

S10 (cont)

For a spade rudder with trunk extending inside the rudder, the rudder stock scantlings shall be checked against the two cases defined in Annex S10.3.

4.3 Before significant reduction in rudder stock diameter are granted due to the application of steel with specified minimum yield stress exceeding 235 N/mm², 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:

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

T_{sc} = scantling draught, in m.

C_R = rudder force, in N, according to S10.2.1.1.

A = rudder area, in m².

$$\beta = \sqrt{1.1 - 0.5(s/b)^2} \quad \text{max. 1.00 if } b/s \geq 2.5.$$

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.

S10

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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.

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 cm³, 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:

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

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

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

$$b = s_v + 2 H_x / 3 \quad [\text{m}]$$

where:

s_v = spacing between the two vertical webs, in m, (see Figure 4).

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

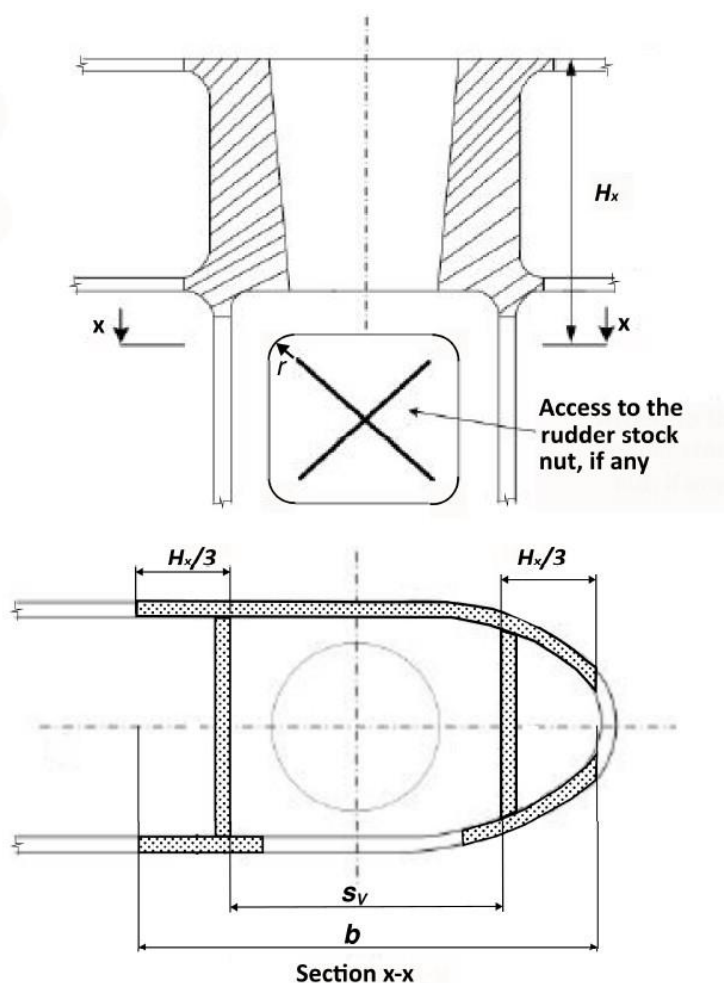


Figure 4 Cross-section of the connection between rudder blade structure and rudder stock housing, example with opening in only one side shown

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:

$$t_H = 1.2 t \quad [\text{mm}]$$

$$t_H = 0.045 d_s^2 / s_H \quad [\text{mm}]$$

S10

(cont)

where:

t = defined in S10.5.2.

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.

S10

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5.4.2 Blade thickness

The blade thickness is not to be less than:

$$t_b = 1.5sV\sqrt{k} + 2.5 \quad [\text{mm}]$$

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.

5.4.3 Arms

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

$$t_a = t_b \quad [\text{mm}]$$

The section modulus is not to be less than:

$$Z_a = 0.5 s C_1^2 V^2 k \quad [\text{cm}^3]$$

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, in mm.

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

e_m = mean distance, in 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:

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

S10

(cont)

$$t_f = 0.9d_b$$

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 5 or equivalent.

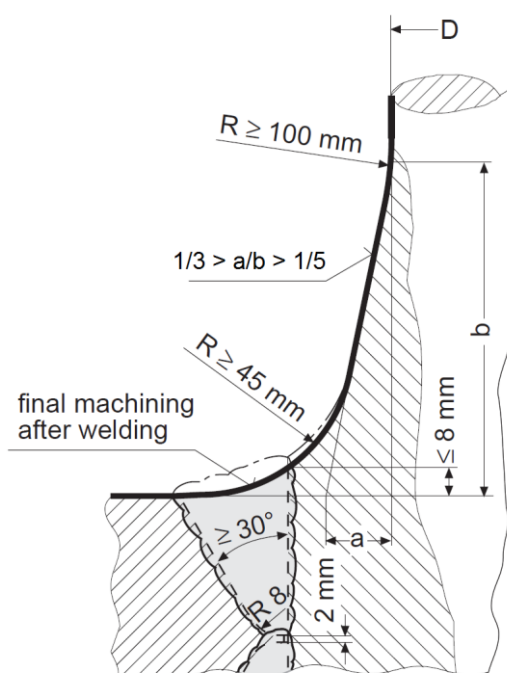


Figure 5 Welded joint between rudder stock and coupling flange

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, in 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.

S10 (cont)

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:

$$m = 0.00043 d^3 \quad [\text{cm}^3]$$

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.

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:

$$c = (d_o - d_u) / \ell_c \quad (\text{see Figure 6 and 7b})$$

The diameters d_o , in mm, and d_u , in mm, are shown in Figure 6 and the cone length, ℓ_c , in mm, is defined in Figure 7b.

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 , in mm, is to be, in general, not less than $1.5d_o$.

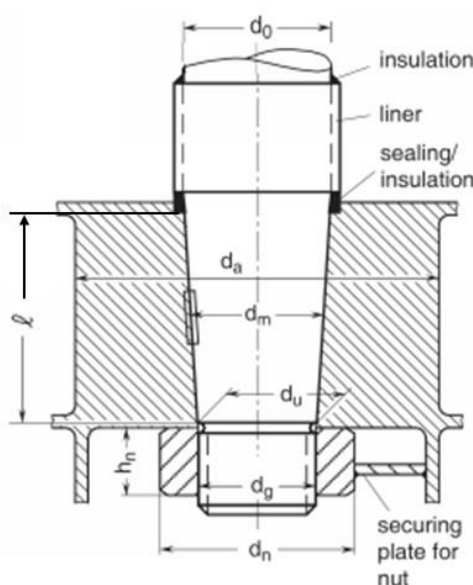


Figure 6 Cone coupling with key

S10

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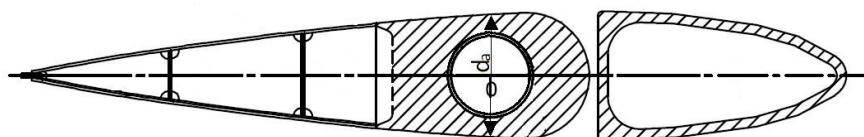


Figure 7a – Gudgeon outer diameter(d_a) measurement

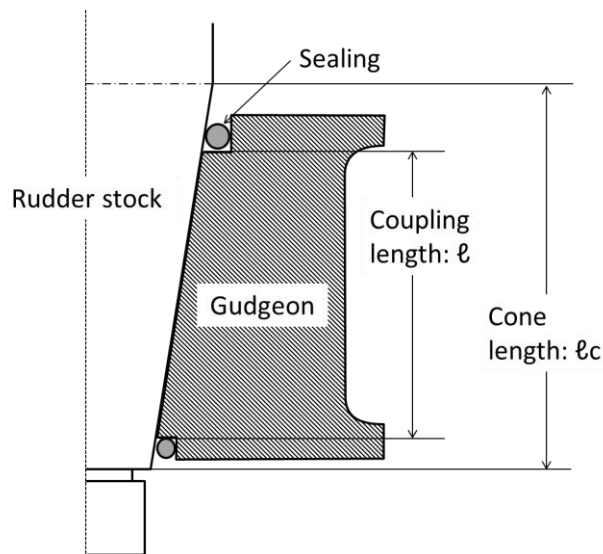


Figure 7b Cone length and coupling length

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:

$$a_s = \frac{17.55Q_F}{d_k R_{eH1}}$$

where:

Q_F = design yield moment of rudder stock, in Nm.

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

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.

S10

(cont)

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

R_{eH1} = specified minimum yield stress of the key material, in N/mm².

The effective surface area, in cm², of the key (without rounded edges) between key and rudder stock or cone coupling is not to be less than:

$$a_k = \frac{5Q_F}{d_k R_{eH2}}$$

where:

R_{eH2} = specified minimum yield stress of the key, stock or coupling material, in N/mm², whichever is less.

6.3.3 The dimensions of the slugging nut are to be as follows (see Figure 6):

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.

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, $c \approx 1:12$ to $\approx 1:20$.

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.

S10

(cont)

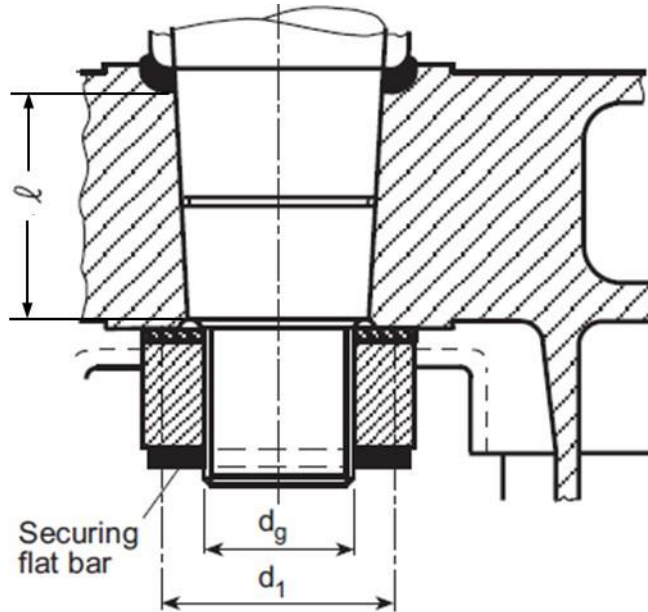


Figure 8 Cone coupling without key

6.4.2 Push-up pressure

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

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

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

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 6.

ℓ = coupling length, in mm.

μ_0 = frictional coefficient, equal to 0.15.

M_c = bending moment in rudder stock at the top of the cone coupling (e.g. in case of spade rudders), in Nm.

For spade rudder with trunk extending inside the rudder, the coupling shall be checked against the two cases defined in Annex S10.3

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:

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

S10

(cont)

where:

$$p_b = \frac{3.5M_c}{d_m \ell^2} 10^3 \text{ [N/mm}^2\text{]}$$

R_{eH} = specified minimum yield stress of the material of the gudgeon, in N/mm².

α = d_m / d_a

d_m = diameter, in mm, see Figure 6.

d_a = outer diameter of the gudgeon, in mm, see Figure 6 and Figure 7a. (The least diameter is to be considered).

The outer diameter of the gudgeon in mm shall not be less than 1.25 d_o , with d_o defined in Figure 6.

6.4.3 Push-up length

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

$$\Delta \ell_1 \leq \Delta \ell \leq \Delta \ell_2$$

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.

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

(cont)

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 case of dry fitting, in N/mm², is to be determined by p_{req1} as given below.

The required push-up pressure for pintle in case of oil injection fitting, in N/mm², is to be determined by the maximum pressure of p_{req1} and p_{req2} as given below:

$$p_{req1} = 0.4 \frac{B d_0}{d_m^2 \ell} \quad [\text{N/mm}^2]$$

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

where:

B = Supporting force in the pintle, in N, e.g. B_1 as defined in figure A4 for semi-spade rudder.

d_0 = Pintle diameter, in mm, see Figure 9.

M_{bp} = bending moment in the pintle cone coupling to be determined by:

$$M_{bp} = B \ell_a \quad [\text{Nm}]$$

ℓ_a = length between middle of pintle-bearing and top of contact surface between cone coupling and pintle in m, see Figure 9)

S10 (cont)

The required push-up length, Δl_1 , is to be calculated similarly as in S10.6.4.3, using the required push-up pressure as defined above, and properties for the pintle.

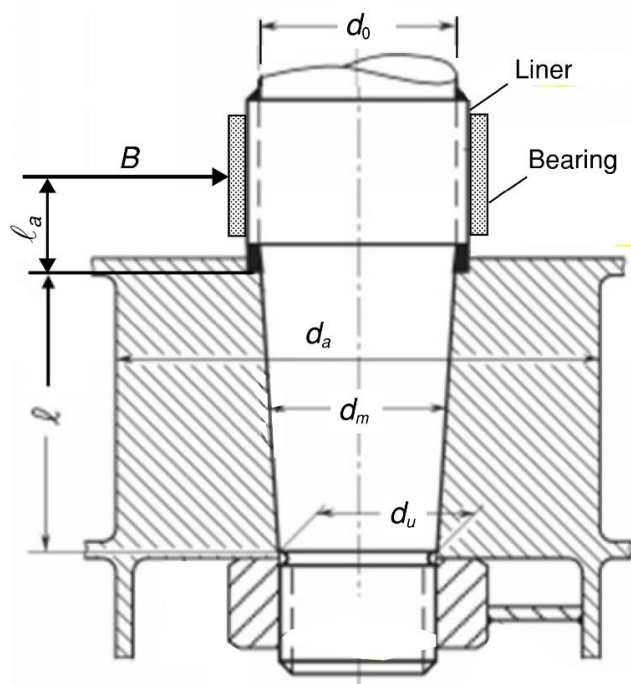


Figure 9 pintle cone coupling indicating l_a

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. For rudder stocks and pintles having diameter less than 200 mm, liners in way of bushes may be provided optionally. 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:

S10

(cont)

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

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:

$$A_b = P / q_a \text{ [mm}^2\text{]}$$

where:

P = reaction force, in N, in bearing as determined in S10.3.2.

q_a = allowable surface pressure according to the table below.

The allowable 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:

Table 3 Allowable surface pressure q_a

Bearing material	q_a [N/mm ²]
lignum vitae	2.5
white metal, oil lubricated	4.5
synthetic material with hardness greater than 60 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, in mm, is to be such that:

S10

(cont)

$$D_p \leq L_p \leq 1.2 D_p$$

where:

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

8.4 Bearing clearances

With metal bearings, clearances should not be less than $d_b / 1000 + 1.0$, in 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.

S10.9 Strength of sole pieces and of rudder horns

9.1 Sole piece

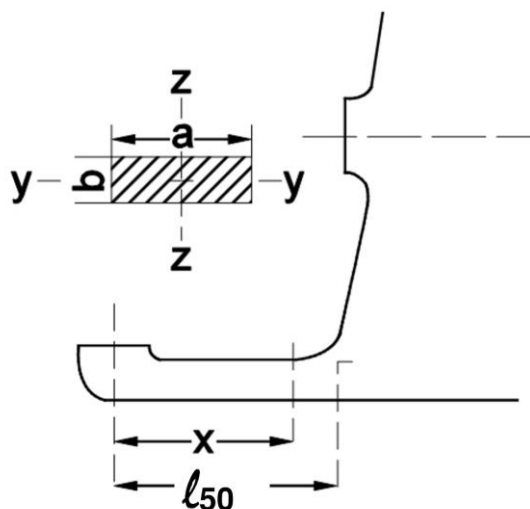


Figure 10 Sole piece

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

$$Z_z = M_b k / 80 \quad [\text{cm}^3]$$

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:

$$A_s = B_1 k / 48 \quad [\text{mm}^2]$$

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

S10

(cont)

9.1.1 Equivalent stress

At no section within the length ℓ_{50} is the equivalent stress to exceed $115 / k$, in N/mm^2 . The equivalent stress is to be determined by the following formula:

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

where:

$$\sigma_b = M_b / Z_z(x) \quad [\text{N/mm}^2]$$

$$\tau = B_1 / A_s \quad [\text{N/mm}^2]$$

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

$$M_b = B_1 x \quad [\text{Nm}]$$

$$M_{b\max} = B_1 \ell_{50} \quad [\text{Nm}]$$

B_1 = supporting force in the pintle bearing, in 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:

$$Z_x = M_b k / 67 \quad [\text{cm}^3]$$

M_b = bending moment at the section considered, in Nm.

S10

(cont)

The shear stress is not to be larger than:

$$\tau = 48 / k \quad [\text{N/mm}^2]$$

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 $120 / k$, in N/mm^2 . The equivalent stress is to be calculated by the following formula:

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

$$\sigma_b = M_b / Z_x \quad [\text{N/mm}^2]$$

$$\tau = B_1 / A_h \quad [\text{N/mm}^2]$$

B_1 = supporting force in the pintle bearing, in N.

A_h = effective shear area of rudder horn in y-direction, in mm^2 .

$$\tau_T = M_T 10^3 / 2 A_T t_h \quad [\text{N/mm}^2]$$

M_T = torsional moment, in Nm.

A_T = area in the horizontal section enclosed by the rudder horn, in mm^2 .

t_h = plate thickness of rudder horn, in mm.

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

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, in m.

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 11.

Brackets or stringer are to be fitted internally in horn, in line with outside shell plate, as shown in Figure 11.

S10

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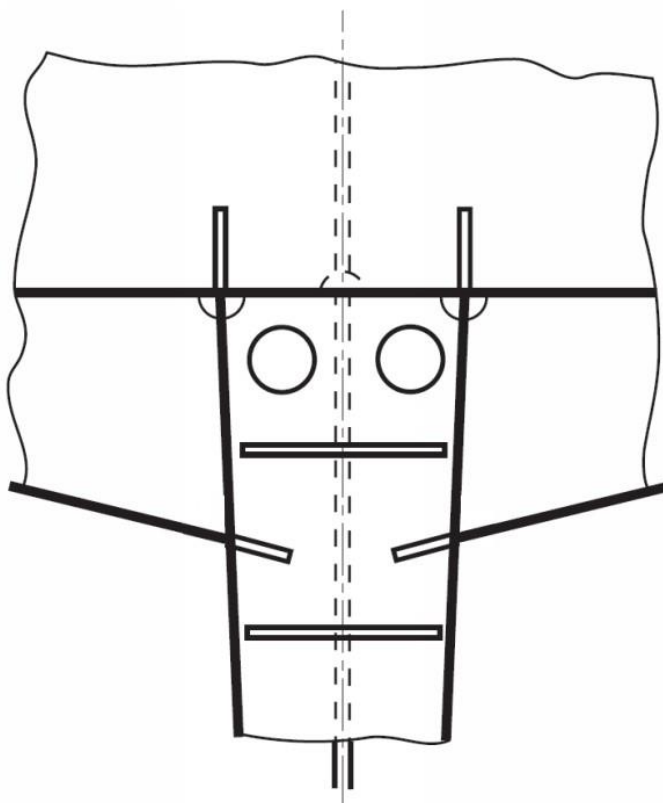


Figure 11 Connection of rudder horn to aft ship structure

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.

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

The requirements in this section apply to trunk configurations which are extended below stern frame and arranged in such a way that the trunk is stressed by forces due to rudder action.

9.3.1 Materials, welding and connection to hull

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.

S10

(cont)

The weld at the connection between the rudder trunk and the shell or the bottom of the skeg is to be full penetration.

For rudder trunks extending below shell or skeg, the fillet shoulder radius r , in mm, (see Figure 12) is to be as large as practicable and to comply with the following formulae:

$$r = 0.1d_c / k$$

without being less than:

r	= 60 [mm]	when $\sigma \geq 40 / k$ [N/mm ²]
r	= 30 [mm]	when $\sigma < 40 / k$ [N/mm ²]

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 for the rudder trunk 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.

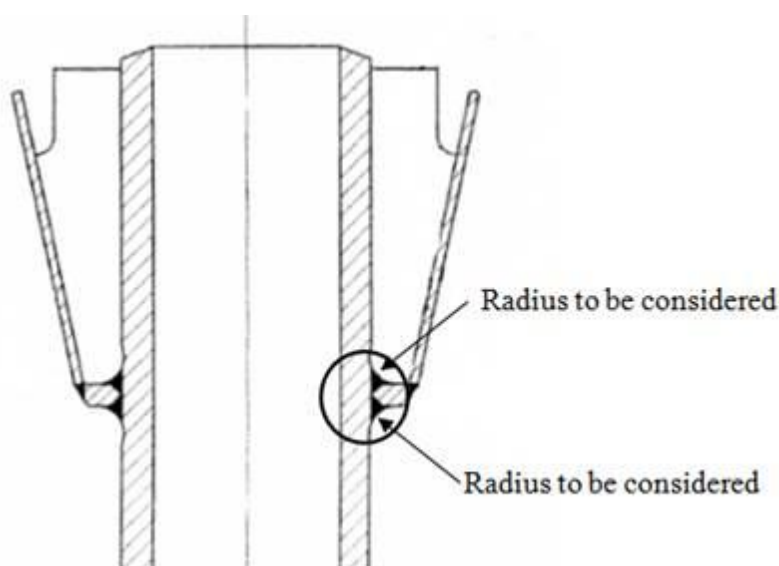


Figure 12 Fillet shoulder radius

S10

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9.3.2 Scantlings

The scantlings of the trunk are to be such that:

- the equivalent stress due to bending and shear does not exceed $0.35 R_{eH}$.
- the bending stress on welded rudder trunk is to be in compliance with the following formula:

$$\sigma \leq 80 / k \quad [\text{N/mm}^2]$$

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.

R_{eH} = specified minimum yield stress, in 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.

Guidelines for calculation of bending moment and shear force distribution

Annex S10.1 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 Annex S10.2-Annex S10.6.

S10

(cont)

Annex S10.2 Spade rudder

Data for the analysis

$\ell_{10} - \ell_{30}$ = 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:

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

Moments and forces

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

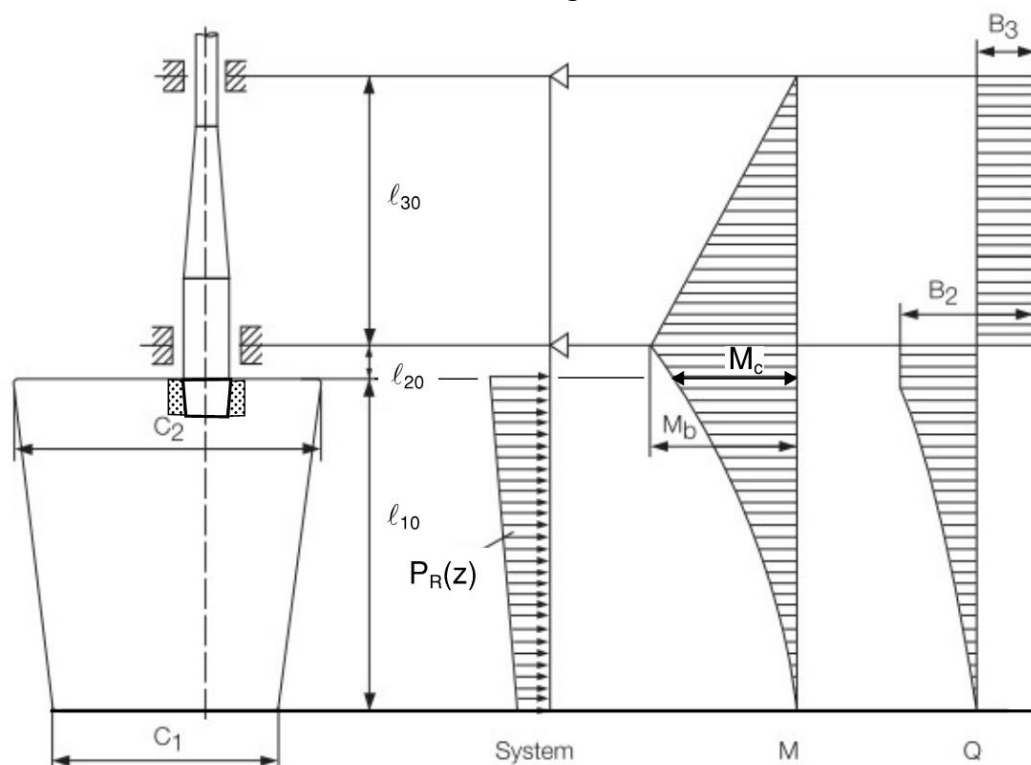
$$M_b = C_R (\ell_{20} + (\ell_{10} (2 C_1 + C_2) / 3 (C_1 + C_2))) \quad [\text{Nm}]$$

$$B_3 = M_b / \ell_{30} \quad [\text{N}]$$

$$B_2 = C_R + B_3 \quad [\text{N}]$$

The maximum moment, M_C , in top of the cone coupling as shown in Figure A1 is applicable for the connection between the rudder and the rudder stock.

Figure A 1



S10

(cont)

Annex S10.3 Spade rudder with trunk

Data for the analysis

$\ell_{10} - \ell_{30}$ = 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:

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

Moments and forces

For a spade rudder with trunk extending inside the rudder, the strength shall be checked against the following two cases:

- pressure applied on the entire rudder area
- pressure applied only on rudder area below the middle of neck bearing.

The moments and forces for the two cases defined above may be determined according to Figure A2 a) and b), respectively.

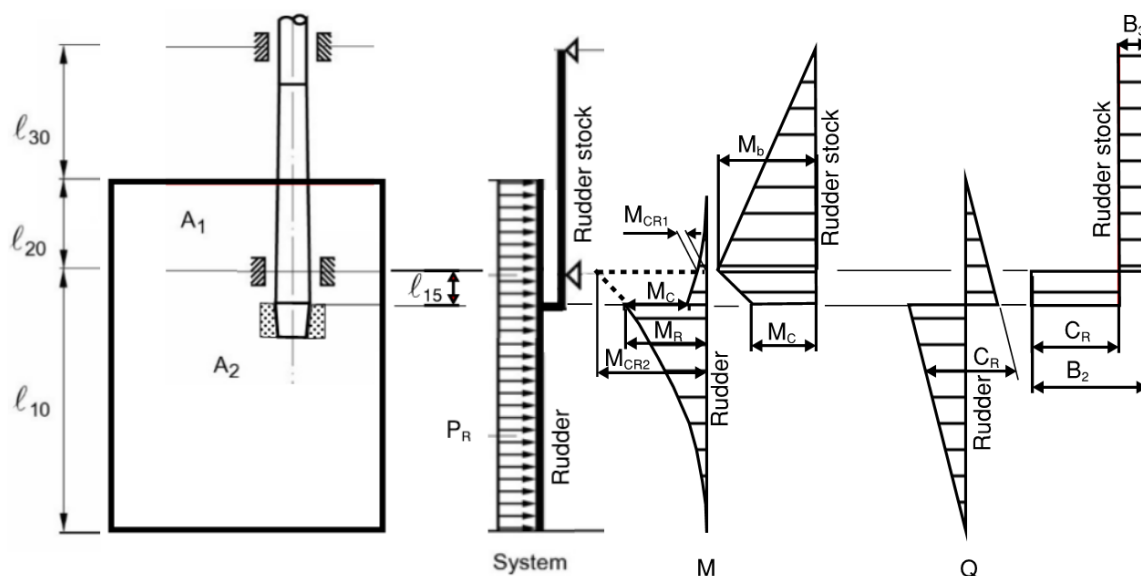


Figure A2 a)

Full rudder force $C_R = C_{R1} + C_{R2}$ and total rudder torque $Q_R = Q_{R1} + Q_{R2}$ with rudders stock bending moment $M_b = M_{CR2} - M_{CR1}$

S10

(cont)

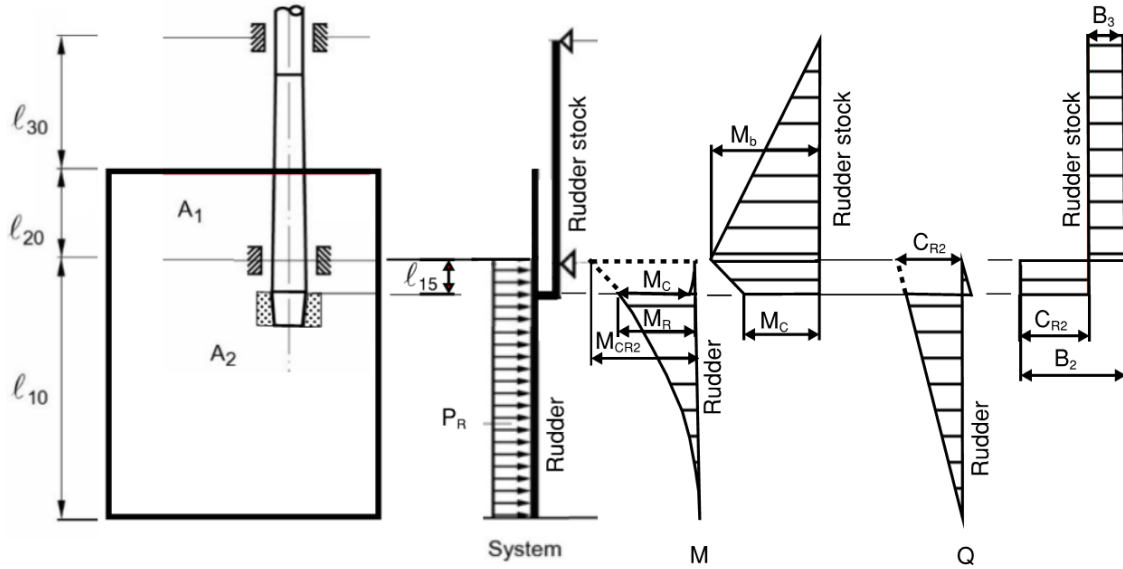


Figure A2 b)

Rudder force C_{R2} corresponding to rudder torque Q_{R2} acting at rudder blade area A_2 with rudders stock bending moment $M_b = M_{CR2}$

$$M_{CR1} = C_{R1} (CG_{1Z} - l_{10})$$

$$M_{CR2} = C_{R2} (l_{10} - CG_{2Z})$$

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.

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

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

$$B_2 = C_R + B_3$$

Annex S10.4 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 .

S10

(cont)

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, in cm^4 .

ℓ_{50} = effective length of sole piece, in m.

Load of rudder body:

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

Z = spring constant of support in the sole piece.

$Z = 6.18 \times I_{50} / \ell_{50}^3$ [kN/m]

Moments and forces

Moments and shear forces are indicated in Figure A 3

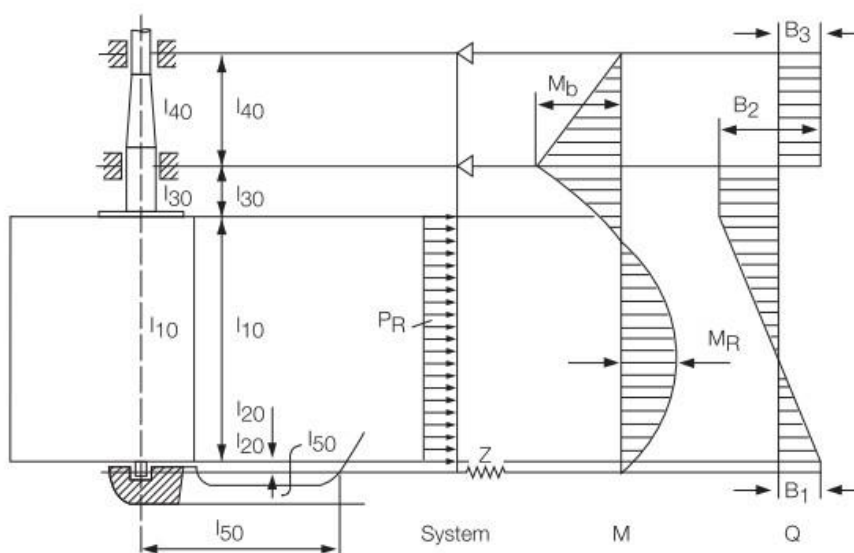


Figure A 3

S10

(cont)

Annex S10.5 Semi spade rudder with one elastic support

Data for the analysis

$\ell_{10} - \ell_{50}$ = 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 = $de^2 \sum u_i / t_i / (3.14 \times 10^8 F_T^2)$ [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.

$e(z)$ = distance as defined in Figure A 5, in m.

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.

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:

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

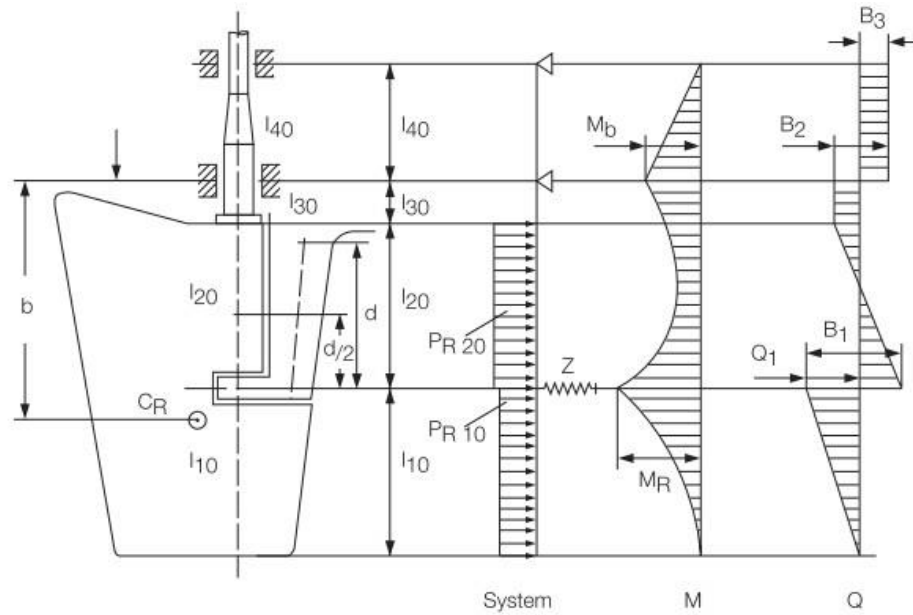


Figure A 4

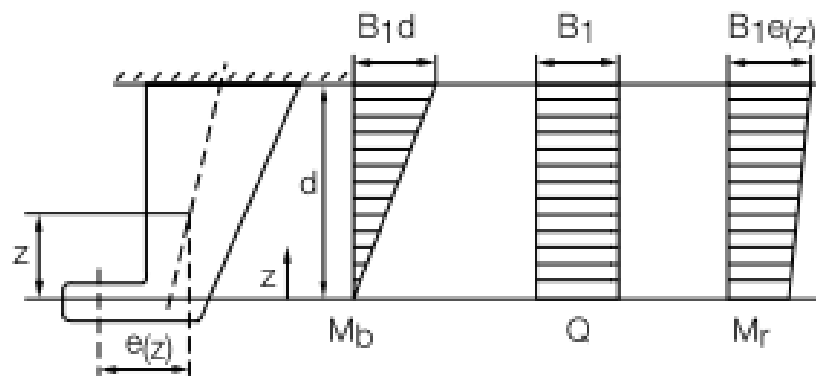


Figure A 5

S10

(cont)

Annex S10.6 Semi spade rudder with 2-conjugate elastic support

Data for the analysis

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

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

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

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

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 $\lambda = 0$, 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 m⁴, 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 $d - \lambda$ (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:

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

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

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/mm², to be obtained from the following formula:

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

τ_T : Torsional stress, in N/mm², to be obtained for hollow rudder horn from the following formula:

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

S10

(cont)

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/mm², to be obtained from the following formula:

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

τ_T : Torsional stress, in N/mm², to be obtained for hollow rudder horn from the following formula:

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

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 mm², 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 m².

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/mm², 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 cm³, around the x-axis (see Figure A 7).

S10
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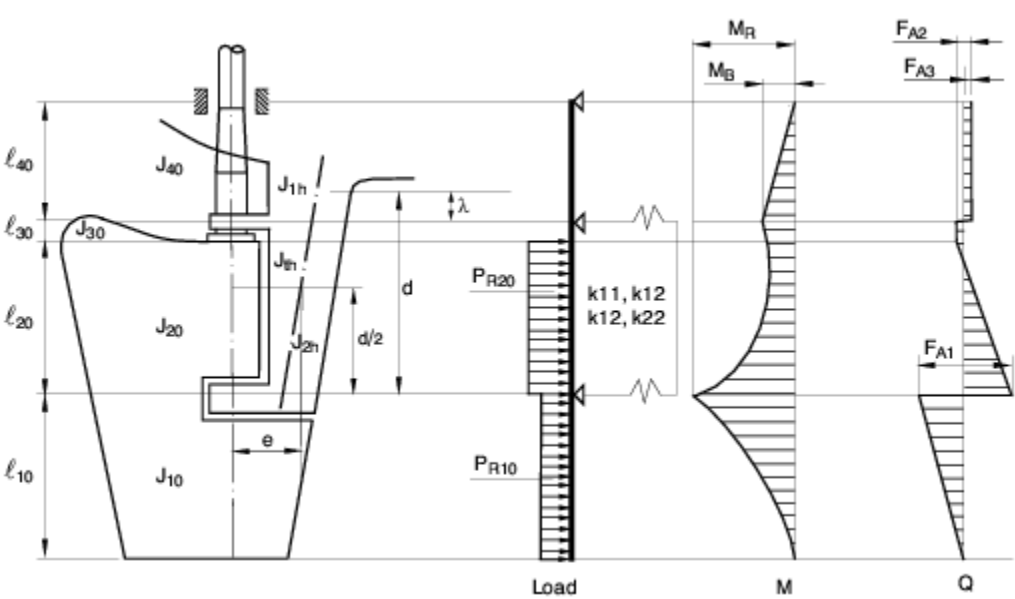


Figure A 6

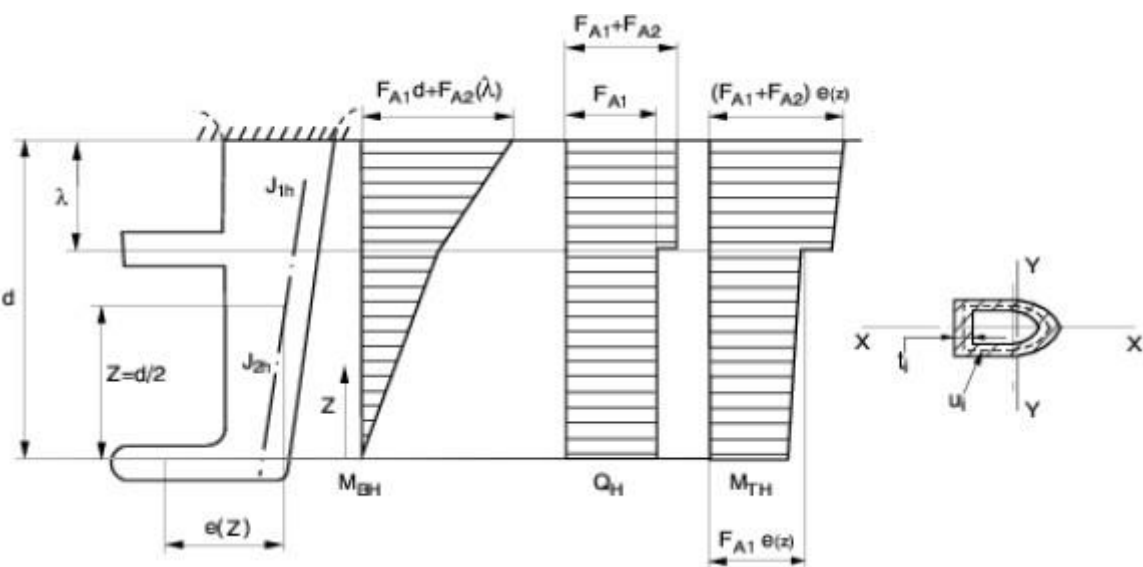


Figure A 7

End of
Document

S11 Longitudinal Strength Standard

(1989)
(Rev.1
1993)
(Rev.2
Nov 2001)
(Rev.3
Jun 2003)
(Rev.4
July 2004)
(Rev.5
Jan 2006)
(Rev.6
May 2010)
(Rev.7
Nov 2010)
(Rev.8
Jun 2015)
(Rev.9
June 2019)
(Rev.10
Dec 2020)

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	$L/B \leq 5$	$B/D \geq 2.5$
(ii)	Length	$L \geq 500 \text{ m}$	
(iii)	Block coefficient	$C_b < 0.6$	
(iv)	Large deck opening		
(v)	Ships with large flare		
(vi)	Carriage of heated cargoes		
(vii)	Unusual type or design		

For ships other than bulk carriers, 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, except otherwise mentioned, 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, M_s (kNm), and still water shear forces, F_s (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.

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.
5. Changes introduced in Rev.9 of this UR are to be uniformly implemented by IACS Members on ships contracted for construction on or after 1 July 2020.
6. Changes introduced in Rev.10 of this UR are to be uniformly implemented by IACS Members on ships contracted for construction on or after 1 January 2022.

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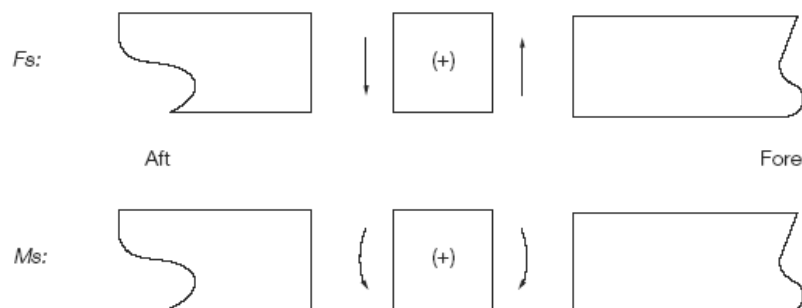


Fig.1 Sign Conventions of M_s and F_s

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 M_s and F_s are as shown in Fig. 1.

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 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 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, 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., light load conditions at less than the maximum draught, heavy cargo, empty holds or non-homogeneous cargo conditions, deck cargo conditions, etc., where 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

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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.

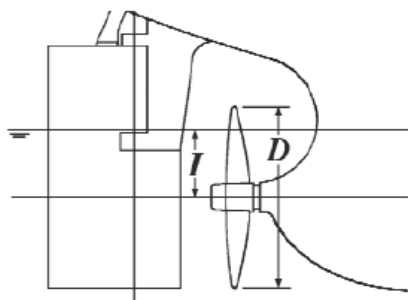
However, for conventional ore carriers with large wing water ballast tanks in cargo area, where empty or full ballast water filling levels of one or maximum two pairs of these tanks lead to the ship's trim exceeding one of the following conditions, it is sufficient to demonstrate compliance with maximum, 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)

Annex 1 contains the guidance for partially filled ballast tanks in ballast loading conditions.

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, M_w , at each section along the ship length are given by the following formulae:

$$M_w(+)=+190MCL^2BC_b \times 10^{-3} \quad (\text{kNm}) \text{ For positive moment}$$

$$M_w(+)= -110MCL^2B(C_b + 0.7) \times 10^{-3} \quad (\text{kNm}) \text{ For negative moment}$$

Where,

M = Distribution factor given in Fig. 2

$$C = 10.75 - \left[\frac{300 - L}{100} \right]^{1.5} \quad \text{for } 90 \leq L \leq 300$$

$$\text{or } 10.75 \quad \text{for } 300 \leq L \leq 350$$

$$\text{or } 10.75 - \left[\frac{L - 350}{150} \right]^{1.5} \quad \text{for } 350 \leq L \leq 500$$

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

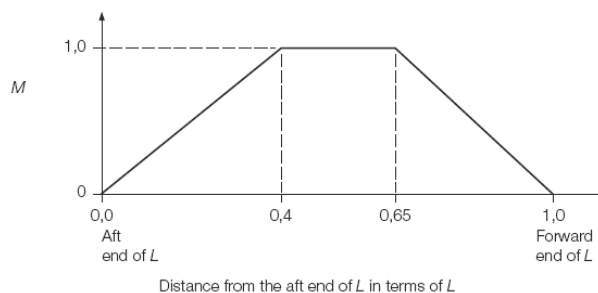


Fig.2 Distribution factor M

S11.2.2.2 Wave shear force

The wave shear forces, F_w , at each section along the length of the ship are given by the following formulae:

S11

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$$F_w(+)=+30F1CLB(C_b+0.7)\times 10^{-2} \quad (\text{kN}) \quad \text{For positive shear force}$$

$$F_w(-)=-30F2CLB(C_b+0.7)\times 10^{-2} \quad (\text{kN}) \quad \text{For negative shear force}$$

where,

$F1, F2$ = Distribution factors given in Figs. 3 and 4

C, L, B, C_b = As specified in S11.2.2.1

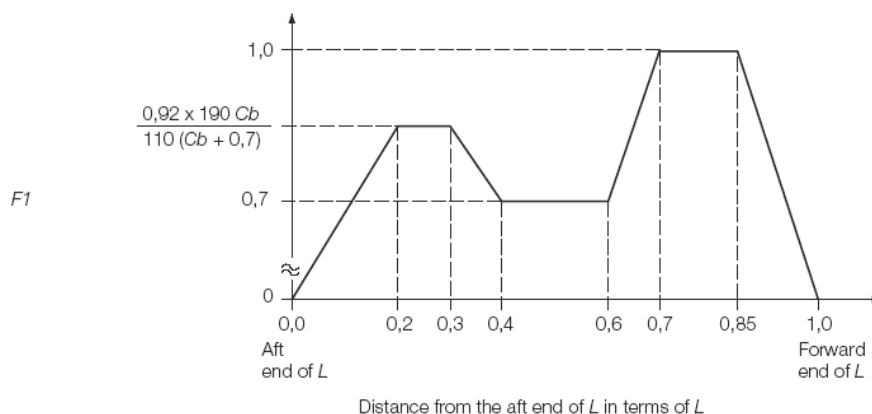


Fig.3 Distribution factor $F1$

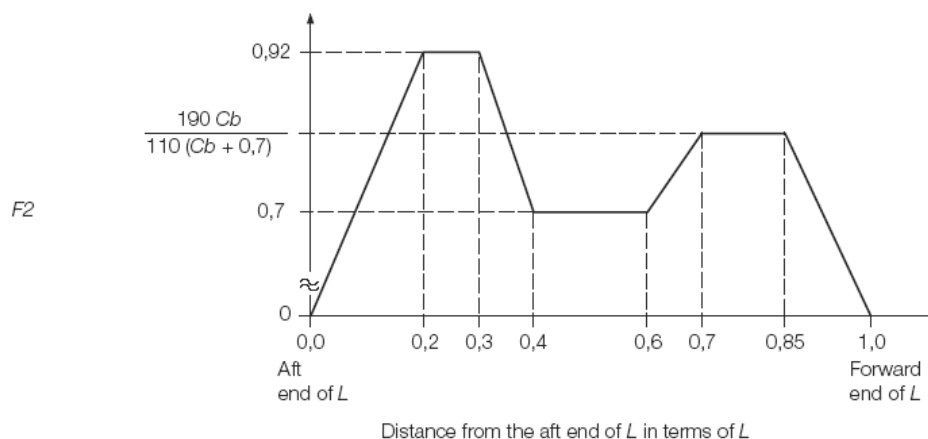


Fig.4 Distribution factor $F2$

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:

$$\frac{|Ms + Mw|}{\sigma} \times 10^3 \quad (\text{cm}^3)$$

S11

(cont)

where,

σ = permissible bending stress = $175/k$ (N/mm²)

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

$$I_{\min} = 3CL^3B(C_b + 0.7) \quad (\text{cm}^4)$$

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 $0.4L$ 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 to 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, 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/mm²).

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 F_s given in S11.2.1.1 and the wave shear forces F_w given in S11.2.2.2, respectively:

$$t = \frac{0.5|F_s + F_w|}{\tau} \frac{S}{I} \times 10^2 \quad (\text{mm})$$

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 F_s 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:

$$t = \frac{|(0.5 - \phi)(F_s + F_w) + \Delta F_{sh}|}{\tau} \frac{S}{I} \times 10^2 \quad (\text{mm})$$

For longitudinal bulkheads:

$$t = \frac{|\phi(F_s + F_w) + \Delta F_{bl}|}{\tau} \frac{S}{I} \times 10^2 \quad (\text{mm})$$

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:

$$\sigma_E = 0.9mE \left(\frac{t_b}{1000s} \right)^2 \quad (\text{N/mm}^2)$$

For plating with longitudinal stiffeners (parallel to compressive stress):

$$m = \frac{8.4}{\psi + 1.1} \quad \text{for } 0 \leq \psi \leq 1$$

For plating with transverse stiffeners (perpendicular to compressive stress)

$$m = c \left[1 + \left(\frac{s}{\ell} \right)^2 \right]^2 \frac{2.1}{\psi + 1.1} \quad \text{for } 0 \leq \psi \leq 1$$

where,

E = modulus of elasticity of material

= 2.06×10^5 N/mm² 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° 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° to the horizontal line - Two side exposure to ballast and/or liquid cargo Vertical surfaces and surfaces sloped at an angle greater than 25° to the horizontal line	0.10 t	2 - 3

S11

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- Two side exposure to ballast and/or liquid cargo Horizontal surfaces and surfaces sloped at an angle less than 25° to the horizontal line	0.15 t	2 - 4
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- 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:

$$\tau_E = 0.9k_t E \left(\frac{t_b}{1000s} \right)^2 \quad (\text{N/mm}^2)$$

$$k_t = 5.34 + 4 \left(\frac{s}{\ell} \right)^2$$

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:

$$\sigma_E = 0.001E \frac{I_a}{A\ell^2} \quad (\text{N/mm}^2)$$

where:

- 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:

$$\sigma_E = \frac{\pi^2 E L_w}{10^4 I_p \ell^2} \left(m^2 + \frac{K}{m^2} \right) + 0.385 E \frac{I_t}{I_p} \quad (\text{N/mm}^2)$$

S11

(cont)

where:

$$K = \frac{C\ell^4}{\pi^4 E I_w} 10^6$$

m = number of half waves, given by the following table:

	$0 < K < 4$	$4 < K < 36$	$36 < K < 144$	$(m-1)^2 m^2 < K \leq m^2 (m+1)^2$
m	1	2	3	m

$$\begin{aligned} I_t &= \text{St Venant's moment of inertia, in cm}^4, \text{ of profile (without plate flange)} \\ &= \frac{h_w t_w^3}{3} 10^{-4} && \text{for flat bars (slabs)} \\ &= \frac{1}{3} \left[h_w t_w^3 + b_f t_f^3 \left(1 - 0.63 \frac{t_f}{b_f} \right) \right] 10^{-4} && \text{for flanged profiles} \end{aligned}$$

$$\begin{aligned} I_p &= \text{polar moment of inertia, in cm}^4, \text{ of profile about connection of stiffener to plate} \\ &= \frac{h_w^3 t_w}{3} 10^{-4} && \text{for flat bars (slabs)} \\ &= \left(\frac{h_w^3 t_w}{3} + h_w^2 b_f t_f \right) 10^{-4} && \text{for flanged profiles} \end{aligned}$$

$$\begin{aligned} I_w &= \text{sectorial moment of inertia, in cm}^6, \text{ of profile about connection of stiffener to plate} \\ &= \frac{h_w^3 t_w^3}{36} 10^{-6} && \text{for flat bars (slabs)} \\ &= \frac{t_f b_f^3 h_w^2}{12} 10^{-6} && \text{for "Tee" profiles} \\ &= \frac{b_f^3 h_w^2}{12(b_f + h_w)^2} \left[t_f (b_f^2 + 2b_f h_w + 4h_w^2) + 3t_w b_f h_w \right] 10^{-6} && \text{for angles and bulb profiles} \end{aligned}$$

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:

$$\sigma_E = 3.8E \left(\frac{t_w}{h_w} \right)^2 \quad (\text{N/mm}^2)$$

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:

$$\begin{aligned} \sigma_c &= \sigma_E & \text{when } \sigma_E &\leq \frac{\sigma_F}{2} \\ &= \sigma_F \left(1 - \frac{\sigma_F}{4\sigma_E} \right) & \text{when } \sigma_E &> \frac{\sigma_F}{2} \end{aligned}$$

σ_F = yield stress of material, in N/mm². σ_F may be taken as 235 N/mm² 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:

$$\begin{aligned} \tau_c &= \tau_E & \text{when } \tau_E &\leq \frac{\tau_F}{2} \\ &= \tau_F \left(1 - \frac{\tau_F}{4\tau_E} \right) & \text{when } \tau_E &> \frac{\tau_F}{2} \end{aligned}$$

where:

$$\tau_F = \frac{\sigma_F}{\sqrt{3}}$$

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:

$$\sigma_a = \frac{M_s + M_w}{I_n} y \times 10^5 \quad \text{N/mm}^2$$

$$= \text{minimum } \frac{30}{k}$$

where:

M_s = still water bending moment (kNm), as given in S11.2.1

M_w = wave bending moment (kNm) 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

$$\tau_a = \frac{0.5|F_s + F_w|}{t} \frac{S}{I} 10^2 \quad \text{N/mm}^2$$

where:

F_s , F_w , t , S , I as specified in S11.4.2.

2. Ships with two effective longitudinal bulkheads

For side shell

$$\tau_a = \frac{|(0.5 - \phi)(F_s + F_w) + \Delta F_{sh}|}{t} \frac{S}{I} 10^2 \quad \text{N/mm}^2$$

For longitudinal bulkheads

$$\tau_a = \frac{|\phi(F_s + F_w) + \Delta F_{bl}|}{t} \frac{S}{I} 10^2 \quad \text{N/mm}^2$$

where:

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:

$$\begin{array}{ll} \beta &= 1 \quad \text{for plating and for web plating of stiffeners (local buckling)} \\ \beta &= 1.1 \quad \text{for stiffeners} \end{array}$$

The critical buckling stress τ_c of plate panels (as calculated in S11.5.3.2) is not to be less than:

$$\tau_c \geq \tau_a$$

Annex 1 - Guidelines for UR S11.2.1.3 for ballast loading conditions of cargo vessels involving partially filled ballast tanks

1. General guidance note regarding the use of UR S11.2.1.3

1.1 This document is intended for guidance and interpretation of UR S11.2.1.3 “Partially filled ballast tanks in ballast loading conditions”.

1.2 Case A and B are generally applicable for ballast loading conditions for any cargo vessel which might have one Ballast Water (BW) Tank (or one pair of BW Tanks) partially filled.

1.3 Case C is showing the conditions necessary for checking longitudinal strength for a conventional ore carrier with two pairs of large wing water ballast tanks partly filled during the ballast voyage.

1.4 Where applicable, similar considerations are to be given to other cargo vessels covered by UR S11 where ballast loading conditions involving partially filled ballast tanks may cause concerns for the longitudinal strength of the vessels.

1.5 This Annex does not apply to CSR Bulk Carriers and Oil Tankers or to container ships to which UR S11A is applicable.

1.6 In the Figures, the conditions only intended for strength verification (not operational) are marked with a star (*).

2. Case A and B

2.1 Case A

Fig. 1 shows Case A, with a cargo vessel where partial filling of BW Tank no. 6 (P/S) is permitted and may take place at any time during the ballast voyage. Intermediate condition(s) should be specified as shown in the Figure, however filling/partial filling of BW Tank no. 6 (P/S) may be done at any step to keep acceptable trim and propeller immersion during the ballast voyage.

To obtain full operational flexibility regarding the filling level of BW Tank no. 6 (P/S), loading conditions A2 (full at departure)* and A8 (empty at arrival)* shall be added for strength verification. Additional conditions (full and empty BW Tank no. 6 (P/S)) related to the intermediate conditions A3-A6 are not necessary as A2* and A8* will be the most critical one.

2.2 Case B

Fig. 2 shows Case B, with a cargo vessel where partial filling of BW Tank no. 6 (P/S) to a given level ($f_{6-int\%}$) will be done after a specified % consumables is reached, see conditions B2 and B3. Before this % consumables (shown as 50% in this Figure) is reached, BW Tank no. 6 (P/S) shall be kept empty. When reaching a given level of consumables (shown as 20% in Figure 2), BW Tank no. 6 (P/S) shall be kept full, see conditions B5 and B6. Two additional intermediate conditions (B4* and B7*) shall be added for longitudinal strength verification.

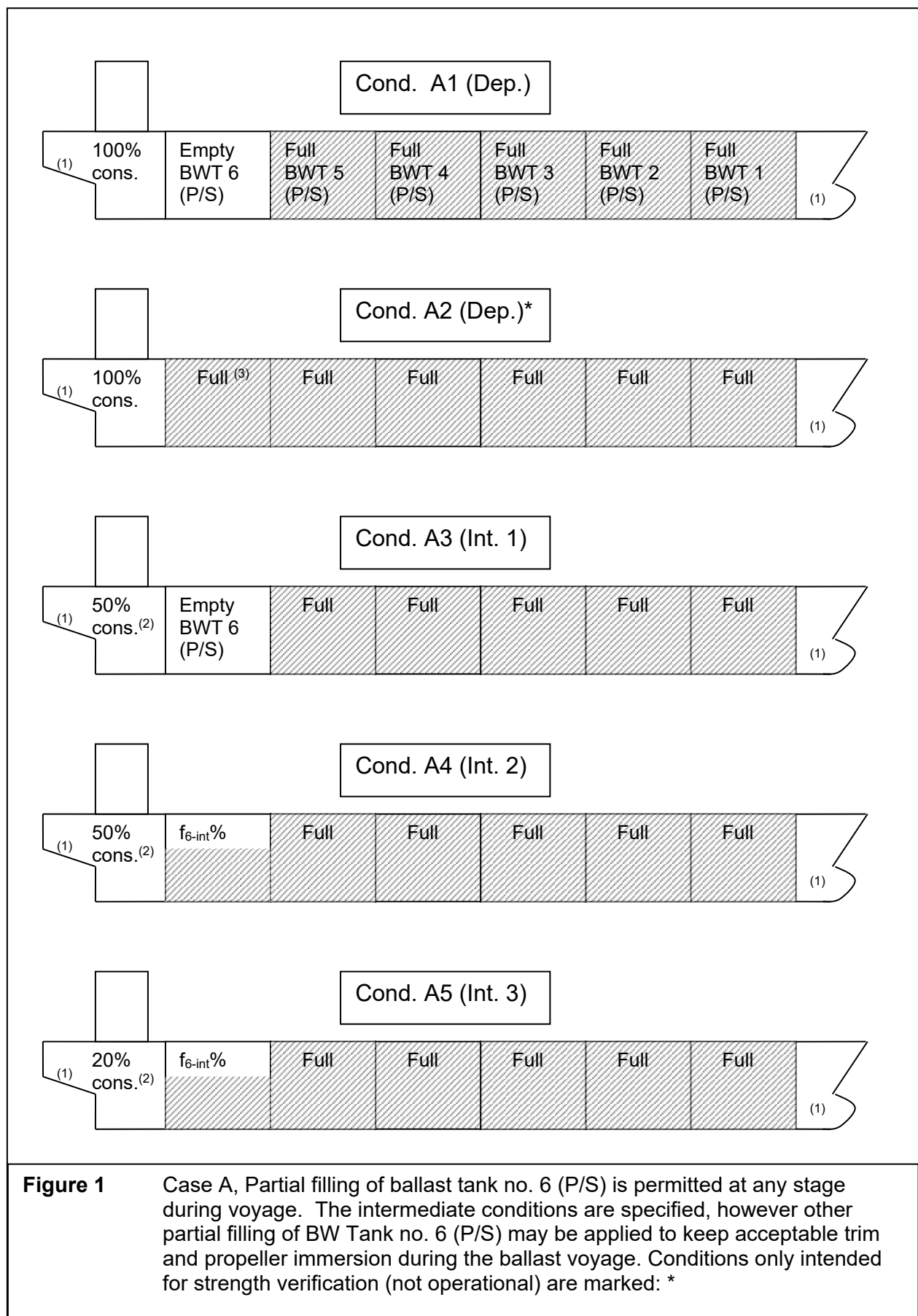
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In order to categorize a vessel according to Case B, clear operational guidance for partial filling of ballast tanks, in association with the consumption level as shown in Figure 2, is to be given in the loading manual. If such operational guidance is not given, Case A is to be applied.

Case A has no limitation of consumables, whereas Case B has limitation of consumables.

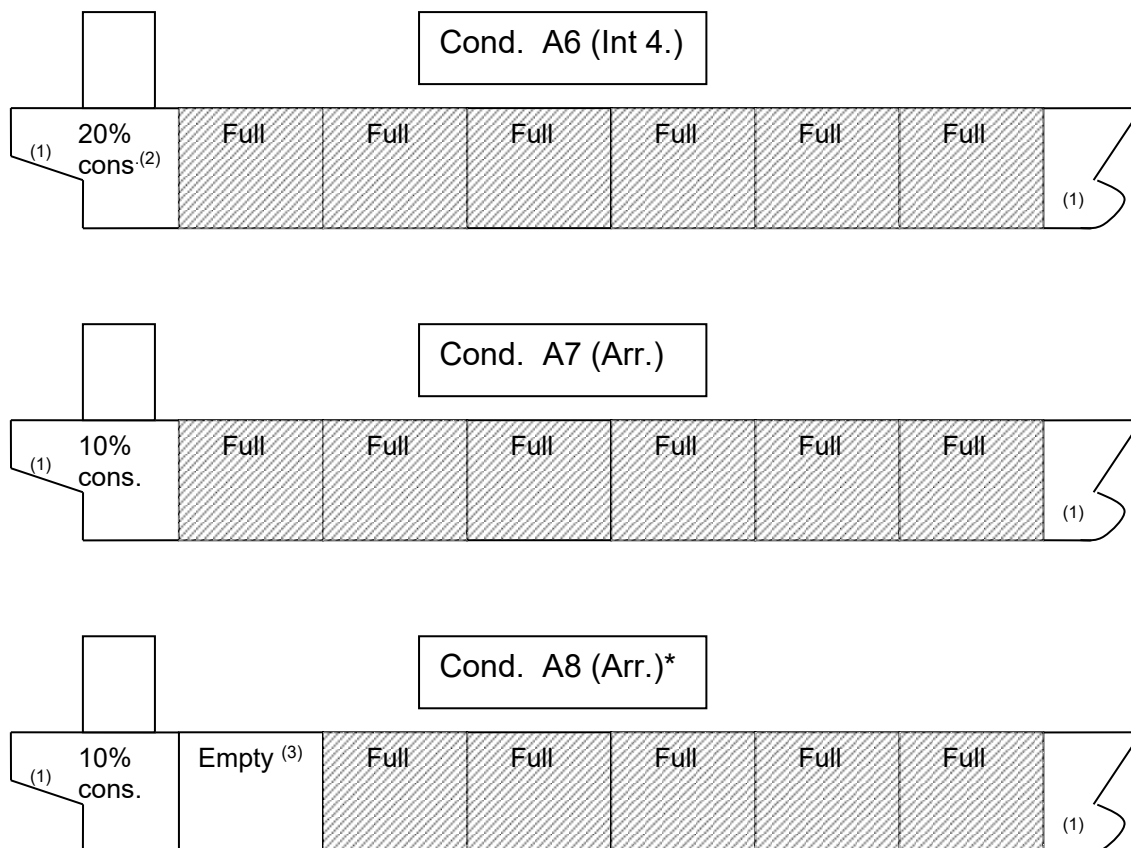
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Notes

- (1) For peak tanks intended to be partially filled, all combinations of full or partially filled at intended level for those tanks are to be investigated.
- (2) The intermediate condition(s) to be specified incl. % consumables.
- (3) For bulk carriers carrying ore and with large wing water ballast tanks full/empty may be replaced with maximum/minimum filling levels according to trim limitations given in S11.2.1.3.

Figure 1

(Continued)

Case A, Partial filling of ballast tank no. 6 (P/S) is permitted at any stage during voyage. The intermediate condition is specified, however other partial filling of BW Tank no. 6 (P/S) may be applied to keep acceptable trim and propeller immersion during the ballast voyage. Conditions only intended for strength verification (not operational) are marked: *

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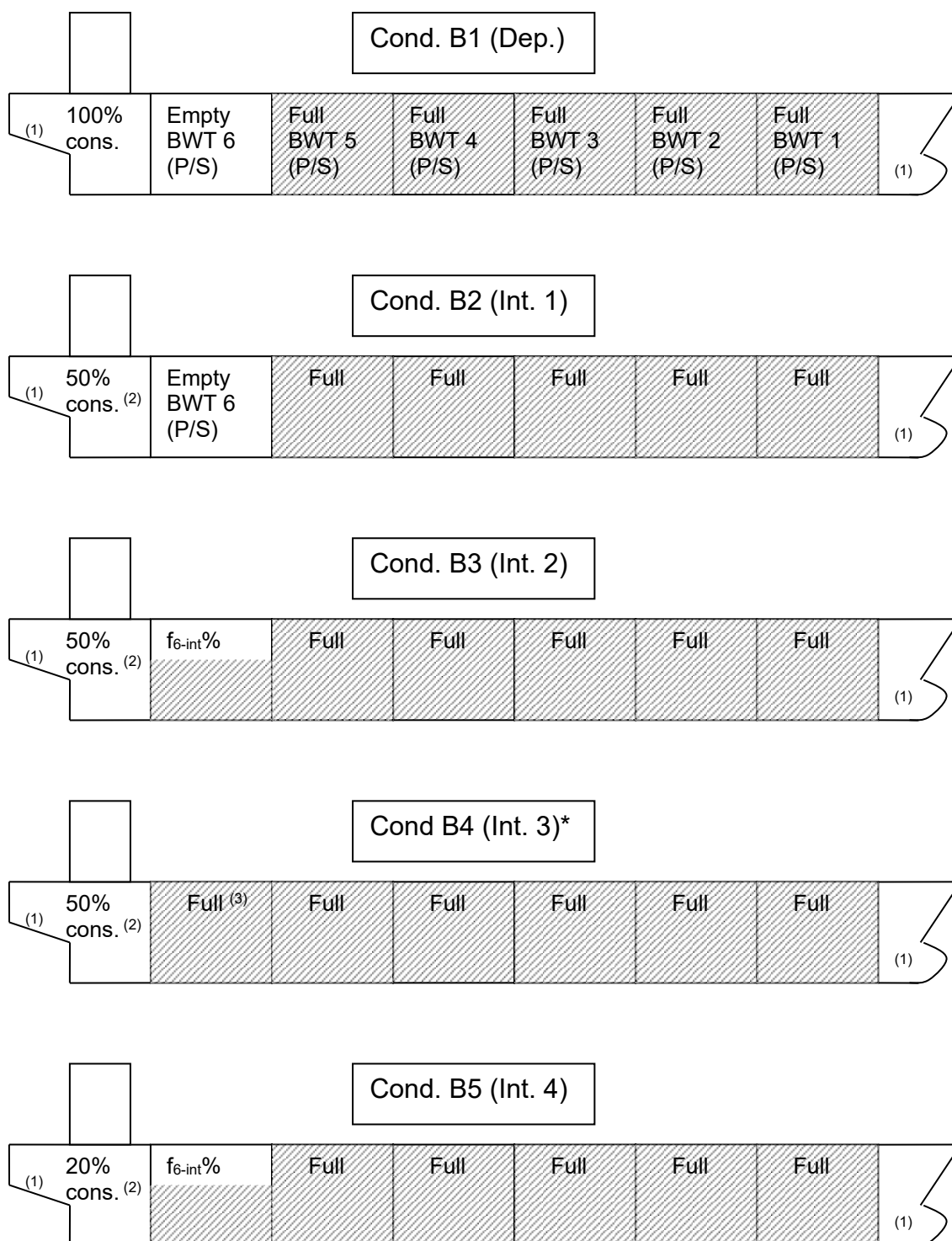
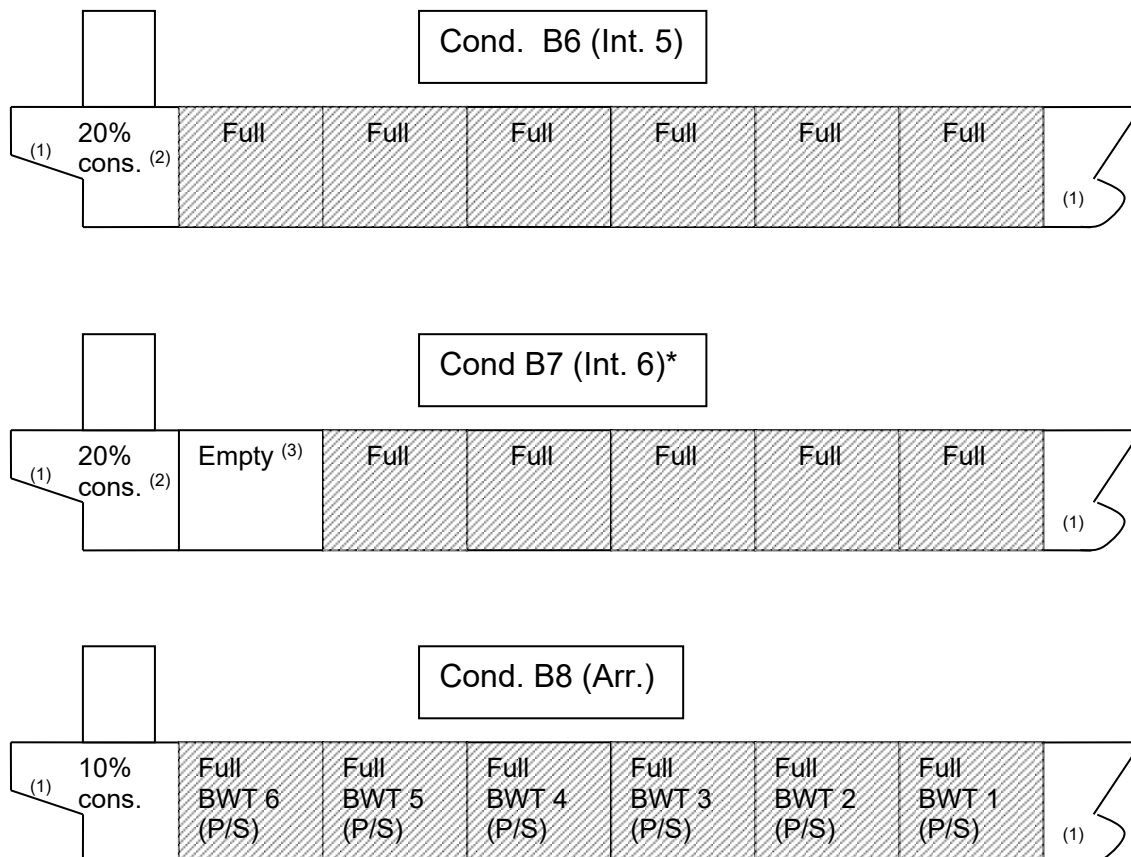


Figure 2 Case B, Partial filling of BW Tank no. 6 (P/S) only allowed during intermediate conditions, in this example between 50-20% consumables. Conditions only intended for strength verification (not operational) are marked: *

S11

(cont)



Notes

- (1) For peak tanks intended to be partially filled, all combinations of full or partially filled at intended level for those tanks are to be investigated.
- (2) The intermediate condition(s) to be specified incl. % consumables.
- (3) For bulk carriers carrying ore and with large wing water ballast tanks full/empty may be replaced with maximum/minimum filling levels according to trim limitations given in S11.2.1.3.

Figure 2

(Continued)

Case B, Partial filling of BW Tank no. 6 (P/S) only allowed during intermediate conditions, in this example between 50-20% consumables. Conditions only intended for strength verification (not operational) are marked: *

S11

(cont)

3. Case C – Conventional (with usual arrangement of WBT) ore carrier with two pairs of partially filled ballast water tanks

Fig. 3(a) show the operational loading conditions, departure condition (C1), four intermediate conditions (C2-C5) and arrival condition (C6), for a conventional (with usual arrangement of WBT) ore carrier with partial filling of both BW tank no.1 (P/S) and 7 (P/S) during voyage.

Loading cond.	Consumables	Filling level, WBT 1(P/S)	Filling level, WBT 7(P/S)
C1 - Departure	100%	$f_{1dep}\%$	$f_{7dep}\%$
C2 – Intermediate 1	50% ⁽ⁱ⁾	$f_{1dep}\%$	$f_{7dep}\%$
C3 – Intermediate 2	50% ⁽ⁱ⁾	$f_{1int}\%$	$f_{7int}\%$
C4 – Intermediate 3	20% ⁽ⁱ⁾	$f_{1int}\%$	$f_{7int}\%$
C5 – Intermediate 4	20% ⁽ⁱ⁾	$f_{1arr}\%$	$f_{7arr}\%$
C6 - Arrival	10%	$f_{1arr}\%$	$f_{7arr}\%$

Note:

(i) % consumables to be specified, indicated to 50% and 20 %

Table 1 Filling level in partially filled BW tanks nos.1 (P/S) and 7 (P/S) for the operational conditions during ballast voyage.

Fig. 3(b) and Fig. 3(c) show the additional twelve loading conditions (C1-1 ~ C1-12) which shall be added for longitudinal strength verification of the departure condition (C1).

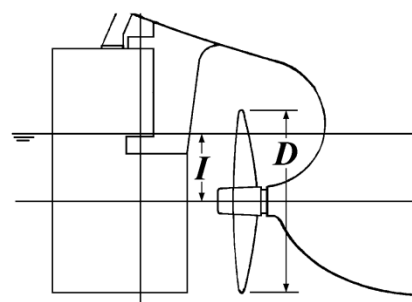
Fig. 3(d) and Fig. 3(i) show the additional 32 loading conditions (C2-1 ~ C2-12, C3-1 ~ C3-4, C4-1 ~ C4-12 and C5-1 ~ C5-4) which shall be added for longitudinal strength verification of the intermediate conditions (C2 ~ C5).

Fig. 3(j) and Fig. 3(k) show the additional twelve loading conditions (C6-1 ~ C6-12) which shall be added for longitudinal strength verification of the arrival condition (C6).

For the additional loading conditions, the maximum and the minimum filling level of BW tank are according to trim and propeller immersion limitations given in S11.2.1.3:

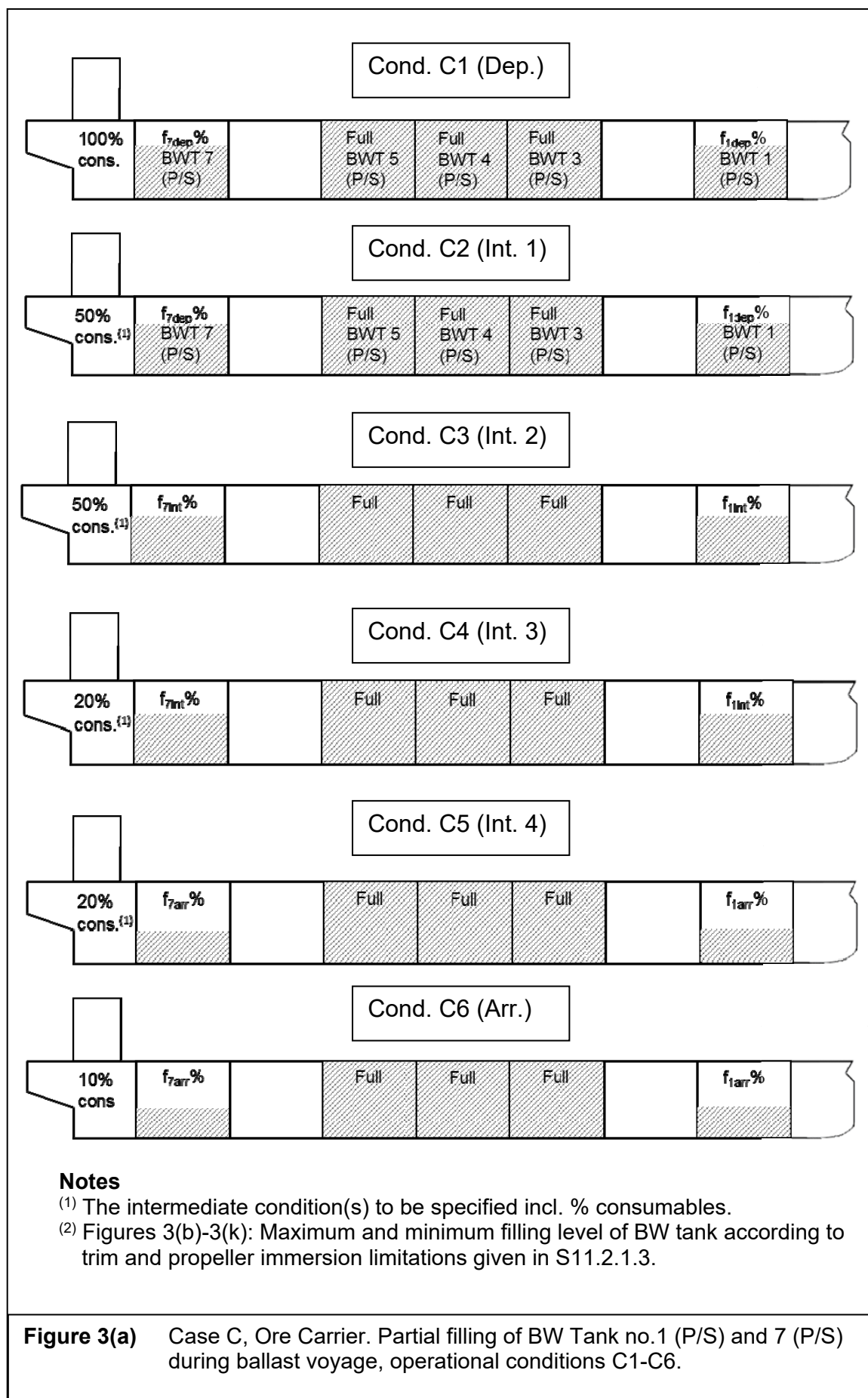
However, for conventional ore carriers with large wing water ballast tanks in cargo area, where empty or full ballast water filling levels of one or maximum two pairs of these tanks lead to the ship's trim exceeding one of the following conditions, it is sufficient to demonstrate compliance with maximum, 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 centerline to the waterline
 D = propeller diameter
 (see the following figure)



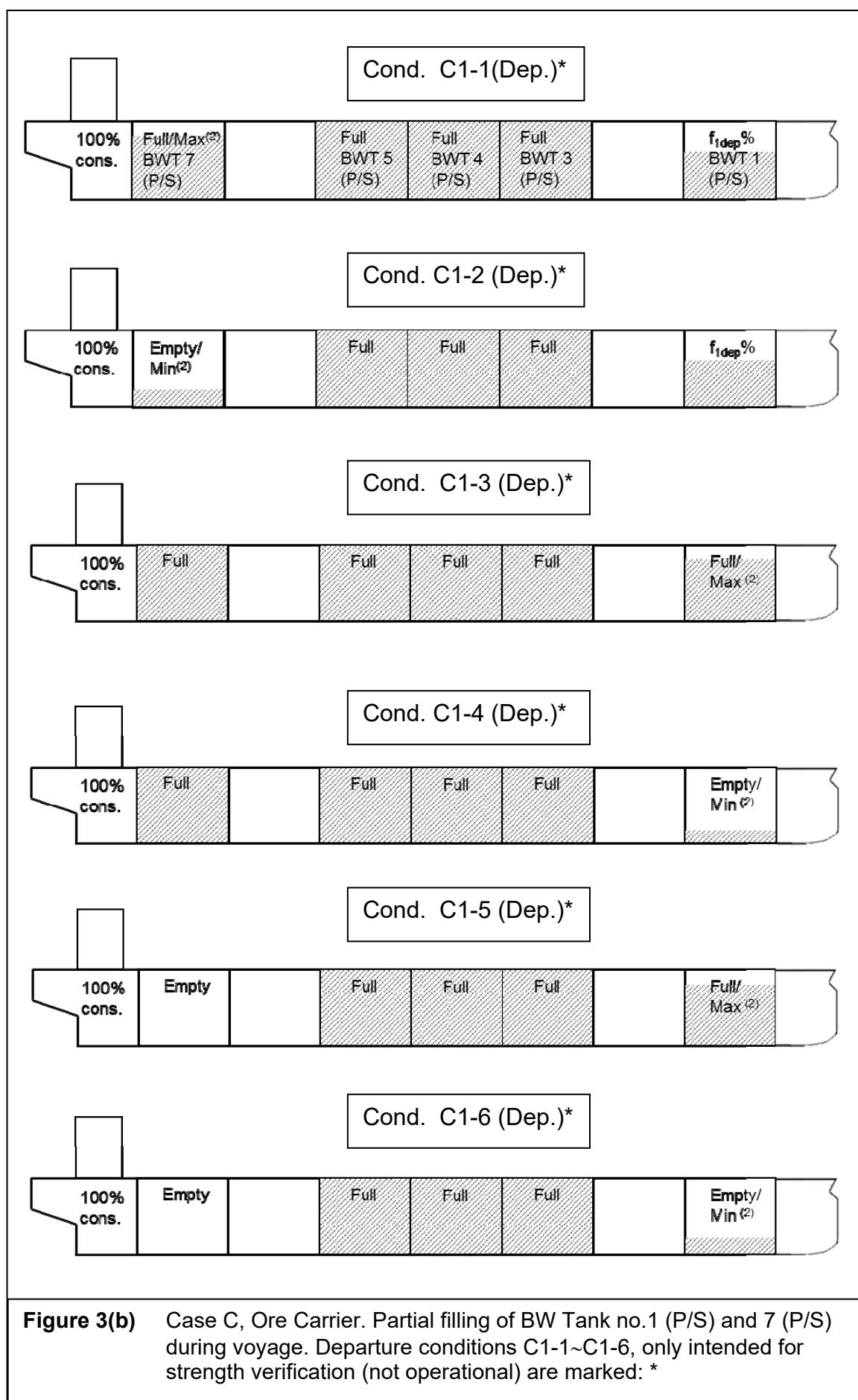
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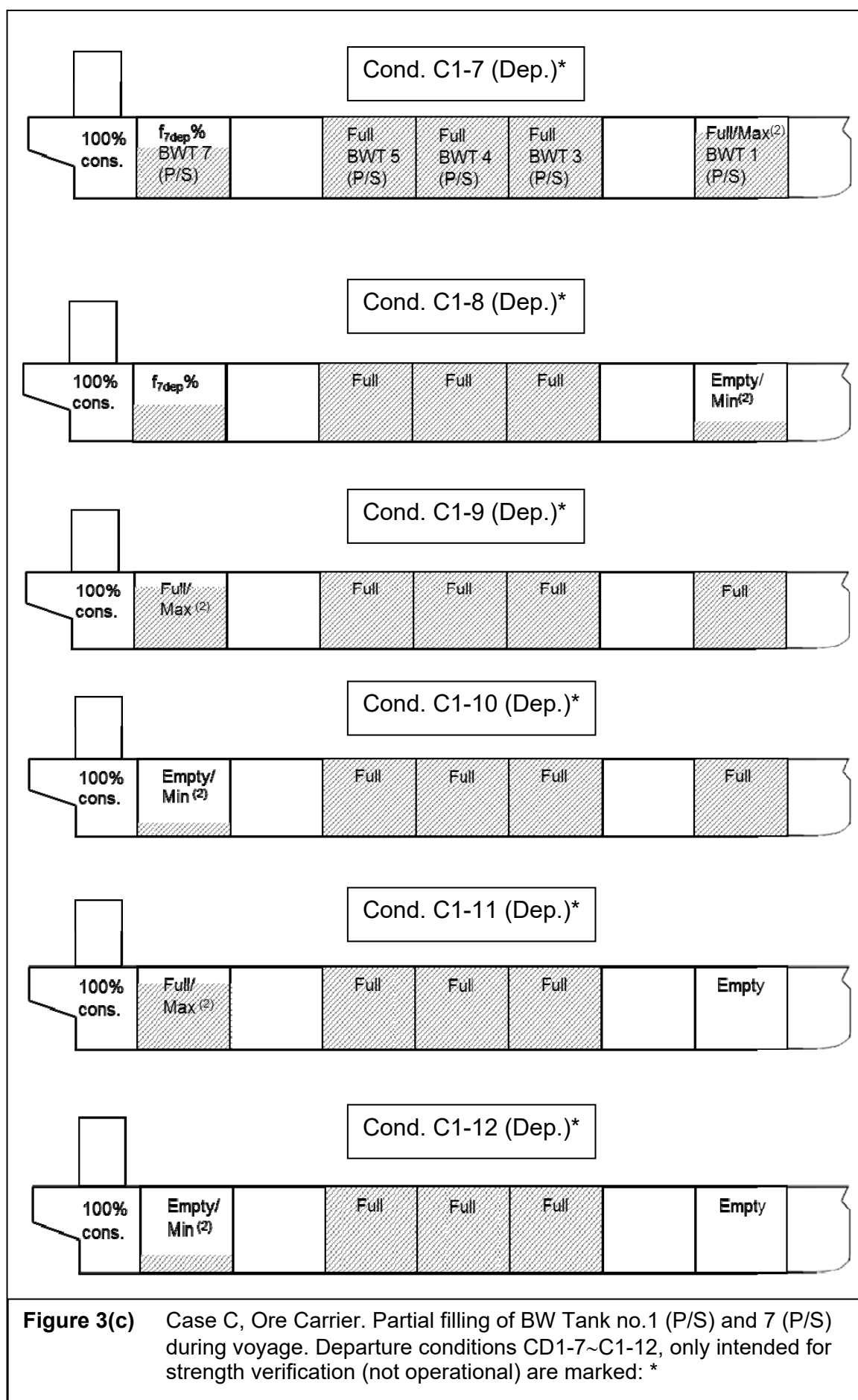
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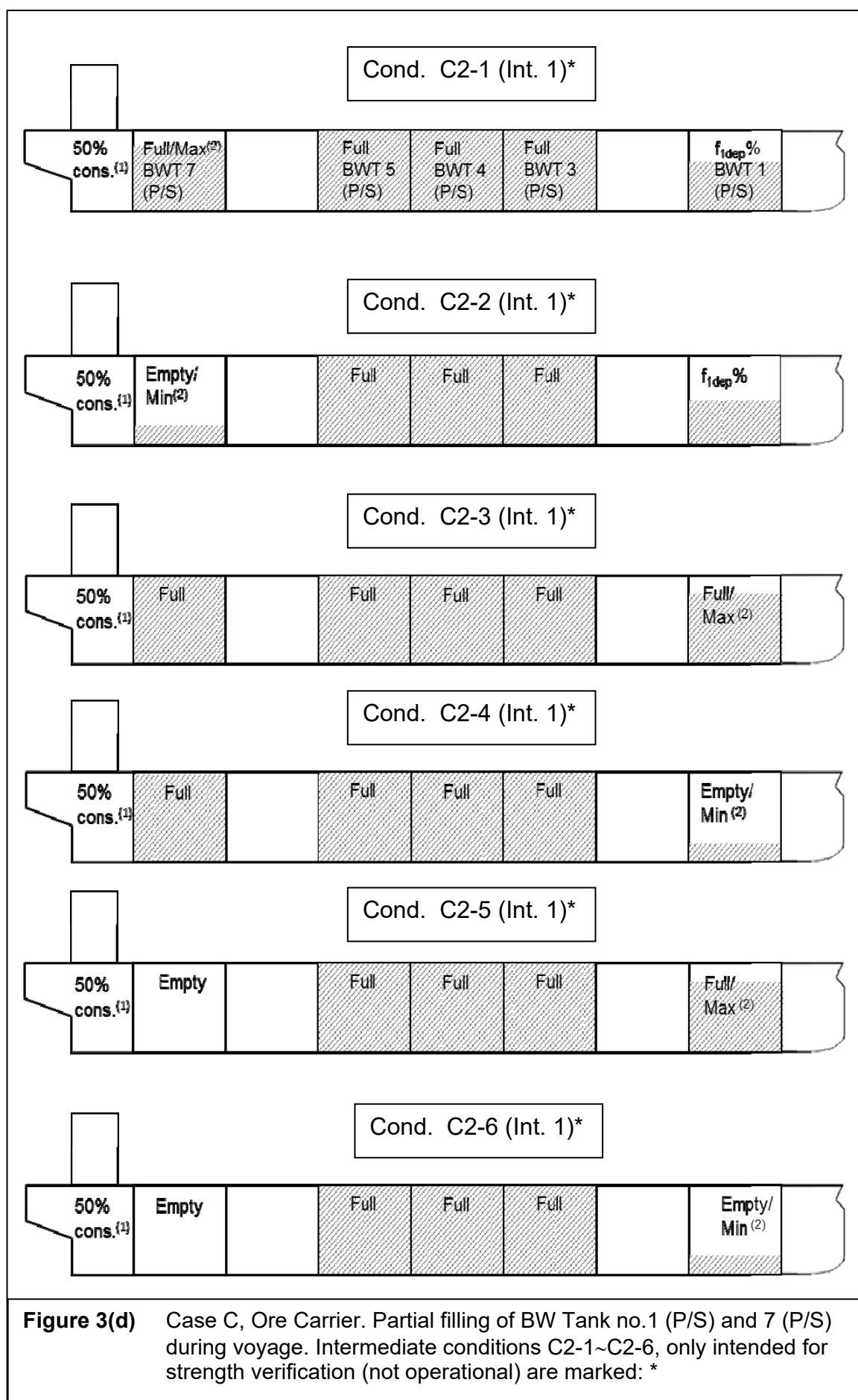
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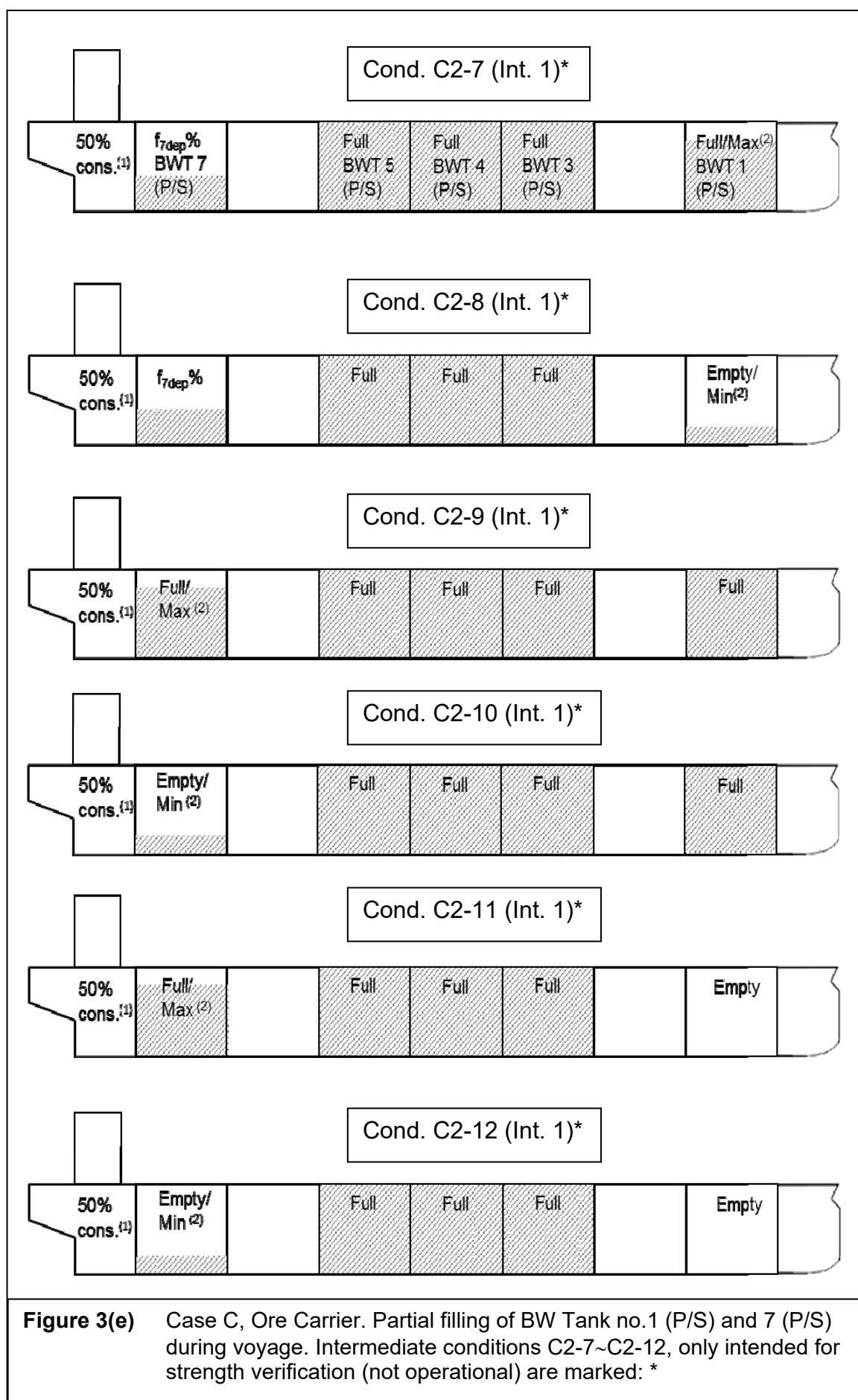
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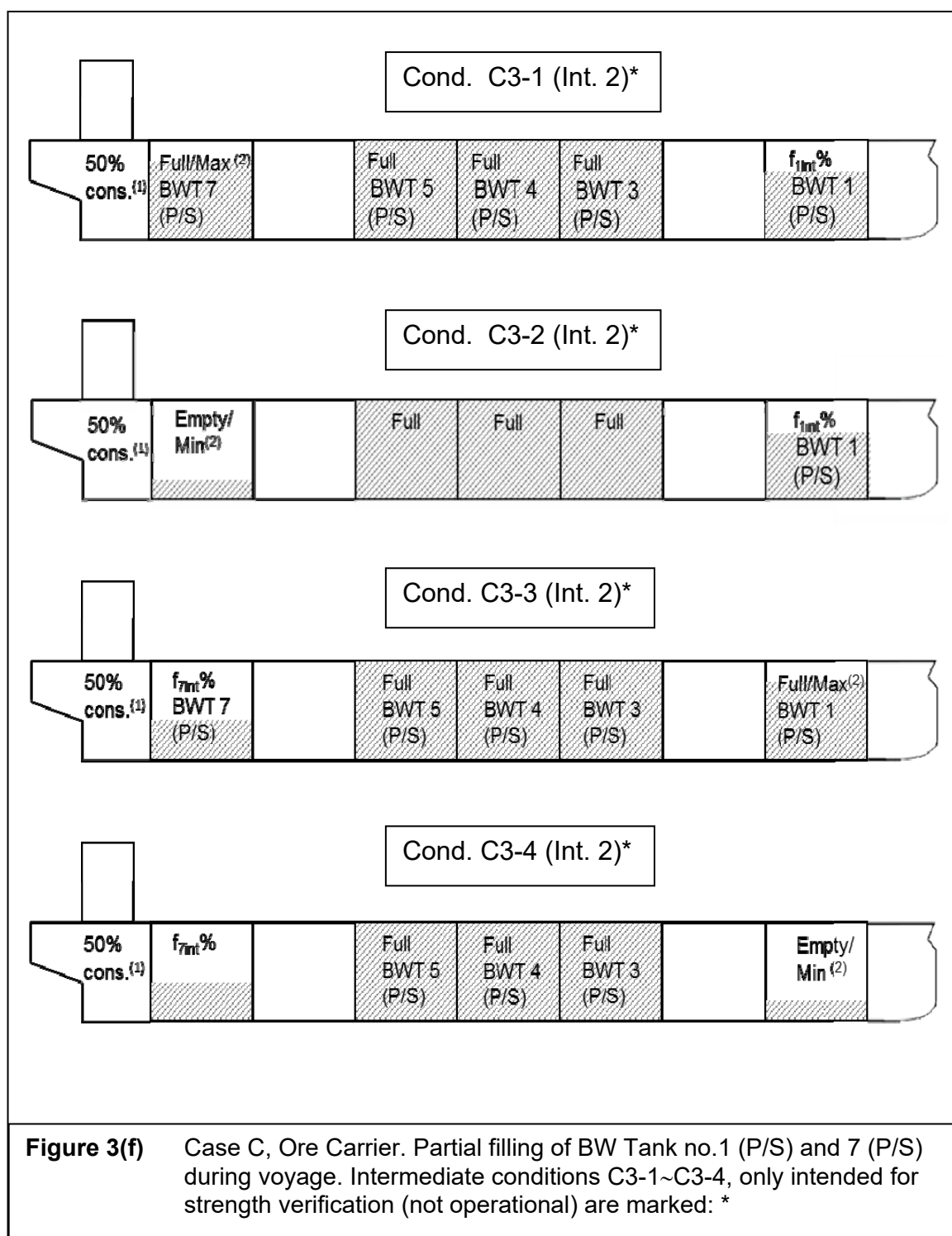
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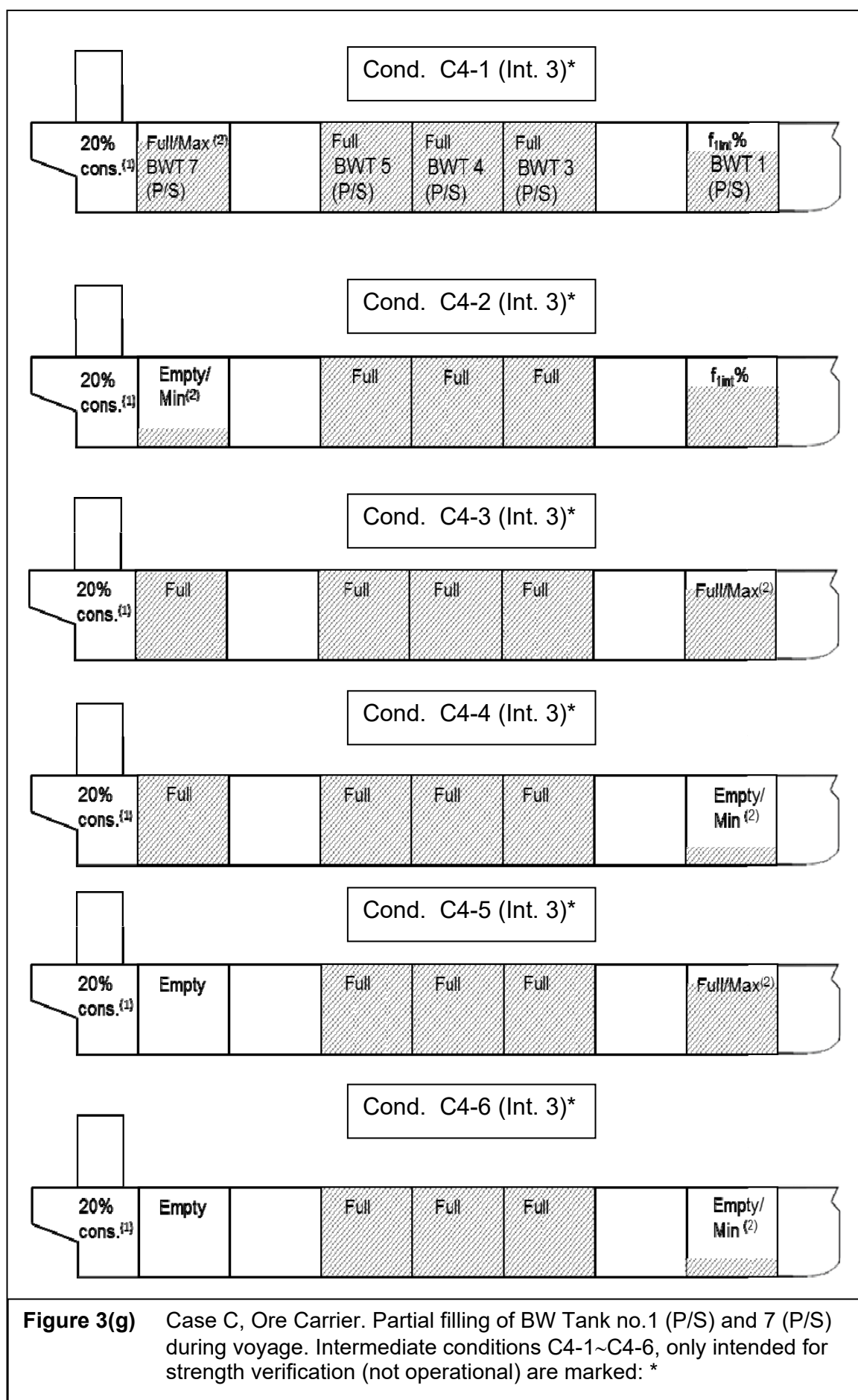
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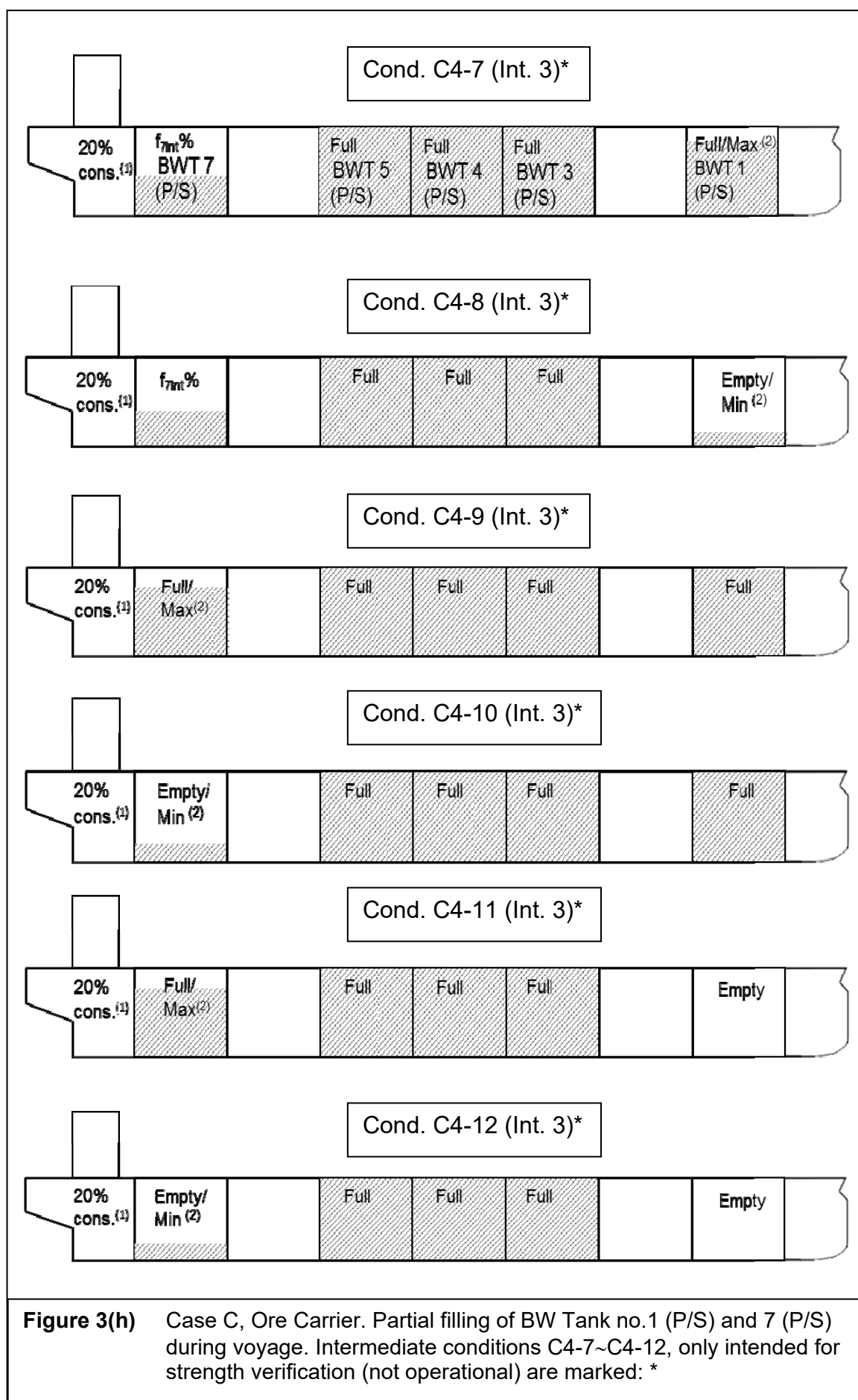
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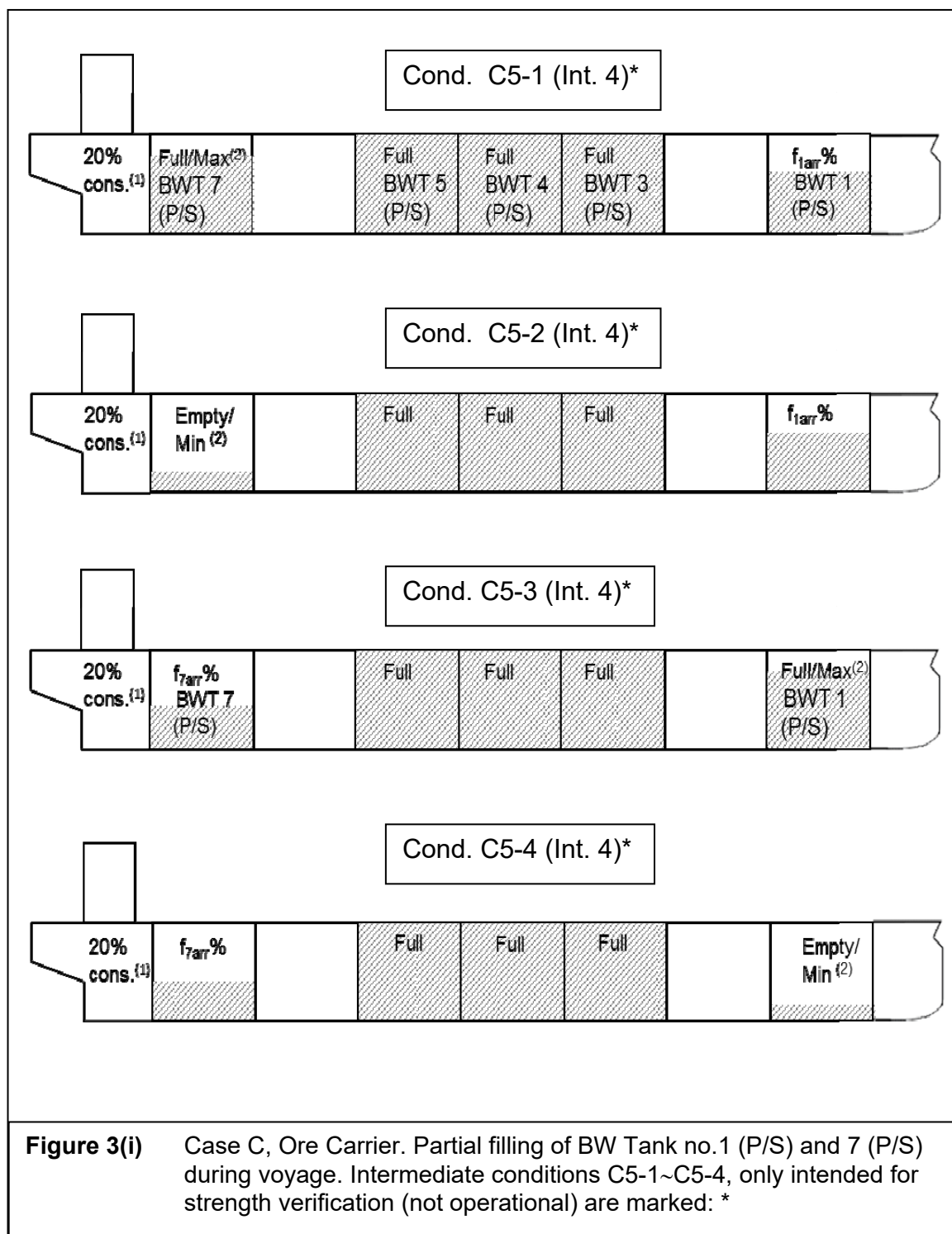
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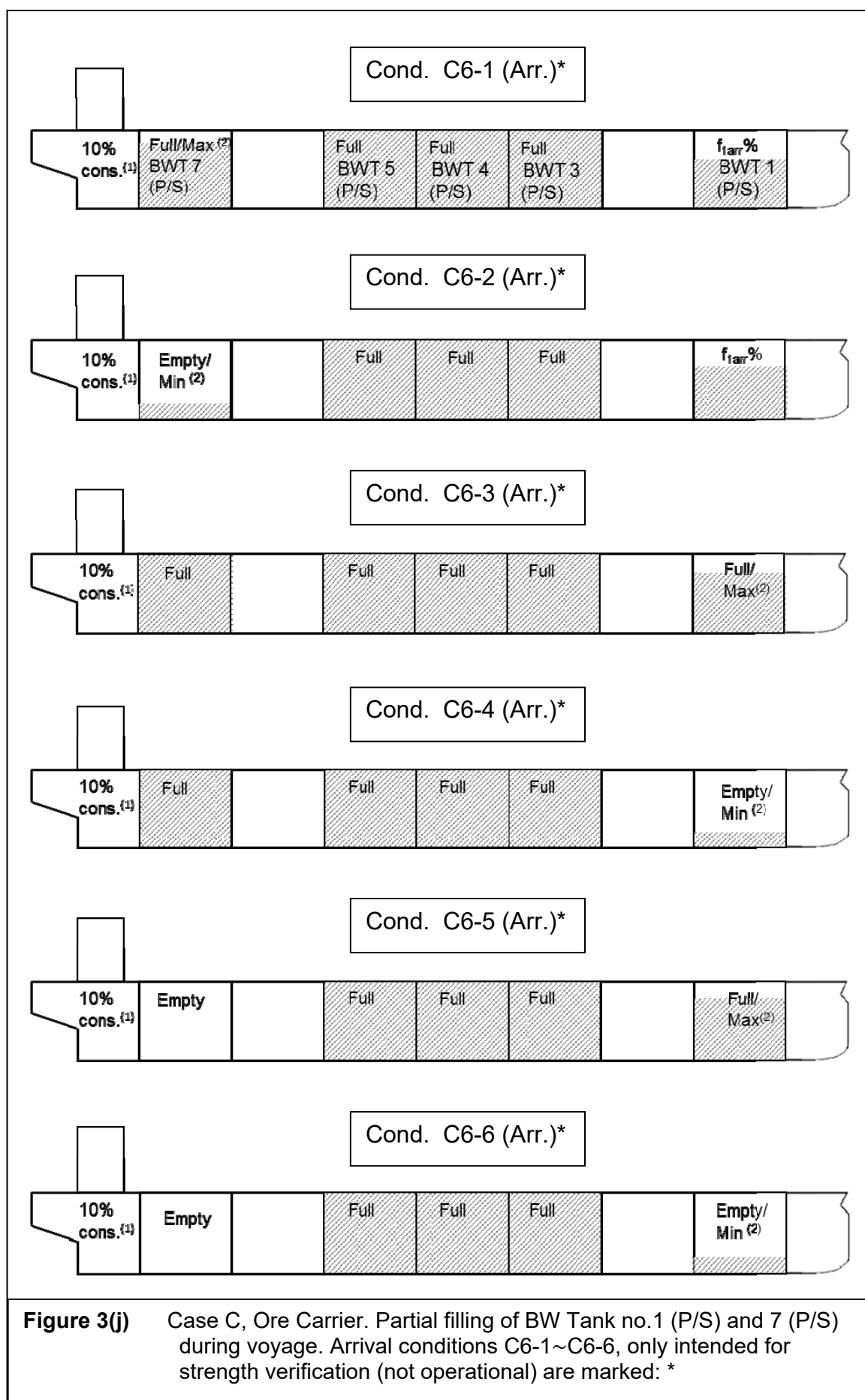
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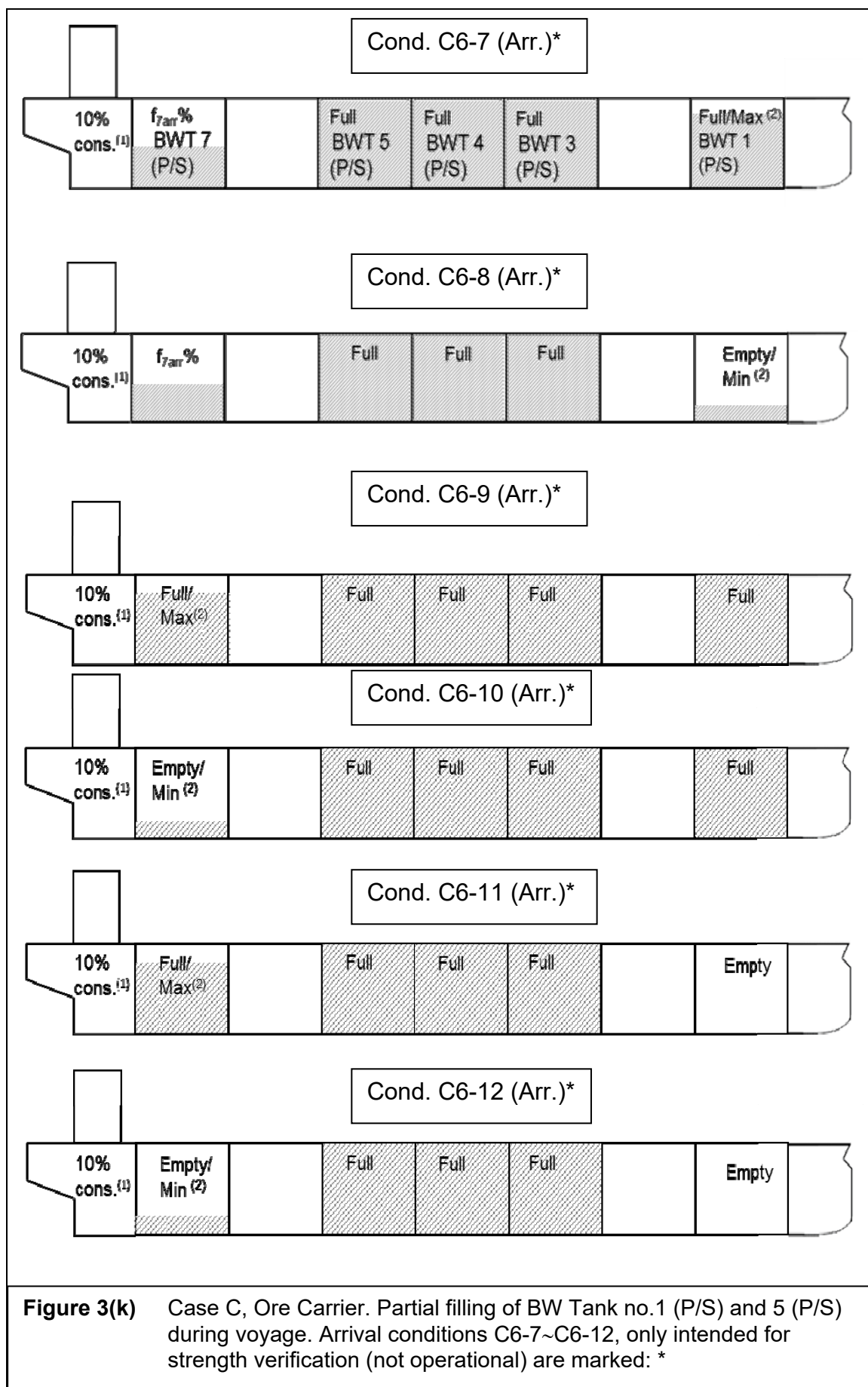
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S11A Longitudinal Strength Standard for Container Ships

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

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 $E = 2.06 \cdot 10^5$ 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-Hog}	Non-linear correction factor for hogging, see 2.3.2
f_{NL-Sag}	Non-linear correction factor for sagging, see 2.3.2

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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).

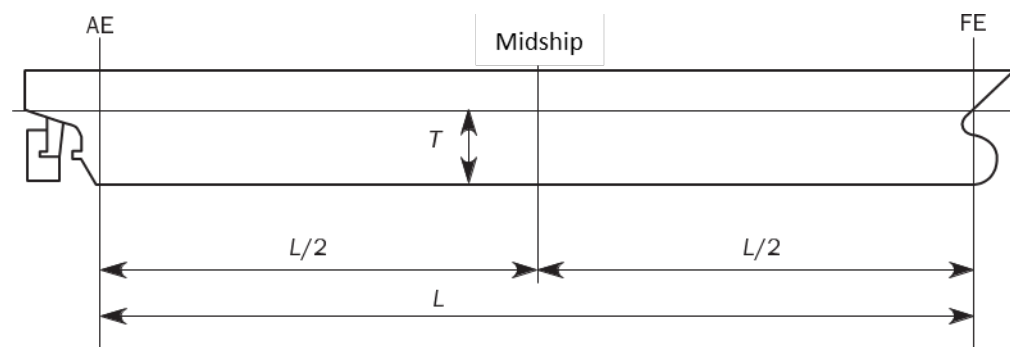


Figure 1: Ends of length L

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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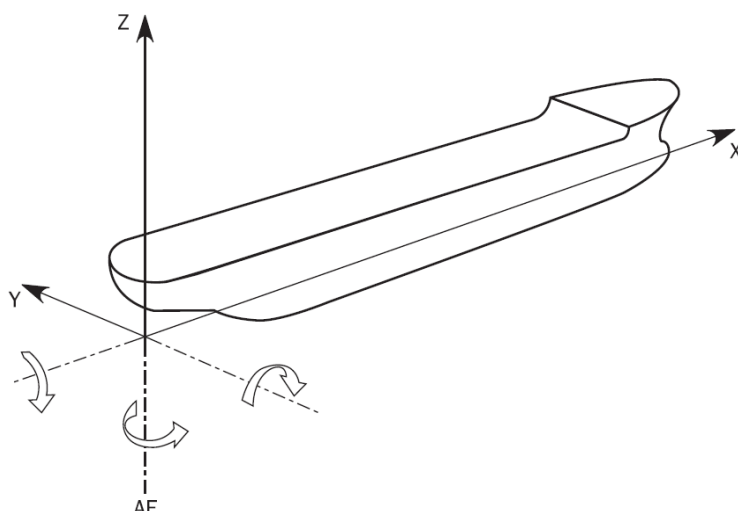


Figure 2: Reference coordinate system

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:

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

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

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

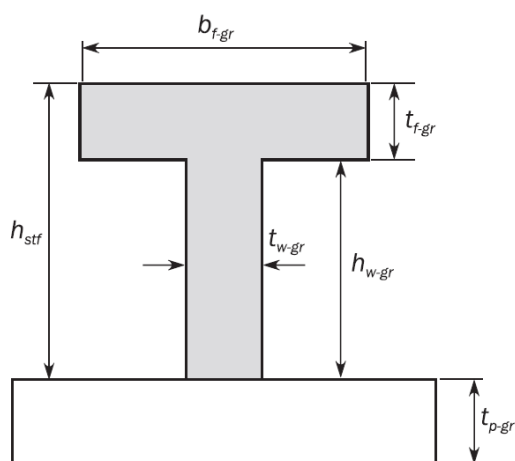
The corrosion addition of a stiffener is to be determined according to the location of its connection to the attached plating.

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

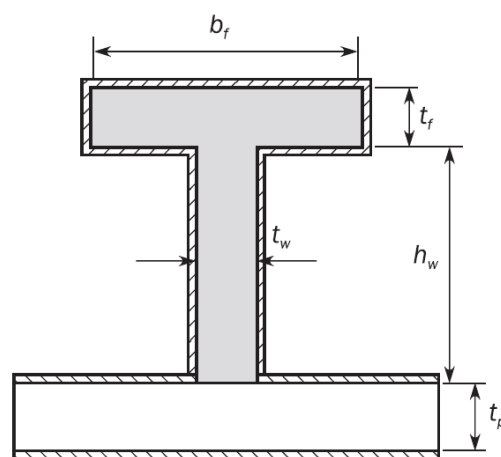
Compartment type	One side corrosion addition t_{c1} or t_{c2} [mm]
Exposed to sea water	1.0
Exposed to atmosphere	1.0
Ballast water tank	1.0
Void and dry spaces	0.5
Fresh water, fuel oil and lube oil tank	0.5
Accommodation spaces	0.0
Container holds	1.0
Compartment types not mentioned above	0.5

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 $0.5 at_c$ deducted from the surface of the profile cross-section.

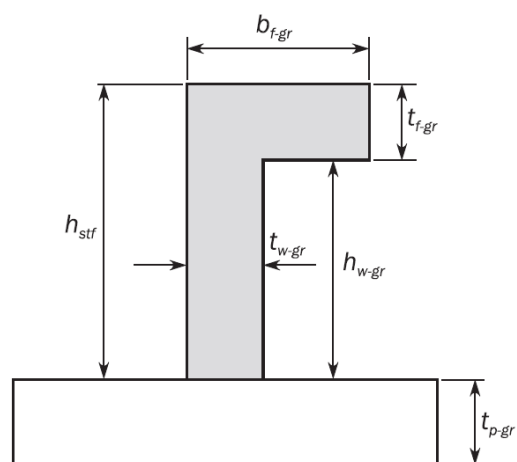


T - Profile

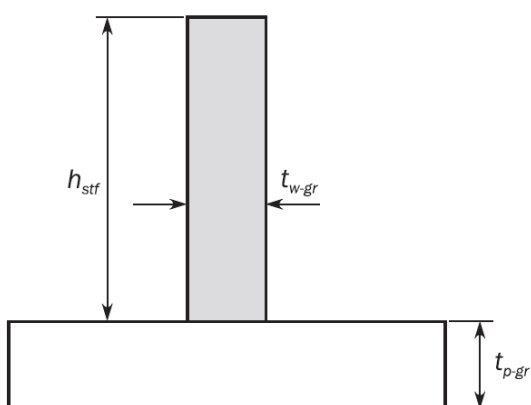
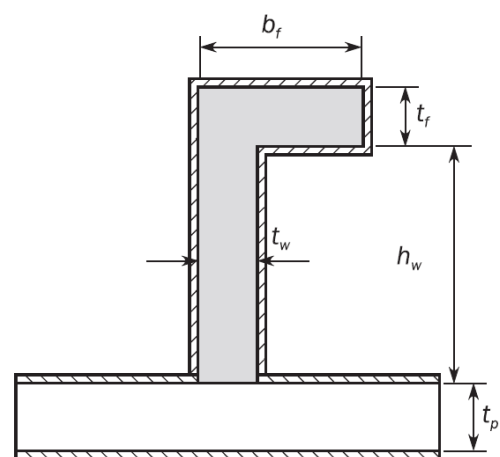


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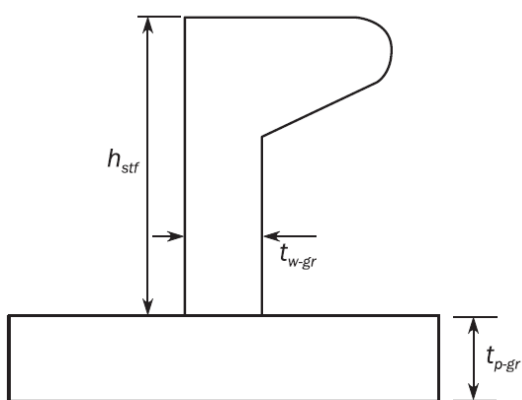
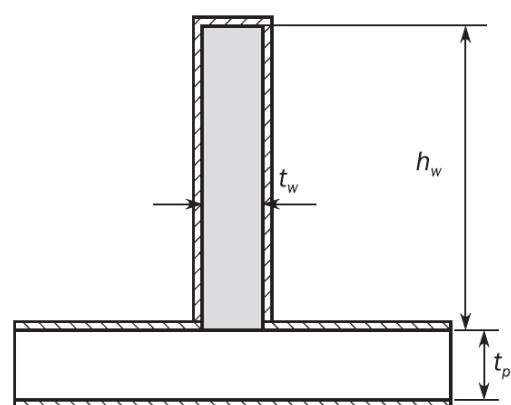
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L - Profile



FB - Profile



Bulb and similar profiles

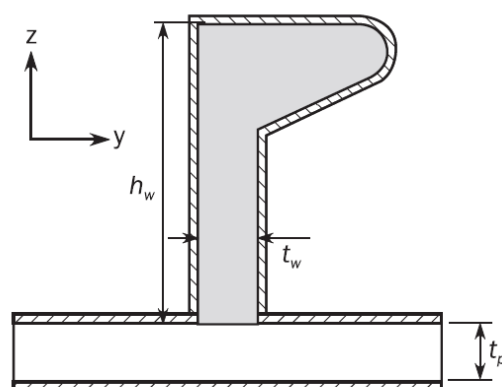


Figure 3: Net sectional properties of supporting members

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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.

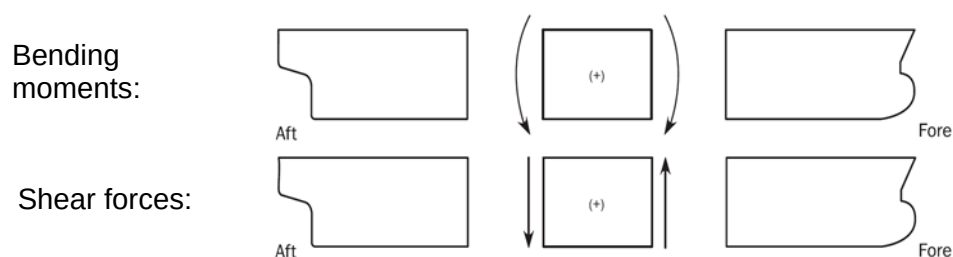


Figure 4: Sign conventions of bending moments and shear forces

S11A
(cont)**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.

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S11A.2.3 Wave loads**S11A.2.3.1 Wave parameter**

The wave parameter is defined as follows:

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

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

where:

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

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

$L_{ref} = 330C_W^{-1.3}$ 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

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(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 m² including the forecastle deck, if any, extending from 0.8L forward (see Figure 5). Any other structures, e.g. plated bulwark, are to be excluded.

A_{WL} : Waterplane area, in m², at draught T , extending from 0.8L 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.

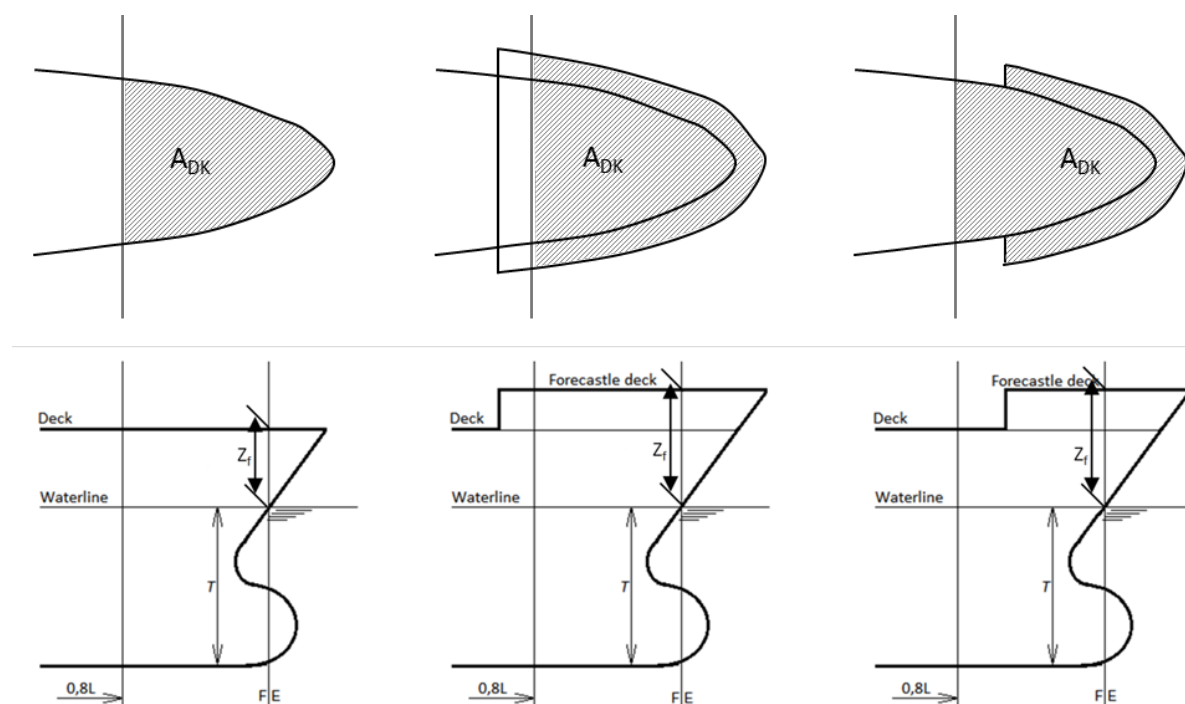


Figure 5: Projected area A_{DK} and vertical distance z_f

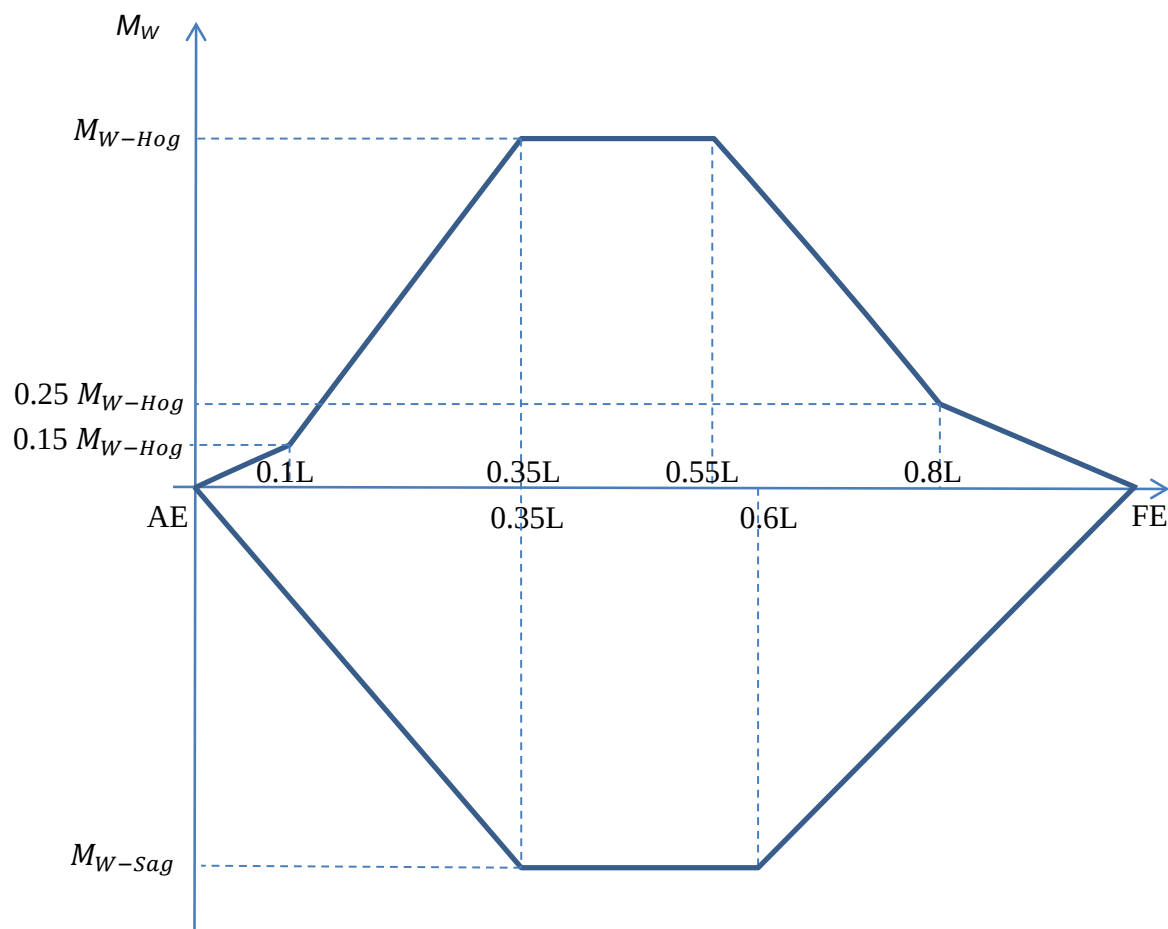
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Figure 6: Distribution of vertical wave bending moment M_W along the ship length

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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,

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

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

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

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

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

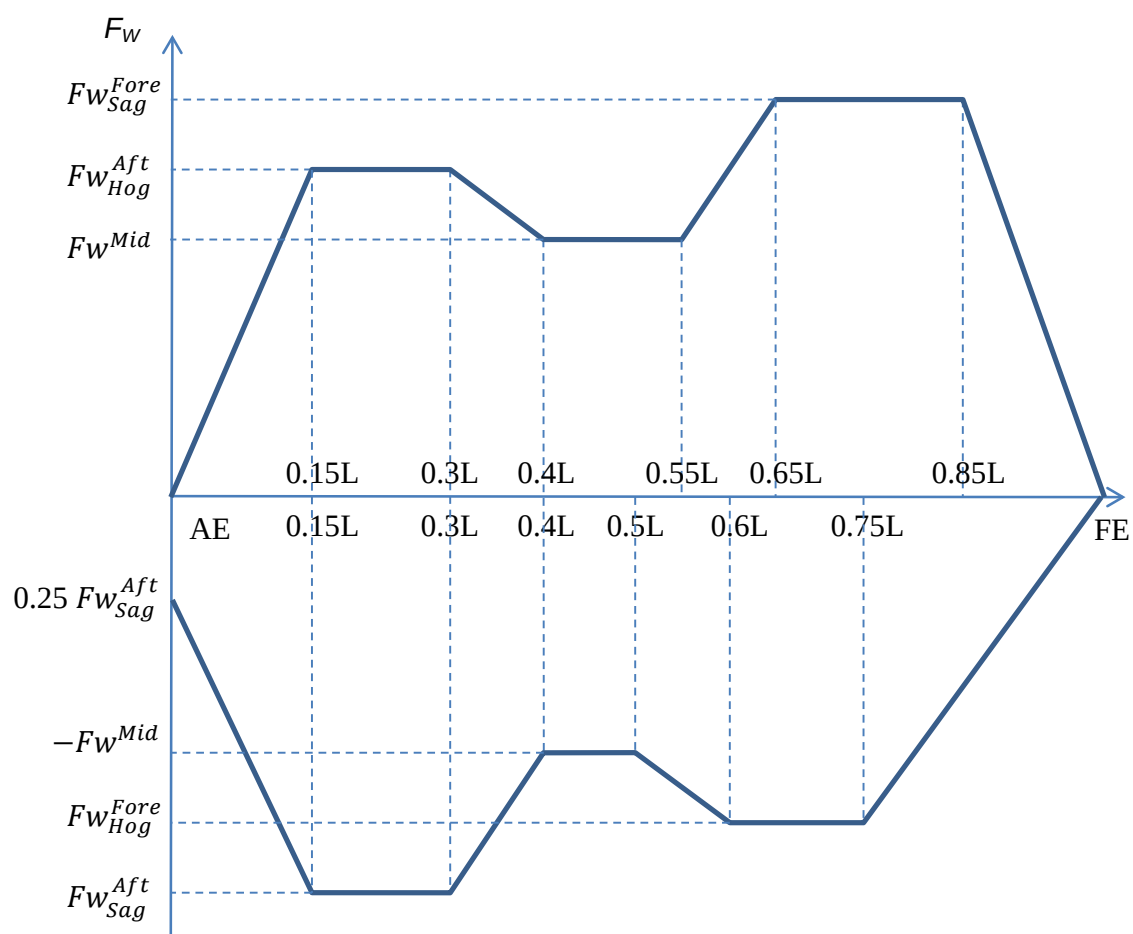


Figure 7: Distribution of vertical wave shear force F_w along the ship length

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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 $x \leq 0.5L$	F_{Wmax} for $x \leq 0.5L$
			F_{Smin} for $x > 0.5L$	F_{Wmin} for $x > 0.5L$
Sagging	M_{Smin}	M_{WS}	F_{Smin} for $x \leq 0.5L$	F_{Wmin} for $x \leq 0.5L$
			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.				

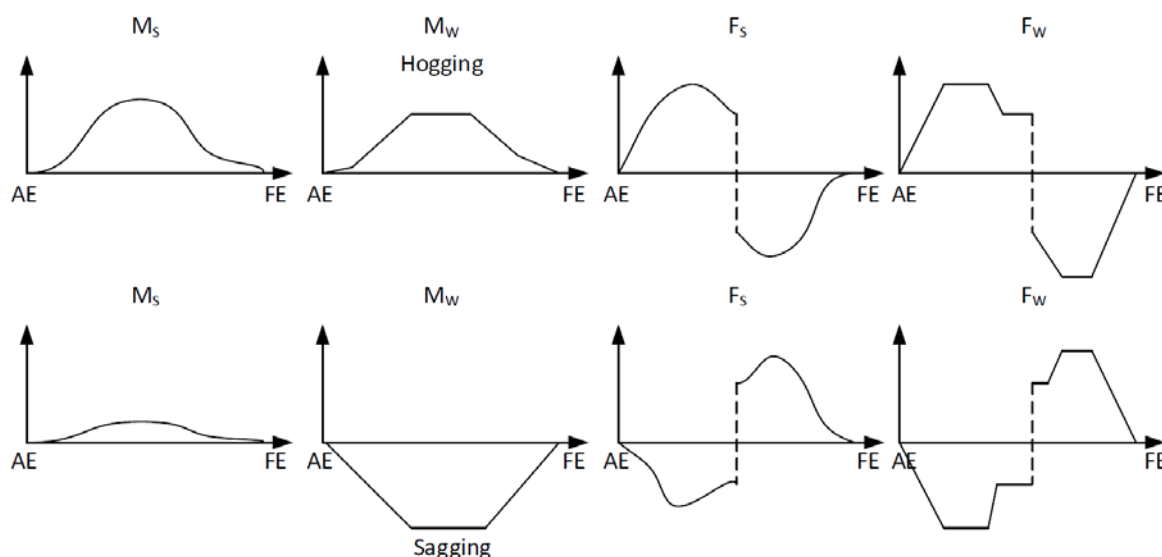


Figure 8: Load combination to determine the maximum hogging and sagging load cases as given in Table 3

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S11A.2.5 Hull girder stress

The hull girder stresses in N/mm² 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:

$$\gamma_s = 1.0$$

$$\gamma_w = 1.0$$

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 m⁴, is not to be less than:

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

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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/mm², is less than the permissible stress σ_{perm} , in N/mm², 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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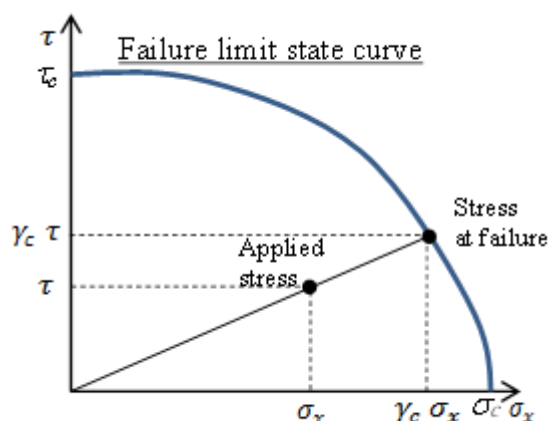


Figure 9: Example of failure limit state curve and stress multiplication factor at failure

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:

$$\begin{aligned}\sigma_x &= \sigma_{HG} \\ \sigma_y &= 0 \\ \tau &= 0.7\tau_{HG}\end{aligned}$$

Stress combination 2 with:

$$\begin{aligned}\sigma_x &= 0.7\sigma_{HG} \\ \sigma_y &= 0 \\ \tau &= \tau_{HG}\end{aligned}$$

b) Transverse stiffening arrangement:

Stress combination 1 with:

$$\begin{aligned}\sigma_x &= 0 \\ \sigma_y &= \sigma_{HG} \\ \tau &= 0.7\tau_{HG}\end{aligned}$$

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		

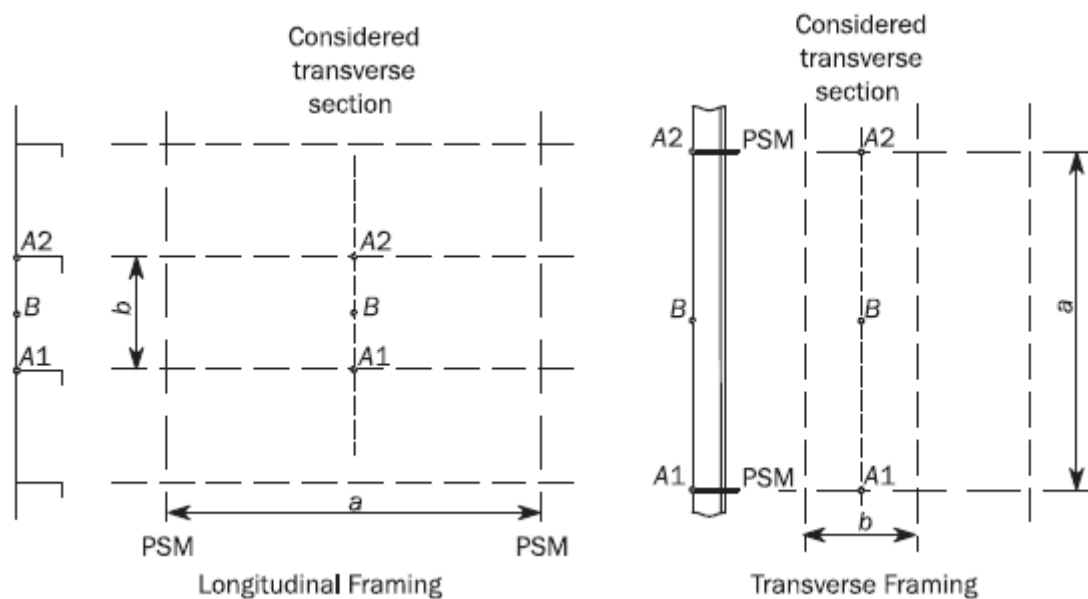


Figure 10: LCP for plate buckling – assessment, PSM stands for primary supporting members

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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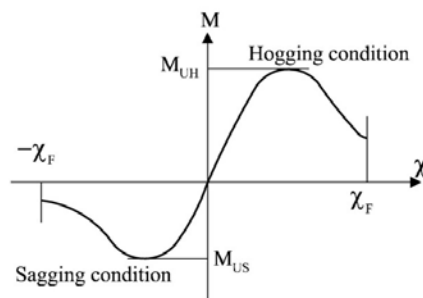


Figure 11: Bending moment M versus curvature χ

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:
 $\gamma_M = 1.05$

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: $\gamma_{DB} = 1.15$
- For sagging condition: $\gamma_{DB} = 1.0$

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 Annex 1 – Calculation of shear flow

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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:

$$q_D(s) = -\frac{1}{10^6 I_{y-net}} \int_0^s (z - z_n) t_{net} ds$$

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.

- S11A** ℓ : Length of line segments, in m.
- (cont) 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.

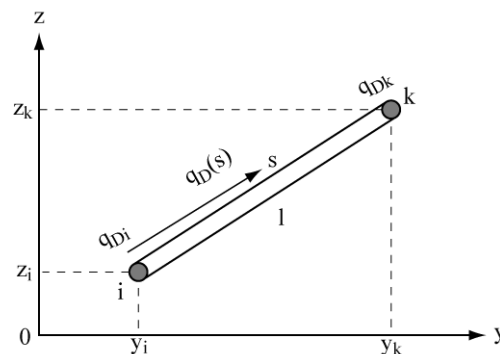


Figure 1: Definition of line segment

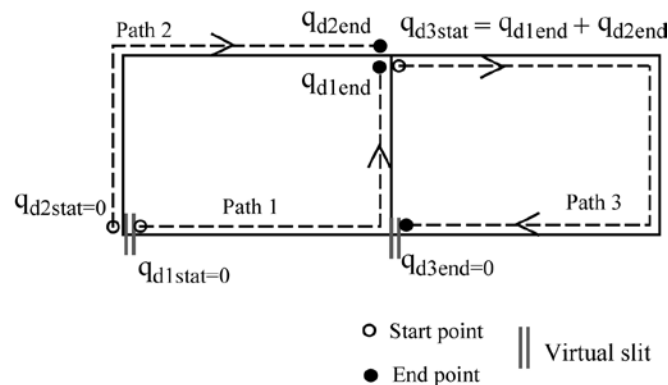


Figure 2: Placement of virtual slits and calculation of determinate shear flow at bifurcation points

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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$$q_{Ic} \oint_C \frac{1}{t_{net}} ds - \sum_{m=1}^{N_w} \left(q_{Im} \oint_{c\&m} \frac{1}{t_{net}} ds \right) = - \oint_c \frac{q_D}{t_{net}} ds$$

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:

$$q_{Ic} \sum_{j=1}^{N_c} \left(\frac{\ell}{t_{net}} \right)_j - \sum_{m=1}^{N_w} \left\{ q_{Im} \left[\sum_{j=1}^{N_m} \left(\frac{\ell}{t_{net}} \right)_j \right]_m \right\} = - \sum_{j=1}^{N_c} \phi_j$$

$$\phi_j = \left[- \frac{\ell^2}{6 \cdot 10^3 I_{Y-net}} (z_k + 2z_i - 3z_n) + \frac{\ell}{t_{net}} q_{Di} \right]_j$$

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.

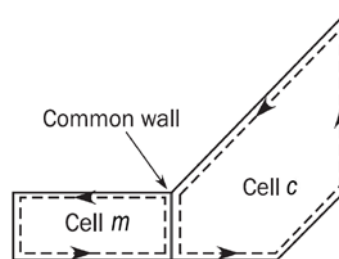


Figure 3: Closed cells and common wall

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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$$\ell = \sqrt{(y_k - y_i)^2 + (z_k - z_i)^2}$$

$$a_{net} = 10^{-3} \ell t_{net}$$

$$A_{net} = \sum a_{net}$$

$$s_{y-net} = \frac{a_{net}}{2} (z_k + z_i)$$

$$s_{y-net} = \sum s_{y-net}$$

$$i_{y0-net} = \frac{a_{net}}{3} (z_k^2 + z_k z_i + z_i^2)$$

$$I_{y0-net} = \sum i_{y0-net}$$

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:

$$I_{y-net} = I_{y0-net} - z_n^2 A_{net}$$

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/mm^2
σ_b	: Bending stress in the stiffener, in N/mm^2
σ_w	: Warping stress in the stiffener, in N/mm^2
$\sigma_{cx}, \sigma_{cy}, \tau_c$	: 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/mm^2
R_{eH_P}	: Specified minimum yield stress of the plate, in N/mm^2
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/mm^2
σ_2	: Minimum stress, in N/mm^2
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.

S11A

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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.

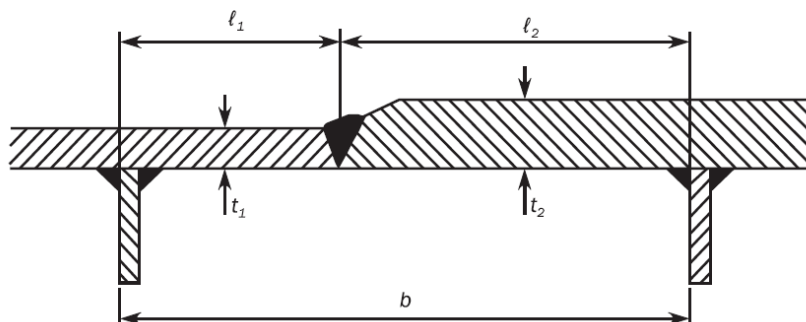


Figure 1: Plate thickness change over the width

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:

S11A

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$$\tau_c = C_\tau \frac{R_{eH-P}}{\sqrt{3}}$$

where:

C_x, C_y, C_τ : 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}

Structural element types			F_{long}	c
Unstiffened Panel			1.0	N/A
Stiffened Panel	Stiffener not fixed at both ends		1.0	N/A
	Stiffener fixed at both ends	Flat bar ⁽¹⁾	$F_{long} = c + 1 \quad \text{for} \quad \frac{t_w}{t_p} > 1$	0.10
		Bulb profile		0.30
		Angle profile		0.40
		T profile	$F_{long} = c \left(\frac{t_w}{t_p} \right)^3 + 1 \quad \text{for} \quad \frac{t_w}{t_p} \leq 1$	0.30
	Girder of high rigidity (e.g. bottom transverse)		1.4	N/A

⁽¹⁾ t_w is the net web thickness, in mm, without the correction defined in 4.3.5

S11A

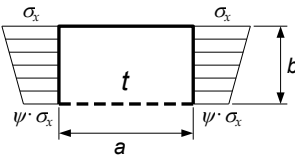
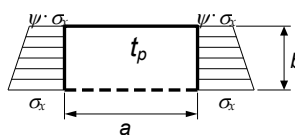
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Table 2: Buckling Factor and reduction factor for plane plate panels

Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
1	$\psi \geq 0$		$K_x = F_{long} \frac{8.4}{\psi + 1.1}$	$C_x = 1$ for $\lambda \leq \lambda_c$ $C_x = c \left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2} \right)$ for $\lambda > \lambda_c$ where: $c = (1.25 - 0.12\psi) \leq 1.25$ $\lambda_c = \frac{c}{2} \left(1 + \sqrt{1 - \frac{0.88}{c}} \right)$
	$0 > \psi \geq -1$		$K_x = F_{long} [7.63 - \psi (6.26 - 10\psi)]$	
	$\psi < -1$		$K_x = F_{long} [5.975(1 - \psi)^2]$	
2	$\psi \geq 0$		$K_y = \frac{2 \left(1 + \frac{1}{\alpha^2} \right)^2}{1 + \psi + \frac{(1 - \psi)}{100} \left(\frac{2.4}{\alpha^2} + 6.9f_1 \right)}$	$C_y = c \left(\frac{1}{\lambda} - \frac{R + F^2(H - R)}{\lambda^2} \right)$ where: $c = (1.25 - 0.12\psi) \leq 1.25$ $R = \lambda(1 - \lambda/c)$ for $\lambda < \lambda_c$ $R = 0.22$ for $\lambda \geq \lambda_c$ $\lambda_c = 0.5c \left(1 + \sqrt{1 - 0.88/c} \right)$ $F = \left(1 - \left(\frac{K}{0.91} - 1 \right) / \lambda_p^2 \right) c_1 \geq 0$ $\lambda_p^2 = \lambda^2 - 0.5$ for $1 \leq \lambda_p^2 \leq 3$ $c_1 = \left(1 - \frac{1}{\alpha} \right) \geq 0$ $H = \lambda - \frac{2\lambda}{c(T + \sqrt{T^2 - 4})} \geq R$ $T = \lambda + \frac{14}{15\lambda} + \frac{1}{3}$
		$\alpha \leq 6$	$f_1 = (1 - \psi)(\alpha - 1)$	
		$\alpha > 6$	$f_1 = 0.6 \left(1 - \frac{6\psi}{\alpha} \right) \left(\alpha + \frac{14}{\alpha} \right)$ But not greater than $14.5 - \frac{0.35}{\alpha^2}$	
	$0 > \psi \geq 1 - 4\alpha/3$		$K_y = \frac{200(1 + \beta^2)^2}{(1 - f_3)(100 + 2.4\beta^2 + 6.9f_1 + 23f_2)}$	
		$\alpha > 6(1 - \psi)$	$f_1 = 0.6 \left(\frac{1}{\beta} + 14\beta \right)$ but not greater than $14.5 - 0.35\beta^2$ $f_2 = f_3 = 0$	
		$\frac{3(1 - \psi) \leq \alpha \leq 6(1 - \psi)}{6(1 - \psi)}$	$f_1 = \frac{1}{\beta} - 1$ $f_2 = f_3 = 0$	
		$\frac{1.5(1 - \psi) \leq \alpha < 3(1 - \psi)}{3(1 - \psi)}$	$f_1 = \frac{1}{\beta} - (2 - \omega\beta)^4 - 9(\omega\beta - 1) \left(\frac{2}{3} - \beta \right)$ $f_2 = f_3 = 0$	

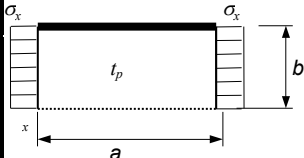
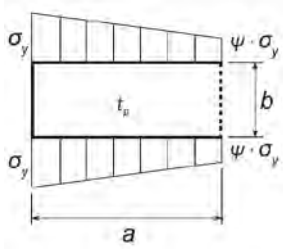
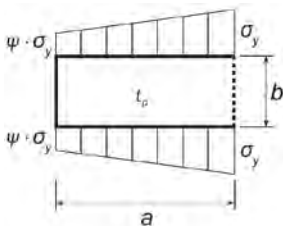
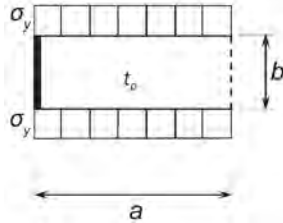
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Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
		$1 - \psi \leq \alpha < 1.5(1 - \psi)$	For $\alpha > 1.5$: $f_1 = 2 \left(\frac{1}{\beta} - 16 \left(1 - \frac{\psi}{3} \right)^4 \right) \left(\frac{1}{\beta} - 1 \right)$ $f_2 = 3\beta - 2$ $f_3 = 0$ For $\alpha \leq 1.5$: $f_1 = 2 \left(\frac{1.5}{1 - \psi} - 1 \right) \left(\frac{1}{\beta} - 1 \right)$ $f_2 = \frac{\psi(1 - 16f_4^2)}{1 - \alpha}$ $f_3 = 0$ $f_4 = (1.5 - \text{Min}(1.5; \alpha))^2$	
		$0.75(1 - \psi) \leq \alpha < 1 - \psi$	$f_1 = 0$ $f_2 = 1 + 2.31(\beta - 1) - 48 \left(\frac{4}{3} - \beta \right) f_4^2$ $f_3 = 3f_4(\beta - 1) \left(\frac{f_4}{1.81} - \frac{\alpha - 1}{1.31} \right)$ $f_4 = (1.5 - \text{Min}(1.5; \alpha))^2$	
	$\psi < 1 - 4\alpha/3$		$K_y = 5.972 \frac{\beta^2}{1 - f_3}$ where: $f_3 = f_5 \left(\frac{f_5}{1.81} + \frac{1 + 3\psi}{5.24} \right)$ $f_5 = \frac{9}{16} (1 + \text{Max}(-1; \psi))^2$	
3		$1 \geq \psi \geq 0$	$K_x = \frac{4(0.425 + 1/\alpha^2)}{3\psi + 1}$	$C_x = 1 \quad \text{for } \lambda \leq 0.7$ $C_x = \frac{1}{\lambda^2 + 0.51} \quad \text{for } \lambda > 0.7$
		$0 > \psi \geq -1$	$K_x = 4(0.425 + 1/\alpha^2)(1 + \psi)$ $-5\psi(1 - 3.42\psi)$	
4		$1 \geq \psi \geq -1$	$K_x = \left(0.425 + \frac{1}{\alpha^2} \right) \frac{3 - \psi}{2}$	

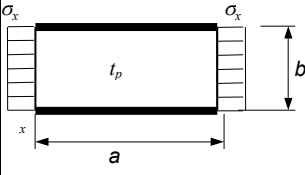
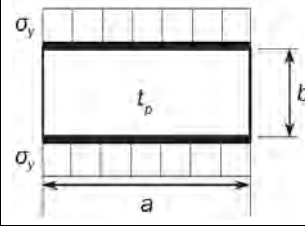
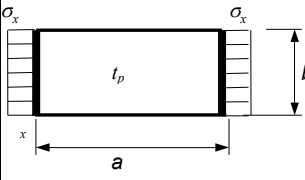
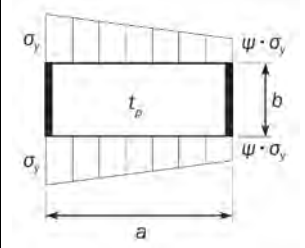
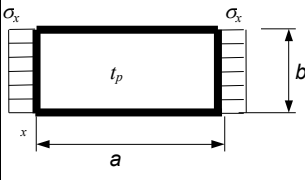
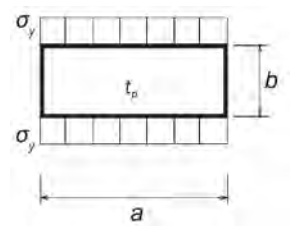
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Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
5 	—	$\alpha \geq 1.64$	$K_x = 1.28$	$C_y = 1$ for $\lambda \leq 0.7$ $C_y = \frac{1}{\lambda^2 + 0.51}$ for $\lambda > 0.7$
		$\alpha < 1.64$	$K_x = \frac{1}{\alpha^2} + 0.56 + 0.13\alpha^2$	
6 	$1 \geq \psi \geq 0$	$K_y = \frac{4(0.425 + \alpha^2)}{(3\psi + 1)\alpha^2}$		
	$0 > \psi \geq -1$	$K_y = 4(0.425 + \alpha^2)(1 + \psi) \frac{1}{\alpha^2} - 5\psi(1 - 3.42\psi) \frac{1}{\alpha^2}$		
7 	$1 \geq \psi \geq -1$	$K_y = (0.425 + \alpha^2) \frac{(3 - \psi)}{2\alpha^2}$		
8 	-	$K_y = 1 + \frac{0.56}{\alpha^2} + \frac{0.13}{\alpha^4}$		

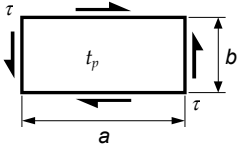
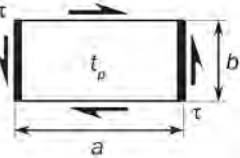
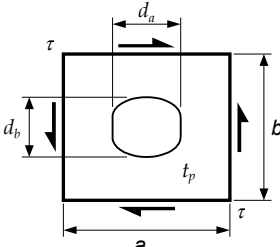
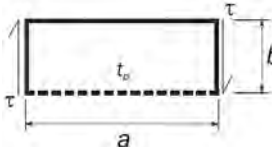
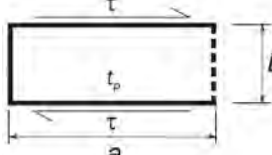
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Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
9 	-		$K_x = 6.97$	$C_x = 1$ for $\lambda \leq 0.83$ $C_x = 1.13 \left[\frac{1}{\lambda} - \frac{0.22}{\lambda^2} \right]$ for $\lambda > 0.83$
10 	-		$K_y = 4 + \frac{2.07}{\alpha^2} + \frac{0.67}{\alpha^4}$	
11 	-	$\alpha \geq 4$ $\alpha < 4$	$K_x = 4$ $K_x = 4 + 2.74 \left(\frac{4 - \alpha}{3} \right)^4$	
12 	-		$K_y = K_y$ determined as per case 2	- For $\alpha < 2$: $C_y = C_{y2}$ - For $\alpha \geq 2$: $C_y = \left(1.06 + \frac{1}{10\alpha} \right) C_{y2}$ where: $C_{y2} = C_y$ determined as per case 2
13 	-	$\alpha \geq 4$ $\alpha < 4$	$K_x = 6.97$ $K_x = 6.97 + 3.1 \left(\frac{4 - \alpha}{3} \right)^4$	$C_x = 1$ for $\lambda \leq 0.83$ $C_x = 1.13 \left[\frac{1}{\lambda} - \frac{0.22}{\lambda^2} \right]$ for $\lambda > 0.83$
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 $\lambda \leq 0.83$ $C_y = 1.13 \left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2} \right)$ for $\lambda > 0.83$

S11A

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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 $\lambda \leq 0.84$ $C_\tau = \frac{0.84}{\lambda}$ for $\lambda > 0.84$
16 	-		$K_\tau = \sqrt{3} \left\{ 5.34 + \text{Max} \left[\frac{4}{\alpha^2}; \frac{7.15}{\alpha^{2.5}} \right] \right\}$	
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 $\frac{d_a}{a} \leq 0.7$ and $\frac{d_b}{b} \leq 0.7$	
18 	-		$K_\tau = 3^{0.5} (0.6 + 4/\alpha^2)$	$C_\tau = 1$ for $\lambda \leq 0.84$ $C_\tau = \frac{0.84}{\lambda}$ 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 (σ_x, σ_y) is to be understood in local coordinates.				

2.2 Curved plate panels

This requirement for curved plate limit state is applicable when $R/t_p \leq 2500$. 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:

$$\left(\frac{\gamma_c \sigma_{ax}}{C_{ax} R_{eH_P}} \right)^{1.25} + \left(\frac{\gamma_c \tau \sqrt{3}}{C_\tau R_{eH_P}} \right)^2 = 1.0$$

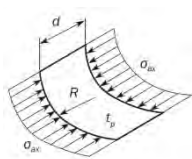
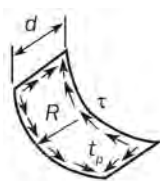
where:

σ_{ax} : Applied axial stress to the cylinder corresponding to the curved plate panel, in N/mm². In case of tensile axial stresses, $\sigma_{ax}=0$.

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 $R/t_p \leq 2500$

Case	Aspect ratio	Buckling factor K	Reduction factor C
1 	$\frac{d}{R} \leq 0.5 \sqrt{\frac{R}{t_p}}$	$K = 1 + \frac{2}{3} \frac{d^2}{R t_p}$	For general application: $C_{ax} = 1$ for $\lambda \leq 0.25$ $C_{ax} = 1.233 - 0.933\lambda$ for $0.25 < \lambda \leq 1$ $C_{ax} = 0.3/\lambda^3$ for $1 < \lambda \leq 1.5$ $C_{ax} = 0.2/\lambda^2$ for $\lambda > 1.5$ For curved single fields, e.g. bilge strake, which are bounded by plane panels: $C_{ax} = 0.65/\lambda^2 \leq 1.0$
	$\frac{d}{R} > 0.5 \sqrt{\frac{R}{t_p}}$	$K = 0.267 \frac{d^2}{R t_p} \left[3 - \frac{d}{R} \sqrt{\frac{t_p}{R}} \right]$ $\geq 0.4 \frac{d^2}{R t_p}$	
2 	$\frac{d}{R} \leq 8.7 \sqrt{\frac{R}{t_p}}$	$K = \sqrt{3} \sqrt{28.3 + \frac{0.67 d^3}{R^{1.5} t_p^{1.5}}}$	$C_\tau = 1$ for $\lambda \leq 0.4$ $C_\tau = 1.274 - 0.686\lambda$ for $0.4 < \lambda \leq 1.2$ $C_\tau = 0.65/\lambda^2$ for $\lambda > 1.2$
	$\frac{d}{R} > 8.7 \sqrt{\frac{R}{t_p}}$	$K = \sqrt{3} \frac{0.28 d^2}{R \sqrt{R t_p}}$	
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:

$$\ell_{eff} = \frac{\ell}{\sqrt{3}} \quad \text{for stiffener fixed at both ends.}$$

$$\ell_{eff} = 0.75\ell \quad \text{for stiffener simply supported at one end and fixed at the other.}$$

$$\ell_{eff} = \ell \quad \text{for stiffener simply supported at both ends.}$$

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:

$$b_{eff} = \min(b_{eff1}, \chi_s s)$$

where:

χ_s : Effective width coefficient to be taken as:

- $\chi_s = \min \left[\frac{1.12}{1 + \frac{1.75}{\left(\frac{\ell_{eff}}{s}\right)^{1.6}}}; 1 \right] \quad \text{for } \frac{\ell_{eff}}{s} \geq 1$
- $\chi_s = 0.407 \frac{\ell_{eff}}{s} \quad \text{for } \frac{\ell_{eff}}{s} < 1$

S11A

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4.3.4 Net thickness of attached plating t_p

The net thickness of plate 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 (S/I).
- 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 *moment* 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:

S11A

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$$\alpha = 1.1 + \frac{(120 - h'_w)^2}{3000} \quad \text{for } h'_w \leq 120$$

$$\alpha = 1.0 \quad \text{for } h'_w > 120$$

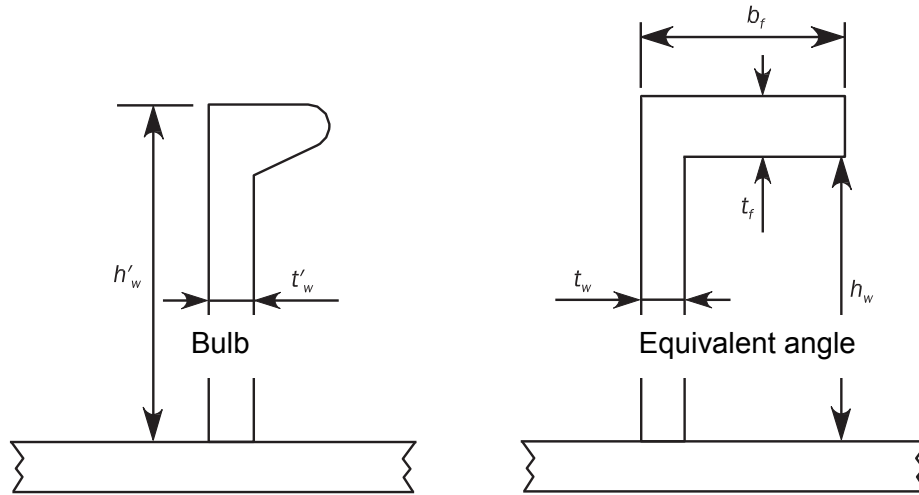


Figure 2: Idealisation of bulb stiffener

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/mm², defined in 4.4.3.

σ_w : Stress due to torsional deformation, in N/mm², defined in 4.4.4.

R_{eH} : Specified minimum yield stress of the material, in N/mm²:

- $R_{eH} = R_{eH-S}$ for stiffener induced failure (SI).
- $R_{eH} = R_{eH-P}$ for plate induced failure (PI).

S11A

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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/mm², 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 mm², 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 :

$$M_1 = C_i \frac{|P| s \ell^2}{24} 10^{-3} \quad \text{for continuous stiffener}$$

$$M_1 = C_i \frac{|P| s \ell^2}{8} 10^{-3} \quad \text{for sniped stiffener}$$

P : Lateral load, in kN/m², to be taken equal to the static pressure at the load calculation point of the stiffener.

C_i : Pressure coefficient:

$$C_i = C_{SI} \quad \text{for stiffener induced failure (SI).}$$

$$C_i = C_{PI} \quad \text{for plate induced failure (PI).}$$

C_{PI} : Plate induced failure pressure coefficient:

$$C_{PI} = 1 \quad \text{if the lateral pressure is applied on the side opposite to the stiffener.}$$

$$C_{PI} = -1 \quad \text{if the lateral pressure is applied on the same side as the stiffener.}$$

C_{SI} : Stiffener induced failure pressure coefficient:

$$C_{SI} = -1 \quad \text{if the lateral pressure is applied on the side opposite to the stiffener.}$$

$$C_{SI} = 1 \quad \text{if the lateral pressure is applied on the same side as the stiffener.}$$

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/mm², acting on the stiffener due to stresses σ_x and τ , in the attached plating in way of the stiffener mid span:

S11A

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$$P_z = \frac{t_p}{s} \left(\sigma_{x\ell} \left(\frac{\pi s}{\ell} \right)^2 + \sqrt{2} \tau_1 \right)$$

$$\sigma_{x\ell} = \gamma_c \sigma_x \left(1 + \frac{A_s}{s t_p} \right) \text{ but not less than } 0$$

$$\tau_1 = \left(\gamma_c |\tau| - t_p \sqrt{R_{eH-p} E \left(\frac{m_1}{a^2} + \frac{m_2}{s^2} \right)} \right) \geq 0 \text{ but not less than } 0$$

m_1, m_2 : 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:

- $w = \ell \cdot 10^{-3}$ 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/mm², 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:

$$c_{xa} = \left(\frac{\ell}{2s} + \frac{2s}{\ell} \right)^2 \quad \text{for } \ell \geq 2s$$

$$c_{xa} = \left(1 + \left(\frac{\ell}{2s} \right)^2 \right)^2 \quad \text{for } \ell < 2s$$

S11A

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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:

$$\sigma_w = E y_w \left(\frac{t_f}{2} + h_w \right) \Phi_0 \left(\frac{\pi}{\ell} \right)^2 \left(\frac{1}{1 - \frac{0.4 R_{eH-S}}{\sigma_{ET}}} - 1 \right) \text{ for stiffener induced failure (SI).}$$

$$\sigma_w = 0 \quad \text{for plate induced failure (PI).}$$

where:

y_w : Distance, in mm, from centroid of stiffener cross-section to the free edge of stiffener flange, to be taken as:

$$y_w = \frac{t_w}{2} \quad \text{for flat bar.}$$

$$y_w = b_f - \frac{h_w t_w^2 + t_f b_f^2}{2 A_s} \quad \text{for angle and bulb profiles.}$$

$$y_w = \frac{b_f}{2} \quad \text{for Tee profile.}$$

$$\Phi_0 = \frac{\ell}{h_w} 10^{-3}$$

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.

$$\varepsilon = 1 + \frac{\left(\frac{\ell}{\pi} \right)^2 10^{-3}}{\sqrt{I_\omega \left(\frac{0.75 S}{t_p^3} + \frac{e_f^{-0.5} t_f}{t_w^3} \right)}}$$

S11A

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Table 4: Moments of inertia

	Flat bars	Bulb, angle and Tee profiles
I_P	$\frac{h_w^3 t_w}{3 \cdot 10^4}$	$\left(\frac{A_w (e_f - 0.5 t_f)^2}{3} + A_f e_f^2 \right) 10^{-4}$
I_T	$\frac{h_w t_w^3}{3 \cdot 10^4} \left(1 - 0.63 \frac{t_w}{h_w} \right)$	$\frac{(e_f - 0.5 t_f) t_w^3}{3 \cdot 10^4} \left(1 - 0.63 \frac{t_w}{e_f - 0.5 t_f} \right)$ $+ \frac{b_f t_f^3}{3 \cdot 10^4} \left(1 - 0.63 \frac{t_f}{b_f} \right)$
I_w	$\frac{h_w^3 t_w^3}{36 \cdot 10^6}$	$\frac{A_f e_f^2 b_f^2}{12 \cdot 10^6} \left(\frac{A_f + 2.6 A_w}{A_f + A_w} \right)$ for bulb and angle profiles. $\frac{b_f^3 t_f e_f^2}{12 \cdot 10^6}$ for Tee profiles.
A_w : Net web area, in mm ² . A_f : Net flange area, in mm ² .		

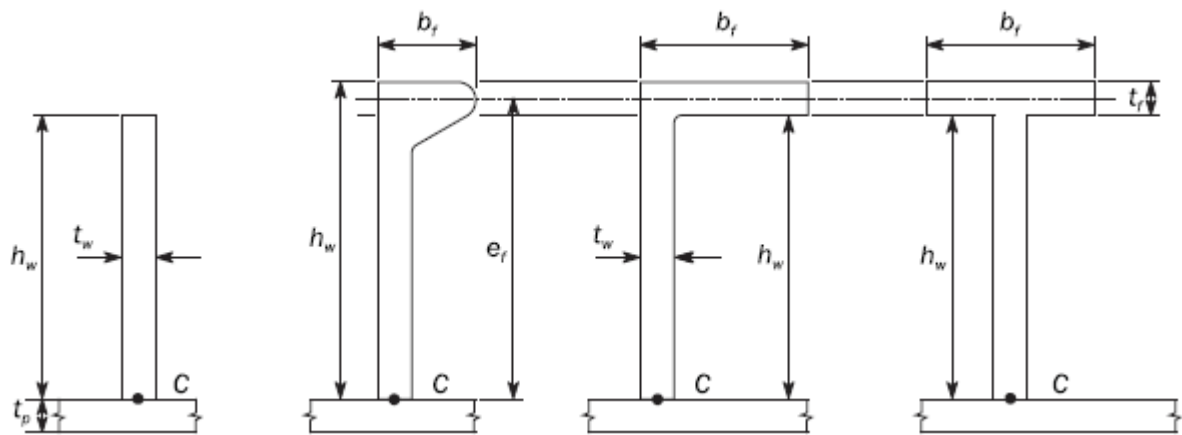


Figure 3: Stiffener cross sections

S11A Annex 3 - Hull girder ultimate bending capacity

(Cont)

Symbols

I_{y-net} :	Net moment of inertia, in m^4 , of the hull transverse section around its horizontal neutral axis
Z_{B-net} , Z_{D-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-net} :	Net sectional area, in cm^2 , of stiffener, without attached plating.
A_{p-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 .

S11A

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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.

$$M_{Y1} = 10^3 R_{eH} Z_{B-net}.$$

$$M_{Y2} = 10^3 R_{eH} Z_{D-net}.$$

If the value χ_F is not sufficient to evaluate the peaks of the curve $M_{-\chi}$, 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 $M_{-\chi}$ 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

S11A

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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:

$$\Sigma A_{i-net} \sigma_i = \Sigma A_{j-net} \sigma_j \quad (i\text{-th element is under compression, } j\text{-th element under tension}).$$

- f) Step 6: Calculate the corresponding moment by summing the contributions of all elements as:

$$M_U = \sum \sigma_{U_i} A_{i-net} (z_i - z_{NA_cur})$$

- g) Step 7: Compare the moment in the current incremental step with the moment in the previous incremental step. If the slope in $M_{-\chi}$ 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.

S11A

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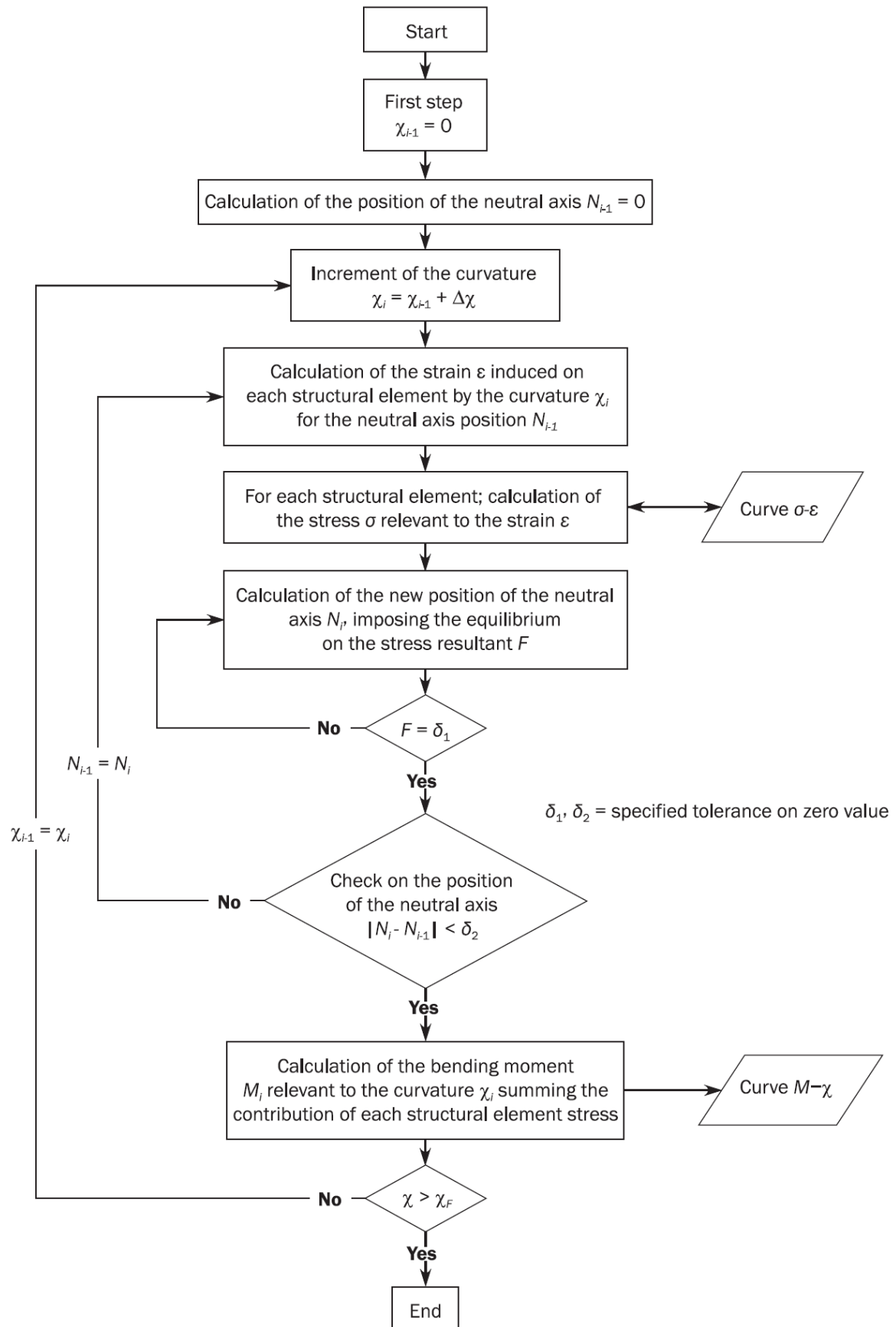


Figure 1: Flow chart of the procedure for the evaluation of the curve $M-\chi$

S11A**(cont)****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.

S11A

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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.

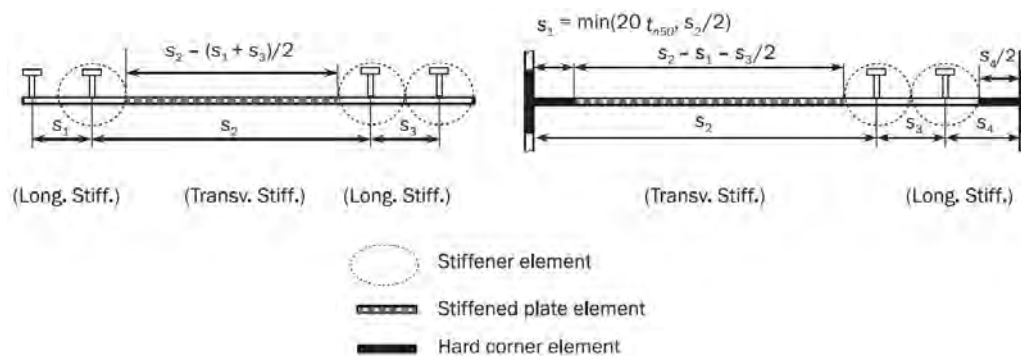


Figure 2: Extension of the breadth of the attached plating and hard corner element

S11A

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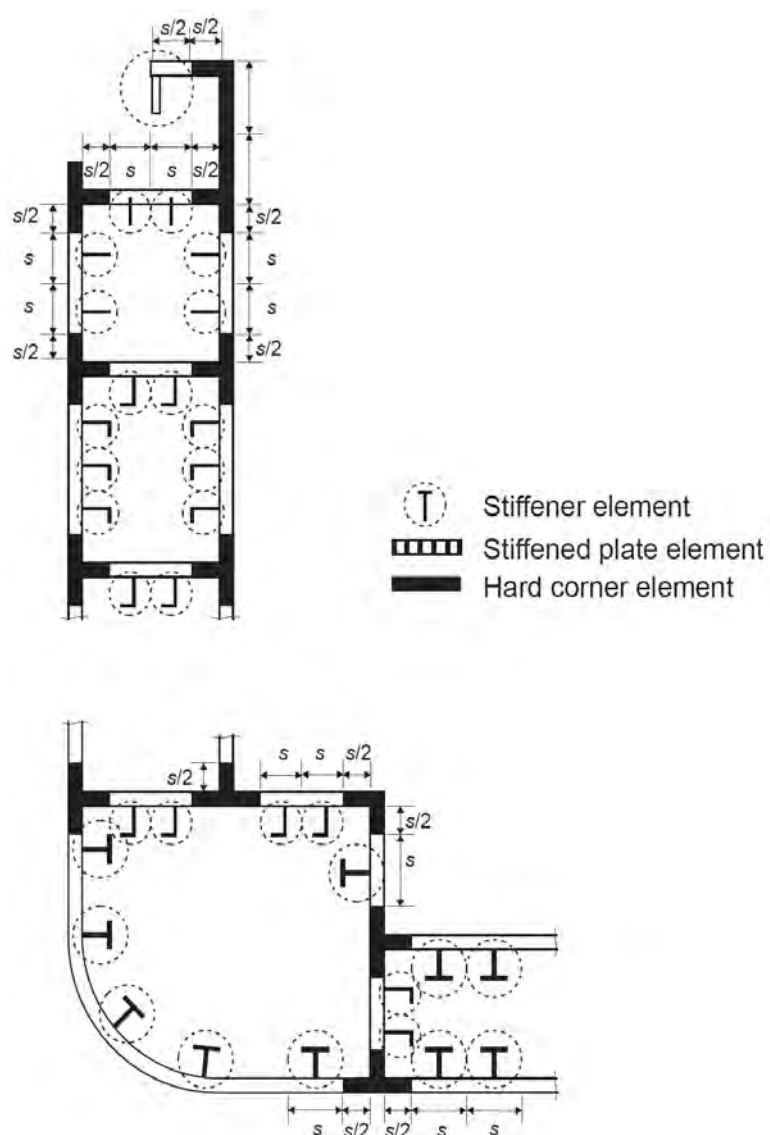


Figure 3: Examples of the configuration of stiffened plate elements, stiffener elements and hard corner elements on a hull section

S11A

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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.

$$t_{net} = \frac{t_{1-net} s_1 + t_{2-net} s_2}{s} \quad R_{eH-P} = \frac{R_{eH-P1} t_{1-net} s_1 + R_{eH-P2} t_{2-net} s_2}{t_{net} s}$$

where R_{eH-P1} , R_{eH-P2} , t_{1-net} , t_{2-net} , s_1 , s_2 and s are shown in Figure 5

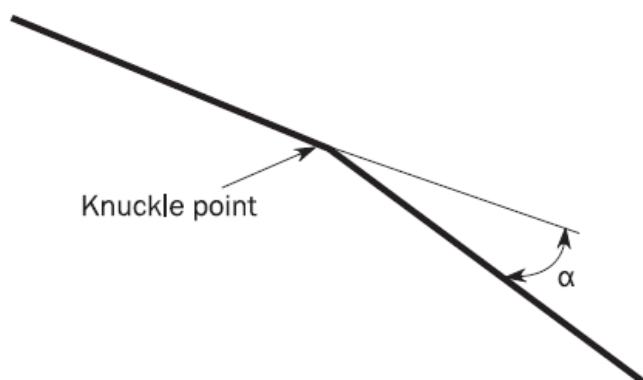


Figure 4: Plating with knuckle point

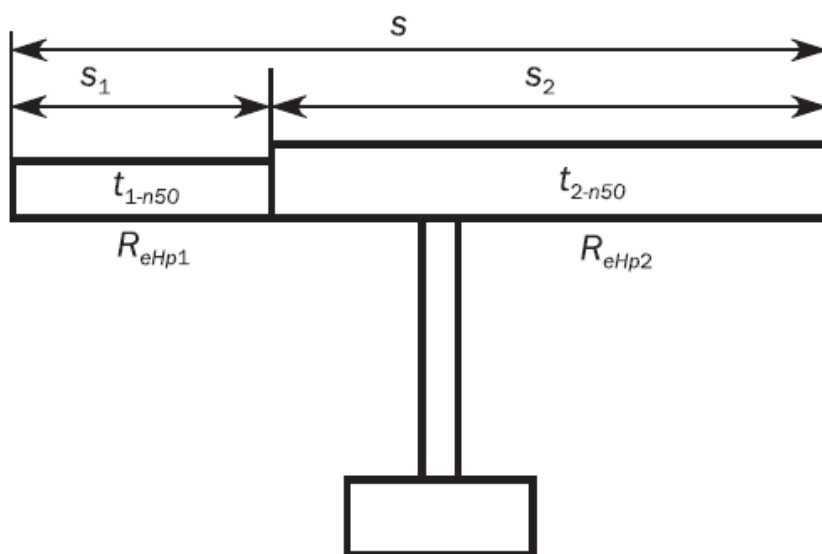


Figure 5: Element with different thickness and yield strength

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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:

S11A

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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:

$$\begin{aligned}\Phi &= -1 \text{ for } \varepsilon < -1 \\ \Phi &= \varepsilon \text{ for } -1 \leq \varepsilon \leq 1 \\ \Phi &= 1 \text{ for } \varepsilon > 1\end{aligned}$$

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/mm², 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/mm², 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 cm², equal to:

S11A

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$$A_{pEI-net} = 10b_{E1}t_{net}$$

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/mm², 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 cm⁴, with attached plate of width b_{E1}

A_{E-net} : Net area, in cm², 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:

$$b_{E1} = \frac{s}{\beta_E} \quad \text{for } \beta_E > 1.0$$

$$b_{E1} = s \quad \text{for } \beta_E \leq 1.0$$

$$\beta_E: \quad \beta_E = 10^3 \frac{s}{t_{net}} \sqrt{\frac{\varepsilon R_{eH-P}}{E}}$$

A_{pE-net} : Net area, in cm², of attached plating of width b_E , equal to:

$$A_{pE-net} = 10b_E t_{net}$$

b_E : Effective width, in m, of the attached plating, equal to:

$$b_E = \left(\frac{2.25}{\beta_E} - \frac{1.25}{\beta_E^2} \right) s \quad \text{for } \beta_E > 1.25$$

$$b_E = s \quad \text{for } \beta_E \leq 1.25$$

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

S11A

(cont)

σ_{C2} : Critical stress, in N/mm², equal to:

$$\sigma_{C2} = \frac{\sigma_{E2}}{\varepsilon} \quad \text{for } \sigma_{E2} \leq \frac{R_{eH-S}}{2} \varepsilon$$

$$\sigma_{C2} = R_{eH-S} \left(1 - \frac{R_{eH-S} \varepsilon}{4\sigma_{E2}} \right) \quad \text{for } \sigma_{E2} > \frac{R_{eH-S}}{2} \varepsilon$$

ε : Relative strain, as defined in 2.3.2

σ_{E2} : Euler column buckling stress, in N/mm², taken as σ_{ET} defined in Annex 2 4.4.4

σ_{CP} : Buckling stress of the attached plating, in N/mm², equal to:

$$\sigma_{CP} = \left(\frac{2.25}{\beta_E} - \frac{1.25}{\beta_E^2} \right) R_{eH-P} \quad \text{for } \beta_E > 1.25$$

$$\sigma_{CP} = R_{eH-P} \quad \text{for } \beta_E \leq 1.25$$

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:

$$h_{we} = \left(\frac{2.25}{\beta_w} - \frac{1.25}{\beta_w^2} \right) h_w \quad \text{for } \beta_w \geq 1.25$$

$$h_{we} = h_w \quad \text{for } \beta_w < 1.25$$

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/mm², as defined in 2.3.4.

σ_{C4} : Critical stress, in N/mm², equal to:

$$\begin{aligned} \sigma_{C4} &= \frac{\sigma_{E4}}{\varepsilon} & \text{for } \sigma_{E4} \leq \frac{R_{eH-S}}{2} \varepsilon \\ \sigma_{C4} &= R_{eH-S} \left(1 - \frac{R_{eH-S} \varepsilon}{4 \sigma_{E4}} \right) & \text{for } \sigma_{E4} > \frac{R_{eH-S}}{2} \varepsilon \end{aligned}$$

σ_{E4} : Local Euler buckling stress, in N/mm², 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

S11A

(cont)

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, $M_{-}\chi$, 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

S12 Side Structures in Single Side Skin Bulk Carriers

(1992)
(Rev.1
1997)
(Rev.2.1
1997)
(Rev.3
Sept
2000)
(Rev.4
July
2004)
(Rev.5
May
2010)

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:

$$r = \frac{0.4b_f^2}{t_f}$$

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.

S12
(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

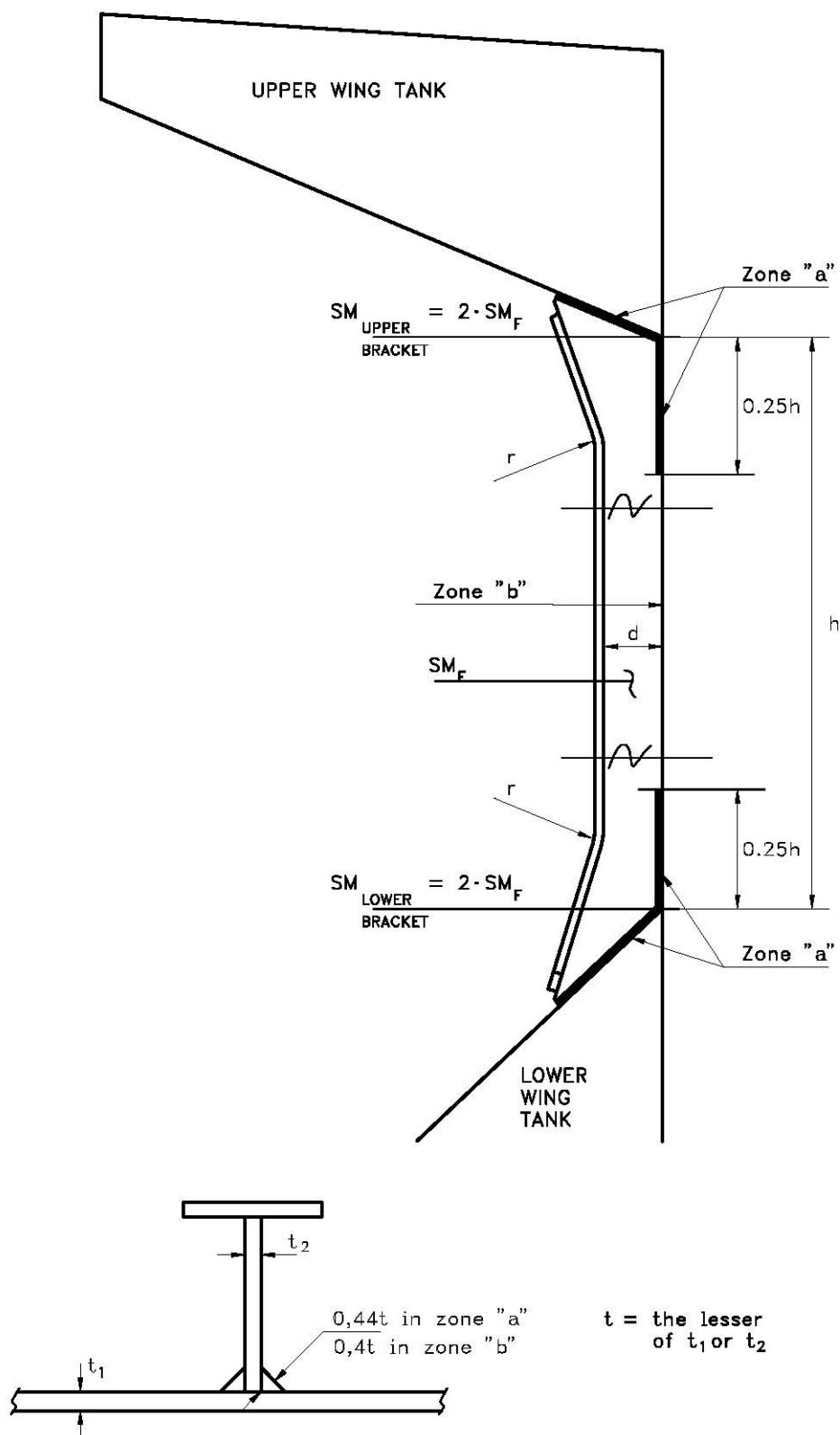
The thickness of side shell plating located between hopper and upper wing tanks is not to be less than $t_{p,min}$ in mm, given by:

$$t_{p,min} = \sqrt{L}$$

S12

(cont)

Figure 1



S12

(cont)

Figure 2

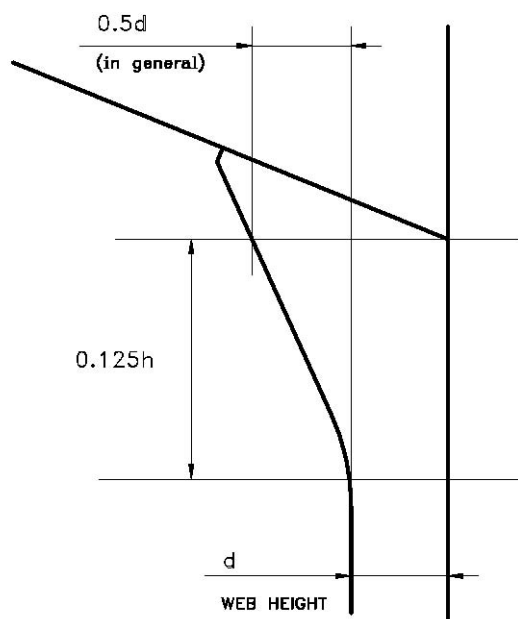
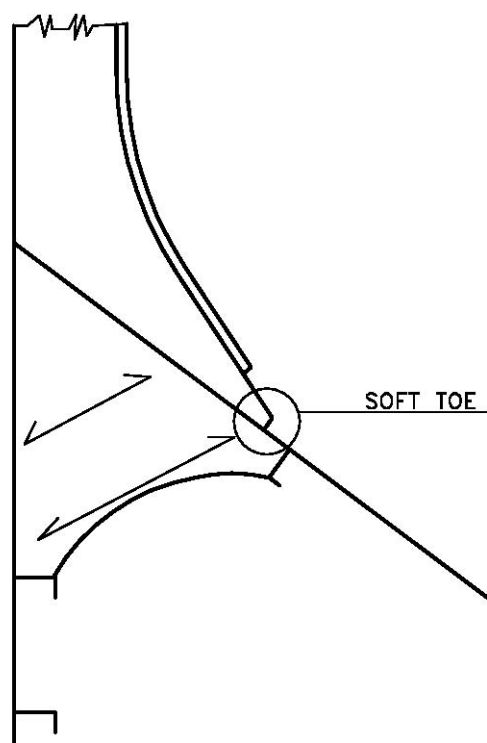


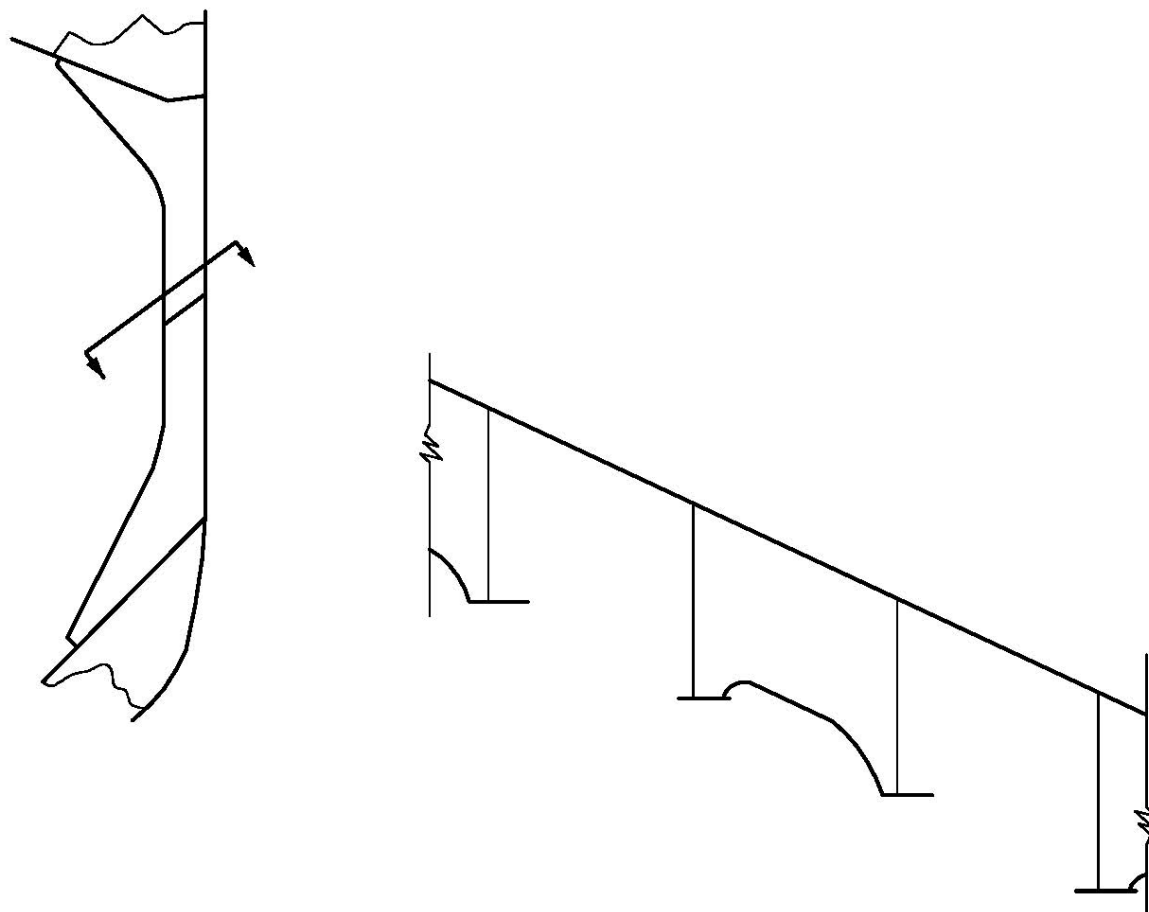
Figure 3



S12
(cont)

Figure 4

Tripping brackets to be fitted in way of foremost hold



End of
Document

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)

(Rev.7

Dec 2022)

S14.1 Application

S14.1.1 Revision 7 of this UR is to be complied with in respect of the testing of watertight compartments in accordance with Notes 1 to 5.

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 three parts, PART A, PART B and PART C as follows:

- PART A - SOLAS Ships (including CSR BC & OT)
- PART B - SOLAS Exempt/Equivalent Ships
- PART C - Non-SOLAS 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.
5. Revision 7 of this UR is to be applied by IACS Societies to ships contracted for construction on or after 1 January 2024.

S14

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S14.2.3 Testing procedures of watertight compartments are to be carried out in accordance with PART B for 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.

S14.2.4 Testing procedures of watertight compartments are to be carried out in accordance with PART C for non-SOLAS ships, see SOLAS Chapter I, Regulation 1 and Regulation 3.

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, watertight boundaries and the structural adequacy of tanks which form part of the watertight subdivisions¹ 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 repairs² 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 tanks³ 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.

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.

S14

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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).

3.3 The 'top of the overflow' is defined as being the top of any overflow system which is used to prevent overfilling of a tank. Such system can be an overflow pipe, airpipe, intermediate tank. For gravity tanks (i.e. sewage, grey water and similar tanks, not filled with pumps) the top of the overflow is to be taken as the highest point of the filling line.

Note: Gauging devices are not considered equivalent to an overflow system with the exception of fuel oil overflow tanks not intended to hold fuel which have been fitted with a level alarm.

Where a tank is fitted with multiple means of preventing overfilling, the decision on which overflow system is to be used to determine the test head is to be based on the highest point to which the liquid may rise in service.

S14

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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.

Alternative equivalent tank testing procedures may be considered for tanks which are constructed from composite materials such as glass reinforced plastic (GRP) and fibre reinforced plastic (FRP) based on the recommendations of the composite manufacturer.

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 ship¹, 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 ship¹, may be exempted from structural testing provided that the water-tightness of boundaries of exempted spaces is verified by leak tests and inspections.

¹ Watertight subdivision means the main transverse and longitudinal subdivisions of the ship required to satisfy the subdivision requirements of SOLAS Chapter II-1.

S14

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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.

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, but the test pressure shall not exceed the maximum design internal pressure at the top of tank.

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.

S14

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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 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.

S14
(cont)**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.

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.

S14

(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 ¹⁰ , - 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 ¹⁰ , - 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 ¹⁰ , or - to 2.4m above top of tank ²	
6	Cargo oil tanks	Leak and structural ¹	The greater of - top of the overflow ¹⁰ , - to 2.4m above top of tank ² , or - to top of tank ² plus the design vapour pressure	
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 ¹⁰ , 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	
11	.1 Watertight bulkheads	Leak ⁸	See 4.4.3 through 4.4.6, as applicable ⁷	

S14

(cont)

	Tank or boundary to be tested	Test type	Test head or pressure	Remarks
	.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 ¹⁰ , - to 2.4m above top of tank ² , or - to top of tank ² plus the design vapour pressure, or - to bulkhead deck	
22	Fuel oil overflow tanks not intended to hold fuel	Leak and structural ¹	The greater of - top of the overflow ¹⁰ , - to 2.4m above top of tank ² , 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.

S14

(cont)

- 4 Including tanks arranged in accordance with the provisions of SOLAS regulation II-1/9.4.
- 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.1/Circ.1572/Rev.1.
- 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.
- 10 Refer to section 3.3

S14

(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 ³ , 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 the design vapour pressure	Where a cargo tank is designed for the carriage of cargoes with specific gravities larger than 1.0, see section 4.4.1

Note:

- 1 Refer to section 4.2.2
- 2 Top of tank is deck forming the top of the tank excluding any hatchways.
- 3 Refer to section 3.3

S14

(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 - SOLAS Exempt/Equivalent Ships****1 GENERAL**

1.1 These test procedures are to confirm the watertightness of tanks, watertight boundaries and the structural adequacy of tanks which form part of the watertight subdivisions¹ 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 repairs² 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 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".

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.

2.5 For tanks which are less than 2 m³ in volume, structural testing may be replaced by leak testing.

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.

S14

(cont)

2.6 Where the structural adequacy of the tanks and spaces of a vessel were verified by the structural testing required by either PART A or PART B 2.3, 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 and spaces are verified by leak tests and thorough inspections are carried out.
2. structural testing is carried out for at least one tank or space of each type among all tanks/spaces of each sister vessel.
3. additional tanks and spaces 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, 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.

2.7 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 2.6 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. The work is to be carried out in accordance with the Rules and under survey of the Classification Society.

ANNEX I**PROCEDURES FOR TESTING TANKS AND TIGHT BOUNDARIES****PART C – Non-SOLAS Ships****1 GENERAL**

1.1 These test procedures are to confirm the watertightness of tanks, watertight boundaries and the structural adequacy of tanks which form part of the watertight subdivisions¹ 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 repairs² 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 C for non-SOLAS ships, see SOLAS Chapter I, Regulation 1 and Regulation 3.

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”.

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 The requirements given in Table 1 of Part A to structurally test tanks to 2.4 metres above the top of the tank do not apply. Instead, the minimum test pressure for structural testing is to be taken as $0.3D + 0.76$ metres above the top of the tank where the top of the tank is the deck forming the top of the tank, excluding any hatchways and D is the depth of the ship. The minimum test pressure need not be taken greater than 2.4 metres above the top of the tank.

2.4 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 the boundaries of tanks for segregated cargoes or pollutant cargoes in other types of ships.

2.5 Additional tanks may require structural testing if found necessary after the structural testing of the first tank.

2.6 For tanks which are less than 2 m³ in volume, structural testing may be replaced by leak testing.

¹ Watertight subdivision means the main transverse and longitudinal subdivisions of the ship.

² Major repair means a repair affecting structural integrity.

S14
(cont)

2.7 Where the structural adequacy of the tanks and spaces of a vessel were verified by the structural testing required by either PART A or PART C section 2.4, 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 and spaces are verified by leak tests and thorough inspections are carried out.
2. structural testing is carried out for at least one tank or space among all tanks/spaces of each sister vessel.
3. additional tanks and spaces 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, 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.

2.8 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 C 2.7 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. 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-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 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.



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 S8.6.2g, 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 permissible 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 Longitudinal Strength of Hull Girder in Flooded Condition for Non-CSR Bulk Carriers

(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)
(Rev.10
Mar 2019)

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/m³ 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. This application is to be applied to self-unloading bulk carriers (SUBC) where the unloading system maintains the watertightness during seagoing operations. In SUBCs with unloading systems that do not maintain watertightness, the longitudinal strength in the flooded conditions are to be considered using the extent to which the flooding may occur.

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.
3. Revision 10 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 2020.

S17

(cont)

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.

S17.3 Flooding criteria

To calculate the weight of ingressed water, the following assumptions are to be made:

- The permeability of empty cargo spaces and volume left in loaded cargo spaces above any cargo is to be taken as 0.95.
- 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/m³ is to be used. For cement, a minimum permeability of 0.3 with a corresponding bulk density of 1.3 t/m³ 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/mm², 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 cm³, 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.

End of Document

S18 Evaluation of Scantlings of Corrugated Transverse Watertight Bulkheads in Non-CSR Bulk Carriers Considering Hold Flooding

(1997)
(Rev.1
1997)
(Rev.1.1
Mar 1998
/Corr.1)
(Rev.2
Sep 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)
(Rev.10
Mar 2019)

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/m³ 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.

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.
3. Revision 10 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 2020.

S18

(cont)

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. This application is to be applied to self-unloading bulk carriers (SUBC) where the unloading system maintains the watertightness during seagoing operations. In SUBCs with unloading systems that do not maintain watertightness, the combination loads acting on the bulkheads in the flooded conditions are to be considered using the extent to which the flooding may occur.

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

S18

(cont)

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/m³ 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

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/m², is given by:

$$p_c = \rho_c g h_1 \tan^2 \gamma$$

where:

ρ_c = bulk cargo density, in t/m³

g = 9.81 m/s², 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° - ($\phi/2$)

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

(cont)

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/m², is given by:

$$p_{c,f} = \rho g h_f$$

where:

ρ = sea water density, in t/m³

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/m², 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/m³), coal cargoes and for cement (corresponding bulk cargo density for cement may generally be taken as 1.3 t/m³)

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/m², at the lower end of the corrugation

S18

(cont)

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:

$\rho_c, g, h_1, \gamma =$ 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:

$$p_{c,f} = \rho g h_f + [\rho_c h_1 - \rho(1 - \text{perm})h_f] g \tan^2 \gamma$$

where:

$\rho, h_f, \text{perm} =$ as given in a) above

$\rho_c, g, h_1, \gamma =$ 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:

$s_1, \rho_c, g, d_1, \gamma, h_{DB}, h_{LS} =$ 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

$\rho =$ as given in S18.2.4.1 a)

$d_f =$ as given in S18.2.2

S18

(cont)

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:

$$F = F_{c,f} - 0.8F_c$$

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

(cont)

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.

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).

S18

(cont)

(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 than 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 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:

$$10^3 \cdot \frac{M}{0.5Z_{le}\sigma_{a,le} + Z_m\sigma_{a,m}} \leq 0.95$$

where:

M = bending moment, in kNm, as given in S18.3.1

S18

(cont)

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;
- 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

S18

(cont)

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/m², 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/mm², 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 $(\sin \phi)$, 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.

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 cm², may be increased by:

$$\left(2.5a\sqrt{t_f t_{sh}}\right) \quad (\text{not to be taken greater than } 2.5at_f)$$

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 cm², 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

S18

(cont)

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 45° 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 45°, the effectiveness of the web may be obtained by linear interpolation between 30% for 0° and 100% for 45°.

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/mm², given by:

$$\sigma_a = \sigma_F$$

$$\tau_a = 0.5 \sigma_F$$

σ_F = the minimum upper yield stress, in N/mm², 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:

$$C_e = \frac{2.25}{\beta} - \frac{1.25}{\beta^2} \quad \text{for } \beta > 1.25$$

$$C_e = 1.0 \quad \text{for } \beta \leq 1.25$$

$$\beta = 10^3 \frac{a}{t_f} \sqrt{\frac{\sigma_f}{E}}$$

t_f = net flange thickness, in mm

a = width, in m, of the corrugation flange (see Figure 2a)

S18

(cont)

σ_F = minimum upper yield stress, in N/mm², of the material

E = modulus of elasticity of the material, in N/mm², 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/mm² obtained by the following:

$$\begin{aligned} \tau_c &= \tau_E & \text{when } \tau_E \leq \frac{\tau_F}{2} \\ &= \tau_F \left(1 - \frac{\tau_F}{4\tau_E} \right) & \text{when } \tau_E > \frac{\tau_F}{2} \end{aligned}$$

where:

$$\tau_F = \frac{\sigma_F}{\sqrt{3}}$$

σ_F = minimum upper yield stress, in N/mm², of the material

$$\tau_E = 0.9k_t E \left(\frac{t}{1000c} \right)^2 \quad (\text{N/mm}^2)$$

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:

$$t = 14.9s_w \sqrt{\frac{1.05p}{\sigma_F}}$$

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/m², 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

S18

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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/mm², 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:

$$t_n = 14.9s_n \sqrt{\frac{1.05p}{\sigma_F}}$$

s_n being the width, in m, of the narrower plating.

The net thickness of the wider plating, in mm, is not to be taken less than the maximum of the following

$$t_w = 14.9s_w \sqrt{\frac{1.05p}{\sigma_F}}$$

and

$$t_w = \sqrt{\frac{440s_w^2 1.05p}{\sigma_F} - t_{np}^2}$$

where $t_{np} \leq$ actual net thickness of the narrower plating and not to be greater than

$$14.9s_w \sqrt{\frac{1.05p}{\sigma_F}}$$

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.

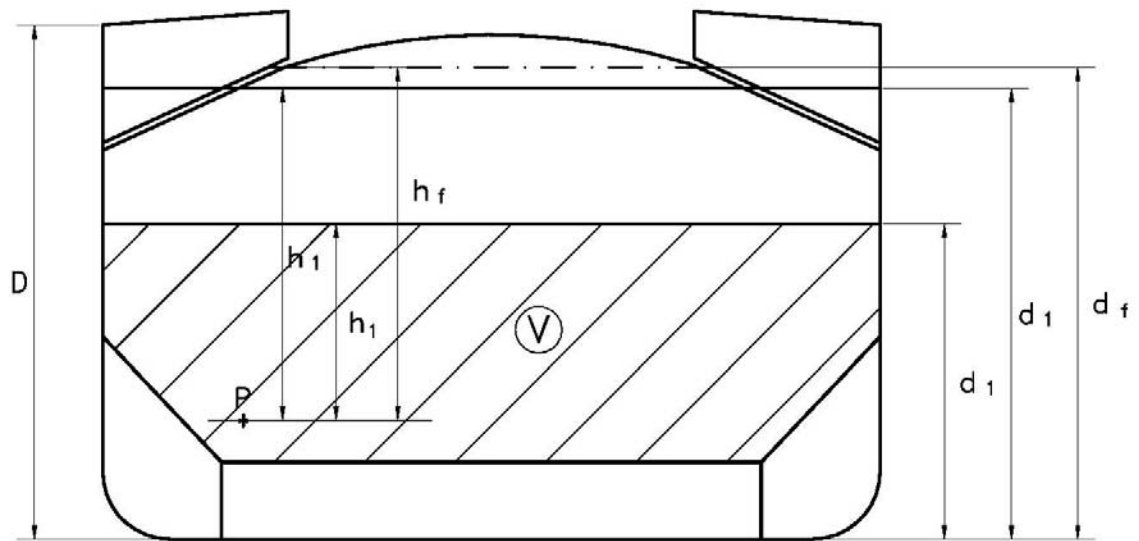
S18.6 - Corrosion addition and steel renewal

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.

Figure 1

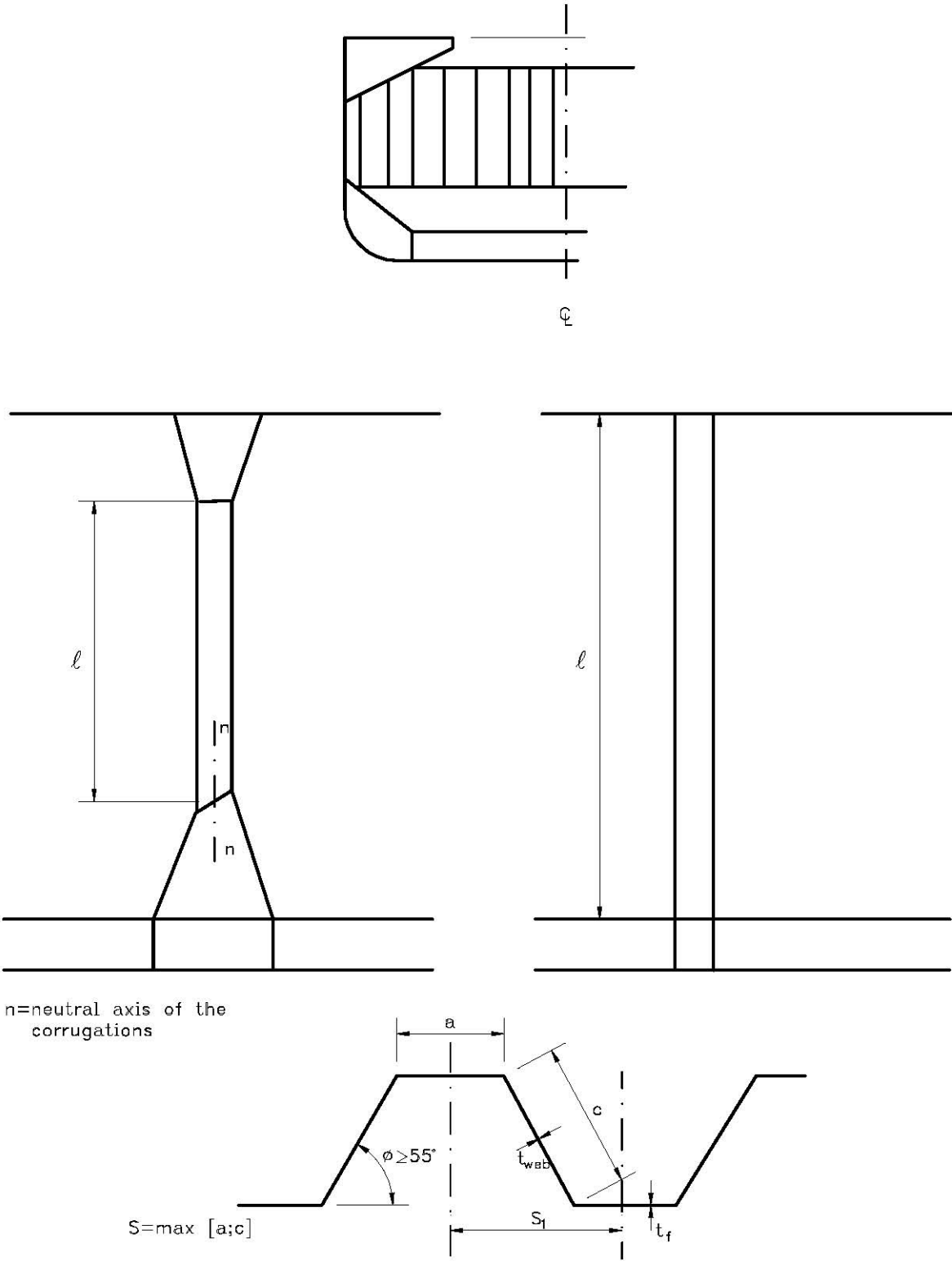


V = Volume of cargo

P = Calculation point

S18
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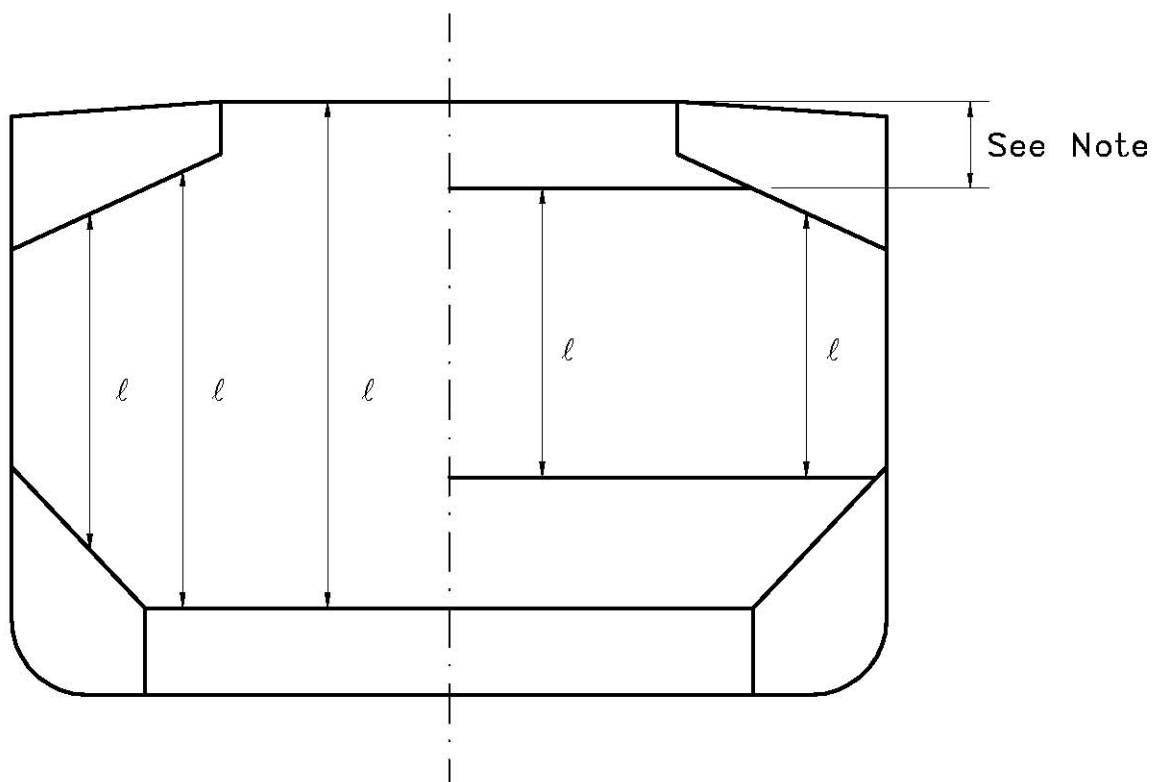
Figure 2a



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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

S18

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Figure 3a
Symmetric shedder plates

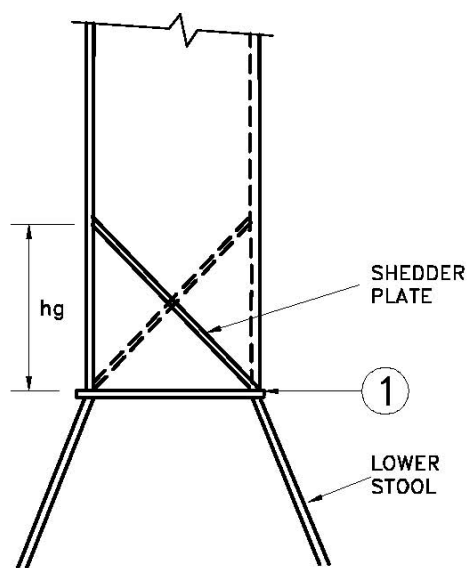


Figure 3b
Asymmetric shedder plates

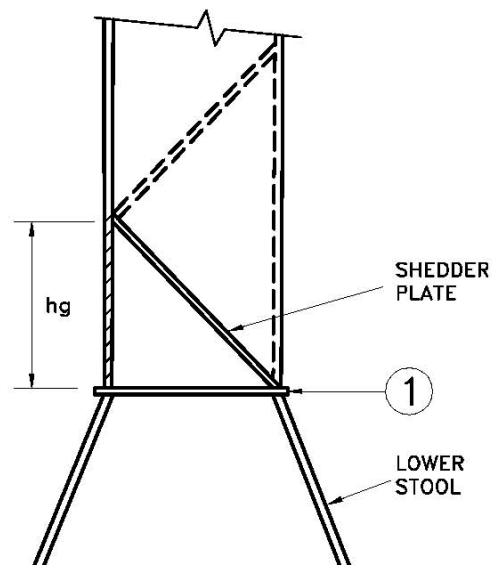


Figure 4a
Symmetric gusset / shedder plates

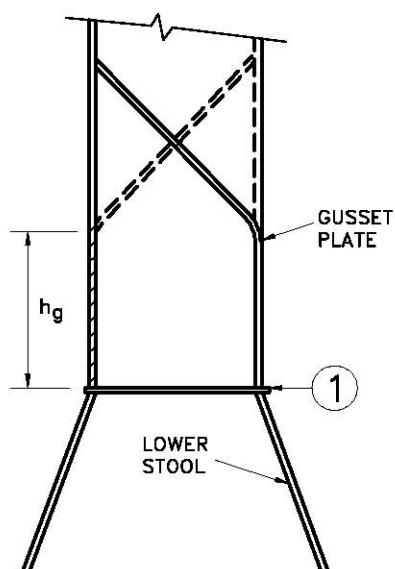
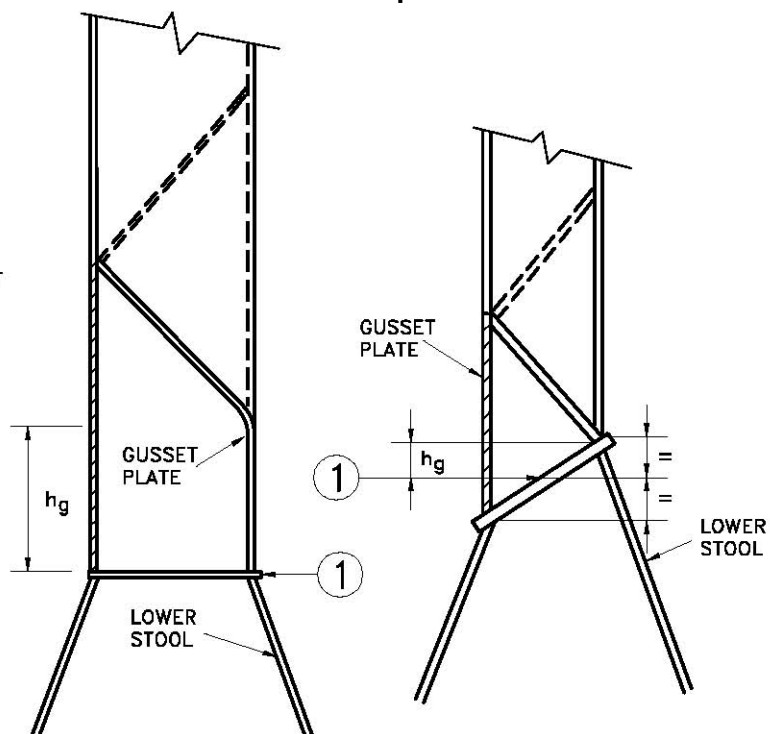


Figure 4b
Asymmetric gusset / shedder plates



S18

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Figure 5
Permitted distance, d , from edge of stool top plate to surface of corrugation flange

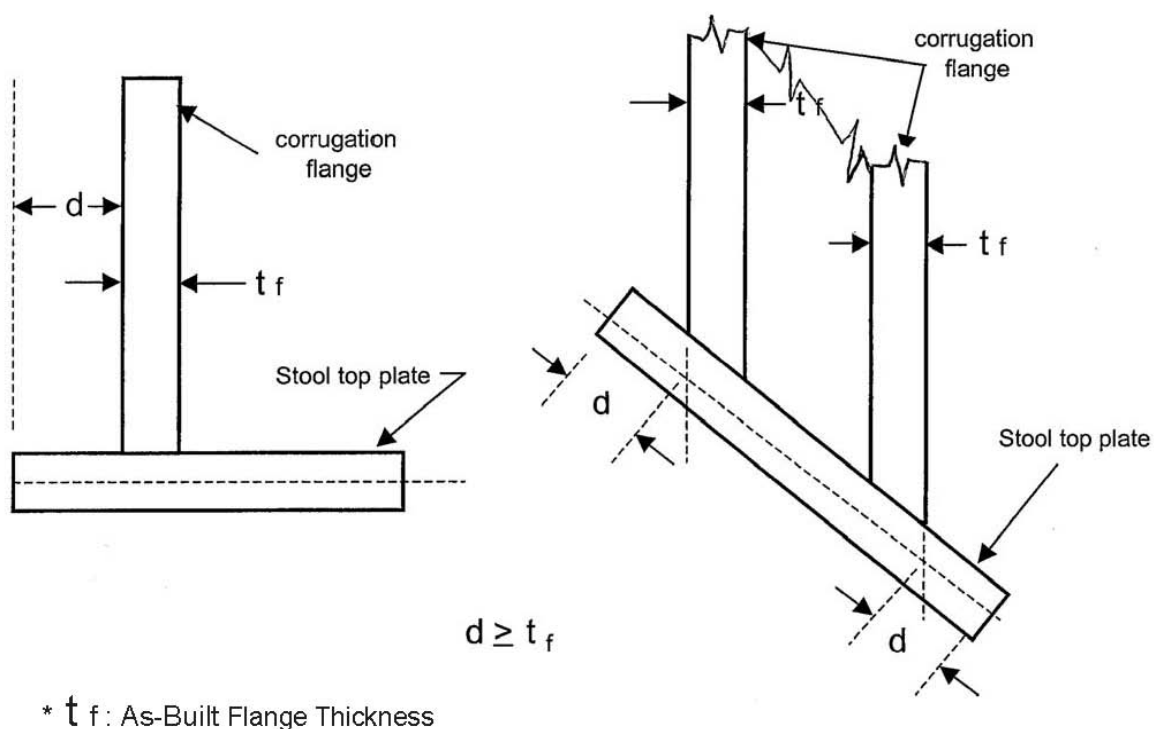
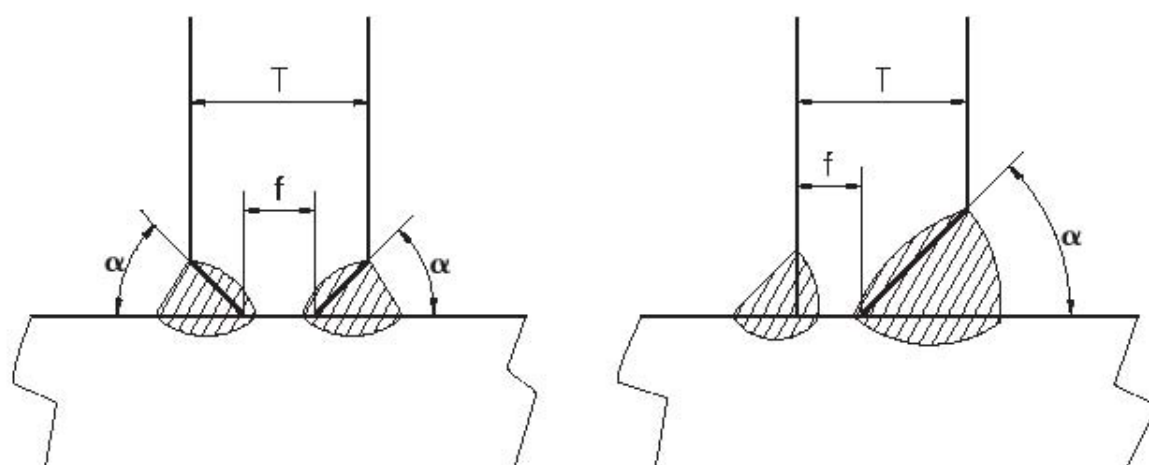


Figure 6



Root Face (f) : 3 mm to $T/3$ mm
Groove Angle (α) : 40° to 60°

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Document

S19 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

(1997)
(Rev. 1
1997)
(Rev. 2
Feb. 1998)
(Rev.3
Jun. 1998)
(Rev.4
Sept. 2000)
(Rev.5
July 2004)

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 $1,78 \text{ t/m}^3$, 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.

S19

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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 d_1 and d_f , d_1 (see Figure 1) being a distance from the baseline given, in m, by:

$$d_1 = \frac{M_c}{\rho_c \cdot l_c \cdot B} + \frac{V_{LS}}{l_c \cdot B} + (h_{HT} - h_{DB}) \cdot \frac{b_{HT}}{B} + h_{DB}$$

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.

S19

cont'd

$$a) \quad d_f \geq d_1$$

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 = $9,81 \text{ m/s}^2$, 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:

$$p_{c,f} = \rho \cdot g \cdot h_f + [\rho_c - \rho \cdot (1 - \text{perm})] \cdot g \cdot h_1 \cdot \tan^2 \gamma$$

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 $3,0 \text{ t/m}^3$),

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 = $45^\circ - (\phi/2)$

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:

$$F_{c,f} = s_1 \cdot \left(\rho \cdot g \cdot \frac{(d_f - d_1)^2}{2} + \frac{\rho \cdot g \cdot (d_f - d_1) + (p_{c,f})_{le}}{2} \cdot (d_1 - h_{DB} - h_{LS}) \right)$$

S19

cont'd

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:

$$p_{c,f} = \rho \cdot g \cdot h_f + [\rho_c \cdot h_1 - \rho \cdot (1 - \text{perm}) \cdot h_f] \cdot g \cdot \tan^2 \gamma$$

where:

$\rho, g, h_f, \rho_c, h_1, \text{perm}, \gamma$ = as given in a) above

The force $F_{c,f}$, in kN, acting on a corrugation is given by:

$$F_{c,f} = s_1 \cdot \left(\rho_c \cdot g \cdot \frac{(d_1 - d_f)^2}{2} \cdot \tan^2 \gamma + \frac{\rho_c \cdot g \cdot (d_1 - d_f) \cdot \tan^2 \gamma + (p_{c,f})_{le} \cdot (d_f - h_{DB} - h_{LS})}{2} \right)$$

where:

- $s_1, \rho_c, g, \gamma, (p_{c,f})_{le}, h_{LS}$ = as given in a) above
 d_1, h_{DB} = as given in S19.2.3.1
 d_f = as given in S19.2.2.

S19

cont'd

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:

$\rho_c, g, s_1, h_{LS}, \gamma$ = 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:

$$p = \rho_{c,f} - 0,8 \cdot \rho_c$$

S19
cont'd

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:

$$p = p_{c,f}$$

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 $\text{kN}\cdot\text{m}$, 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

S19

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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 is 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 $0,15 \cdot l$.

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 $0,3 \cdot l$.

S19.4.2 - Bending capacity and shear stress τ

The bending capacity is to comply with the following relationship:

$$10^3 \cdot \frac{M}{0,5 \cdot Z_{le} \cdot \sigma_{a,le} + Z_m \cdot \sigma_{a,m}} \leq 1,0$$

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

S19

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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.

S19

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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 cm², 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/mm², of the material used for the shedder plates

σ_{Ffl} = minimum upper yield stress, in N/mm², 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 cm², may be increased by $(7 \cdot h_g \cdot t_{gu})$ 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 45° 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 45°, the effectiveness of the web may be obtained by linear interpolation between 30% for 0° and 100% for 45°.

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.

S19

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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:

$$C_e = \frac{2,25}{\beta} - \frac{1,25}{\beta^2} \quad \text{for } \beta > 1,25$$

$$C_e = 1,0 \quad \text{for } \beta \leq 1,25$$

$$\beta = 10^3 \cdot \frac{a}{t_f} \cdot \sqrt{\frac{\sigma_F}{E}}$$

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 $2,06 \cdot 10^5 \text{ N/mm}^2$ 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:

$$\begin{aligned} \tau_C &= \tau_E & \text{when } \tau_E &\leq \frac{\tau_F}{2} \\ &= \tau_F \left(1 - \frac{\tau_F}{4\tau_E} \right) & \text{when } \tau_E &> \frac{\tau_F}{2} \end{aligned}$$

S19

cont'd

$$\tau_F = \frac{\sigma_F}{\sqrt{3}}$$

where:

σ_F = minimum upper yield stress, in N/mm², of the material

$$\tau_E = 0.9k_t E \left(\frac{t}{1000c} \right)^2 \quad (\text{N/mm}^2)$$

k_t , E , t and c are given by:

$$k_t = 6.34$$

E = modulus of elasticity of material as given in 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/m², 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/mm², 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

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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 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 $t_{np} \leq$ 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:

$$0,8 \cdot (\sigma_{Ffl} \cdot t_{fl}) \geq \sigma_{Fs} \cdot t_{st}$$

S19

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where:

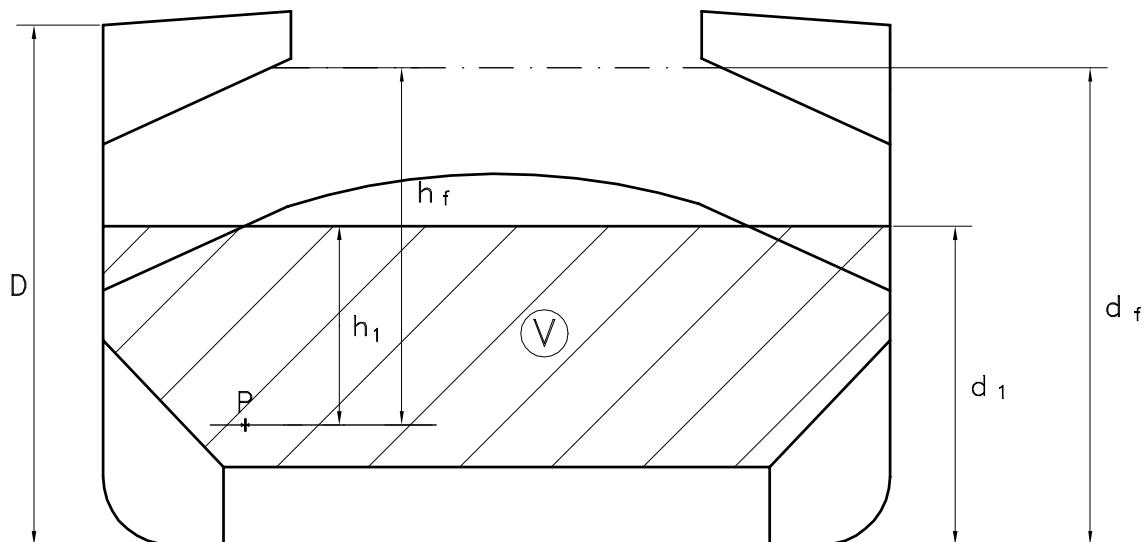
σ_{Ffl}	=	minimum upper yield stress, in N/mm ² , of the material used for the corrugation flanges
σ_{Fs}	=	minimum upper yield stress, in N/mm ² , of the material used for the lower stool side plating or floors (if no stool is fitted)
t_{fl}	=	flange thickness, in mm, which is found to be acceptable 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).

Figure 1



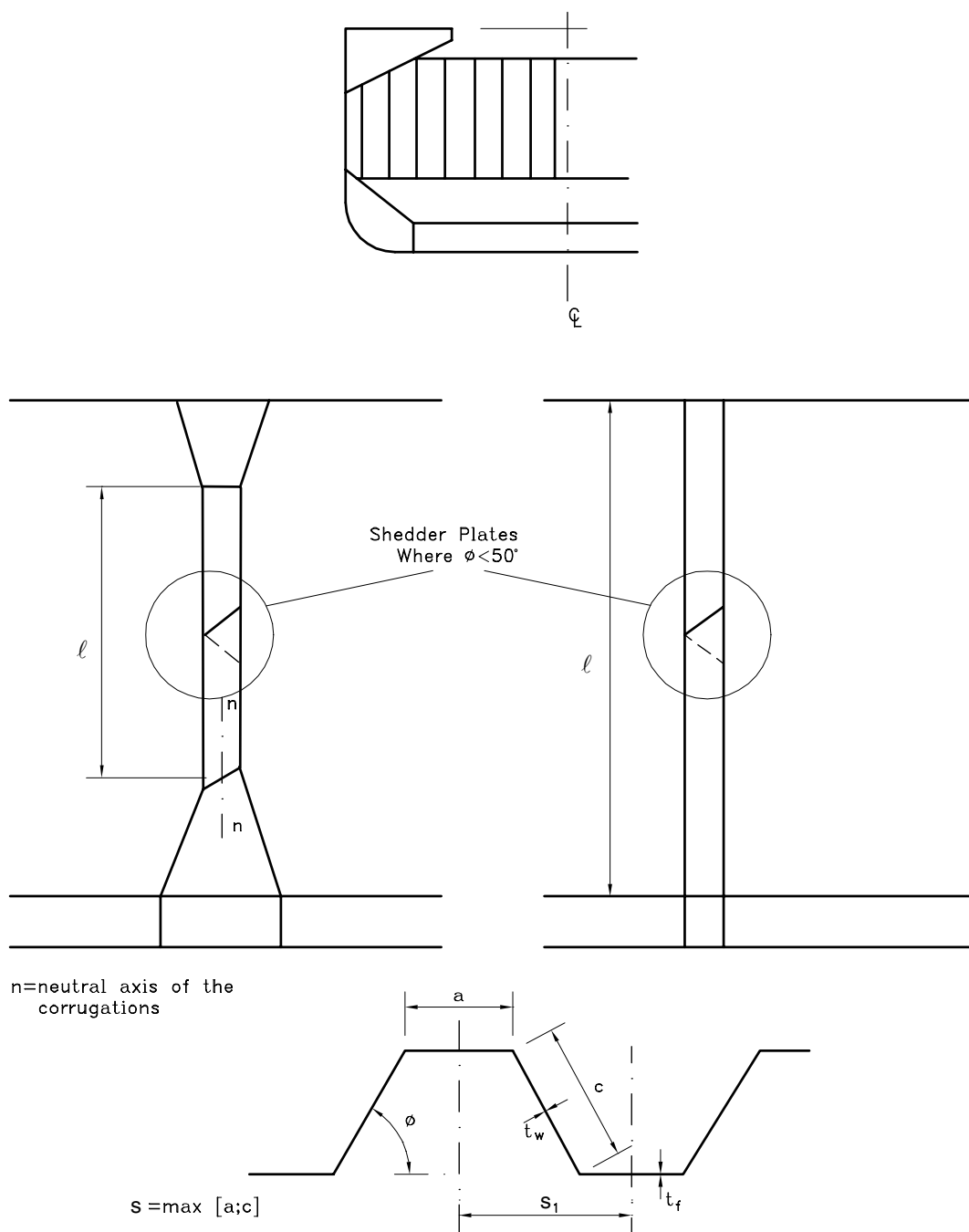
V = Volume of cargo

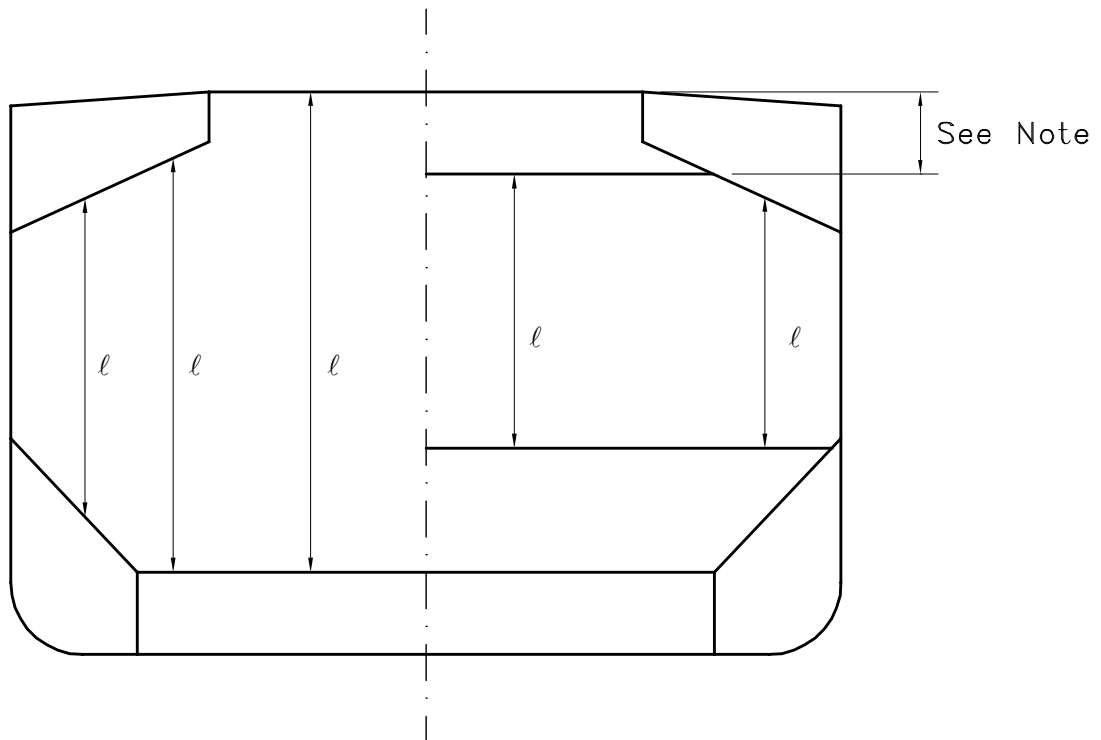
P = Calculation point

S19

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Figure 2a



S19
cont'd**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
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Figure 3a
Symmetric shedder plates

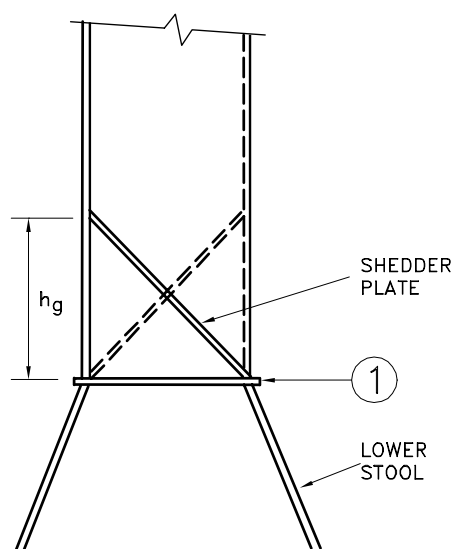
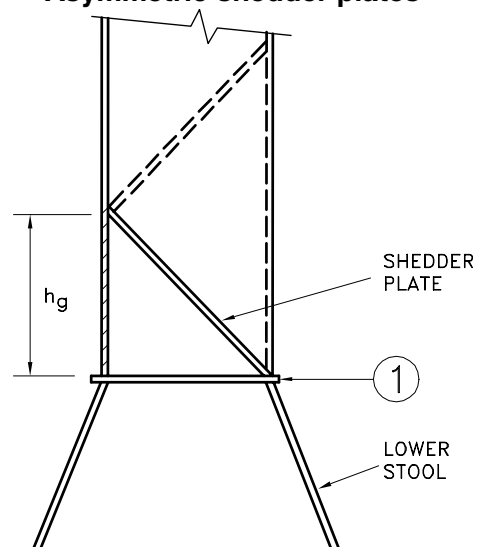


Figure 3b
Asymmetric shedder plates



S19
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Figure 4a
Symmetric gusset / shedder
plates

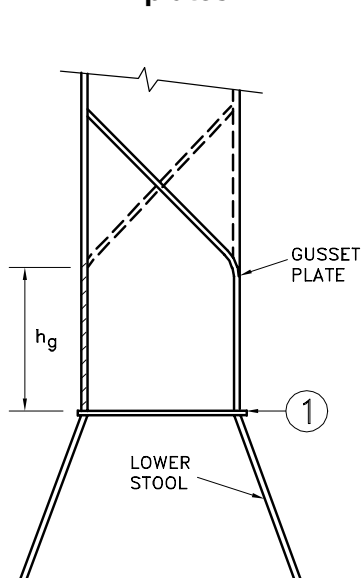
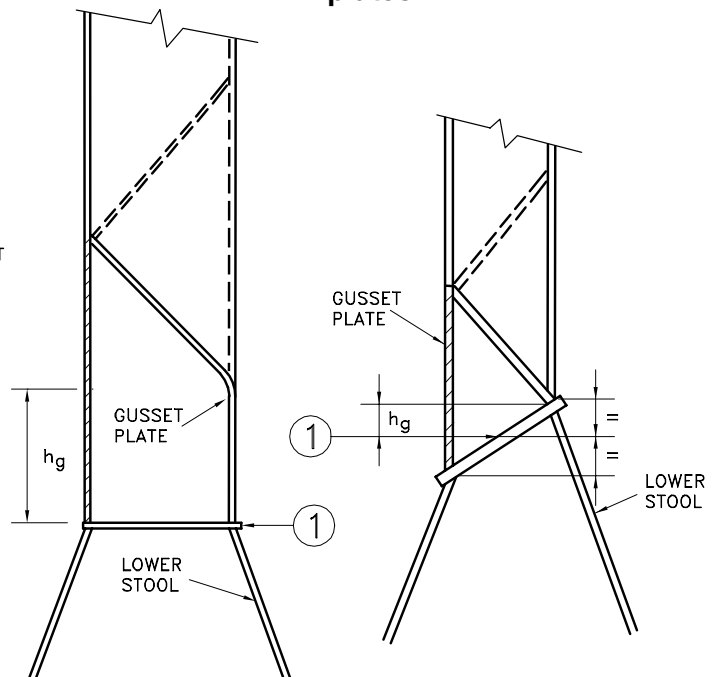
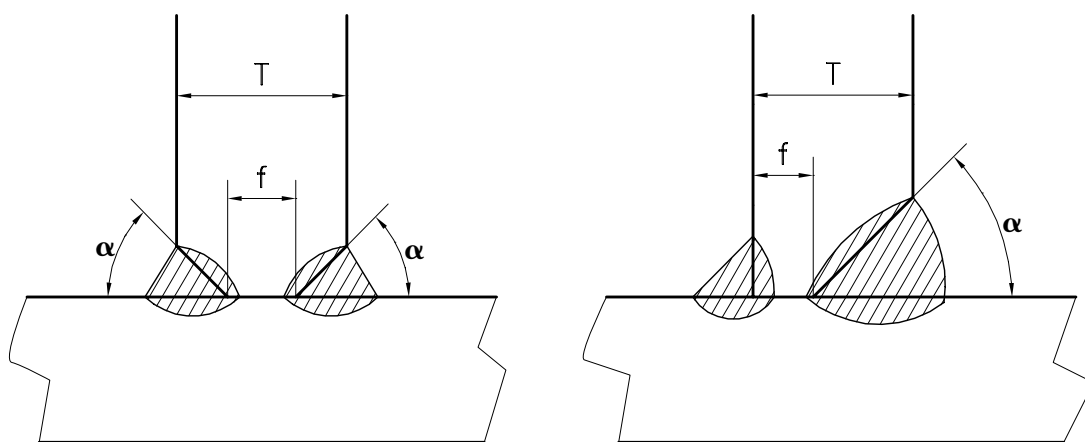


Figure 4b
Asymmetric gusset / shedder
plates



S19
cont'd**Figure 5**

Root Face (f) : 3 mm to $T/3$ mm
Groove Angle (α) : 40° to 60°

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

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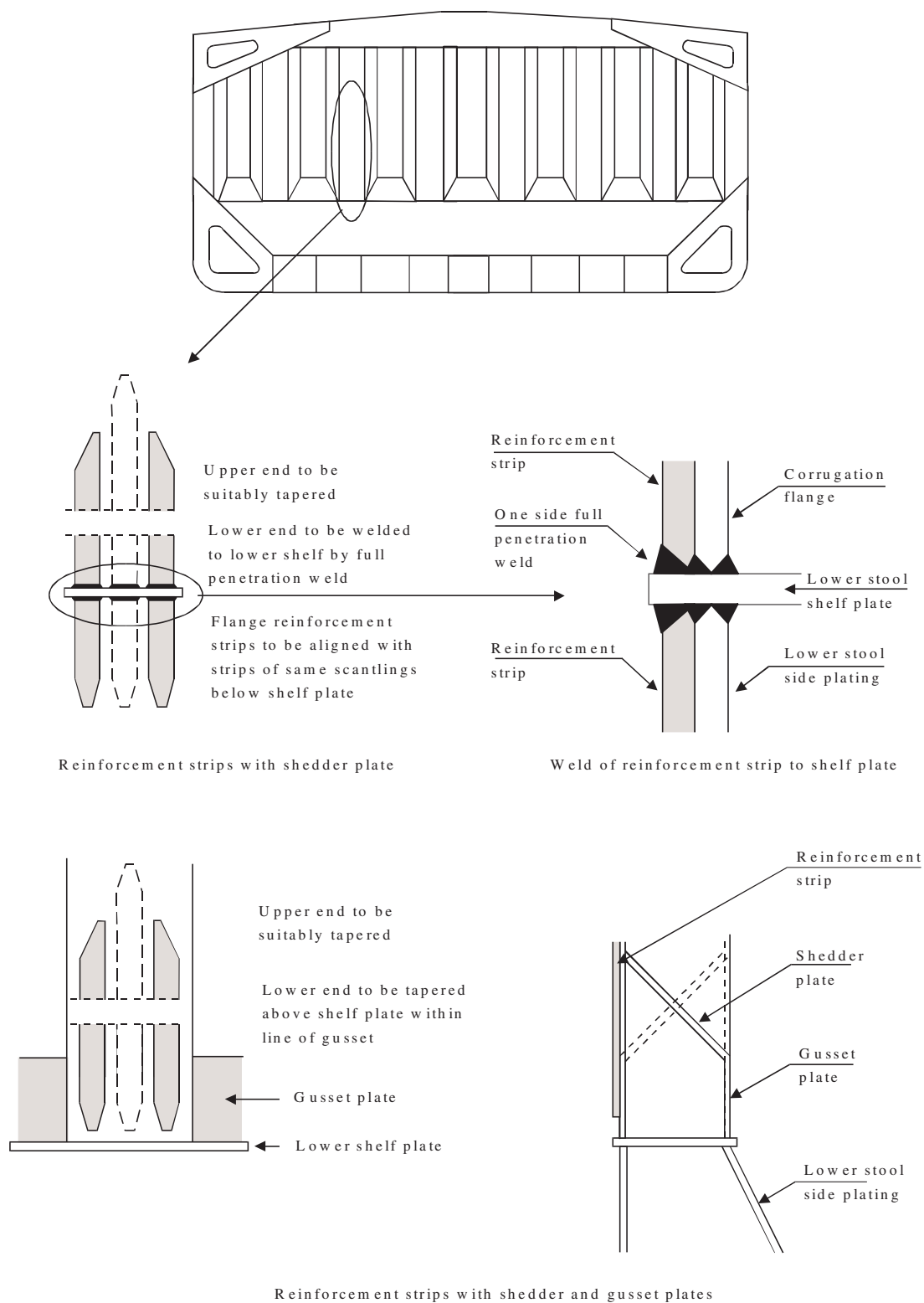


Figure 1

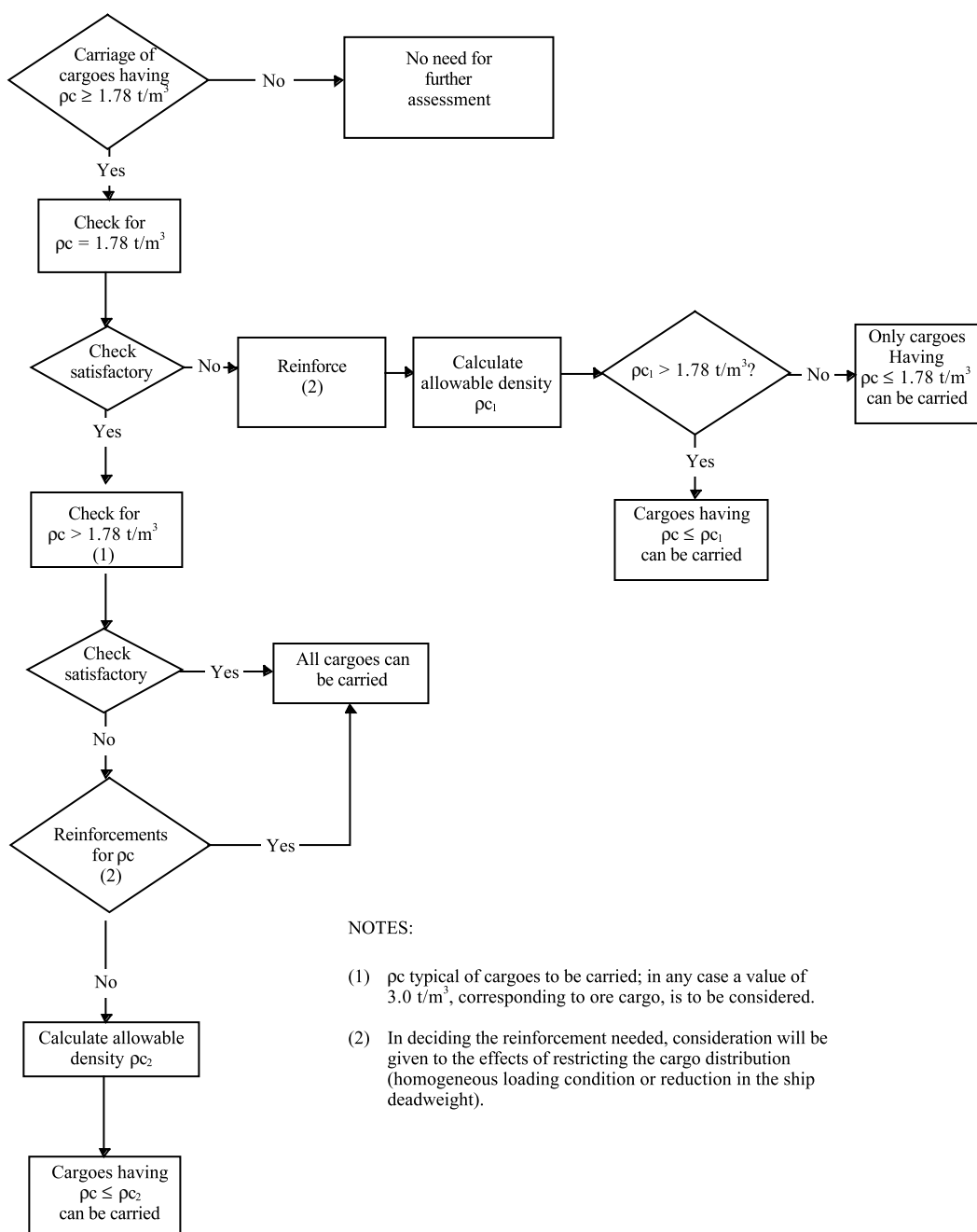
S19
cont'd**Notes to Figure 1 on reinforcement:-**

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. Sheddens and gussets are to be same material as flange material.

ANNEX 2

S19
cont'd

**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) ρ_c 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

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Evaluation of Allowable Hold Loading for Non-CSR Bulk Carriers Considering Hold Flooding

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/m³ 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

$$\eta_1 = 1.10$$

$$\eta_2 = 1.20$$

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:

$$X_1 = \frac{Z + \rho g(E - h_f)}{1 + \frac{\rho}{\rho_c}(\text{perm} - 1)}$$

$$X_2 = Z + \rho g(E - h_f \text{perm})$$

X = for steel products, X may be taken as X_1 , using $\text{perm} = 0$

ρ = sea water density, in t/m^3

g = 9.81 m/s^2 , gravity acceleration

S20

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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)

$$A_{DB,h} = \sum_{i=1}^{i=n} S_i B_{DB,i}$$

$$A_{DB,e} = \sum_{i=1}^{i=n} S_i (B_{DB} - s_1)$$

n = number of floors between stools (or transverse bulkheads, if no stool is fitted)

S_i = space of i th-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)

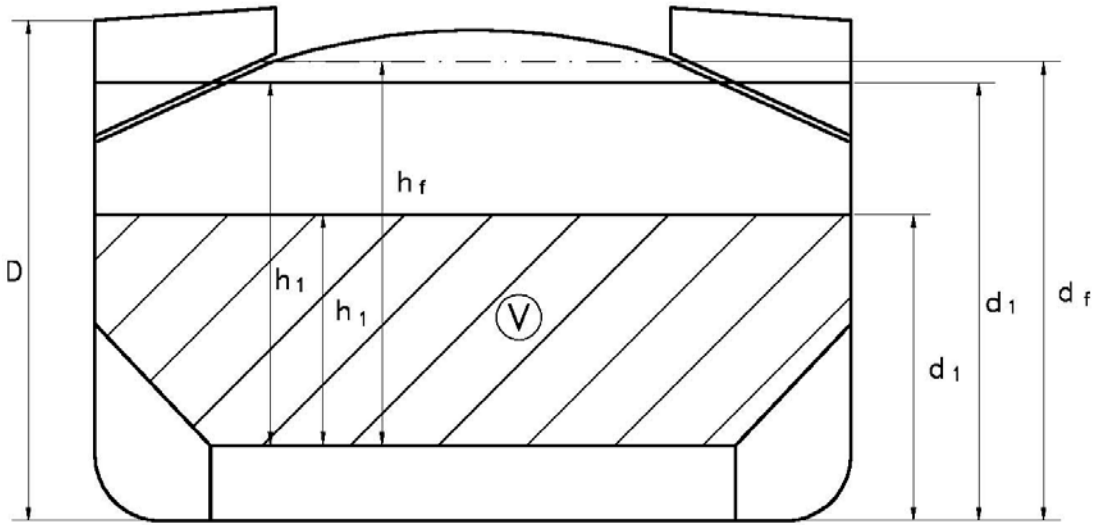
B_{DB} = breadth of double bottom, in m, between hoppers (see Figure 3)

$B_{DB,h}$ = distance, in m, between the two considered opening (see Figure 3)

s_1 = spacing, in m, of double bottom longitudinals adjacent to hoppers

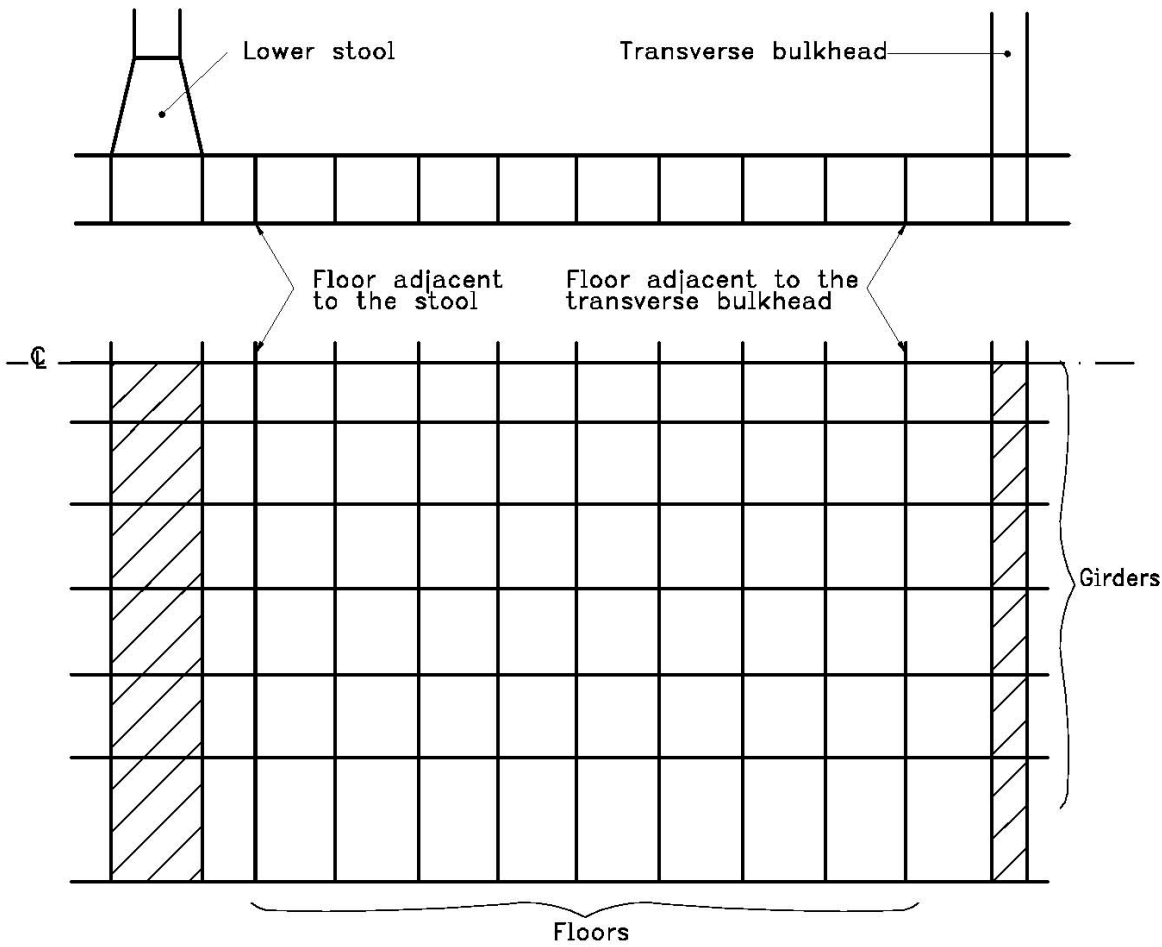
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Figure 1



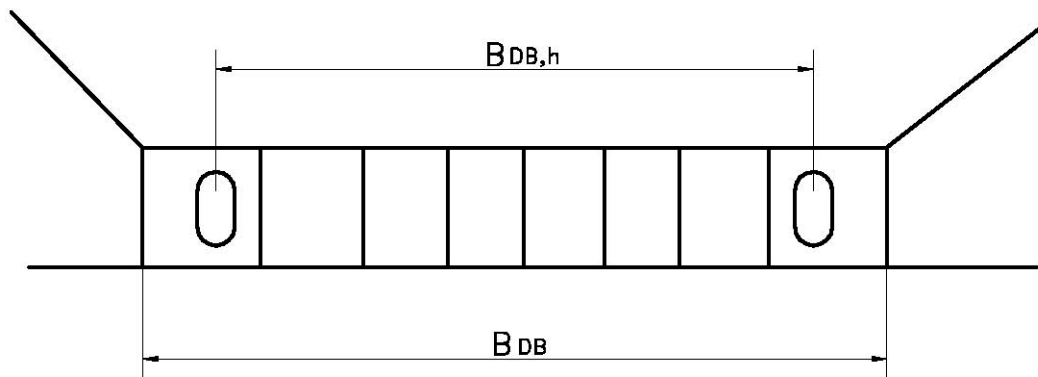
V = Volume of cargo

Figure 2



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Figure 3



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 (Rev.6
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Requirements concerning STRENGTH OF SHIPS

Evaluation of Scantlings of Hatch Covers and Hatch Coamings and Closing Arrangements of Cargo Holds of Ships

TABLE OF CONTENTS

1	APPLICATION AND DEFINITIONS.....	4
1.1	Application.....	4
1.2	Definitions.....	4
1.2.1	Hatch cover types.....	4
1.2.2	Positions.....	5
1.3	Material.....	5
1.4	General requirements.....	5
1.5	Net scantling approach.....	5
2	HATCH COVER AND COAMING LOAD MODEL	6
2.1	Vertical weather design load.....	6
2.2	Horizontal weather design load	8
2.2.1	General horizontal weather design load.....	8
2.2.2	Horizontal weather design load applicable to coamings of Type-2 ships	10
2.3	Cargo loads	11
2.3.1	Distributed loads	11
2.3.2	Point loads.....	11
2.4	Container loads	11
2.4.1	General.....	11
2.4.2	Corner loads for ship in upright condition.....	11
2.4.3	Corner loads for ship in heel condition.....	12
2.4.4	Load cases with partial loading.....	13
2.4.5	Mixed stowage of 20' and 40' containers on hatch cover	14
2.5	Loads due to elastic deformations of the ship's hull	14
3	HATCH COVER STRENGTH CRITERIA.....	15
3.1	Permissible stresses and deflections	15
3.1.1	Yield strength.....	15

S21		
(cont)		
	3.1.2 Deflection.....	16
	3.2 Local net plate thickness.....	16
	3.2.1 Local net plate thickness of hatch covers for wheel loading	17
	3.2.2 Lower plating of double skin hatch covers and box girders	17
	3.3 Net scantling of stiffeners	17
	3.4 Net scantling of primary supporting members.....	19
	3.4.1 Primary supporting members	19
	3.4.2 Edge girders (Skirt plates)	19
	3.5 Strength calculations	19
	3.5.1 General requirements for FEM calculations	20
	3.6 Buckling strength of hatch cover structures.....	20
	3.6.1 General.....	20
	3.6.2 Slenderness requirements.....	21
	3.6.3 Buckling requirements	21
	4 DETAILS OF HATCH COVERS.....	24
	4.1 Container foundations on hatch covers.....	24
	4.2 Weather tightness.....	24
	4.2.1 Packing material (General)	24
	4.2.2 Dispensation of weather tight gaskets.....	24
	4.2.3 Drainage arrangements	25
	5 HATCH COAMING STRENGTH AND LOCAL DETAILS.....	25
	5.1 Local net plate thickness of coamings	25
	5.2 Net scantling of stiffeners of coamings	26
	5.3 Coaming stays.....	27
	5.3.1 Coaming stay section modulus and web thickness	27
	5.3.2 Coaming stays under friction load	28
	5.4 Further requirements for hatch coamings	28
	5.4.1 Longitudinal strength	28
	5.4.2 Local details	29
	5.4.3 Stays.....	29
	5.4.4 Extend of coaming plates.....	29
	5.4.5 Drainage arrangement at the coaming	29
	6 CLOSING ARRANGEMENTS	30
	6.1 Securing devices	30
	6.1.1 General.....	30
	6.1.2 Rod cleats.....	30

S21

(cont)

6.1.3	Hydraulic cleats	30
6.1.4	Cross-sectional area of the securing devices	30
6.1.5	Anti lifting devices.....	31
6.2	Hatch cover supports, stoppers and supporting structures.....	31
6.2.1	Horizontal mass forces.....	31
6.2.2	Hatch cover supports.....	32
6.2.3	Hatch cover stoppers.....	33
7	CORROSION ADDITION AND STEEL RENEWAL.....	34
7.1	Corrosion addition for hatch covers and hatch coamings.....	34
7.2	Steel renewal.....	35

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. Rev. 3 of this UR applies to ships contracted for construction on or after 1 January 2004.
3. Till Rev. 5 of this UR, it only applies to Type-2 ships as defined in 1.1.
4. Rev.6 of this UR applies to both Type-1 and Type-2 ships as defined in 1.1 which are contracted for construction on or after 1 July 2024. UR S21A originally applicable to Type-1 ships is superseded by this UR since 1 July 2024.

S21

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1 Application and definitions

1.1 Application

These requirements apply to all ships except CSR bulk carriers, and are for all cargo hatch covers and coamings on exposed decks.

As specified in this UR, parts of the requirements are for some specific ship types as categorized below:

- Type-1 ships, including all ships except bulk carriers, self-unloading bulk carriers, ore carriers and combination carriers, as defined in UR Z11.
- Type-2 ships, including all bulk carriers, self-unloading bulk carriers, ore carriers and combination carriers, as defined in UR Z11.

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.

Hatch covers and hatch coamings of fishing vessels are to comply with the requirements of the individual class society.

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**

S21 (cont)

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 (also called lift-on/lift-off, or just simply LoLo 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 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.

Generally, the spacing of primary supporting members parallel to the direction of stiffeners is not to exceed 1/3 of the span of primary supporting members. If sufficient strength based on FE analysis can be verified, this requirement may be waived.

Stiffeners of hatch coamings are to be continuous over the breadth and length of hatch coamings, as far as practical.

1.5 Net scantling approach

Unless otherwise quoted, the thicknesses t of the following sections are net thicknesses.

S21 (cont)

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_c , given in Tab.8 in 7.1.

Strength calculations using FEM are to be performed with net scantlings.

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} = freeboard length of ship, in m, as defined in ICLL Regulation 3
- x = longitudinal coordinate of midpoint 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
 $= 1,05 + 0,01L_{LL}, 1,8 \leq h_N \leq 2,3$

2.1 Vertical weather design load

The pressure P_{HC} , 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.

For hatch covers of cargo holds designed for carriage of ballast or liquid cargo, the internal lateral pressures are also to be considered according to the Rules of individual societies.

S21

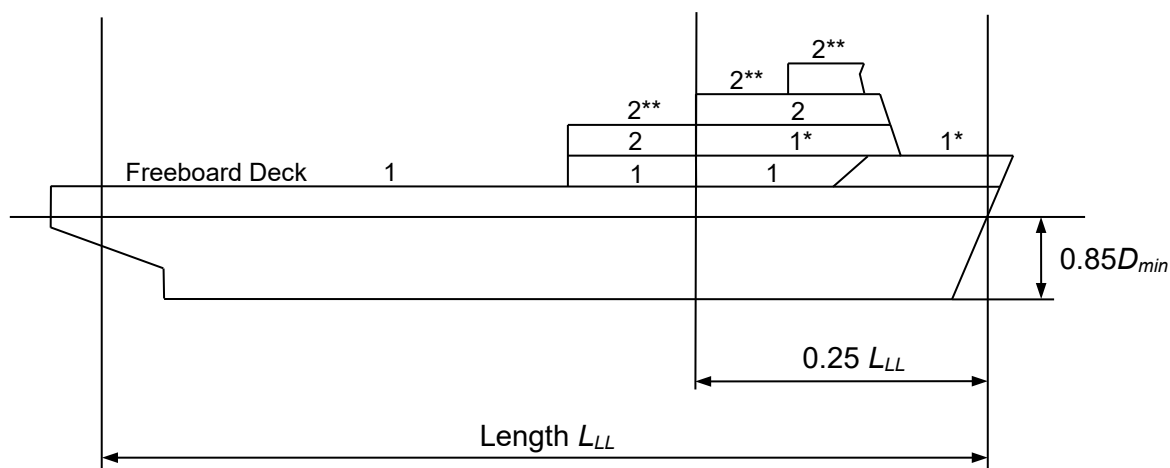
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Tab.1 Design load P_{HC} of weather deck hatches

Position	Design load P_{HC} [kN/m ²]	
	$\frac{x}{L_{LL}} \leq 0.75$	$0.75 < \frac{x}{L_{LL}} \leq 1.0$
1	for $24 \text{ m} \leq L_{LL} \leq 100 \text{ m}$	
	$\frac{9.81}{76} (1.5L_{LL} + 116)$	on freeboard deck $\frac{9.81}{76} \left[(4.28L_{LL} + 28) \frac{x}{L_{LL}} - 1.71L_{LL} + 95 \right]$
		upon exposed superstructure decks located at least one superstructure standard height above the freeboard deck $\frac{9.81}{76} (1.5L_{LL} + 116)$
	for $L_{LL} > 100 \text{ m}$	
	9.81×3.5	on freeboard deck for type B ships according to ICLL $9.81 \left[(0.0296 \cdot L_1 + 3.04) \cdot \frac{x}{L_{LL}} - 0.0222 \cdot L_1 + 1.22 \right]$
		on freeboard deck for ships with less freeboard than type B according to ICLL $9.81 \left[(0.1452L_1 - 8.52) \frac{x}{L_{LL}} - 0.1089L_1 + 9.89 \right]$ $L_1 = L_{LL}$ but not more than 340 m
		upon exposed superstructure decks located at least one superstructure standard height above the freeboard deck 9.81×3.5
2	for $24 \text{ m} \leq L_{LL} \leq 100 \text{ m}$	
	$\frac{9.81}{76} (1.1L_{LL} + 87.6)$	
	for $L_{LL} > 100 \text{ m}$	
	9.81×2.6	
	upon exposed superstructure decks located at least one superstructure standard height above the lowest Position 2 deck 9.81×2.1	

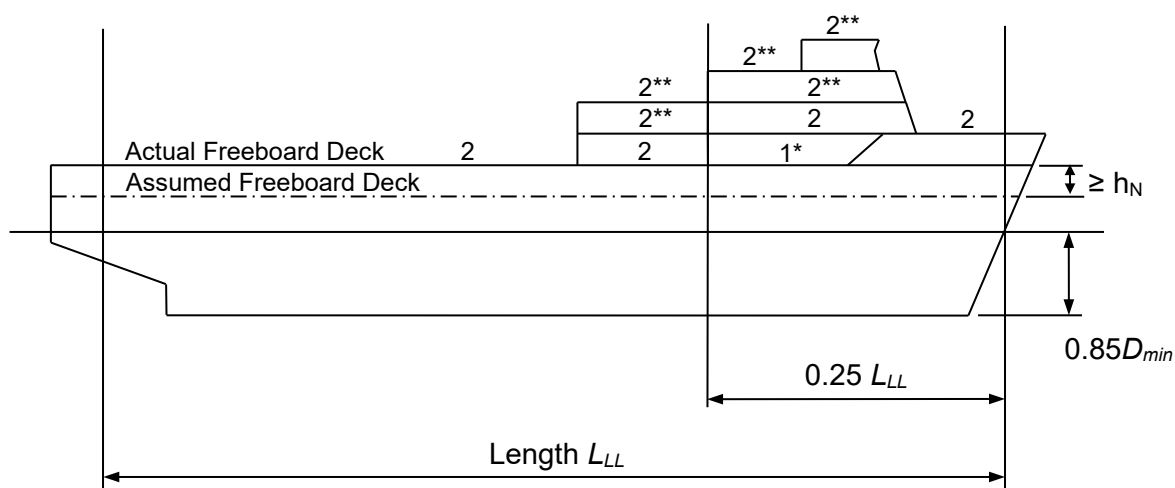
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- * reduced load upon exposed superstructure decks located at least one superstructure standard height above the freeboard deck
- ** reduced load upon exposed superstructure decks of vessels with $L_{LL} > 100$ m located at least one superstructure 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

2.2 Horizontal weather design load

2.2.1 General horizontal weather design load

The horizontal weather design load P_A , in kN/m^2 , for determining the scantlings of outer edge girders (skirt plates) of weather deck hatch covers and of hatch coamings is:

S21

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$$P_A = f_n f_c (f_b c_L C_w - z)$$

$$C_w = \frac{L}{25} + 4.1 \quad \text{for } L < 90 \text{ m}$$

$$= 10.75 - \left(\frac{300 - L}{100} \right)^{1.5} \quad \text{for } 90 \text{ m} \leq L < 300 \text{ m}$$

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

$$= 10.75 - \left(\frac{L - 350}{150} \right)^{1.5} \quad \text{for } 350 \text{ m} \leq L \leq 500 \text{ m}$$

$$c_L = \sqrt{\frac{L}{90}} \quad \text{for } L < 90 \text{ m}$$

$$= 1 \quad \text{for } L \geq 90 \text{ m}$$

$$f_n = 20 + \frac{L_1}{12} \quad \text{for unprotected front coamings and hatch cover skirt plates.}$$

$$= 10 + \frac{L_1}{12} \quad \text{for unprotected front coamings and hatch cover skirt plates, where}$$

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 .

$$= 5 + \frac{L_1}{15} \quad \text{for side and protected front coamings and hatch cover skirt plates.}$$

$$= 7 + \frac{L_1}{100} - 8 \frac{x'}{L} \quad \text{for aft ends of coamings and aft hatch cover skirt plates abaft}$$

amidships.

$$= 5 + \frac{L_1}{100} - 4 \frac{x'}{L} \quad \text{for aft ends of coamings and aft hatch cover skirt plates forward of}$$

amidships.

$$L_1 = L, \text{ need not be taken greater than } 300 \text{ m.}$$

$$f_b = 1.0 + \left(\frac{\frac{x'}{L} - 0.45}{C_B + 0.2} \right)^2 \quad \text{for } \frac{x'}{L} < 0.45$$

$$= 1.0 + 1.5 \cdot \left(\frac{\frac{x'}{L} - 0.45}{C_B + 0.2} \right)^2 \quad \text{for } \frac{x'}{L} \geq 0.45$$

$0.6 \leq C_B \leq 0.8$, 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.

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 $0.15L$ each, and x' is to be taken as the distance between aft end of the length L and the centre of each part considered.

S21 (cont)

z = vertical distance in m from the summer load line to the midpoint of stiffener span, or to the middle of the plate field.

$$f_c = 0.3 + 0.7 \frac{b'}{B'}$$

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 P_{A-min} given in Tab.2.

Tab.2 Minimum design load P_{A-min}

L	P_{A-min} in kN/m ² for	
	unprotected fronts	elsewhere
≤ 50	30	15
> 50	$25 + \frac{L}{10}$	$12.5 + \frac{L}{20}$
< 250		
≥ 250	50	25

2.2.2 Horizontal weather design load applicable to coamings of Type-2 ships

The pressure P_{Coam} , in kN/m², on the No. 1 forward transverse hatch coaming is given by:

$$P_{Coam} = 220, \text{ when a forecastle is fitted in accordance with UR S28} \\ = 290 \text{ in the other cases}$$

The pressure P_{Coam} , in kN/m², on the other coamings is given by:

$$P_{Coam} = 220$$

Note:

The horizontal weather design loads P_A and P_{Coam} 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.

S21

(cont)

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:

$$P_L = P_{Cargo}(1 + a_V)$$

where:

P_{Cargo} = uniform cargo load in kN/m²

a_V = vertical acceleration addition as follows:

$$a_V = F \cdot m$$

$$F = 0.11 \frac{v_0}{\sqrt{L}}$$

$$m = m_0 - 5(m_0 - 1) \frac{x}{L} \quad \text{for } 0 \leq \frac{x}{L} \leq 0.2$$

$$= 1.0 \quad \text{for } 0.2 < \frac{x}{L} \leq 0.7$$

$$= 1 + \frac{m_0 + 1}{0.3} \left[\frac{x}{L} - 0.7 \right] \quad \text{for } 0.7 < \frac{x}{L} \leq 1.0$$

$$m_0 = 1.5 + F$$

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 General

The loads defined in 2.4.2 to 2.4.4 are to be applied where containers are stowed on the hatch cover.

2.4.2 Corner loads for ship in upright condition

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:

$$P = 9.81 \frac{M}{4} (1 + a_V)$$

S21 (cont)

where:

a_v = acceleration addition according to 2.3.1.

M = maximum designed mass of container stack in t.

2.4.3 Corner loads for ship in heel condition

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):

$$A_z = 9.81 \frac{M}{2} (1 + a_v) \left(0.45 - 0.42 \frac{h_m}{b} \right)$$

$$B_z = 9.81 \frac{M}{2} (1 + a_v) \left(0.45 + 0.42 \frac{h_m}{b} \right)$$

$$B_y = 2.4M$$

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.

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).

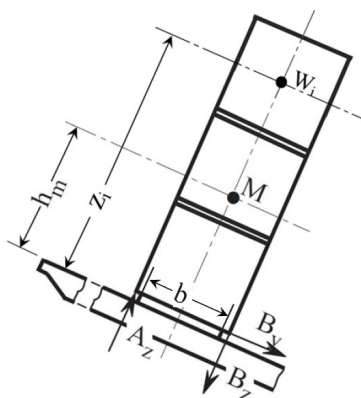


Fig.3 Forces due to container loads

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.

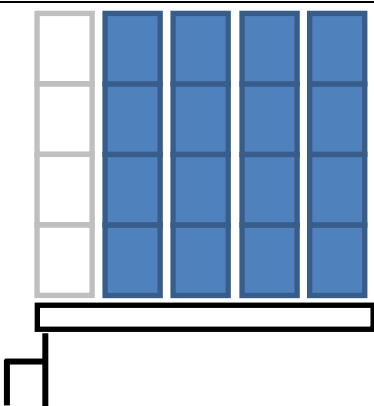
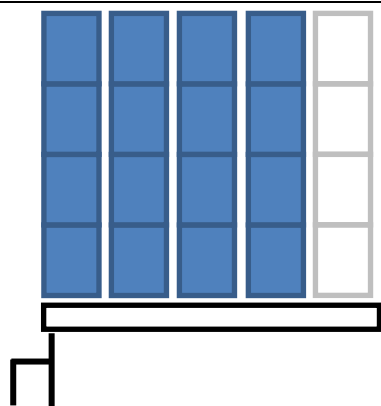
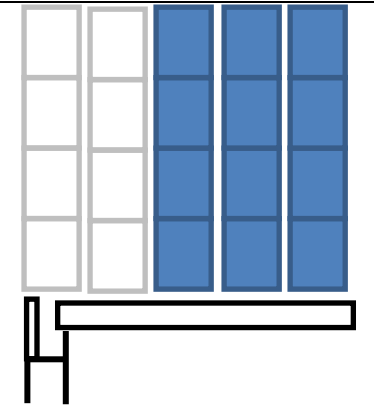
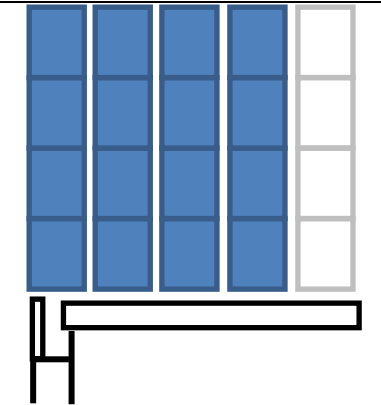
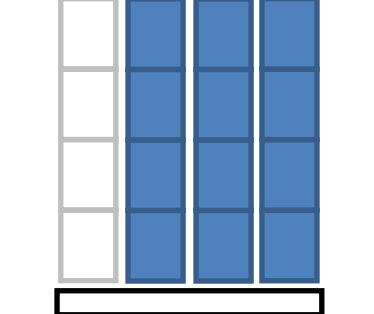
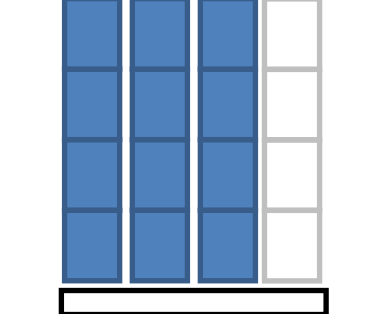
In addition, the case where only the stack places supported partially by the hatch cover and partially by container stanchions are left empty is to be assessed in order to consider the maximum loads in the vertical hatch cover supports.

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.

S21

(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.

S21

(cont)

3 Hatch cover strength criteria

3.1 Permissible stresses and deflections

3.1.1 Yield strength

All hatch cover structural members are to comply with the following formulae

$\sigma_{vm} \leq \sigma_a$ for shell elements in general.

$\sigma_{axial} \leq \sigma_a$ for rod or beam elements in general.

where:

σ_a : Allowable stress as defined in Tab. 4.

R_{eH} : Specified minimum yield stress, in N/mm², of the material.

σ_{vm} : Von Mises stress, in N/mm², to be taken as follows:

$$\sigma_{vm} = \sqrt{\sigma_x^2 - \sigma_x \sigma_y + \sigma_y^2 + 3\tau_{xy}^2}$$

σ_x : Normal stress, in N/mm², in x -direction.

σ_y : Normal stress, in N/mm², in y -direction.

τ_{xy} : Shear stress, in N/mm², in the x - y plane.

σ_{axial} : Axial stress in rod or beam elements, in N/mm².

Indices x and y are coordinates of a two-dimensional Cartesian system in the plane of the considered structural element.

In case of finite element(FE) calculations using shell (or plate) 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.

For steels with a minimum yield stress of more than 355 N/mm², the value of R_{eH} 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.

Stress concentrations are to be assessed to the satisfaction of the individual classification society.

Tab. 4 Allowable stresses

Members of	Subject to	σ_a , in N/mm ²
------------	------------	-----------------------------------

S21

(cont)

Hatch cover structure	External pressure, as defined in 2.1	0.80 R_{eH}
	Other loads, as defined in 2.2 to 2.5	0.90 R_{eH} for static+dynamic load case 0.72 R_{eH} for static load case

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 $0.0056l_g$, 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 within 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:

$$t = 0.0158 F_p s \sqrt{\frac{P}{0.95 R_{eH}}}$$

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
= $1.9 \frac{\sigma}{\sigma_a}$, for $\frac{\sigma}{\sigma_a} \geq 0.8$ for the attached plate flange of primary supporting members

where:

s = stiffener spacing in mm
 P = pressure P_{HC} 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 = as defined in Tab. 4

For flange plates under compression sufficient buckling strength according to 3.6 is to be demonstrated.

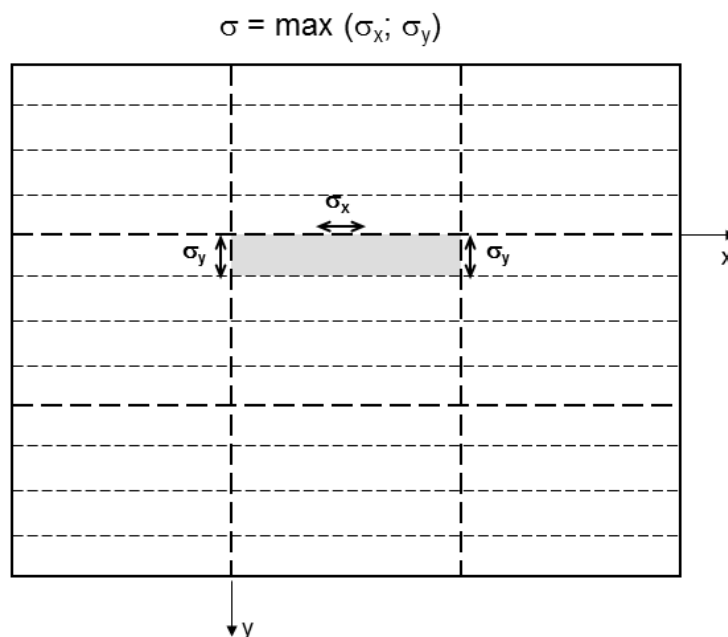


Fig.4 Determination of normal stress of the hatch cover plating

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:

$$t = 6.5s \times 10^{-3} \text{ mm}$$

where:

s = stiffener spacing in mm

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.

3.3 Net scantling of stiffeners

The net section modulus Z and net shear area A_{shr} of uniformly loaded hatch cover stiffeners constraint at both ends must not be less than:

S21 (cont)

$$Z = \frac{Psl^2}{f_{bc}\sigma_a}, \text{ in cm}^3,$$

$$A_{shr} = \frac{8.7Psl}{\sigma_a} 10^{-3}, \text{ in cm}^2,$$

where:

l = 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 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 unsupported span, for each bracket

s = stiffener spacing in mm

P = pressure P_{HC} and P_L , in kN/m^2 , as defined in 2.

f_{bc} = boundary coefficient of stiffener, taken equal to:

$f_{bc} = 8$, in the case of stiffener simply supported at both ends or simply supported at one end and clamped at the other end

$f_{bc} = 12$, in the case of stiffener clamped at both ends.

σ_a = allowable stress as defined in Tab.4

For stiffeners of lower plating of double skin hatch covers, requirements mentioned above are not applied if there are no lateral loads. For double skin hatch covers of holds designed for ballast or liquid cargo, the stiffeners on lower plating are to be strengthened according to individual class society rules.

The net thickness, in mm, of the stiffener (except U-type/trapeze stiffeners) web is to be taken not less than 4 mm.

The net section modulus of the stiffeners is to be determined based on an attached plate width assumed equal to the stiffener spacing.

Stiffeners parallel to primary supporting 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.

For hatch cover stiffeners under compression sufficient safety against lateral and torsional buckling according to 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.

S21

(cont)

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.

The net thickness, in mm, of webs of primary supporting members shall not be less than:

$$t = 6.5s \times 10^{-3} \text{ in mm}$$

$$t_{\min} = 5 \text{ mm}$$

where:

s = stiffener spacing in mm

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:

$$t = 0.0158s \sqrt{\frac{P_A}{0.95R_{eH}}}$$

$$t = 8.5s \times 10^{-3} \text{ in mm}$$

$$t_{\min} = 5 \text{ mm}$$

where:

P_A = horizontal pressure as defined in 2.2.1

s = stiffener spacing in mm

For the required moment of inertia of edge girders, refer to 6.1.4.

3.5 Strength calculations

The stresses in hatch covers are to be determined by FE analysis.

The stress calculation model in this section is to be used for both yielding and buckling strength assessments in accordance with 3.1 and 3.6, respectively.

The net scantlings as defined in 1.5 are to be used.

S21 (cont)

3.5.1 General requirements for FEM calculations

For the strength assessments of hatch covers by means of FE analysis, the hatch cover geometry shall be idealized as realistically as possible. In no case shall element width be larger than stiffener spacing. In way of force transfer points and cutouts the mesh is to be refined where applicable. The ratio of element length to width shall not exceed 3.

The element size along the height of webs of primary supporting member is not to exceed one-third of the web height. Stiffeners, which support plates subjected to lateral pressure loads, are to be included in the FE model idealization. Stiffeners may be modelled by using beam elements, or shell/plate elements. Buckling stiffeners may be disregarded for the stress calculation.

Hatch covers fitted with U-type stiffeners as shown in Fig. 5 are to be assessed by means of FE analysis. The geometry of the U-type stiffeners is to be accurately modelled using shell/plate elements. Nodal points are to be properly placed on the intersections between the webs of a U-type stiffener and the hatch cover plate, and between the webs and flange of the U-type stiffener.

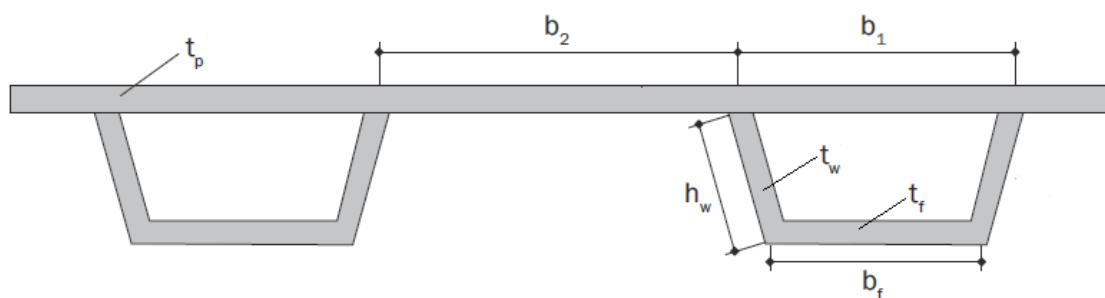


Fig.5: Example of hatch cover fitted with U-type stiffeners

Wherever applicable the following boundary conditions are to be applied to the FE model:

- Boundary nodes in way of a bearing pad on the hatch coamings are to be fixed against displacement in the direction perpendicular to the pad.
- Lifting stoppers are to be fixed against displacements in the direction determined by the stoppers.
- For a folding type hatch cover, the FE nodes connected through a hinge are to have the same translational displacement in the direction perpendicular to the hatch cover top plating.

3.6 Buckling strength of hatch cover structures

3.6.1 General

Buckling strength of all hatch cover structures is to be checked. Buckling assessments are to be performed in compliance with the requirements in UR S35 for the conditions specified in 3.6.2 and 3.6.3.

The net scantlings as defined in 1.5 are to be used for buckling check.

S21
(cont)**3.6.2 Slenderness requirements**

The slenderness requirements are to be in accordance with those specified in UR S35/Sec 2. The slenderness requirements need not be applied to the lower boundary of double skin hatch covers unless the cargo hold is designed for carriage of ballast or liquid cargo.

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.

3.6.3 Buckling requirements**3.6.3.1 Application**

These requirements apply to the buckling assessment of hatch cover structures subjected to compressive and shear stresses and lateral pressures. The buckling assessment is to be performed for the following structural elements:

- Stiffened and unstiffened panels, including curved panels and panels stiffened with U-type stiffeners.
- Web panels of primary supporting members in way of openings.

The buckling strength assessment of coaming parts is to be done according to the individual Society's rules.

For rule application, the panel types and assessment methods, the applied lateral pressure and stresses, safety factors and buckling check criteria are defined in 3.6.3.2, 3.6.3.3, 3.6.3.4 and 3.6.3.5, respectively. The procedure and detailed requirements for buckling assessment are given in UR S35/Sec4, including idealization of irregular plate panels, definition of reference stresses and buckling criteria.

Unless otherwise specified, the symbols used in 3.6.3 are defined in UR S35.

3.6.3.2 Panel types and assessment methods

The plate panel of a hatch cover structure is to be modelled as stiffened panel (SP) or unstiffened panel (UP) as defined in UR S35/Sec 4, [2]. Assessment Method A (-A) and Method B (-B) as defined in UR S35/Sec 1, [3] are to be used in accordance with Tab. 5, Fig. 6 and Fig. 7. For a web panel with opening, the procedure for opening should be used for its buckling assessment.

For a hatch cover fitted with U-type stiffeners, the additional buckling assessment requirements specific for panels with U-type stiffeners in UR S35/Sec 5, [2.5] are also to be followed.

Tab.5 Structural members and assessment methods

Structural elements	Assessment method ⁽¹⁾⁽²⁾	Normal panel definition
Hatch cover top/bottom plating structures, see Fig. 6		
Hatch cover top/bottom plating	SP-A	Length: between transverse girders Width: between longitudinal girders
Irregularly stiffened panels	UP-B	Plate between local stiffeners/PSM
Hatch cover web panels of primary supporting members, see Fig. 7		
Web of transverse/longitudinal girder (single skin type)	UP-B	Plate between local stiffeners/face plate/PSM
Web of transverse/longitudinal girder (double skin type)	SP-B ⁽³⁾	Length: between PSM Width: full web depth
Web panel with opening	Procedure for opening	Plate between local stiffeners/face plate/PSM
Irregularly stiffened panels	UP-B	Plate between local stiffeners/face plate/PSM
Note 1: SP and UP stand for stiffened and unstiffened panel respectively. Note 2: A and B stand for Method A and Method B respectively. Note 3: In case that the buckling carlings/brackets are irregularly arranged in the web of transverse/longitudinal girder, UP-B method may be used.		

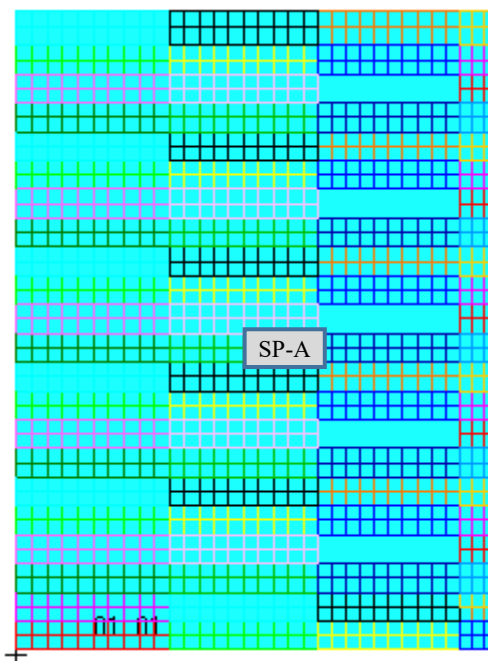


Fig.6 Hatch cover top/bottom plating structures

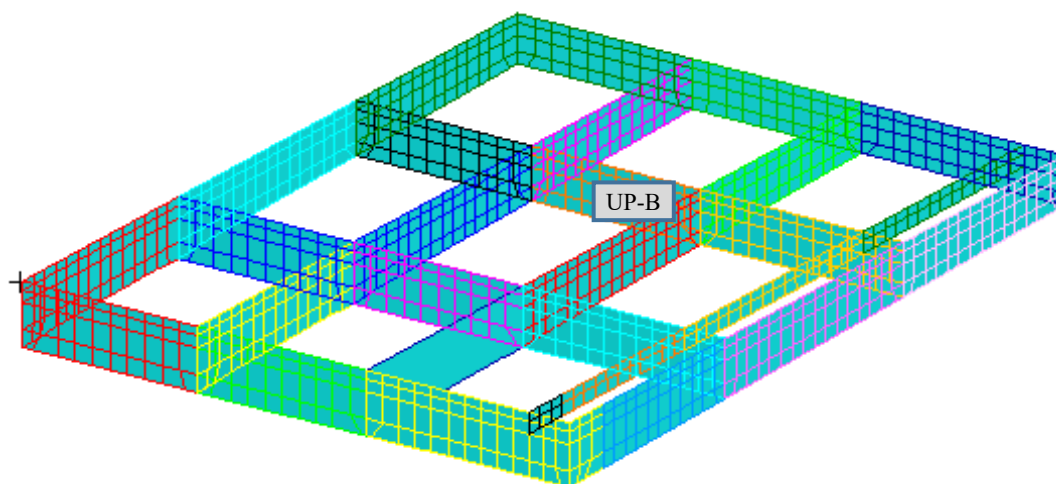


Fig.7 Hatch cover webs of primary supporting members

3.6.3.3 Applied lateral pressure and stresses

The buckling assessment of hatch covers is based on the lateral pressure as defined in S2.1 and 2.2, and stresses obtained from FE analysis, refer to 3.5.

3.6.3.4 Safety factors

For all hatch cover structural members, safety factor $S=1.0$ is to be applied to both of the plating and stiffener buckling capacity formulas as defined in UR S35/Sec5/2.2 and UR S35/Sec5/2.3, respectively.

3.6.3.5 Buckling acceptance criteria

A structural member is considered to have an acceptable buckling strength if it satisfies the following criterion:

$$\eta_{act} \leq \eta_{all}$$

where:

η_{act} : Buckling utilisation factor based on the applied stress, as defined in UR S35 /Sec1 [3.2.2] and UR S35/Sec4, and calculated per UR S35/Sec5.

η_{all} : Allowable buckling utilisation factor, taken as given in Tab. 6.

Tab.6 Allowable buckling utilisation factors

Structural component	Subject to	η_{all} , Allowable buckling utilisation factor
Plates and stiffeners Web of PSM	External pressure, as defined in 2.1	0.80
	Other loads, as defined in 2.2 to 2.5	0.90 for static+dynamic load case 0.72 for static load case

S21

(cont)

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. The specification or grade of the packing material is to be indicated on the drawings.

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:

$$H(x) \geq T_{fb} + f_b + h \text{ in m}$$

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

$$h = 4.6 \text{ m for } \frac{x}{L_{LL}} \leq 0.75$$

$$= 6.9 \text{ m for } \frac{x}{L_{LL}} > 0.75$$

- 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.

S21

(cont)

- 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 and local details

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:

(1) For Type-1 ships:

$$t = 0.0142s \sqrt{\frac{P_A}{0.95R_{eH}}} \text{ in mm}$$

$$t_{min} = 6 + \frac{L_1}{100} \text{ mm}$$

(2) For Type-2 ships:

$$t = 0.016s \sqrt{\frac{P_{coam}}{0.95R_{eH}}} \text{ in mm,}$$

$$t_{min} = 9.5 \text{ mm}$$

where:

P_A = pressure, in kN/m², as defined in S21.2.2.1

P_{coam} = pressure, in kN/m², as defined in S21.2.2.2

s = stiffener spacing in mm

L_1 = L , need not be taken greater than 300 m

In addition, for both Type-1 and Type-2 ships, longitudinal strength aspects are to be observed.

S21

(cont)

5.2 Net scantling of 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_{shr} in cm^2 , calculated on the basis of net thickness, must not be less than:

(1) For Type-1 ships:

$$Z = \frac{P_A s l^2}{f_{bc} R_{eH}}$$

$$A_{shr} = \frac{P_A s l}{R_{eH}} 10^{-2}$$

where:

$f_{bc} = 12$ in general

$= 8$ for the end spans of stiffeners sniped at the coaming corners

$l =$ stiffener span, in m, to be taken as the spacing of coaming stays

$s =$ stiffener spacing in mm

Note that for sniped stiffeners of coaming at hatch corners shear area at the fixed support has to be increased by 35%. The gross thickness of the coaming plate at the sniped stiffener end shall not be less than:

$$t_{gr} = 19.6 \sqrt{\frac{P_A s (l - 0.0005s)}{1000 R_{eH}}} \text{ in mm}$$

(2) For Type-2 ships:

$$Z = 1.21 \frac{P_{Coam} s l^2}{f_{bc} c_p R_{eH}}$$

where:

$f_{bc} = 16$ in general

$= 12$ for the end spans of stiffeners sniped at the coaming corners

$l =$ span, in m, of stiffeners

$s =$ spacing, in mm, of stiffeners

$P_A =$ pressure in kN/m^2 as defined in 2.2.1

$P_{Coam} =$ pressure in kN/m^2 as defined in 2.2.2

$c_p =$ ratio of the plastic section modulus to the elastic section modulus of the 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

S21

(cont)

In addition, for both Type-1 and Type-2 ships, 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 net thickness t_w , in mm, of the coaming stays designed as beams with flange (examples 1 and 2 are shown in Fig.8) are to be taken not less than:

$$Z = \frac{P s_c H_c^2}{1.9 R_{eH}} \text{ in cm}^3$$

$$t_w = \frac{2 P s_c H_c}{h R_{eH}} \text{ in mm}$$

where:

H_c = stay height, in m

s_c = stay spacing, in mm

h = stay depth, in mm, at the connection with the deck

P = pressure on coaming, in kN/m^2 , taken as P_A defined in 2.2.1 in general and as P_{Coam} defined in 2.2.2 for Type-2 ships.

For other designs of coaming stays, such as those shown in Fig. 8, examples 3 and 4, the stresses are to be determined through 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. 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.

Webs are to be connected to the deck by fillet welds on both sides with a throat thickness of $a = 0.44 t_w$.

For Type-2 ships, toes of stay webs are to be connected to the deck plating with full or partial penetration double bevel welds extending over a distance not less than 15% of the stay width. For other ship types 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.

S21

(cont)

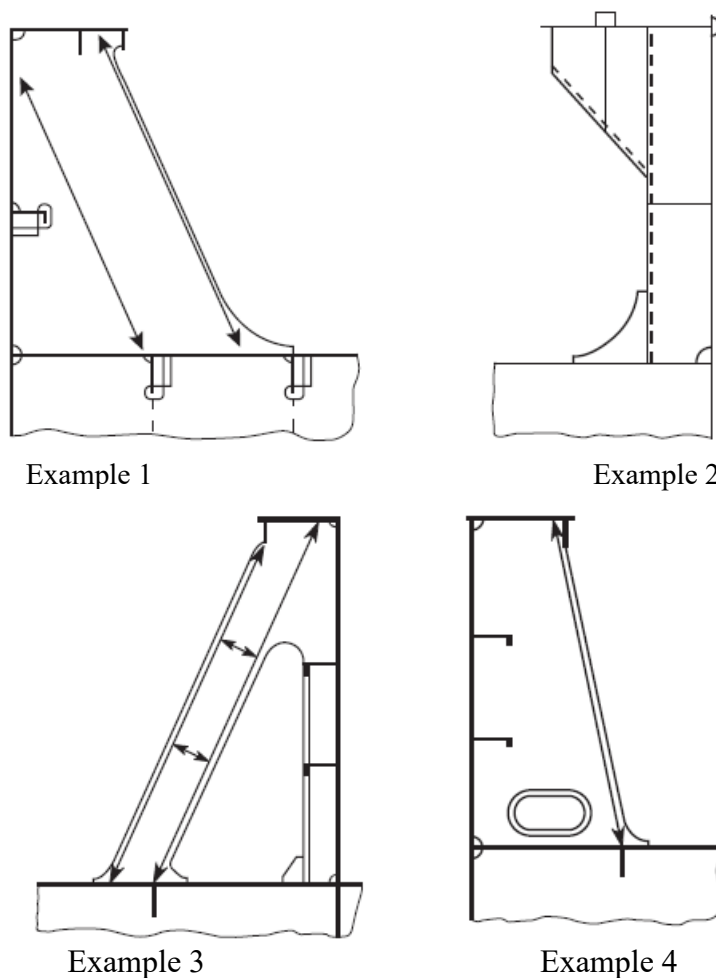


Fig.8 Examples of coaming stays

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 $0.1L$ 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.

S21

(cont)

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. 9 gives an example.

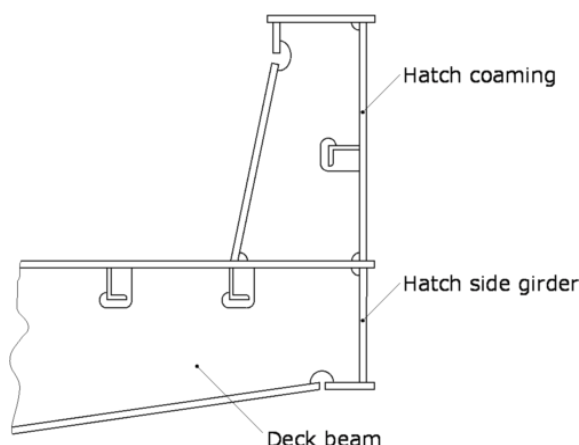


Fig.9 Example for a hatch side girder

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.

S21

(cont)

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.

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 cm² of the securing devices is not to be less than:

$$A = 0.28qS_{SD}k_l$$

Correspondingly, the stiffness of edge girders is to be sufficient to maintain adequate sealing pressure between securing devices. The moment of inertia, in cm⁴, of edge girders is not to be less than:

$$I = 6qS_{SD}^4$$

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.

S21 (cont)

$$k_l = \left(\frac{235}{R_{eH}} \right)^e$$

R_{eH} is the minimum yield strength of the material in N/mm^2 , but is not to be taken greater than $0.7R_m$, where R_m is the tensile strength of the material in N/mm^2 .

$$e = \begin{cases} 0.75 & \text{for } R_{eH} > 235 \text{ N/mm}^2 \\ 1.00 & \text{for } R_{eH} \leq 235 \text{ N/mm}^2 \end{cases}$$

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. The packing line pressure q is to be specified, and as load, 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.10. 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:

$$\sigma_{vm} = \frac{150}{k_l} \text{ in N/mm}^2$$

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.

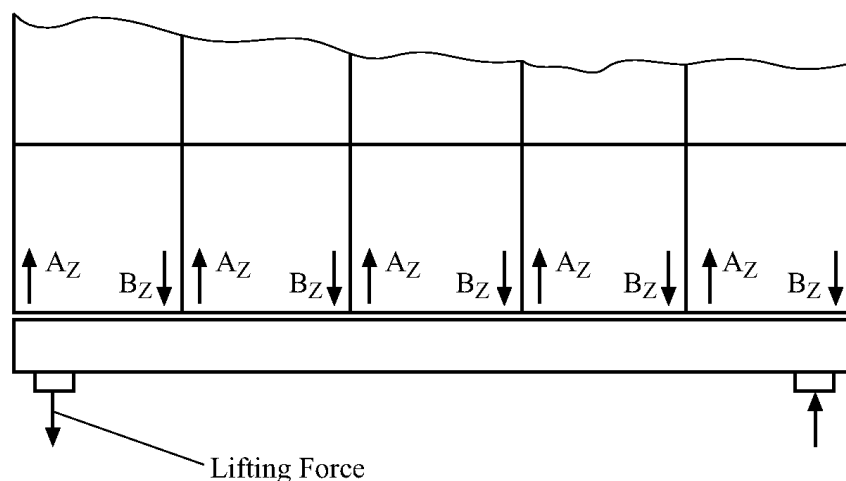


Fig.10 Lifting forces at a hatch cover

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:

S21

(cont)

$a_x = 0.2g$ in longitudinal direction

$a_y = 0.5g$ 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:

$$P_{nmax} = dP_n \text{ in N/mm}^2$$

$$d = 3.75 - 0.015L$$

$$d_{max} = 3.0$$

$$d_{min} = 1.0 \text{ in general}$$

$$= 2.0 \text{ for partial loading conditions, see 2.4.1}$$

$$P_n = \text{permissible nominal surface pressure, see Tab.7}$$

For metallic supporting surfaces not subjected to relative displacements the nominal surface pressure applies:

$$p_{nmax} = 3p_n \text{ in N/mm}^2$$

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. 7 Permissible nominal surface pressure P_n

Support material	P_n [N/mm ²] 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.

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.

S21
(cont)

Specifically for Type-2 ships, the following additional requirements are to be complied with:

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 $0.8R_{eH}$.

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_c :

Tab. 8 Corrosion additions t_c for hatch covers and hatch coamings

Application	Structure	t_c [mm]
Weather deck cargo 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 cargo hatches of Type-2 ships	Hatch covers in general	2.0
	Top and bottom plating of double skin hatch covers	2.0
	Internal structure of double skin hatch covers	1.5
	Hatch coamings and coaming stays	1.5
Weather deck cargo 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_c of which are provided in Tab. 8.

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 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 $t_c = 1.0$ 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.

S21
(cont)

For coaming structures, the corrosion additions t_c of which are not provided in Tab. 8, steel renewal and coating or annual gauging are to be in accordance with the individual classification society's requirements.

End of Document

S21A

(May 2011)
(Corr.1
Oct 2011)
(Rev.1
May 2015)
(Corr.1
Feb 2018)
(Corr.2
Mar 2019)
(Deleted
Jan 2023)

Requirements concerning STRENGTH OF SHIPS

Evaluation of Scantlings of Hatch Covers and Hatch Coamings and Closing Arrangements of Cargo Holds of Ships

Deleted on 1 July 2024 as UR S21A was superseded by UR S21 Rev.6

S22 Evaluation of Allowable Hold Loading of Cargo Hold No. 1 with Cargo Hold No. 1 Flooded, for Existing Bulk Carriers

(1997)
(Rev. 1
1997)
(Rev. 2
Sept.
2000)
(Rev. 3
July 2004)

S22.1 - 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 $1,78 \text{ t/m}^3$, or above, with single deck, topside tanks and hopper tanks, 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 S20,
- (ii) the foremost hold is double side skin construction 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 S20 (Rev. 2, Sept. 2000).

Early completion of a special survey coming due after 1 July 1998 to postpone compliance is not allowed.

The loading in cargo hold No. 1 is not to exceed the allowable hold loading in the flooded condition, calculated as per S22.4, using the loads given in S22.2 and the shear capacity of the double bottom given in S22.3.

In no case, the allowable hold loading in flooding condition is to be taken greater than the design hold loading in intact condition.

S22.2 - Load model

S22.2.1 - General

The loads to be considered as acting on the double bottom of hold No. 1 are those given by the external sea pressures and the combination of the cargo loads with those induced by the flooding of hold No. 1.

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 limit.

S22.2.2 - 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:

- D in general
- $0,95 \cdot D$ for ships less than 50,000 tonnes deadweight with Type B freeboard.

D being the distance, in m, from the baseline to the freeboard deck at side amidship (see Figure 1).

Note:

- 1 Changes introduced in Rev.2 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.

S22

cont'd

S22.3 - Shear capacity of the double bottom of hold No. 1

The shear capacity C of the double bottom of hold No. 1 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.

The strength of girders or floors which run out and are not directly attached to the boundary stool or hopper girder 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 the double bottom is to be calculated according to the Society's criteria.

In calculating the shear strength, the net thicknesses of floors and girders are to be used. The net thickness t_{net} , in mm, is given by:

$$t_{\text{net}} = t - t_c$$

where:

t = as built thickness, in mm, of floors and girders

t_c = corrosion diminution, equal to 2 mm, in general; a lower value of t_c may be adopted, provided that measures are taken, to the Society's satisfaction, to justify the assumption made.

S22.3.1 - 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 "outermost" bay (i.e. that bay which is closest to hopper) S_{f2} , in kN, are given by the following expressions:

$$S_{f1} = 10^{-3} \cdot A_f \cdot \frac{\tau_a}{\eta_1}$$

$$S_{f2} = 10^{-3} \cdot A_{f,h} \cdot \frac{\tau_a}{\eta_2}$$

where:

A_f = sectional area, in mm², of the floor panel adjacent to hoppers

$A_{f,h}$ = net sectional area, in mm², of the floor panels in way of the openings in the "outermost" bay

S22

cont'd

(i.e. that bay which is closest to hopper)

τ_a = allowable shear stress, in N/mm², to be taken equal to : $\sigma_F / \sqrt{3}$

σ_F = minimum upper yield stress, in N/mm², of the material

η_1 = 1,10

η_2 = 1,20

η_2 may be reduced, at the Society's discretion, down to 1,10 where appropriate reinforcements are fitted to the Society's satisfaction

S22.3.2 - 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 "outermost" bay (i.e. that bay which is closest to stool, or transverse bulkhead, if no stool is fitted) S_{g2} , in kN, are given by the following expressions:

$$S_{g1} = 10^{-3} \cdot A_g \cdot \frac{\tau_a}{\eta_1}$$

$$S_{g2} = 10^{-3} \cdot A_{g,h} \cdot \frac{\tau_a}{\eta_2}$$

where:

A_g = minimum sectional area, in mm², of the girder panel adjacent to stools (or transverse bulkheads, if no stool is fitted)

$A_{g,h}$ = net sectional area, in mm², of the girder panel in way of the largest opening in the "outermost" bay (i.e. that bay which is closest to stool, or transverse bulkhead, if no stool is fitted)

τ_a = allowable shear stress, in N/mm², as given in S22.3.1

η_1 = 1,10

η_2 = 1,15

η_2 may be reduced, at the Society's discretion, down to 1,10 where appropriate reinforcements are fitted to the Society's satisfaction

S22.4 - Allowable hold loading

The allowable hold loading W, in t, is given by:

$$W = \rho_c \cdot V \cdot \frac{1}{F}$$

where:

F = 1,05 in general
1,00 for steel mill products

ρ_c = cargo density, in t/m³; for bulk cargoes see S22.2.1; for steel products, ρ_c is to be taken as the

S22

cont'd

density of steel

V = volume, in m³, occupied by cargo at a level h₁

$$h_1 = \frac{X}{\rho_c \cdot g}$$

X = for bulk cargoes, the lesser of X₁ and X₂ given by

$$X_1 = \frac{Z + \rho \cdot g \cdot (E - h_f)}{1 + \frac{\rho}{\rho_c} (perm - 1)}$$

$$X_2 = Z + \rho \cdot g \cdot (E - h_f \cdot perm)$$

X = for steel products, X may be taken as X₁, using perm = 0

ρ = sea water density, in t/m³

g = 9,81 m/s², gravity acceleration

E = d_f - 0,1 · D

d_f, D = as given in S22.2.2

h_f = flooding head, in m, as defined in S22.2.2

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/m³).

Z = the lesser of Z₁ and Z₂ 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 S22.3, considering, for each floor, the lesser of the shear strengths S_{f1} and S_{f2} (see S22.3.1) and, for each girder, the lesser of the shear strengths S_{g1} and S_{g2} (see S22.3.2)

C_e= shear capacity of the double bottom, in kN, as defined in S22.3, considering, for each floor, the shear strength S_{f1} (see S22.3.1) and, for each girder, the lesser of the shear strengths S_{g1} and S_{g2} (see S22.3.2)

S22

cont'd

$$A_{DB,h} = \sum_{i=1}^{i=n} S_i \cdot B_{DB,i}$$

$$A_{DB,e} = \sum_{i=1}^{i=n} S_i \cdot B_{DB} - s$$

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 for floors whose shear strength is given by Sf₁ (see S22.3.1)

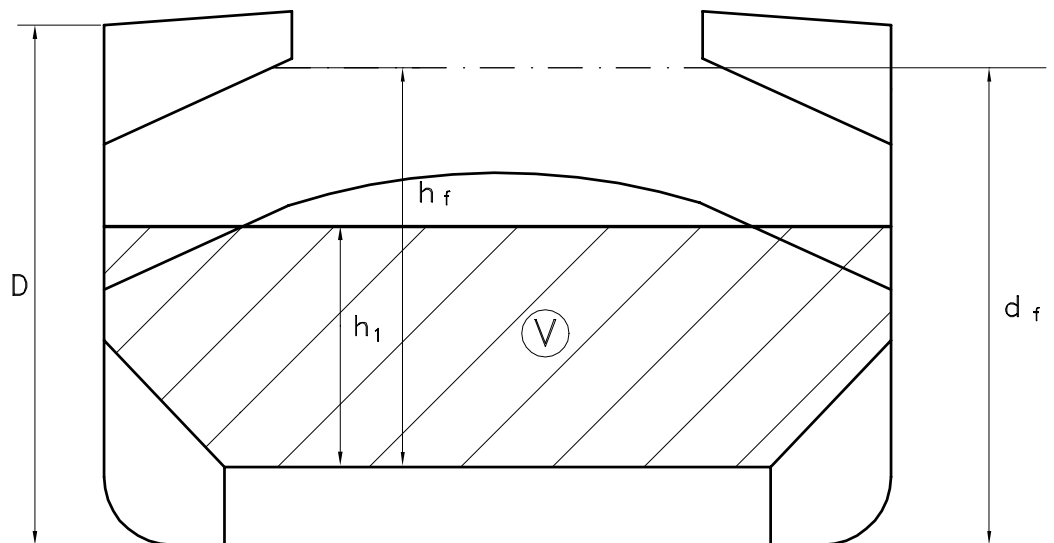
B_{DB,i} = B_{DB,h} for floors whose shear strength is given by Sf₂ (see S22.3.1)

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 = spacing, in m, of double bottom longitudinals adjacent to hoppers

Figure 1



V = Volume of cargo

Figure 2

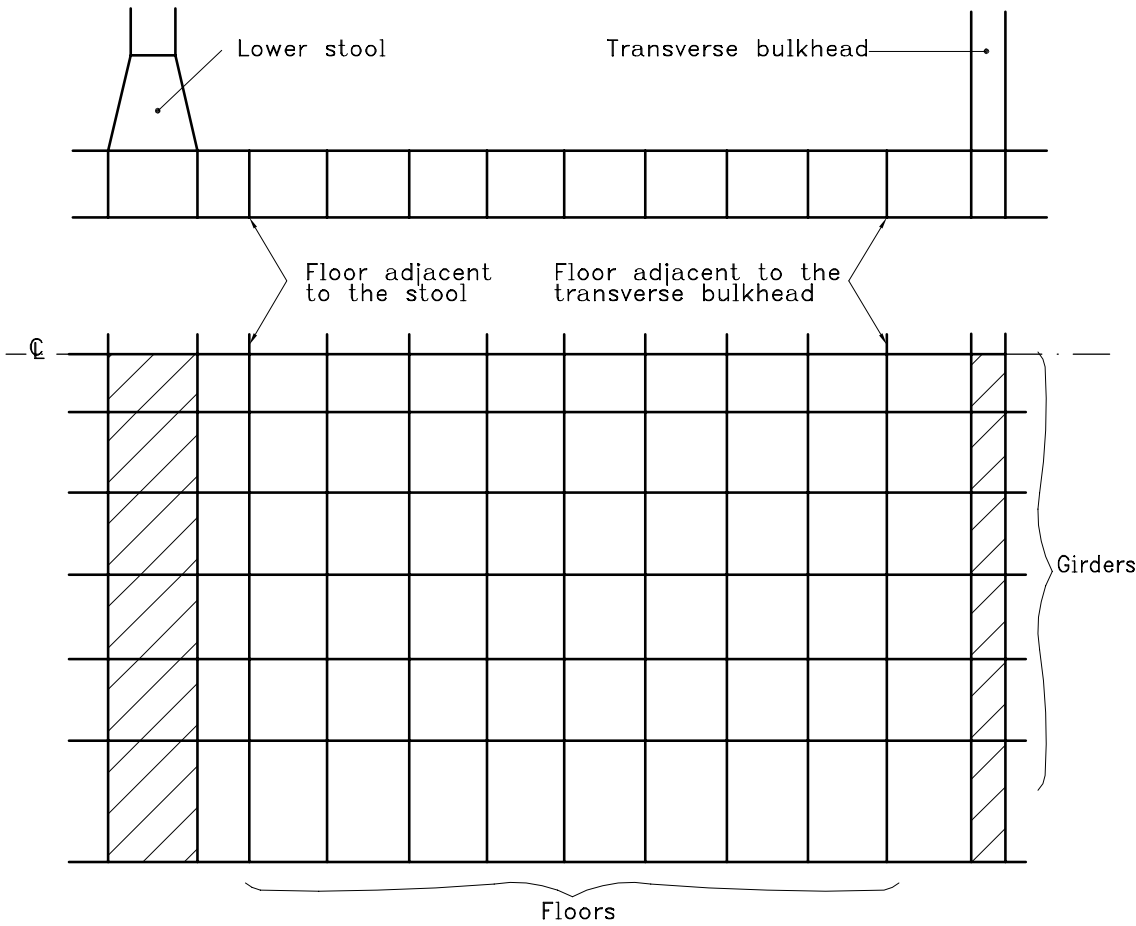
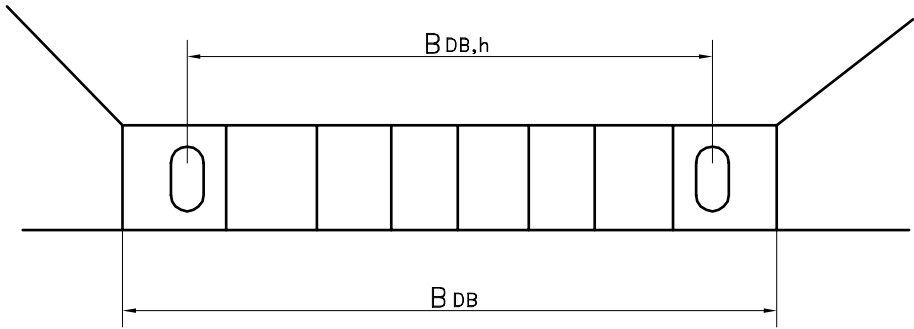


Figure 3



END

S23

(1997)
 (Rev. 1
 1997)
 (Rev. 2
 April 1998)
 (Rev. 2.1
 November
 1998)
 (Rev.3
 Mar. 2002)
 (Rev.3.1
 Dec.2002)
 (Rev.4
 Aug 2007)

Implementation of IACS Unified Requirements S19 and S22 for Existing Single Side Skin Bulk Carriers

S23.1 Application and Implementation Timetable*

- a. Unified Requirements S19 and S22 are to be applied in conjunction with the damage stability requirements set forth in S23.2. Compliance is required:
 - i. for ships which were 20 years of age or more on 1 July 1998, by the due date of the first intermediate, or the due date of the first special survey to be held after 1 July 1998, whichever comes first;
 - ii. for ships which were 15 years of age or more but less than 20 years of age on 1 July 1998, by the due date of the first special survey to be held after 1 July 1998, but not later than 1 July 2002;
 - iii. for ships which were 10 years of age or more but less than 15 years of age on 1 July 1998, by the due date of the first intermediate, or the due date of the first special survey to be held after the date on which the ship reaches 15 years of age but not later than the date on which the ship reaches 17 years of age;
 - iv. for ships which were 5 years of age or more but less than 10 years of age on 1 July 1998, by the due date, after 1 July 2003, of the first intermediate or the first special survey after the date on which the ship reaches 10 years of age, whichever occurs first;
 - v. for ships which were less than 5 years of age on 1 July 1998, by the date on which the ship reaches 10 years of age.
- b. Completion prior to 1 July 2003 of an intermediate or special survey with a due date after 1 July 2003 cannot be used to postpone compliance. However, completion prior to 1 July 2003 of an intermediate survey the window for which straddles 1 July 2003 can be accepted.

S23.2 Damage Stability

- a. Bulk carriers which are subject to compliance with Unified Requirements S19 and S22 shall, when loaded to the summer loadline, be able to withstand flooding of the foremost cargo hold in all loading conditions and remain afloat in a satisfactory condition of equilibrium, as specified in SOLAS regulation XII/4.3 to 4.7.
- b. A ship having been built with an insufficient number of transverse watertight bulkheads to satisfy this requirement may be exempted from the application of Unified Requirements S19, S22 and this requirement provided the ship fulfills the requirement in SOLAS regulation XII/9.

* See Annex for details.



1. **Surveys to be held**
The term "survey to be held" is interpreted to mean that the survey is "being held" until it is "completed".
2. **Due dates and completion allowance**
 - 2.1 intermediate survey :
 - 2.1.1 Intermediate survey carried out either at the second or third annual survey: 3 months after the due date (i.e. 2nd or 3rd anniversary) can be used to carry out and complete the survey;
 - 2.1.2 Intermediate survey carried out between the second and third annual survey: 3 months after the due date of the 3rd Annual Survey can be used to carry out and complete the survey;
 - 2.2 special survey : 3 months extension after the due date may be allowed subject to the terms/conditions of PR4;
 - 2.3 ships controlled by "1 July 2002": same as for special survey;
 - 2.4 ships controlled by "age 15 years" or "age 17 years": same as for special survey.
3. **Intermediate Survey Interpretations/Applications**
 - 3.1 If the 2nd anniversary is prior to or on 1 July 1998 and the intermediate survey is completed prior to or on 1 July 1998, the ship need not comply until the next special survey.
 - 3.2 If the 2nd anniversary is prior to or on 1 July 1998 and the intermediate survey is completed within the window of the 2nd annual survey but after 1 July 1998, the ship need not comply until the next special survey.
 - 3.3 If the 2nd anniversary is prior to or on 1 July 1998 and the intermediate survey is completed outside the window of the 2nd annual survey and after 1 July 1998, it is taken that the intermediate survey is held after 1 July 1998 and between the second and third annual surveys. Therefore, the ship shall comply no later than 3 months after the 3rd anniversary.
 - 3.4 If the 2nd anniversary is after 1 July 1998 and the intermediate survey is completed within the window of the 2nd annual survey but prior to or on 1 July 1998, the ship need not comply until the next special survey
 - 3.5 If the 3rd anniversary is prior to or on 1 July 1998 and the intermediate survey is completed prior to or on 1 July 1998, the ship need not comply until the next special survey.
 - 3.6 If the 3rd anniversary is prior to or on 1 July 1998 and the intermediate survey is completed within the window of the 3rd annual survey but after 1 July 1998, the ship need not comply until the next special survey.
 - 3.7 If the 3rd anniversary is after 1 July 1998 and the intermediate survey is completed within the window prior to or on 1 July 1998, the ship need not comply until the next special survey.
4. **Special Survey Interpretations/Applications**
 - 4.1 If the due date of a special survey is after 1 July 1998 and the special survey is completed within the 3 month window prior to the due date and prior to or on 1 July 1998, the ship need not comply until the next relevant survey (i.e. special survey for ships under 20 years of age on 1 July 1998, intermediate survey for ships 20 years of age or more on 1 July 1998).
5. **Early Completion of an Intermediate Survey (coming due after 1 July 1998 to postpone compliance is not allowed):**
 - 5.1 Early completion of an intermediate survey means completion of the survey prior to the opening of the window (i.e. completion more than 3 months prior to the 2nd anniversary since the last special survey).
 - 5.2 The intermediate survey may be completed early and credited from the completion date but in such a case the ship will still be required to comply not later than 3 months after the 3rd anniversary.
6. **Early Completion of a Special Survey (coming due after 1 July 1998 to postpone compliance is not allowed):**
 - 6.1 Early completion of a special survey means completion of the survey more than 3 months prior to the due date of the special survey.
 - 6.2 The special survey may be completed early and credited from the completion date, but in such a case the ship will still be required to comply by the due date of the special survey.



S24

(September
1998)
(Deleted
Jan2004)

**Detection of Water Ingress into Cargo Holds
of Bulk Carriers**

URS24 superceded by UI SC 179 and SC 180

Deleted on 1 January 2004



S25

(June
2002)
(Rev.1
Feb
2003)
(Corr.1
May
2004)
(Rev.2
July
2004)

Harmonised Notations and Corresponding Design Loading Conditions for Bulk Carriers

Deleted May 2010.

End of
Document

S26 Strength and Securing of Small Hatches on the Exposed Fore Deck

(Nov 2002)
(Rev.1
Nov 2003)
(Rev.2
July 2004)
(Rev.3
Aug 2006)
(Rev.4
May 2010)
(Rev.5
May 2023)

1. General

1.1 The strength of, and securing devices for, small hatches fitted on the exposed fore deck are to comply with the requirements of this UR.

1.2 Small hatches in the context of this UR are hatches designed for access to spaces below the deck and are capable of being closed weather-tight or watertight, as applicable. Their opening is normally 2.5 square metres or less.

1.3 Hatches designed for emergency escape need not comply with the requirements 5.1 (i) and (ii), 6.3 and 7 of this UR.

1.4 Securing devices of hatches designed for emergency escape are to be of a quick-acting type (e.g., one action wheel handles are provided as central locking devices for latching/unlatching of hatch cover) operable from both sides of the hatch cover.

2. Application

2.1 For ships that are contracted for construction on or after 1 January 2004 on the exposed deck over the forward 0.25L, applicable to:

All ship types of sea going service of length 80 m or more, where the height of the exposed deck in way of the hatch is less than 0.1L or 22 m above the summer load waterline, whichever is the lesser.

2.2 For ships that are contracted for construction prior to 1 January 2004 only for hatches on the exposed deck giving access to spaces forward of the collision bulkhead, and to spaces which extend over this line aft-wards, applicable to:

Bulk carriers, ore carriers, and combination carriers (as defined in UR Z11) and general dry cargo ships (excluding container vessels, vehicle carriers, Ro-Ro ships and woodchip carriers), of length 100 m or more.

2.3 The ship length L is as defined in UR S2.

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

2.5 This UR does not apply to small hatches on container ship giving access to a cargo hold which comply with UI LL64 except the requirement of clause 4 & 5. Such hatch covers are considered non-weather-tight regardless of whether it is actually weather-tight or not. However, for scantlings of small hatches, the strength requirements in clause 4 of this UR could be applied instead of clause 6 of UI LL64.

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 PR No. 29.

2. Changes introduced in Rev.5 are to be uniformly implemented by IACS Members for ships contracted for construction on or after 1 July 2024.

S26

(cont)

3. Implementation * (see footnote)

3.1 Ships that are described in paragraph 2.1 that are contracted for construction on or after 1 January 2004 are to comply by the time of delivery.

3.2 Ships described in paragraph 2.2 that are contracted for construction prior to 1 January 2004 are to comply:

- i) for ships which will be 15 years of age or more on 1 January 2004 by the due date of the first intermediate or special survey after that date;
- ii) for ships which will be 10 years of age or more on 1 January 2004 by the due date of the first special survey after that date;
- iii) for ships which will be less than 10 years of age on 1 January 2004 by the date on which the ship reaches 10 years of age.

4. Strength

4.1 For small rectangular steel hatch covers, the plate thickness, stiffener arrangement and scantlings are to be in accordance with Table 1, and Figure 1. Stiffeners, where fitted, are to be aligned with the metal-to-metal contact points, required in 6.1, see Figure 1. Primary stiffeners are to be continuous. All stiffeners are to be welded to the inner edge stiffener, see Figure 2.

4.2 The upper edge of the hatchway coamings is to be suitably reinforced by a horizontal section, normally not more than 170 to 190 mm from the upper edge of the coamings.

4.3 For small hatch covers of circular or similar shape, the cover plate thickness and reinforcement is to be according to the requirements of each Society.

4.4 For small hatch covers constructed of materials other than steel, the required scantlings are to provide equivalent strength.

* The requirements in 1.4, introduced in Rev. 3 of this UR, are to be uniformly applied by IACS Members and Associates:

- (a) to new vessels, contracted for construction on or after 1 July 2007, by the time of delivery;
- (b) to vessels contracted for construction prior to 1 July 2007, by the compliance date specified in Section 3 of this UR, or by the due date of the first special survey after 1 July 2007, whichever is later. Completion prior to 1 July 2007 of a special survey with a due date after 1 July 2007 cannot be used to postpone compliance.

S26
(cont)**5. Primary Securing Devices**

5.1 Small hatches located on exposed fore deck subject to the application of this UR are to be fitted with primary securing devices such that their hatch covers can be secured in place and weather-tight by means of a mechanism employing any one of the following methods:

- i) Butterfly nuts tightening onto forks (clamps),
- ii) Quick acting cleats, or
- iii) Central locking device.

5.2 Dogs (twist tightening handles) with wedges are not acceptable.

6. Requirements for Primary Securing

6.1 The hatch cover is to be fitted with a gasket of elastic material. This is to be designed to allow a metal to metal contact at a designed compression and to prevent over compression of the gasket by green sea forces that may cause the securing devices to be loosened or dislodged. The metal-to-metal contacts are to be arranged close to each securing device in accordance with Figure 1, and of sufficient capacity to withstand the bearing force.

6.2 The primary securing method is to be designed and manufactured such that the designed compression pressure is achieved by one person without the need of any tools.

6.3 For a primary securing method using butterfly nuts, the forks (clamps) are to be of robust design. They are to be designed to minimize the risk of butterfly nuts being dislodged while in use; by means of curving the forks upward, a raised surface on the free end, or a similar method. The plate thickness of unstiffened steel forks is not to be less than 16 mm. An example arrangement is shown in Figure 2.

6.4 For small hatch covers located on the exposed deck forward of the fore-most cargo hatch, the hinges are to be fitted such that the predominant direction of green sea will cause the cover to close, which means that the hinges are normally to be located on the fore edge.

6.5 On small hatches located between the main hatches, for example between Nos. 1 and 2, the hinges are to be placed on the fore edge or outboard edge, whichever is practicable for protection from green water in beam sea and bow quartering conditions.

7. Secondary Securing Device

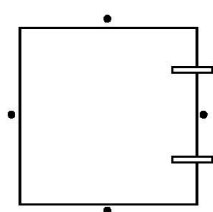
Small hatches on the fore deck are to be fitted with an independent secondary securing device e.g. by means of a sliding bolt, a hasp or a backing bar of slack fit, which is capable of keeping the hatch cover in place, even in the event that the primary securing device became loosened or dislodged. It is to be fitted on the side opposite to the hatch cover hinges.

S26

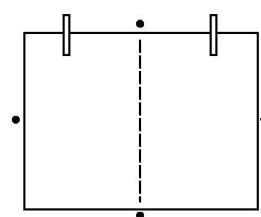
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Table 1: Scantlings for Small Steel Covers on the Fore Deck

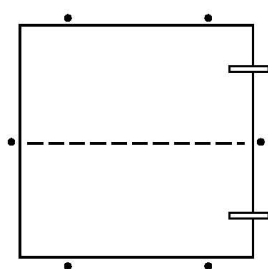
Nominal size (mm x mm)	Cover plate thickness (mm)	Primary stiffeners	Secondary stiffeners
		Flat Bar (mm x mm); number	
630 x 630	8	-	-
630 x 830	8	100 x 8 ; 1	-
830 x 630	8	100 x 8 ; 1	-
830 x 830	8	100 x 10 ; 1	-
1030 x 1030	8	120 x 12 ; 1	80 x 8 ; 2
1330 x 1330	8	150 x 12 ; 2	100 x 10 ; 2



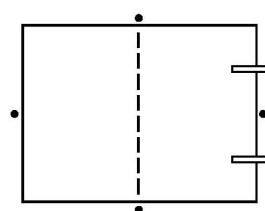
Nominal size 630 x 630



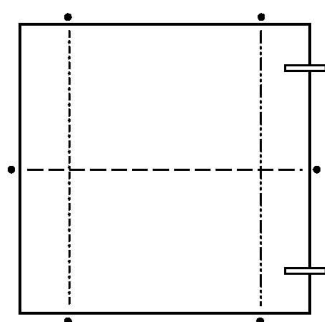
Nominal size 630 x 830



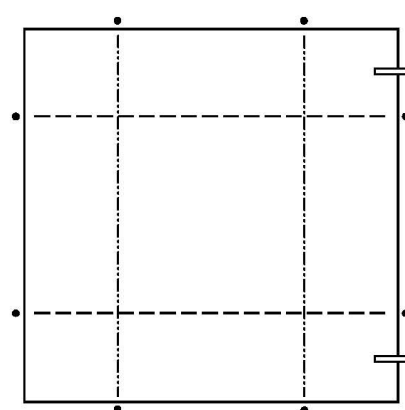
Nominal size 830 x 830



Nominal size 830 x 630



Nominal size 1030 x 1030



Nominal size 1330 x 1330

— Hinge

• Securing device / metal to metal contact

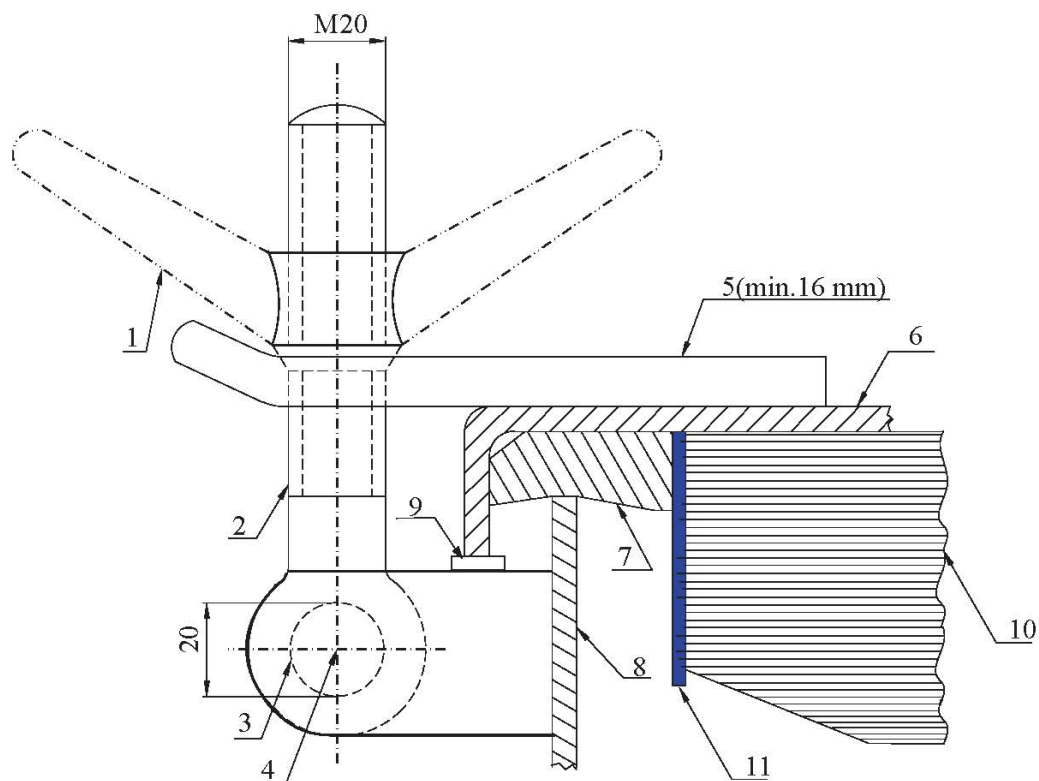
----- Primary stiffener

----- Secondary stiffener

Figure 1. Arrangement of Stiffeners

S26

(cont)



- 1: butterfly nut
- 2: bolt
- 3: pin
- 4: center of pin
- 5: fork (clamp) plate
- 6: hatch cover
- 7: gasket
- 8: hatch coaming
- 9: bearing pad welded on the bracket of a toggle bolt for metal to metal contact
- 10: stiffener
- 11: inner edge stiffener

(Note: Dimensions in millimeters)

Figure 2. Example of a Primary Securing Device

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S27

(Nov 2002)
 (Rev.1 March 2003)
 (Corr.1 July 2003)
 (Rev.2 Nov 2003)
 (Rev.3 July 2004)
 (Rev.4 Nov 2004)
 (Rev.5 May 2010)
 (Rev.6 June 2013)

Strength Requirements for Fore Deck Fittings and Equipment

1. General

1.1 This UR S 27 provides strength requirements to resist green sea forces for the following items located within the forward quarter length:

air pipes, ventilator pipes and their closing devices, the securing of windlasses.

1.2 For windlasses, these requirements are additional to those appertaining to the anchor and chain performance criteria of each Society.

1.3 Where mooring winches are integral with the anchor windlass, they are to be considered as part of the windlass.

2. Application

2.1 For ships that are contracted for construction on or after 1 January 2004 on the exposed deck over the forward 0.25L, applicable to:

All ship types of sea going service of length 80 m or more, where the height of the exposed deck in way of the item is less than 0.1L or 22 m above the summer load waterline, whichever is the lesser.

2.2 For ships that are contracted for construction prior to 1 January 2004 only for air pipes, ventilator pipes and their closing devices on the exposed deck serving spaces forward of the collision bulkhead, and to spaces which extend over this line aft-wards, applicable to:

Bulk carriers, ore carriers, and combination carriers (as defined in UR Z11) and general dry cargo ships (excluding container vessels, vehicle carriers, Ro-Ro ships and woodchip carriers), of length 100m or more.

2.3 The ship length L is as defined in UR S2.

2.4 This UR does not apply to CSR Oil Tankers.

2.5 The requirements of this UR concerning windlasses do not apply to CSR Bulk Carriers.

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. This UR does not apply to the cargo tank venting systems and the inert gas systems of tankers.
3. The changes introduced in Rev.6 apply to ships contracted for construction from 1 July 2014.

S27

(cont)

3. Implementation

3.1 Ships that are described in paragraph 2.1 that are contracted for construction on or after 1 January 2004 are to comply by the time of delivery.

3.2 Ships described in paragraph 2.2 that are contracted for construction prior to 1 January 2004 are to comply:

- i) for ships which will be 15 years of age or more on 1 January 2004 by the due date of the first intermediate or special survey after that date;
- ii) for ships which will be 10 years of age or more on 1 January 2004 by the due date of the first special survey after that date;
- iii) for ships which will be less than 10 years of age on 1 January 2004 by the date on which the ship reaches 10 years of age.

Completion prior to 1 January 2004 of an intermediate or special survey with a due date after 1 January 2004 cannot be used to postpone compliance.

However, completion prior to 1 January 2004 of an intermediate survey the window for which straddles 1 January 2004 can be accepted.

4. Applied Loading

4.1 Air pipes, ventilator pipes and their closing devices

4.1.1 The pressures p , in kN/m^2 acting on air pipes, ventilator pipes and their closing devices may be calculated from:

$$p = 0.5 \rho V^2 C_d C_s C_p$$

where:

ρ = density of sea water (1.025 t/m^3)

V = velocity of water over the fore deck
= 13.5 m/sec for $d \leq 0.5 d_1$

$$= 13.5 \sqrt{2 \left(1 - \frac{d}{d_1}\right)} \text{ m/sec for } 0.5 d_1 < d < d_1$$

d = distance from summer load waterline to exposed deck

d_1 = $0.1L$ or 22 m whichever is the lesser

C_d = shape coefficient

= 0.5 for pipes, 1.3 for air pipe or ventilator heads in general, 0.8 for an air pipe or ventilator head of cylindrical form with its axis in the vertical direction.

C_s = slamming coefficient (3.2)

C_p = protection coefficient:

(0.7) for pipes and ventilator heads located immediately behind a breakwater or forecastle,
(1.0) elsewhere and immediately behind a bulwark.

4.1.2 Forces acting in the horizontal direction on the pipe and its closing device may be calculated from 4.1.1 using the largest projected area of each component.

S27 (cont)

4.2 Windlasses

4.2.1 The following pressures and associated areas are to be applied (see Figure 1):

- 200 kN/m² normal to the shaft axis and away from the forward perpendicular, over the projected area in this direction,
- 150 kN/m² parallel to the shaft axis and acting both inboard and outboard separately, over the multiple of f times the projected area in this direction, where f is defined as:
 $f = 1 + B/H$, but not greater than 2.5

where:

B = width of windlass measured parallel to the shaft axis,

H = overall height of windlass.

4.2.2 Forces in the bolts, chocks and stoppers securing the windlass to the deck are to be calculated. The windlass is supported by N bolt groups, each containing one or more bolts, see Figure 2.

4.2.3 The axial force R_i in bolt group (or bolt) i , positive in tension, may be calculated from:

$$R_{xi} = P_x h x_i A_i / I_x$$

$$R_{yi} = P_y h y_i A_i / I_y$$

$$\text{and } R_i = R_{xi} + R_{yi} - R_{si}$$

where:

P_x = force (kN) acting normal to the shaft axis

P_y = force (kN) acting parallel to the shaft axis, either inboard or outboard whichever gives the greater force in bolt group i

h = shaft height above the windlass mounting (cm)

x_i, y_i = x and y coordinates of bolt group i from the centroid of all N bolt groups, positive in the direction opposite to that of the applied force (cm)

A_i = cross sectional area of all bolts in group i (cm²)

$$I_x = \sum A_i x_i^2 \text{ for } N \text{ bolt groups}$$

$$I_y = \sum A_i y_i^2 \text{ for } N \text{ bolt groups}$$

R_{si} = static reaction at bolt group i , due to weight of windlass.

4.2.4 Shear forces F_{xi} , F_{yi} applied to the bolt group i , and the resultant combined force F_i may be calculated from:

$$F_{xi} = (P_x - \alpha g M) / N$$

$$F_{yi} = (P_y - \alpha g M) / N$$

and

S27

(cont)

$$F_i = (F_{xi}^2 + F_{yi}^2)^{0.5}$$

where:

- α = coefficient of friction (0.5)
- M = mass of windlass (tonnes)
- g = gravity acceleration (9.81 m/sec²)
- N = number of bolt groups.

4.2.5 Axial tensile and compressive forces in 4.2.3 and lateral forces in 4.2.4 are also to be considered in the design of the supporting structure.

5. Strength Requirements

5.1 Air pipes, ventilator pipes and their closing devices

5.1.1 These requirements are additional to IACS Unified Requirement P3 and Unified Interpretation LL36 (Footnote *).

5.1.2 Bending moments and stresses in air and ventilator pipes are to be calculated at critical positions: at penetration pieces, at weld or flange connections, at toes of supporting brackets. Bending stresses in the net section are not to exceed $0.8\sigma_y$, where σ_y is the specified minimum yield stress or 0.2% proof stress of the steel at room temperature. Irrespective of corrosion protection, a corrosion addition to the net section of 2.0 mm is then to be applied.

5.1.3 For standard air pipes of 760 mm height closed by heads of not more than the tabulated projected area, pipe thicknesses and bracket heights are specified in Table 1. Where brackets are required, three or more radial brackets are to be fitted. Brackets are to be of gross thickness 8 mm or more, of minimum length 100 mm, and height according to Table 1 but need not extend over the joint flange for the head. Bracket toes at the deck are to be suitably supported.

5.1.4 For other configurations, loads according to 4.1 are to be applied, and means of support determined in order to comply with the requirements of 5.1.2. Brackets, where fitted, are to be of suitable thickness and length according to their height. Pipe thickness is not to be taken less than as indicated in IACS UI LL36.

5.1.5 For standard ventilators of 900 mm height closed by heads of not more than the tabulated projected area, pipe thicknesses and bracket heights are specified in Table 2. Brackets, where required are to be as specified in 5.1.3.

5.1.6 For ventilators of height greater than 900 mm, brackets or alternative means of support are to be fitted according to the requirements of each Society. Pipe thickness is not to be taken less than as indicated in IACS UI LL36.

5.1.7 All component parts and connections of the air pipe or ventilator are to be capable of withstanding the loads defined in 4.1.

5.1.8 Rotating type mushroom ventilator heads are unsuitable for application in the areas defined in 2.

S27

(cont)

5.2 Windlass Mounts

5.2.1 Tensile axial stresses in the individual bolts in each bolt group i are to be calculated. The horizontal forces F_{xi} and F_{yi} are normally to be reacted by shear chocks. Where "fitted" bolts are designed to support these shear forces in one or both directions, the von Mises equivalent stresses in the individual bolts are to be calculated, and compared to the stress under proof load. Where pour-able resins are incorporated in the holding down arrangements, due account is to be taken in the calculations.

The safety factor against bolt proof strength is to be not less than 2.0.

5.2.2 The strength of above deck framing and hull structure supporting the windlass and its securing bolt loads as defined in 4.2 is to be according to the requirements of each Society.

Footnote *: This does not mean that closing devices of air pipes on all existing ships subject to S27 need to be upgraded to comply with UR P3.

Table 1 : 760 mm Air Pipe Thickness and Bracket Standards

Nominal pipe diameter (mm)	Minimum fitted gross thickness, LL36(c) (mm)	Maximum projected area of head (cm ²)	Height ⁽¹⁾ of brackets (mm)
40A ⁽³⁾	6.0	-	520
50A ⁽³⁾	6.0	-	520
65A	6.0	-	480
80A	6.3	-	460
100A	7.0	-	380
125A	7.8	-	300
150A	8.5	-	300
175A	8.5	-	300
200A	8.5 ⁽²⁾	1900	300 ⁽²⁾
250A	8.5 ⁽²⁾	2500	300 ⁽²⁾
300A	8.5 ⁽²⁾	3200	300 ⁽²⁾
350A	8.5 ⁽²⁾	3800	300 ⁽²⁾
400A	8.5 ⁽²⁾	4500	300 ⁽²⁾

- (1) Brackets (see 5.1.3) need not extend over the joint flange for the head.
- (2) Brackets are required where the as fitted (gross) thickness is less than 10.5 mm, or where the tabulated projected head area is exceeded.
- (3) Not permitted for new ships - reference UR P1.
- Note: For other air pipe heights, the relevant requirements of section 5 are to be applied.

S27

(cont)

Table 2 : 900 mm Ventilator Pipe Thickness and Bracket Standards

Nominal pipe diameter (mm)	Minimum fitted gross thickness, LL36(c) (mm)	Maximum projected area of head (cm ²)	Height of brackets (mm)
80A	6.3	-	460
100A	7.0	-	380
150A	8.5	-	300
200A	8.5	550	-
250A	8.5	880	-
300A	8.5	1200	-
350A	8.5	2000	-
400A	8.5	2700	-
450A	8.5	3300	-
500A	8.5	4000	-

Note: For other ventilator heights, the relevant requirements of section 5 are to be applied.

S27

(cont)

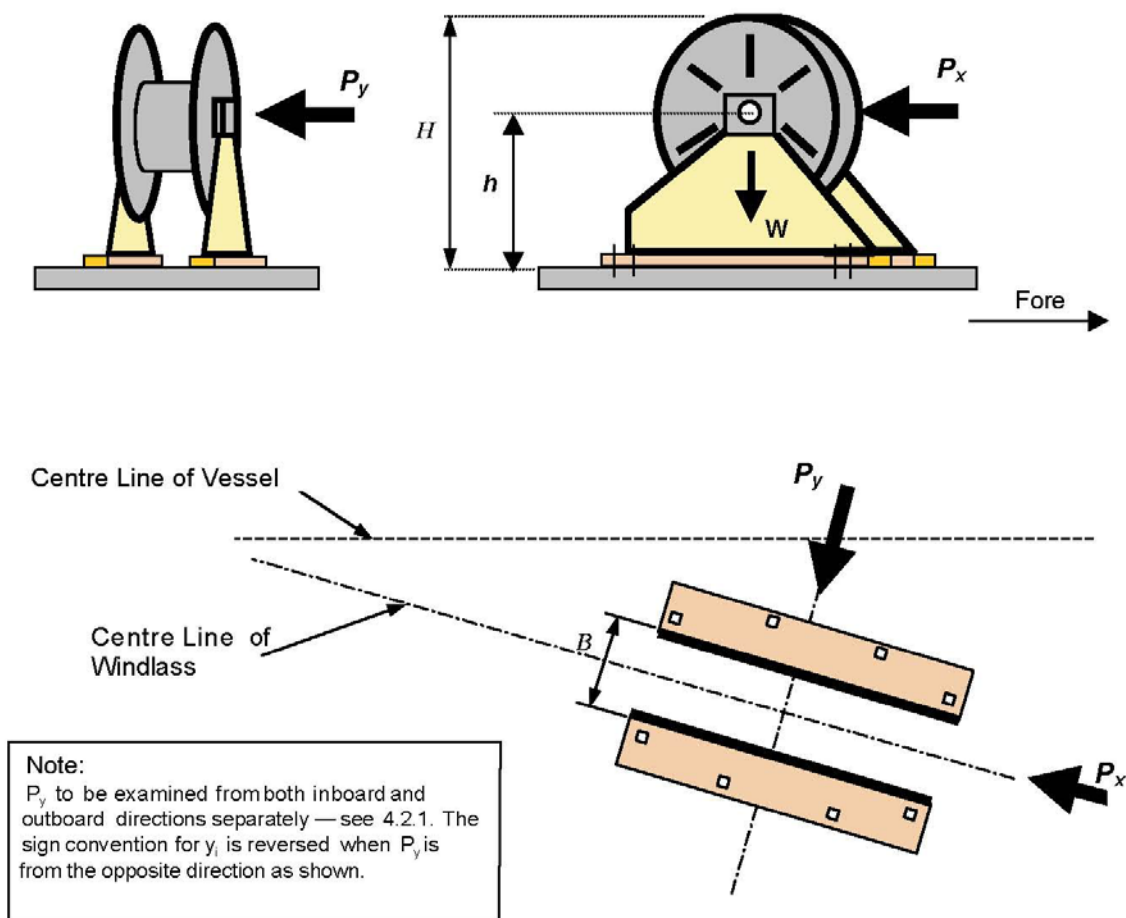


Figure 1. Direction of Forces and Weight

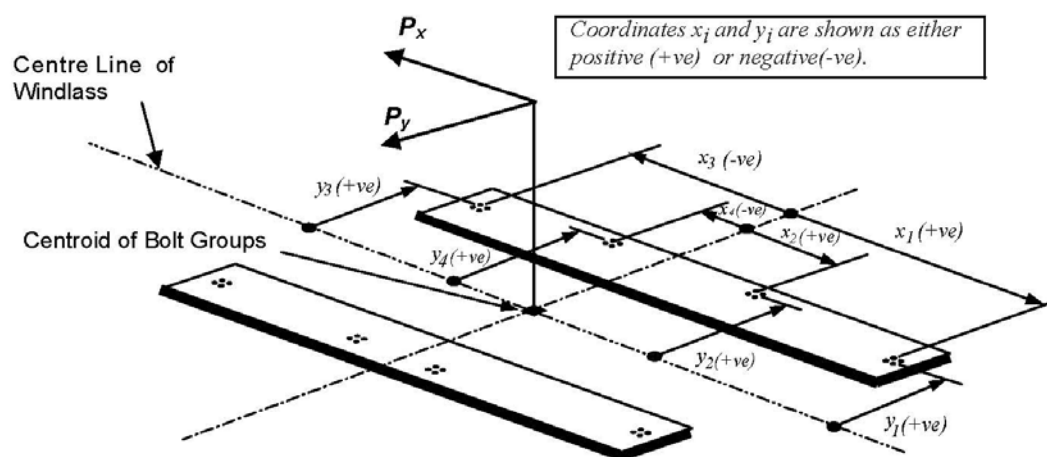


Figure 2. Sign Convention

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Document

S28

(May
2003)
(Rev.1
July
2004)
(Rev.2
Sept
2005)
(Rev.3
May
2010)

Requirements for the Fitting of a Forecastle for Bulk Carriers, Ore Carriers and Combination Carriers

S28.1 Application and definitions

These requirements apply to all bulk carriers, ore carriers and combination carriers, as defined in UR Z11, which are contracted for construction on or after 1 January 2004.

Such ships are to be fitted with an enclosed forecastle on the freeboard deck.

The required dimensions of the forecastle are defined in S28.2.

The structural arrangements and scantlings of the forecastle are to comply with the relevant Society's requirements.

This UR does not apply to CSR Bulk Carriers.

S28.2 Dimensions

The forecastle is to be located on the freeboard deck with its aft bulkhead fitted in way or aft of the forward bulkhead of the foremost hold, as shown in Figure 1.

However, if this requirement hinders hatch cover operation, the aft bulkhead of the forecastle may be fitted forward of the forward bulkhead of the foremost cargo hold provided the forecastle length is not less than 7% of ship length abaft the forward perpendicular where the ship length and forward perpendicular are defined in the International Convention on Load Line 1966 and its Protocol 1988.

The forecastle height H_F above the main deck is to be not less than:

- the standard height of a superstructure as specified in the International Convention on Load Line 1966 and its Protocol of 1988, or
- $H_C + 0.5$ m, where H_C is the height of the forward transverse hatch coaming of cargo hold No.1,

whichever is the greater.

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.

S28

(cont)

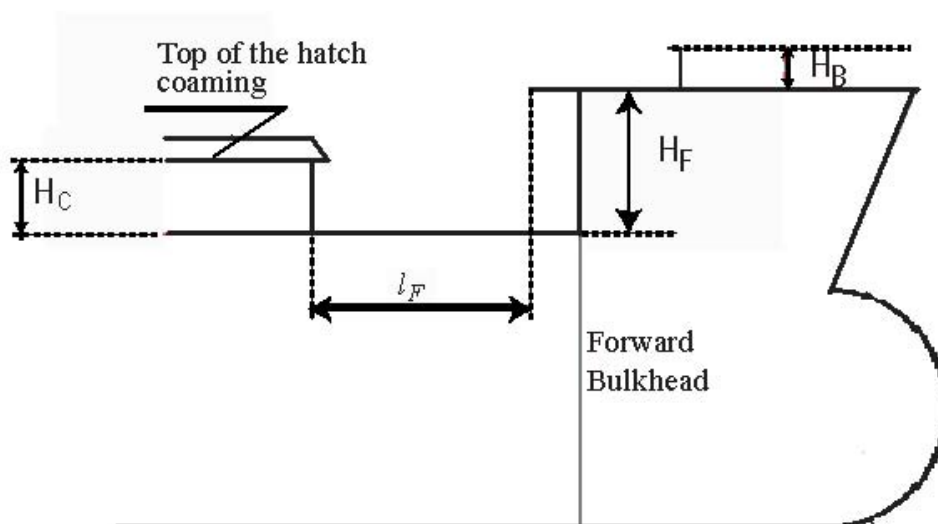
All points of the aft edge of the forecastle deck are to be located at a distance ℓ_F :

$$\ell_F \leq 5\sqrt{H_F - H_C}$$

from the hatch coaming plate in order to apply the reduced loading to the No.1 forward transverse hatch coaming and No.1 hatch cover in applying S21.4.1 and S21.5.2, respectively, of UR S21(Rev.3).

A breakwater is not to be fitted on the forecastle deck with the purpose of protecting the hatch coaming or hatch covers. If fitted for other purposes, it is to be located such that its upper edge at centre line is not less than $H_B / \tan 20^\circ$ forward of the aft edge of the forecastle deck, where H_B is the height of the breakwater above the forecastle (see Figure 1).

Figure 1



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Document

S30 Cargo Hatch Cover Securing Arrangements for Bulk Carriers not Built in accordance with UR S21 (Rev.3)

(Jan 2003)
(Corr.1
May 2003)
(Rev.1
Aug 2003)
(Corr.1
Mar 2019)

1. Application and Implementation

1.1 These requirements apply to all bulk carriers, as defined in UR Z11.2.2, which were not built in accordance with UR S21(Rev.3) and are for steel hatch cover securing devices and stoppers for cargo hold hatchways No.1 and No.2 which are wholly or partially within 0.25L of the fore perpendicular, except pontoon type hatch cover.

1.2 All bulk carriers not built in accordance with UR S21 (Rev.3) are to comply with the requirements of this UR in accordance with the following schedule:

- i. For ships which will be 15 years of age or more on 1 January 2004 by the due date of the first intermediate or special survey after that date;
- ii. For ships which will be 10 years of age or more on 1 January 2004 by the due date of the first special survey after that date;
- iii. For ships which will be less than 10 years of age on 1 January 2004 by the date on which the ship reaches 10 years of age.

1.3 Completion prior to 1 January 2004 of an intermediate or special survey with a due date after 1 January 2004 cannot be used to postpone compliance. However, completion prior to 1 January 2004 of an intermediate survey the window for which straddles 1 January 2004 can be accepted.

1.4 This UR is not applicable to self-unloading bulk carriers.

2. Securing Devices

2.1 The strength of securing devices is to comply with the following requirements:

2.1.1 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.

2.1.2 The net sectional area of each securing device is not to be less than:

$$A = 1.4 a / f \text{ (cm}^2\text{)}$$

where:

- a = spacing between securing devices not to be taken less than 2 meters
- f = $(\sigma_Y / 235)^e$
- σ_Y = specified minimum upper yield stress in N/mm² of the steel used for fabrication, not to be taken greater than 70% of the ultimate tensile strength.

S30

(cont)

$$e = 0.75 \quad \text{for } \sigma_Y > 235$$

$$e = 1.0 \quad \text{for } \sigma_Y \leq 235$$

Rods or bolts are to have a net diameter not less than 19 mm for hatchways exceeding 5 m² in area.

2.1.3 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.

2.1.4 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:

$$I = 6 p a^4 \text{ (cm}^4\text{)}$$

p = packing line pressure in N/mm, minimum 5 N/mm

a = spacing in m of securing devices.

2.1.5 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.

2.1.6 Where rod cleats are fitted, resilient washers or cushions are to be incorporated.

2.1.7 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.

3. Stoppers

3.1 No. 1 and 2 hatch covers are to be effectively secured, by means of stoppers, against the transverse forces arising from a pressure of 175 kN/m².

3.2 No. 2 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/m².

3.3 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/m². This pressure may be reduced to 175 kN/m² if a forecastle is fitted.

3.4 The equivalent stress:

- in stoppers and their supporting structures, and
- calculated in the throat of the stopper welds is not to exceed the allowable value of $0.8 \sigma_Y$

4. Materials and Welding

Where stoppers or securing devices are fitted to comply with this UR, they are to be manufactured of materials, including welding electrodes, meeting relevant IACS requirements.

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S 31 Renewal Criteria for Side Shell Frames and Brackets in Single Side Skin Bulk Carriers and Single Side Skin OBO Carriers not Built in accordance with UR S12 Rev.1 or subsequent revisions

(Nov. 2002)
(Rev.1 June 2003)
(Corr.1 July 2003)
(Corr.2 Nov. 2003)
Corr.3 Jan 2004)
(Rev.2 July 2004)
(Rev.3 Nov. 2005)
(Rev.4 Apr 2007)

S31.1 Application and definitions

These requirements apply to the side shell frames and brackets of cargo holds bounded by the single side shell of bulk carriers constructed with single deck, topside tanks and hopper tanks in cargo spaces intended primarily to carry dry cargo in bulk, which were not built in accordance with UR S12 Rev. 1 or subsequent revisions.

In addition, these requirements also apply to the side shell frames and brackets of cargo holds bounded by the single side shell of Oil/Bulk/Ore(OBO) carriers, as defined in UR Z11 but of single side skin construction.

In the case a vessel as defined above does not satisfy above definition in one or more holds, the requirements in UR S31 do not apply to these individual holds.

For the purpose of this UR, “ships” means both “bulk carriers” and “OBO carriers” as defined above, unless otherwise specified.

Bulk Carriers subject to these requirements are to be assessed for compliance with the requirements of this UR and steel renewal, reinforcement or coating, where required in accordance with this UR, is to be carried out in accordance with the following schedule and at subsequent intermediate and special surveys.

- i. For bulk carriers which will be 15 years of age or more on 1 January 2004 by the due date of the first intermediate or special survey after that date;
- ii. For bulk carriers which will be 10 years of age or more on 1 January 2004 by the due date of the first special survey after that date;
- iii. For bulk carriers which will be less than 10 years of age on 1 January 2004 by the date on which the ship reaches 10 years of age.

Completion prior to 1 January 2004 of an intermediate or special survey with a due date after 1 January 2004 cannot be used to postpone compliance. However, completion prior to 1 January 2004 of an intermediate survey the window for which straddles 1 January 2004 can be accepted.

Note:

1. This UR is to be applied to bulk carriers and OBO carriers of single side skin construction, as defined above, in conjunction with UR Z10.2 (Rev.15, 2003 and Corr.1, 2004). Z10.2.1.1.5 refers.
2. The changes introduced in Rev.3 are to be applied by IACS Members and Associates not later than on assessments for compliance commenced on or after 1 July 2006.
3. The changes introduced in Rev.4 are to be applied by IACS Members and Associates not later than on assessments for compliance commenced on or after 1 July 2008.

OBO carriers subject to these requirements are to be assessed for compliance with the requirements of this UR and steel renewal, reinforcement or coating, where required in accordance with this UR, is to be carried out in accordance with the following schedule and at subsequent intermediate and special surveys.

- i. For OBO carriers which will be 15 years of age or more on 1 July 2005 by the due date of the first intermediate or special survey after that date;
- ii. For OBO carriers which will be 10 years of age or more on 1 July 2005 by the due date of the first special survey after that date;
- iii. For OBO carriers which will be less than 10 years of age on 1 July 2005 by the date on which the ship reaches 10 years of age.

Completion prior to 1 July 2005 of an intermediate or special survey with a due date after 1 July 2005 cannot be used to postpone compliance. However, completion prior to 1 July 2005 of an intermediate survey the window for which straddles 1 July 2005 can be accepted.

These requirements define steel renewal criteria or other measures to be taken for the webs and flanges of side shell frames and brackets as per S31.2.

Reinforcing measures of side frames are also defined as per S31.2.3.

Finite element or other numerical analysis or direct calculation procedures cannot be used as an alternative to compliance with the requirements of this UR, except in cases of unusual side structure arrangements or framing to which the requirements of this UR cannot be directly applied. In such cases, the analysis criteria and the strength check criteria are to be in accordance with each Society's Rules.

S31.1.1 Ice strengthened ships

S31.1.1.1 Where ships are reinforced to comply with an ice class notation, the intermediate frames are not to be included when considering compliance with S31.

S31.1.1.2 The renewal thicknesses for the additional structure required to meet the ice strengthening notation are to be based on the class society's requirements.

S31.1.1.3 If the ice class notation is requested to be withdrawn, the additional ice strengthening structure, with the exception of tripping brackets (see S31.2.1.2.1.b and S31.2.3), is not to be considered to contribute to compliance with S31.

S31.2 Renewal or other measures

S31.2.1 Criteria for renewal or other measures

S31.2.1.1 Symbols used in S31.2.1

t_M	= thickness as measured, in mm
t_{REN}	= thickness at which renewal is required. See S31.2.1.2
$t_{REN,d/t}$	= thickness criteria based on d/t ratio. See S31.2.1.2.1
$t_{REN,S}$	= thickness criteria based on strength. See S31.2.1.2.2
t_{COAT}	= $0.75 t_{S12}$
t_{S12}	= thickness in mm as required by UR S12 (Rev.3) in S12.3 for frame webs and in S12.4 for upper and lower bracket webs
t_{AB}	= thickness as built, in mm
t_C	= See Table 1 below

Table 1 - t_c values, in mm

Ship's length L, in m	Holds other than No. 1		Hold No. 1	
	Span and upper brackets	Lower brackets	Span and upper brackets	Lower brackets
≤100	2.0	2.5	2.0	3.0
150	2.0	3.0	3.0	3.5
≥ 200	2.0	3.0	3.0	4.0
Note: For intermediate ship lengths, t_c is obtained by linear interpolation between the above values.				

S31.2.1.2 Criteria for webs (Shear and other checks)

The webs of side shell frames and brackets are to be renewed when the measured thickness (t_M) is equal to or less than the thickness (t_{REN}) as defined below:

t_{REN} is the greatest of:

- (a) $t_{COAT} - t_c$
- (b) $0.75 t_{AB}$
- (c) $t_{REN,d/t}$ (applicable to Zone A and B only)
- (d) $t_{REN,S}$ (where required by S31.2.1.2.2)

S31.2.1.2.1 Thickness criteria based on d/t ratio

Subject to b) and c) below, $t_{REN,d/t}$ is given by the following equation:

$$t_{REN,d/t} = (\text{web depth in mm})/R$$

where:

$$R = \begin{matrix} \text{for frames} \\ 65 k^{0.5} \\ 55 k^{0.5} \end{matrix} \quad \begin{matrix} \text{for symmetrically flanged frames} \\ \text{for asymmetrically flanged frames} \end{matrix}$$

for lower brackets (see a) below):

$$\begin{matrix} 87 k^{0.5} \\ 73 k^{0.5} \end{matrix} \quad \begin{matrix} \text{for symmetrically flanged frames} \\ \text{for asymmetrically flanged frames} \end{matrix}$$

$k =$ 1.0 for ordinary hull structural steel and according to UR S4 for higher tensile steel.

In no instance is $t_{REN,d/t}$ for lower integral brackets to be taken as less than $t_{REN,d/t}$ for the frames they support.

a) Lower brackets

Lower brackets are to be flanged or face plate is to be fitted, ref. S31.2.1.3.

In calculating the web depth of the lower brackets, the following will apply:

- The web depth of lower bracket may be measured from the intersection of the sloped bulkhead of the hopper tank and the side shell plate, perpendicularly to the face plate of the lower bracket (see Figure 3).
- Where stiffeners are fitted on the lower bracket plate, the web depth may be taken as the distance between the side shell and the stiffener, between the stiffeners or between the outermost stiffener and the face plate of the brackets, whichever is the greatest.

b) Tripping bracket alternative

When t_M is less than $t_{REN,d/t}$ at section b of the side frames, tripping brackets in accordance with S31.2.3 may be fitted as an alternative to the requirements for the web depth to thickness ratio of side frames, in which case $t_{REN,d/t}$ may be disregarded in the determination of t_{REN} in accordance with S31.2.1.2. The value of t_M is to be based on zone B according to UR Z10.2, ANNEX V, see Figure 1.

c) Immediately abaft collision bulkhead

For the side frames, including the lower bracket, located immediately abaft the collision bulkheads, whose scantlings are increased in order that their moment of inertia is such to avoid undesirable flexibility of the side shell, when their web as built thickness t_{AB} is greater than $1.65 \cdot t_{REN,S}$, the thickness $t_{REN,d/t}$ may be taken as the value $t'_{REN,d/t}$ obtained from the following equation:

$$t'_{REN,d/t} = \sqrt[3]{t_{REN,d/t}^2 t_{REN,S}}$$

where $t_{REN,S}$ is obtained from S31.3.3

S31.2.1.2.2 Thickness criteria based on shear strength check

Where t_M in the lower part of side frames, as defined in Figure 1, is equal to or less than t_{COAT} , $t_{REN,S}$ is to be determined in accordance with S31.3.3.

S31.2.1.2.3 Thickness of renewed webs of frames and lower brackets

Where steel renewal is required, the renewed webs are to be of a thickness not less than t_{AB} , $1.2t_{COAT}$ or $1.2t_{REN}$, whichever is the greatest.

S31.2.1.2.4 Criteria for other measures

When $t_{REN} < t_M \leq t_{COAT}$, measures are to be taken, consisting of all the following:

- a) Sand blasting, or equivalent, and coating (see S31.2.2).
- b) Fitting tripping brackets (see S31.2.3), when the above condition occurs for any of the side frame zones A, B, C and D, shown in Figure 1. Tripping brackets not connected to flanges are to have soft toe, and the distance between the bracket toe and the frame flange is not to be greater than about 50 mm, see Figure 4.
- c) Maintaining the coating in "as-new" condition (i.e. without breakdown or rusting) at Special and Intermediate Surveys.

The above measures may be waived if the structural members show no thickness diminution with respect to the as built thicknesses and coating is in "as-new" condition (i.e. without breakdown or rusting).

When the measured frame webs thickness t_M is such that $t_{REN} < t_M \leq t_{COAT}$ and the coating is in GOOD condition, sand blasting and coating as required in a) above may be waived even if not found in "as-new" condition, as defined above, provided that tripping brackets are fitted and the coating damaged in way of the tripping bracket welding is repaired.

S31.2.1.3 Criteria for frames and brackets (Bending check)

When lower end brackets were not fitted with flanges at the design stage, flanges are to be fitted so as to meet the bending strength requirements in S31.3.4. The full width of the bracket flange is to extend up beyond the point at which the frame flange reaches full width. Adequate back-up structure in the hopper is to be ensured, and the bracket is to be aligned with the back-up structure.

Where the length or depth of the lower bracket does not meet the requirements in S12(Rev.3), a bending strength check in accordance with S31.3.4 is to be carried out and renewals or reinforcements of frames and/or brackets effected as required therein.

The bending check needs not to be carried out in the case the bracket geometry is modified so as to comply with S12(Rev.3) requirements.

S31.2.2 Thickness measurements, steel renewal, sand blasting and coating

For the purpose of steel renewal, sand blasting and coating, four zones A, B, C and D are defined, as shown in Figure 1. When renewal is to be carried out, surface preparation and coating are required for the renewed structures as given in UR Z9 for cargo holds of new buildings.

Representative thickness measurements are to be taken for each zone and are to be assessed against the criteria in S31.2.1.

When zone B is made up of different plate thicknesses, the lesser thickness is to be used for the application of the requirements in S31.

In case of integral brackets, when the criteria in S31.2.1 are not satisfied for zone A or B, steel renewal, sand blasting and coating, as applicable, are to be done for both zones A and B.

In case of separate brackets, when the criteria in S31.2.1 are not satisfied for zone A or B, steel renewal, sand blasting and coating is to be done for each one of these zones, as applicable.

When steel renewal is required for zone C according to S31.2.1, it is to be done for both zones B and C. When sand blasting and coating is required for zone C according to S31.2.1, it is to be done for zones B, C and D.

When steel renewal is required for zone D according to S31.2.1, it needs only to be done for this zone. When sand blasting and coating is required for zone D according to S31.2.1, it is to be done for both zones C and D.

Special consideration may be given by the Society to zones previously renewed or re-coated, if found in "as-new" condition (i.e., without breakdown or rusting).

When adopted, on the basis of the renewal thickness criteria in S31.2.1, in general coating is to be applied in compliance with the requirements of UR Z9, as applicable.

Where, according to the requirements in S31.2.1, a limited number of side frames and brackets are shown to require coating over part of their length, the following criteria apply.

- a) The part to be coated includes:
- the web and the face plate of the side frames and brackets,
 - the hold surface of side shell, hopper tank and topside tank plating, as applicable, over a width not less than 100 mm from the web of the side frame.
- b) Epoxy coating or equivalent is to be applied.

In all cases, all the surfaces to be coated are to be sand blasted prior to coating application.

When flanges of frames or brackets are to be renewed according to S31, the outstanding breadth to thickness ratio is to comply with the requirements in UR S12.5.

S31.2.3 Reinforcing measures

Reinforcing measures are constituted by tripping brackets, located at the lower part and at midspan of side frames (see Figure 4). Tripping brackets may be located at every two frames, but lower and midspan brackets are to be fitted in line between alternate pairs of frames.

The thickness of the tripping brackets is to be not less than the as-built thickness of the side frame webs to which they are connected.

Double continuous welding is to be adopted for the connections of tripping brackets to the side shell frames and shell plating.

Where side frames and side shell are made of Higher Strength Steel (HSS), Normal Strength Steel (NSS) tripping brackets may be accepted, provided the electrodes used for welding are those required for the particular HSS grade, and the thickness of the tripping brackets is equal to the frame web thickness, regardless of the frame web material.

S31.2.4 Weld throat thickness

In case of steel renewal the welded connections are to comply with UR S12.7 of UR S12(Rev.3).

S31.2.5 Pitting and grooving

If pitting intensity is higher than 15% in area (see Figure 5), thickness measurement is to be taken to check pitting corrosion.

The minimum acceptable remaining thickness in pits or grooves is equal to:

- 75% of the as built thickness, for pitting or grooving in the frame and brackets webs and flanges
- 70% of the as built thickness, for pitting or grooving in the side shell, hopper tank and topside tank plating attached to the side frame, over a width up to 30 mm from each side of it.

S31.2.6 Renewal of all frames in one or more cargo holds

When all frames in one or more holds are required to be renewed according to UR S31, the compliance with the requirements in URS 12 (Rev. 1) may be accepted in lieu of the compliance with the requirements in UR S31, provided that:

- It is applied at least to all the frames of the hold(s)
- The coating requirements for side frames of “new ships” are complied with
- The section modulus of side frames is calculated according to the Classification Society Rules.

S31.2.7 Renewal of damaged frames

In case of renewal of a damaged frame already complying with S31, the following requirements apply:

- The conditions accepted in compliance with S31 are to be restored as a minimum.
- For localised damages, the extension of the renewal is to be carried out according to the standard practice of each Classification Society.

S31.3 Strength check criteria

In general, loads are to be calculated and strength checks are to be carried out for the aft, middle and forward frames of each hold. The scantlings required for frames in intermediate positions are to be obtained by linear interpolation between the results obtained for the above frames.

When scantlings of side frames vary within a hold, the required scantlings are also to be calculated for the mid frame of each group of frames having the same scantlings. The scantlings required for frames in intermediate positions are to be obtained by linear interpolation between the results obtained for the calculated frames.

S31.3.1 Load model

The following loading conditions are to be considered:

- Homogeneous heavy cargo (density greater than 1,78 t/m³)
- Homogeneous light cargo (density less than 1,78 t/m³)
- Non homogeneous heavy cargo, if allowed
- Multi port loading/unloading conditions need not be considered.

S31.3.1.1 Forces

The forces $P_{fr,a}$ and $P_{fr,b}$, in kN, to be considered for the strength checks at sections a) and b) of side frames (specified in Figure 2; in the case of separate lower brackets, section b) is at the top of the lower bracket), are given by:

$$P_{fr,a} = P_s + \max(P_1, P_2)$$

$$P_{fr,b} = P_{fr,a} \frac{h - 2h_B}{h}$$

where:

$$P_s = \text{still water force, in kN}$$

$$= s h \left(\frac{P_{S,U} + P_{S,L}}{2} \right) \quad \text{when the upper end of the side frame span } h \text{ (see Figure 1) is below the load water line}$$

$$= s h' \left(\frac{P_{S,L}}{2} \right) \quad \text{when the upper end of the side frame span } h \text{ (see Figure 1) is at or above the load water line}$$

P_1 = wave force, in kN, in head sea

$$= sh \left(\frac{p_{1,U} + p_{1,L}}{2} \right)$$

P_2 = wave force, in kN, in beam sea

$$= sh \left(\frac{p_{2,U} + p_{2,L}}{2} \right)$$

h, h_B = side frame span and lower bracket length, in m, defined in Figures 1 and 2, respectively

h' = distance, in m, between the lower end of side frame span h (see Figure 1) and the load water line

s = frame spacing, in m

$p_{S,U}, p_{S,L}$ = still water pressure, in kN/m^2 , at the upper and lower end of the side frame span h (see Figure 1), respectively

$p_{1,U}, p_{1,L}$ = wave pressure, in kN/m^2 , as defined in S31.3.1.2.1) below for the upper and lower end of the side frame span h , respectively

$p_{2,U}, p_{2,L}$ = wave pressure, in kN/m^2 , as defined in S31.3.1.2.2) below for the upper and lower end of the side frame span h , respectively

S31.3.1.2 Wave Pressure

1) Wave pressure p_1

- The wave pressure p_1 , in kN/m^2 , at and below the waterline is given by:

$$p_1 = 1.50 \left[p_{11} + 135 \frac{B}{2(B + 75)} - 1.2(T - z) \right]$$

$$p_{11} = 3k_s C + k_f$$

- The wave pressure p_1 , in kN/m^2 , above the water line is given by:

$$p_1 = p_{1wl} - 7.50(z - T)$$

2) Wave pressure p_2

- The wave pressure p_2 , in kN/m^2 , at and below the waterline is given by

$$p_2 = 13.0 \left[0.5B \frac{50c_r}{2(B + 75)} + C_B \frac{0.5B + k_f}{14} \left(0.7 + 2\frac{z}{T} \right) \right]$$

- The wave pressure p_2 , in kN/m^2 , above the water line is given by:

$$p_2 = p_{2wl} - 5.0 (z - T)$$

where:

p_{1wl}	=	p_1 wave sea pressure at the waterline
p_{2wl}	=	p_2 wave sea pressure at the waterline
L	=	Rule length, in m, as defined in UR S2
B	=	greatest moulded breadth, in m
C_B	=	block coefficient, as defined in UR S2, but not to be taken less than 0.6
T	=	maximum design draught, in m
C	=	coefficient
	=	$10.75 - \left(\frac{300 - L}{100} \right)^{1.5}$ for $90 \leq L \leq 300$ m
	=	10.75 for $300 \text{ m} < L$
C_r	=	$(1.25 - 0.025 \frac{2 k_r}{\sqrt{GM}}) k$
k	=	1.2 for ships without bilge keel
	=	1.0 for ships with bilge keel
k_r	=	roll radius of gyration. If the actual value of k_r is not available
	=	0.39 B for ships with even distribution of mass in transverse section (e.g. alternate heavy cargo loading or homogeneous light cargo loading)
	=	0.25 B for ships with uneven distribution of mass in transverse section (e.g. homogeneous heavy cargo distribution)
GM	=	0.12 B if the actual value of GM is not available
z	=	vertical distance, in m, from the baseline to the load point
k_s	=	$C_B + \frac{0.83}{\sqrt{C_B}}$ at aft end of L
	=	C_B between 0.2 L and 0.6 L from aft end of L
	=	$C_B + \frac{1.33}{C_B}$ at forward end of L

Between the above specified points, k_s is to be interpolated linearly.

$$k_f = 0.8 C$$

S31.3.2 Allowable stresses

The allowable normal and shear stresses σ_a and τ_a , in N/mm^2 , in the side shell frames and brackets are given by:

$$\begin{aligned}\sigma_a &= 0.90 \sigma_F \\ \tau_a &= 0.40 \sigma_F\end{aligned}$$

where σ_F is the minimum upper yield stress, in N/mm^2 , of the material.

S31.3.3 Shear strength check

Where t_M in the lower part of side frames, as defined in Figure 1, is equal to or less than t_{COAT} , shear strength check is to be carried out in accordance with the following.

The thickness $t_{\text{REN},S}$, in mm, is the greater of the thicknesses $t_{\text{REN},Sa}$ and $t_{\text{REN},Sb}$ obtained from the shear strength check at sections a) and b) (see Figure 2 and S31.3.1) given by the following, but need not be taken in excess of $0.75t_{S12}$.

$$\text{- at section a): } t_{\text{REN},Sa} = \frac{1000 k_S P_{fr,a}}{d_a \sin \phi \tau_a}$$

$$\text{- at section b): } t_{\text{REN},Sb} = \frac{1000 k_S P_{fr,b}}{d_b \sin \phi \tau_a}$$

where:

k_S	=	shear force distribution factor, to be taken equal to 0.6
$P_{fr,a}, P_{fr,b}$	=	pressures forces defined in S31.3.1.1
d_a, d_b	=	bracket and frame web depth, in mm, at sections a) and b), respectively (see Figure 2); in case of separate (non integral) brackets, d_b is to be taken as the minimum web depth deducing possible scallops
ϕ	=	angle between frame web and shell plate
τ_a	=	allowable shear stress, in N/mm^2 , defined in S31.3.2.

S31.3.4 Bending strength check

Where the lower bracket length or depth does not meet the requirements in UR S12(Rev.3), the actual section modulus, in cm^3 , of the brackets and side frames at sections a) and b) is to be not less than:

- at section a):

$$Z_a = \frac{1000 P_{fr,a} h}{m_a \sigma_a}$$

- at section b)

$$Z_b = \frac{1000 P_{fr,a} h}{m_b \sigma_a}$$

where:

$P_{fr,a}$	=	pressures force defined in S31.3.1.1
h	=	side frame span, in m, defined in Figure 1
σ_a	=	allowable normal stress, in N/mm^2 , defined in S31.3.2
m_a, m_b	=	bending moment coefficients defined in Table 2

The actual section modulus of the brackets and side frames is to be calculated about an axis parallel to the attached plate, based on the measured thicknesses. For pre-calculations, alternative thickness values may be used, provided they are not less than:

- t_{REN} , for the web thickness
- the minimum thicknesses allowed by the Society renewal criteria for flange and attached plating.

The attached plate breadth is equal to the frame spacing, measured along the shell at midspan of h .

If the actual section moduli at sections a) and b) are less than the values Z_a and Z_b , the frames and brackets are to be renewed or reinforced in order to obtain actual section moduli not less than $1.2 Z_a$ and $1.2 Z_b$, respectively.

In such a case, renewal or reinforcements of the flange are to be extended over the lower part of side frames, as defined in Figure 1.

Table 2 – Bending moment coefficients m_a and m_b

	m_a	m_b		
		$h_B \leq 0.08h$	$h_B = 0.1h$	$h_B \geq 0.125h$
Empty holds of ships approved to operate in non homogeneous loading conditions	10	17	19	22
Other cases	12	20	22	26

Note 1: Non homogeneous loading condition means a loading condition in which the ratio between the highest and the lowest filling ratio, evaluated for each hold, exceeds 1.20 corrected for different cargo densities.

Note 2: For intermediate values of the bracket length h_B , the coefficient m_b is obtained by linear interpolation between the table values.

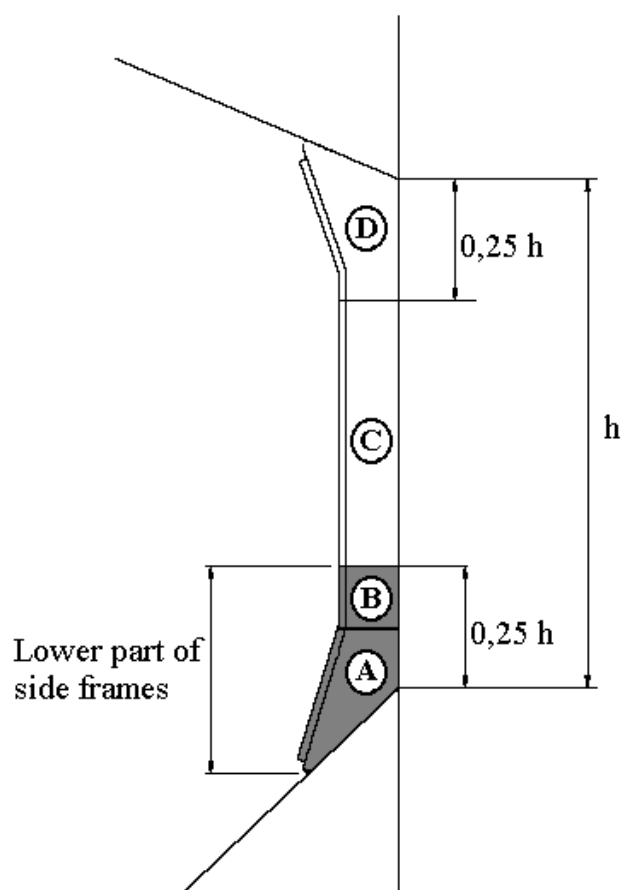
Figure 1 – Lower part and zones of side frames

Figure 2 – Sections a) and b)

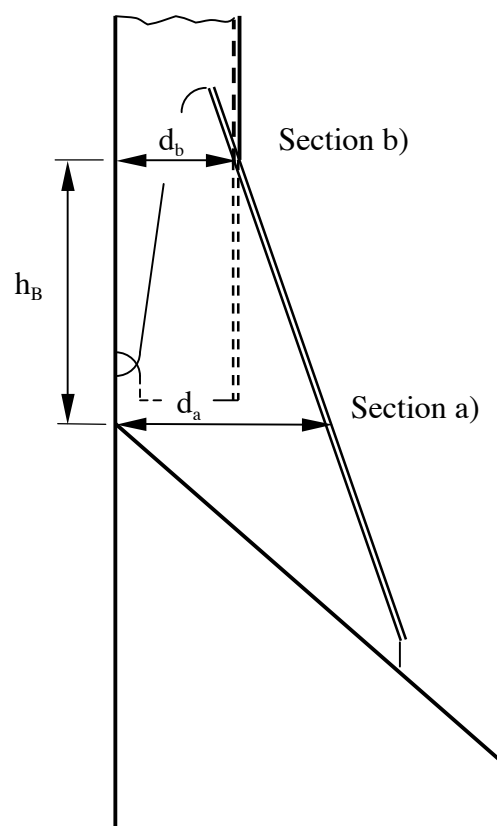
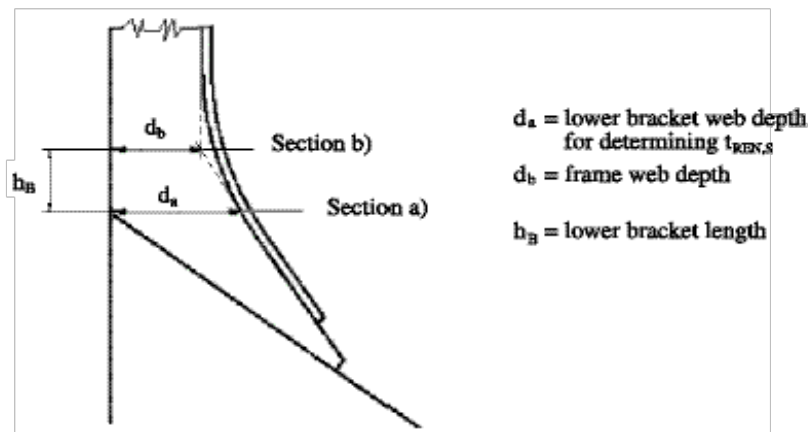


Figure 3 – Definition of the lower bracket web depth for determining $t_{REN, d/t}$

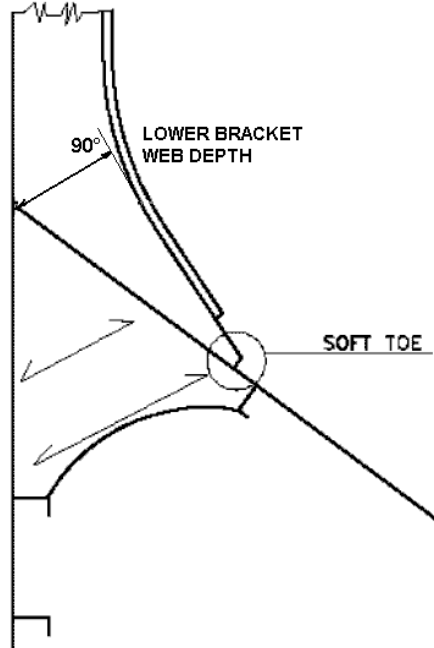


Figure 4 – Tripping brackets

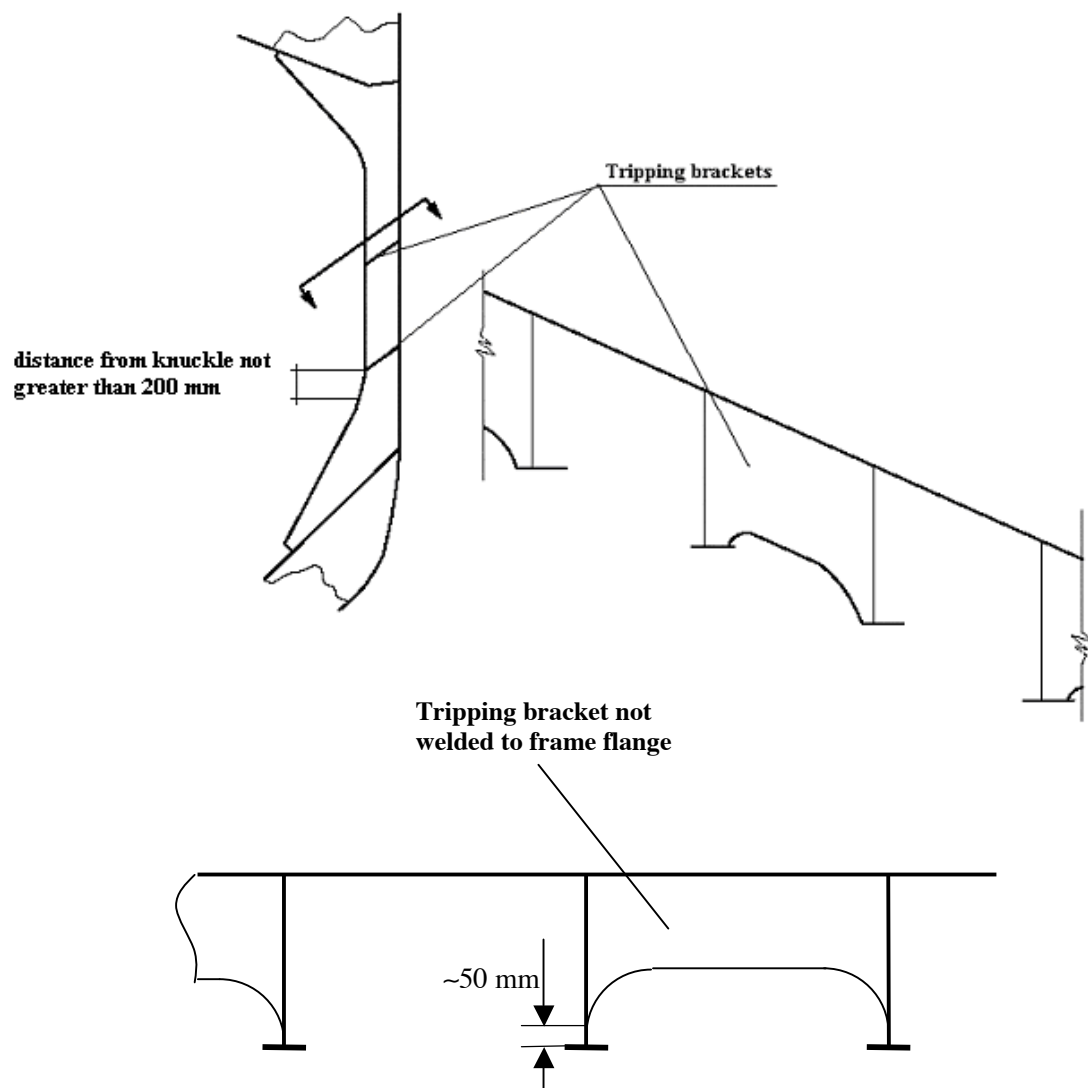
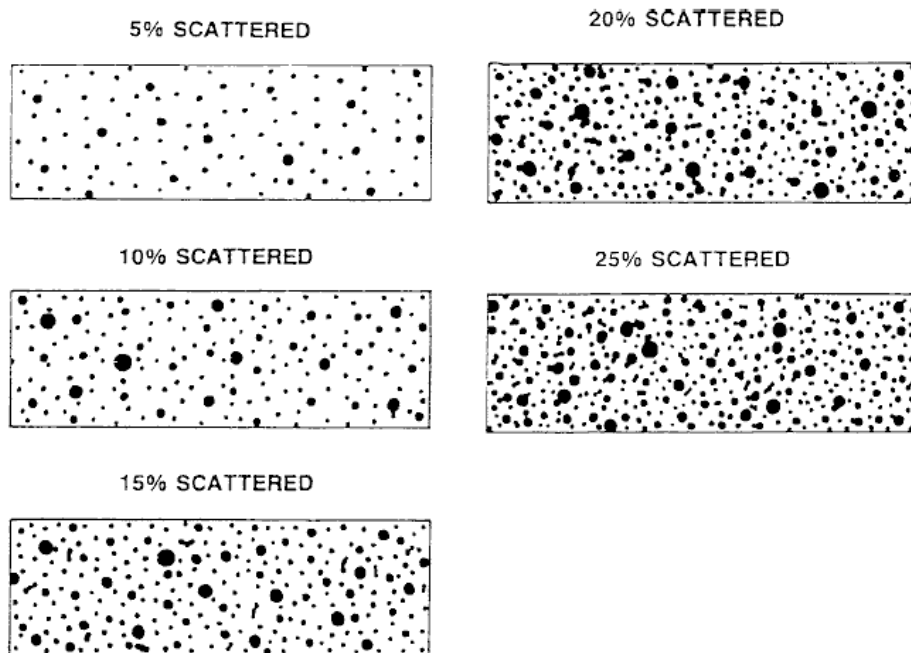


Figure 5 - Pitting intensity diagrams (from 5% to 25% intensity)



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[S32] Local Scantlings of Double Side Skin Structure Draft of Bulk Carriers

29/11/2004 Deleted May 2010.

Please note that draft UR S32 was never issued (although the draft was made available on the IACS website for public information) since it was superseded by the IACS Common Structural Rules for Bulk Carriers produced by the IACS Joint Bulker Project (JBP).

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S33

(Jan 2013)
(Rev.1
Sept 2015)
(Rev.2
Dec 2019)
(Rev.3
Feb 2020)

Requirements for Use of Extremely Thick Steel Plates in Container Ships

1. Application

1.1 General

1.1.1 This UR is to be complied with for container ships incorporating extremely thick steel plates having steel grade and thickness in accordance with 1.2 and 1.3 respectively.

1.1.2 This UR identifies when measures for the prevention of brittle fracture of extremely thick steel plates are required for longitudinal structural members.

1.1.3 This UR defines the following methods to apply to the extremely thick plates of container ships for preventing the crack initiation and propagation:

- Non-Destructive Testing (NDT) during construction detailed in 2,
- Periodic NDT after delivery detailed in 3,
- Brittle crack arrest design detailed in 4.

The application of the measures specified in 2, 3 and 4 is to be in accordance with Annex 1.

1.1.4 This UR gives the basic concepts for application of extremely thick steel plates to longitudinal structural members in the upper deck region.

1.1.5 For the application of this UR, the upper deck region means the upper deck plating, hatch side coaming plating, hatch coaming top plating and their attached longitudinals.

1.2 Steel Grade

1.2.1 This UR is to be applied when any of YP36, YP40 and YP47 steel plates are used for the longitudinal structural members in the upper deck region.

Note: YP36 YP40 and YP47 refers to the minimum specified yield strength of steel 355, 390 and 460 N/mm², respectively as defined in UR W11 and W31.

Notes:

1. This UR is to be applied by IACS Societies to ships contracted for construction on or after 1 January 2014.
2. Revision 1 of this UR is to be applied by IACS Societies to ships contracted for construction on or after 1 January 2017.
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.
4. Revision 2 of this UR is to be applied by IACS Societies to ships contracted for construction on or after 1 January 2021.
5. Revision 3 of this UR is to be applied by IACS Societies to ships contracted for construction on or after 1 July 2021.

S33
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1.2.2 In case YP47 steel plates are used for longitudinal structural members in the upper deck region, the steel plates are to be of EH47 grade as specified in UR W31.

1.3 Thickness

1.3.1 For steel plates with thickness of over 50 mm and not greater than 100 mm, the measures for prevention of brittle crack initiation and propagation specified in 2, 3 and 4 are to be taken.

1.3.2 For steel plates with thickness exceeding 100 mm, appropriate measures for prevention of brittle crack initiation and propagation are to be taken in accordance with the Classification Society's procedures.

1.4 Hull structures (for the purpose of design)**1.4.1 Material factor k**

The material factors of YP36 and YP40 steels are defined in UR S4.

The material factor of YP47 steel for the assessment of hull girder strength is to be taken as $k = 0.62$.

1.4.2 Fatigue assessment

The fatigue assessment of the longitudinal structural members is to be performed in accordance with the Classification Society's procedures.

1.4.3 Details of construction design

Special consideration is to be paid to the construction details where extremely thick steel plates are applied to structural members such as connections between outfitting and hull structures. Connections details are to be in accordance with the Classification Society's requirements.

2. Non-Destructive Testing during construction (Measure No.1 of Annex 1)

Where non-destructive testing (NDT) during construction is required in Annex 1, the NDT is to be in accordance with 2.1 and 2.2. Enhanced NDT as specified in 4.3.1(e) is to be carried out in accordance with an appropriate standard.

2.1 General

2.1.1 Ultrasonic testing (UT) in accordance with UR W33 is to be carried out on all block-to-block butt joints of all upper flange longitudinal structural members in the cargo hold region. Upper flange longitudinal structural members include the topmost strakes of the inner hull/bulkhead, the sheer strake, main deck, coaming plate, coaming top plate, and all attached longitudinal stiffeners. These members are defined in Fig.1.

S33

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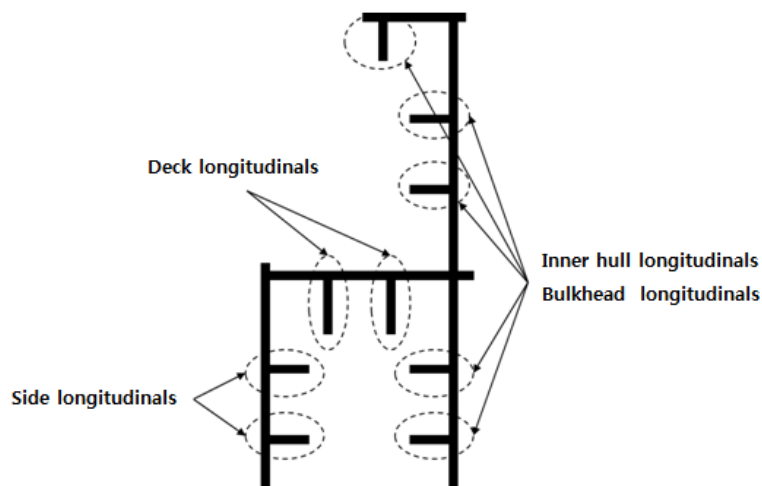


Fig.1 Upper Flange Longitudinal Structural Members

2.2 Acceptance criteria of UT

2.2.1 Acceptance criteria of UT are to be in accordance with UR W33.

2.2.2 The acceptance criteria may be adjusted under consideration of the appertaining brittle crack initiation prevention procedure and where this is more severe than that found in UR W33, the UT procedure is to be amended accordingly to a more severe sensitivity.

3. Periodic NDT after delivery (Measure No.2 of Annex 1)

Where periodic NDT after delivery is required, the NDT is to be in accordance with 3.1, 3.2 and 3.3.

3.1 General

3.1.1 The procedure of the NDT is to be in accordance with UR W33, irrespective of the applicability clause for new building in paragraph 1.1 of UR W33.

3.2 Timing of UT

3.2.1 Where UT is carried out, the frequency of survey is to be in accordance with the Classification Society requirements.

3.3 Acceptance criteria of UT

3.3.1 Where UT is carried out, acceptance criteria of UT are to be in accordance with UR W33, irrespective of the applicability clause for new building in paragraph 1.1 of UR W33.

4. Brittle crack arrest design (Measures No.3, 4 and 5 of Annex 1)

4.1 General

4.1.1 The brittle crack arrest steel method detailed in 4 may be used when the measures No.3, 4 and 5 of Annex 1 are applied and the steel grade material of the upper deck is not

S33

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higher than YP40. Otherwise other means for preventing the crack initiation and propagation shall be agreed with the Classification Society.

4.1.2 Measures for prevention of brittle crack propagation, are to be taken within the cargo hold region. A brittle crack arrest design means a design using these measures.

4.1.3 The measures given in section 4 generally apply to the block-to-block joints but it should be noted that cracks can initiate and propagate away from such joints. Therefore, appropriate measures should also be considered for the cases specified in 4.2.1 (b) (ii).

4.1.4 Brittle crack arrest steels are defined in UR W31.

4.2 Functional requirements of brittle crack arrest design

4.2.1 The purpose of the brittle crack arrest design is to arrest propagation of a crack at a proper position and to prevent large scale fracture of the hull girder.

- (a) The locations of most concern for brittle crack initiation and propagation are the block-to-block butt weld joints either on hatch side coaming or on upper deck plating. Other locations in block fabrication where joints are aligned may also present higher opportunity for crack initiation and propagation along butt weld joints.
- (b) Both of the following cases are to be considered:
 - (i) where the brittle crack runs straight along the butt joint, and
 - (ii) where the brittle crack initiates in the butt joint but deviates away from the weld and into the plate, or where the brittle crack initiates from any other weld (see the figure below for definition of other welds) and propagates into the plate.

“Other weld” includes the following (refer to Fig.2):

1. Fillet weld between hatch side coaming plating, including top plating, and longitudinals;
2. Fillet weld between hatch side coaming plating, including top plating and longitudinals, and attachments. (e.g., Fillet weld between hatch side top plating and hatch cover pad plating.);
3. Fillet weld between hatch side coaming top plating and hatch side coaming plating;
4. Fillet weld between hatch side coaming plating and upper deck plating;
5. Fillet weld between upper deck plating and inner hull/bulkheads;
6. Fillet weld between upper deck plating and longitudinal; and
7. Fillet weld between sheer strakes and upper deck plating.

S33

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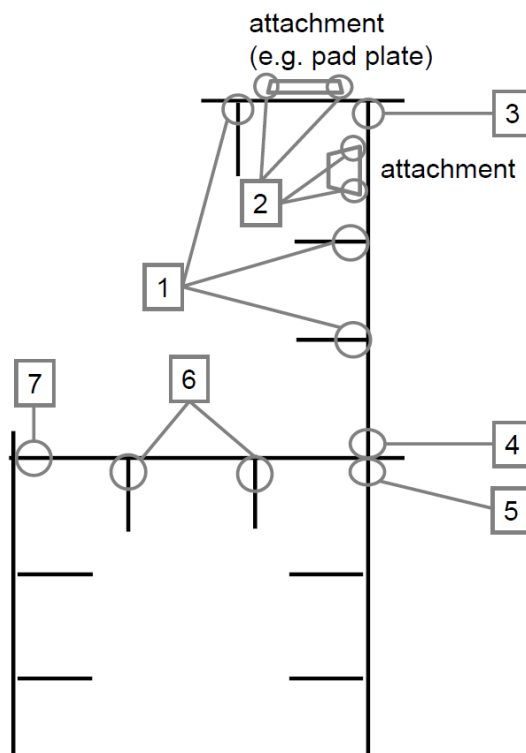


Fig.2 Other Weld Areas

4.3 Concept examples of brittle crack arrest design

4.3.1 The followings are considered acceptable examples of measures that can be used on a brittle crack arrest-design to prevent brittle crack propagations. The detail design arrangements are to be submitted to the Classification Society for their approval. Other measures may be considered and accepted for review by the Classification Society.

Brittle crack arrest design for 4.2.1(b) (ii):

- (a) Brittle crack arrest steel is to be used for the upper deck plating along the cargo hold region in a way suitable to arrest a brittle crack initiating from the coaming and propagating into the structure below.

Brittle crack arrest design for 4.2.1(b) (i):

- (b) Where the block to block butt welds of the hatch side coaming and those of the upper deck are shifted, this shift is to be greater than or equal to 300mm. Brittle crack arrest steel is to be provided for the hatch side coaming plating.
- (c) Where crack arrest holes are provided in way of the block-to-block butt welds at the region where hatch side coaming weld meets the deck weld, the fatigue strength of the lower end of the butt weld is to be assessed. Additional countermeasures are to be taken for the possibility that a running brittle crack may deviate from the weld line into upper deck or hatch side coaming. These countermeasures are to include the application of brittle crack arrest steel in hatch side coaming plating.
- (d) Where arrest insert plates of brittle crack arrest steel or weld metal inserts with high crack arrest toughness properties are provided in way of the block-to-block butt welds at the region where hatch side coaming weld meets the deck weld, additional

S33

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countermeasures are to be taken for the possibility that a running brittle crack may deviate from the weld line into upper deck or hatch side coaming. These countermeasures are to include the application of brittle crack arrest steel in hatch side coaming plating.

- (e) The application of enhanced NDT particularly time of flight diffraction (TOFD) technique using stricter defect acceptance in lieu of standard UT technique specified in 2 can be an alternative to (b), (c) and (d).

4.4 Selection of brittle crack arrest steels

4.4.1 The brittle crack arrest steels fitted in the upper deck region of container ships are to comply with Table 1 where suffixes BCA1 and BCA2 are defined in UR W31.

4.4.2 The brittle crack arrest steel property is to be selected for each individual structural member with thickness above 50 mm according to Table 1.

Table 1: Brittle crack arrest steel requirement in function of structural members and thickness

Structural Members plating (*)	Thickness (mm)	Brittle crack arrest steel requirement
Upper deck	$50 < t \leq 100$	Steel grade YP36 or 40 with suffix BCA1
Hatch coaming side	$50 < t \leq 80$	Steel grade YP 40 or 47 with suffix BCA1
	$80 < t \leq 100$	Steel grade YP 40 or 47 with suffix BCA2
(*) Excluding their attached longitudinals		

4.4.3 When brittle crack arrest steels as specified in Table 1 are used, the weld joints between the hatch coaming side and the upper deck are to be partial penetration weld details approved by the Classification Society.

In the vicinity of ship block joints, alternative weld details may be used for the deck and hatch coaming side connection provided additional means for preventing the crack propagation are implemented and agreed by the Classification Society in this connection area.

S33

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Annex 1 Measures for Extremely Thick Steel Plates

The thickness and the yield strength shown in the following table apply to the hatch coaming top plating and side plating, and are the controlling parameters for the application of the countermeasures given in S33.4.3.1. These controlling parameters are not applicable for the upper deck.

If the as built thickness of the hatch coaming top plating and side plating is below the values contained in the table, countermeasures are not necessary regardless of the thickness and yield strength of the upper deck plating.

Yield Strength (kgf/mm ²)	Thickness (mm)	Option	Measures			
			1	2	3+4	5
36	50 < t ≤ 85	-	N.A.	N.A.	N.A.	N.A.
	85 < t ≤ 100	-	X	N.A.	N.A.	N.A.
40	50 < t ≤ 85	-	X	N.A.	N.A.	N.A.
	85 < t ≤ 100	A	X	N.A.	X	X
		B	X *	N.A. **	N.A.	X
47 (FCAW)	50 < t ≤ 100	A	X	N.A.	X	X
		B	X *	N.A. **	N.A.	X
47 (EGW)	50 < t ≤ 100	-	X	N.A.	X	X
“X” means “To be applied” “N.A.” means “Need not to be applied” “A”, “B”: selectable options *: See 4.3.1 (e) of UR S33. **: may be required at the discretion of the Classification Society						

Measures:

1. NDT other than visual inspection on all target block joints (during construction): See S33.2.
2. Periodic NDT other than visual inspection on all target block joints (after delivery): See S33.3.

S33
(cont)

3. Brittle crack arrest design against straight propagation of brittle crack along weldline to be taken (during construction): See S33.4.3.1 (b), (c) and (d).
4. Brittle crack arrest design against deviation of brittle crack from weldline (during construction): See S33.4.3.1 (a).
5. Brittle crack arrest design against propagation of cracks from other welds such as fillets and attachment welds, as defined in S33.4.2.1 (b), (during construction): See S33.4.3.1 (a).

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S34
(May
2015)

Functional Requirements on Load Cases for Strength Assessment of Container Ships by Finite Element Analysis

S34.1 Application

This UR applies to container ships and ships dedicated primarily to carry their cargo in containers.

S34.2 Principles

The requirements in this UR are functional requirements on load cases to be considered on finite element analysis for the structural strength assessment (yielding and buckling).

The procedure for yielding and buckling assessment are to be in accordance with the Rules of the Classification Society. All in-plane stress components (i.e. bi-axial and shear stresses) induced by hull girder loads and local loads as specified in this UR are to be considered.

All aspects and principles not mentioned explicitly in this UR are to be applied according to the procedures of the Classification Society.

S34.3 Definitions

S34.3.1 Global Analysis

A Global Analysis is a finite element analysis, using a full ship model, for assessing the structural strength of global hull girder structure, cross deck structures and hatch corner radii.

S34.3.2 Cargo Hold Analysis

A Cargo Hold Analysis is a finite element analysis for assessing the structural strength of the cargo hold primary structural members (PSM) in the midship region.

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.

S34

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S34.3.3 Primary Structural Members (PSM)

Primary structural members are members of girder or stringer type which provide the overall structural integrity of the hull envelope and cargo hold boundaries, such as:

- (i) double bottom structure (bottom plate, inner bottom plate, girders, floors)
- (ii) double side structure (shell plating, inner hull, stringers and web frames)
- (iii) bulkhead structure
- (iv) deck and cross deck structure

S34.4 Analysis

S34.4.1 Global Analysis

A Global Analysis is to be carried out for ships of length 290 m or above. Hull girder loads (including torsional effects) are to be considered in accordance with the procedures of the Classification Society. The following methods may be used for Global Analysis:

Method 1: Analysis where hull girder loads only (vertical bending moment, horizontal bending moment and torsional moment) are directly applied to the full ship finite element model

Method 2: Analysis where direct loads transferred from direct load analysis are applied to the full ship finite element model

S34.4.2 Cargo Hold Analysis

Cargo Hold Analysis is to be carried out for ships of length 150 m or above. Local loads such as sea pressure and container loads as well as hull girder loads are to be considered in accordance with the procedures of the Classification Society.

S34.5 Load principles

S34.5.1 Wave environment

The ship is to be considered sailing in the North Atlantic wave environment for yielding and buckling assessments. The corresponding vertical wave bending moments are to be in line with UR S11A and the other hull girder loads are to be taken in accordance with the Rules of the Classification Society. The corresponding local loads are to be taken in accordance with the Rules of the Classification Society.

S34.5.2 Ship operating conditions

Seagoing conditions are to be considered. Harbour conditions and special conditions such as flooded conditions, tank testing conditions may be considered in accordance with the Rules of the Classification Society.

S34.6 Load components

S34.6.1 Global Analysis

The load components to be considered in Global Analysis are shown in Table 1.

S34

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Table 1: Load components to be considered in Global Analysis

	Static load	Dynamic load
Method 1	✓ Still water vertical bending moment ✓ Still water torsional moment	✓ Wave-induced vertical bending moment ✓ Wave-induced horizontal bending moment ✓ Wave-induced torsional moment
Method 2	✓ Static sea pressure ✓ Static container loads ✓ Static loads for ballast and fuel oil ✓ Self-weight of hull structure	✓ Wave-induced sea pressure ✓ Dynamic loads for hull structure, containers, ballast and fuel oil

S34.6.2 Cargo Hold Analysis

The load components to be considered in Cargo Hold Analysis are defined in Table 2.

Table 2: Load components to be considered in Cargo Hold Analysis

	Static load	Dynamic load
Hull girder loads	✓ Still water vertical bending moment	✓ Wave-induced vertical bending moment
Local loads	✓ Static sea pressure ✓ Static container loads ✓ Static loads for ballast and fuel oil⁽¹⁾ ✓ Self-weight of hull structure	✓ Wave-induced sea pressure ✓ Dynamic loads for hull structure, containers, ballast and fuel oil⁽¹⁾
(1) For the minimum set of loading conditions specified in Table 3, all ballast and fuel oil tanks in way of the cargo hold model are to be empty. If additional loading conditions other than those given in Table 3 are considered, ballast and fuel oil loads may be taken into consideration at the discretion of the Classification Society.		

S34.7 Loading conditions

S34.7.1 Global Analysis

Loading conditions to be considered for the Global Analysis are to be in accordance with the Loading Manual and with the Rules of the Classification Society.

S34.7.2 Cargo Hold Analysis

The minimum set of loading conditions is specified in Table 3. In addition, loading conditions from the Loading Manual are to be considered in the Cargo Hold Analysis where deemed necessary.

S34

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Table 3: Minimum set of loading conditions for Cargo Hold Analysis

Loading condition	Draught	Container weight	Ballast and fuel oil tanks	Still water hull girder moment
Full load condition	Scantling draught	Heavy cargo weight ⁽¹⁾ (40' containers)	Empty	Permissible hogging
Full load condition	Scantling draught	Light cargo weight ⁽²⁾ (40' containers)	Empty	Permissible hogging
Full load condition	Reduced draught ⁽³⁾	Heavy cargo weight ⁽¹⁾ (20' containers)	Empty	Permissible sagging (minimum hogging)
One bay empty condition ⁽⁴⁾	Scantling draught	Heavy cargo weight ⁽¹⁾ (40' containers)	Empty	Permissible hogging

(1) Heavy cargo weight of a container unit is to be calculated as the permissible stacking weight divided by the maximum number of tiers planned.

(2) Light cargo weight corresponds to the expected cargo weight when light cargo is loaded in the considered holds.

- Light cargo weight of a container unit in hold is not to be taken more than 55% of its related heavy cargo weight (see (1) above).
- Light cargo weight of a container unit on deck is not to be taken more than 90% of its related heavy cargo weight (see (1) above) or 17 metric tons, whichever is the lesser.

(3) Reduced draught corresponds to the expected draught amidships when heavy cargo is loaded in the considered holds while lighter cargo is loaded in other holds. Reduced draught is not to be taken more than 90% of scantling draught.

(4) For one bay empty condition, if the cargo hold consists of two or more bays, then each bay is to be considered entirely empty in hold and on deck (other bays full) in turn as separate load cases.

S34.8 Wave conditions

S34.8.1 Global Analysis

Wave conditions presumed to lead to the most severe load combinations due to vertical bending moment, horizontal bending moment and torsional moment are to be considered.

S34.8.2 Cargo Hold Analysis

The following wave conditions are to be considered:

- Head sea condition yielding the maximum hogging and sagging vertical bending moments.
- Beam sea condition yielding the maximum roll motion. This condition may be disregarded for some loading conditions defined in Table 3 where deemed not necessary.

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S35 Buckling Strength Assessment of Ship Structural Elements

(Feb 2023)
(Corr.1
Sep 2024)

TABLE OF CONTENTS

SECTION 1 APPLICATION AND DEFINITIONS

- 1. Application**
 - 1.1 General
 - 1.2 Application of this UR
- 2. Terminology and Assumptions**
 - 2.1 Buckling
 - 2.2 Net Scantling Approach
 - 2.3 Structural Idealisation
 - 2.4 Sign Convention
- 3. Assessment Methods and Acceptance Criteria**
 - 3.1 Assessment Methods
 - 3.2 Buckling Utilisation Factor
 - 3.3 Allowable Buckling Utilisation Factor
 - 3.4 Buckling Acceptance Criteria

SECTION 2 SLENDERNESS REQUIREMENTS

- 1. General**
 - 1.1 Introduction
- 2. Stiffeners**
 - 2.1 Proportions of Stiffeners
- 3. Primary Supporting Members**
 - 3.1 Proportions and Stiffness

SECTION 3 BUCKLING REQUIREMENTS FOR HULL GIRDER PRESCRIPTIVE ANALYSIS

- 1. General**
 - 1.1 Introduction
 - 1.2 Definitions
 - 1.3 Assumptions for Equivalent Plate Panels
- 2. Buckling Criteria**
 - 2.1 Overall Stiffened Panel
 - 2.2 Plates
 - 2.3 Stiffeners
 - 2.4 Vertically Corrugated Longitudinal Bulkheads
 - 2.5 Horizontally Corrugated Longitudinal Bulkheads

S35
(cont)**SECTION 4 BUCKLING REQUIREMENTS FOR DIRECT STRENGTH ANALYSIS OF HATCH COVERS**

- 1. General**
 - 1.1 Introduction
- 2. Stiffened and Unstiffened Panels**
 - 2.1 General
 - 2.2 Stiffened Panels
 - 2.3 Unstiffened Panels
 - 2.4 Reference Stress
 - 2.5 Lateral Pressure
 - 2.6 Buckling Criteria

SECTION 5 BUCKLING CAPACITY

- 1. General**
 - 1.1 Introduction
- 2. Buckling Capacity of Plate Panels**
 - 2.1 Overall Stiffened Panels
 - 2.2 Plates
 - 2.3 Stiffeners
 - 2.4 Primary Supporting Members
 - 2.5 Stiffened Panels with U-type Stiffeners
- 3. Buckling Capacity of Column Structures**
 - 3.1 Column Buckling of Corrugations

APPENDIX 1 STRESS BASED REFERENCE STRESSES

- 1. Stress Based Method**
 - 1.1 Introduction
 - 1.2 Stress Application
- 2. Reference Stresses**
 - 2.1 Regular Panel
 - 2.2 Irregular Panel and Curved Panel

Note:

1. This UR is to be applied by IACS Societies to ships according to the application dates, on or after 1 July 2024, of the individual IACS Unified Requirements requiring compliance with this UR S35.
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.

S35

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SECTION 1 APPLICATION AND DEFINITIONS

Abbreviations

EPP	Elementary Plate Panel, as defined in [2.3.1].
PSM	Primary Supporting Member.
SP	Stiffened Panel, as defined in [2.3.3].
UP	Unstiffened Panel, as defined in [2.3.3].
UR-S	IACS Unified Requirements concerning Strength of Ships.

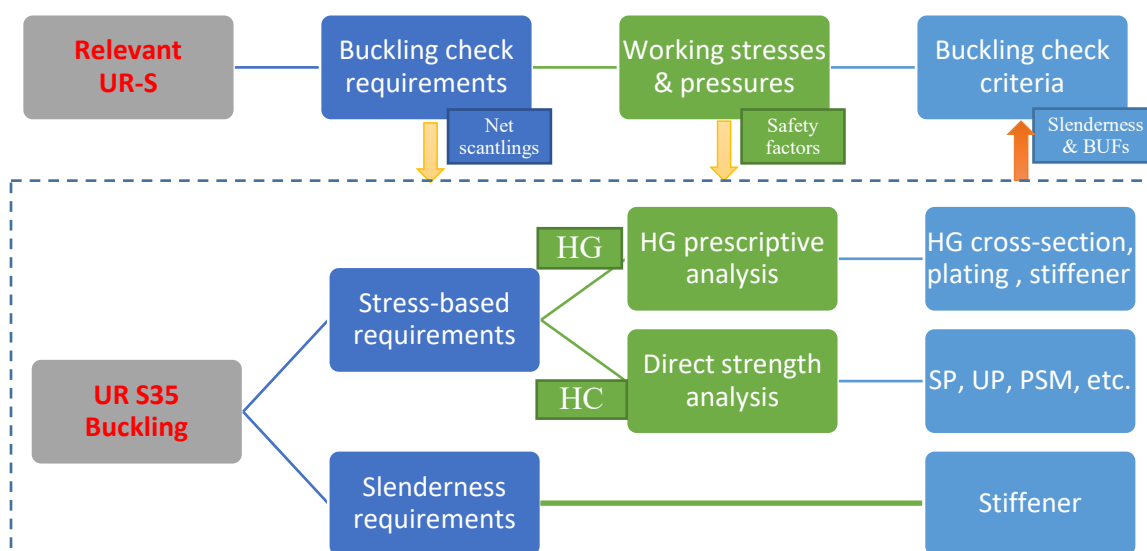
1. Application

1.1 General

1.1.1 Relevant Unified Requirements concerning Strength of Ships

This Unified Requirement (UR) establishes a general buckling assessment procedure as illustrated in Figure 1 and is to be applied in conjunction with UR S21 for hatch cover structures. UR S21 is referred to as Relevant UR-S hereafter in this UR.

Figure 1: Overview of applying this UR in conjunction with Relevant UR-S



Note: BUF stands for Buckling Utilisation Factor, HC stands for Hatch Cover, and HG stands for Hull Girder.

1.2 Application of this UR

1.2.1 Sections of this UR

The buckling checks are to be performed according to:

- Sec 1 for general definitions regarding buckling capacity, allowable buckling utilisation factors and buckling check criteria.
- Sec 2 for the slenderness requirements of longitudinal and transverse stiffeners.

S35 (cont)

- Sec 3 for the prescriptive buckling requirements of plates, longitudinal and transverse stiffeners, primary supporting members and other structures subject to hull girder stresses.
- Sec 4 for direct strength analysis (usually by finite element method) buckling requirements of hatch cover structural members including plates, stiffeners and primary supporting members.
- Sec 5 for the determination of buckling capacities of plate panels, stiffeners, primary supporting members and column structures.

1.2.2 Buckling assessment with this UR

For the buckling assessment of a ship hull girder, a hatch cover or some structural component, the slenderness requirements as defined in Sec 2 and the buckling requirements as defined in Sec 3 or Sec 4 are to be checked as per the requirements of the applicable Relevant UR-S.

1.2.3 Alternative methods

This UR contains the general methods for the determination of buckling capacities of plate panels, stiffeners, primary supporting members, and columns. For special cases not covered in this UR, such as a whole plate structure with stiffeners in two directions (i.e., a stiffened panel with both primary and secondary stiffeners), other more advanced methods, such as finite element analysis methods, can be used as deemed appropriate by the Society.

2 Terminology and Assumptions

2.1 Buckling

2.1.1 Buckling strength

Buckling strength or capacity refers to the strength of a structure under in-plane compressions and/or shear and lateral load. Buckling strength with consideration of the buckling behaviour in [2.1.2] gives a lower bound estimate of ultimate capacity, or the maximum load a structural member can carry without suffering major permanent set. For each structural member, its buckling strength is to be taken as corresponding to the most unfavourable or critical buckling mode.

2.1.2 Buckling behaviour

Buckling strength assessment takes into account both elastic buckling and post-buckling behaviours. Post-buckling can consider the internal redistribution of loads depending on the load situation, slenderness and type of structure. Such as for the buckling assessment of plates, generally its positive elastic post-buckling effect can be utilized.

As such, for slender structures, the calculated buckling strength is typically higher than the ideal elastic buckling stress (minimum eigenvalue). Accepting elastic buckling of slender plate panels implies that large elastic deflections and reduced in-plane stiffness may occur at higher buckling utilisation levels.

S35

(cont)

2.2 Net Scantling Approach

2.2.1 General

Unless otherwise specified, all the scantling requirements, including slenderness requirements, in this UR are based on net scantlings obtained by removing full corrosion addition t_c from the gross offered thicknesses.

2.2.2 Corrosion addition

Corrosion addition t_c referred to in this UR is defined in the Relevant UR-S.

2.2.3 Stress calculation models

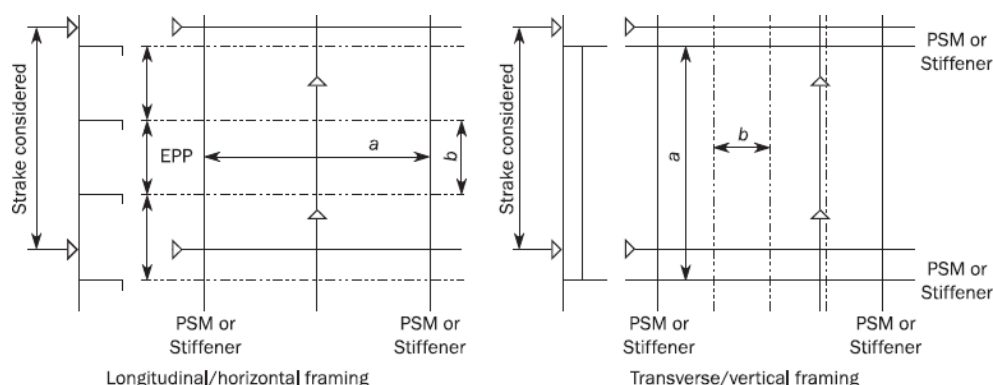
The structural models used for the calculation of stresses to be applied for buckling assessment, which are usually based on net scantlings, are defined in the Relevant UR-S.

2.3 Structural Idealisation

2.3.1 Elementary plate panel

An elementary plate panel (EPP) is the unstiffened part of the plating between stiffeners and/or primary supporting members. The plate panel length, a , and breadth, b , of the EPP are defined respectively as the longest and shortest plate edges, as shown in Figure 2.

Figure 2: Elementary plate panel (EPP) definition



2.3.2 Standard types of stiffeners

Definitions of the cross-sectional dimensions of typical stiffener types are shown in Figure 3, which are flat bars, bulb flats, angles, L2 and T bars. If applicable, other types of stiffeners can be idealized to one of the typical types in Figure 3 for buckling check. For the U-type stiffener which is usually fitted in some hatch covers, the definition of its cross-sectional dimensions is shown in Figure 4.

Unless otherwise specified, the full span or full length l , in mm, of a stiffener is to be used for buckling check, which equals to the spacing between primary supporting members.

S35

(cont)

Symbolic dimensions of the cross-sections are as below:

- b_1 Width of the attached plate enclosed by the U-type stiffener, in mm, as shown in Figure 4.
- b_2 Width of the attached plate between adjacent U-type stiffeners, in mm as shown in Figure 4.
- b_f Width of the flange or face plate of the stiffener, in mm as shown in Figure 3 and Figure 4.
- b_{f-out} Maximum distance, in mm, from mid thickness of the web to the flange edge, in mm, as shown in Figure 3.
- d_f Breadth of the extended part of the flange for L2 profiles, in mm, as shown in Figure 3.
- e_f Distance from attached plating to centre of flange, in mm, as shown in Figure 3. For its detailed definition, refer to Sec 5, Symbols.
- h_w Depth of stiffener web, in mm, as shown in Figure 3 and Figure 4.
- t_f Net flange thickness, in mm.
- t_p Net thickness of plate, in mm.
- t_w Net web thickness, in mm.

Figure 3: Dimensions of typical stiffener cross sections

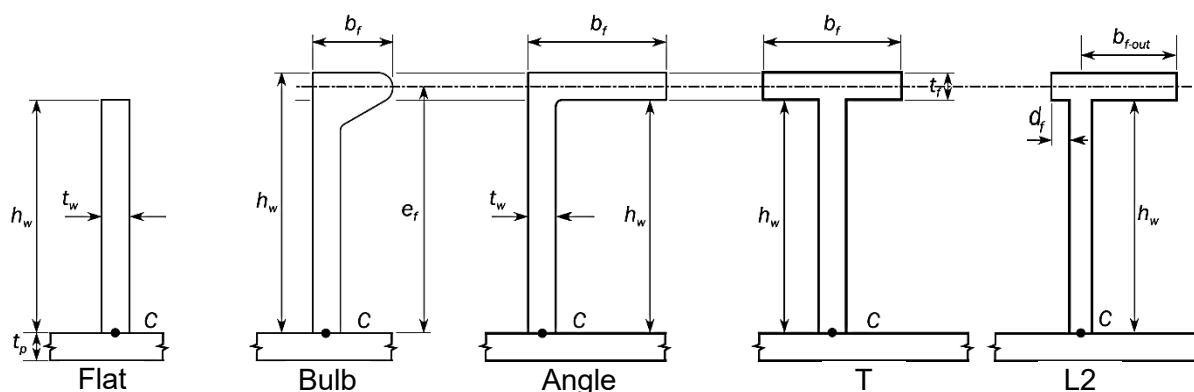
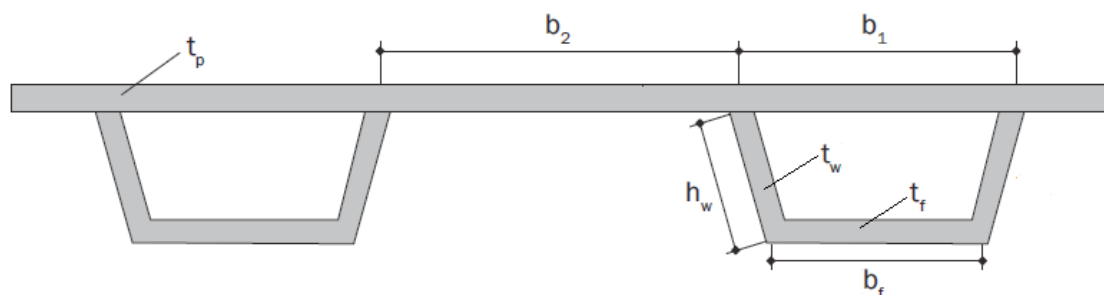


Figure 4: Dimensions of a U-type stiffener cross section



S35 (cont)

2.3.3 Stiffened panel (SP) and Unstiffened panel (UP)

For a panel with relatively strong interactive effect between the stiffener and its attached plate, each stiffener with its attached plate as a whole is to be modelled as a stiffened panel (SP), so as to be able to consider both of its local and global buckling modes.

However, for an EPP, if its buckling strength can be checked without considering its interactive effect with stiffeners fitted along its edges, it's to be modelled as an unstiffened panel (UP).

2.4 Sign Convention

2.4.1 Stresses

In this UR, compressive and shear stresses are to be taken as positive, tension stresses are to be taken as negative.

3. Assessment Methods and Acceptance Criteria

3.1 Assessment Methods

3.1.1 Method A and Method B

The buckling assessment is to be carried out according to one of the following two methods taking into account different boundary condition types:

- Method A: All the edges of the EPP are forced to remain straight (but free to move in the in-plane directions) due to the surrounding structure/neighbouring plates.
- Method B: The edges of the EPP are not forced to remain straight due to low in-plane stiffness at the edges and/or no surrounding structure/neighbouring plates.

3.1.2 SP-A, SP-B, UP-A and UP-B models

For the buckling assessment of the stiffened panel (SP) and unstiffened panel (UP) structural models defined in [2.3.3], with application of either Method A or Method B for the plate buckling assessment, the following four buckling assessment models are established:

- SP-A: a stiffened panel with application of Method A.
- SP-B: a stiffened panel with application of Method B.
- UP-A: an unstiffened panel with application of Method A.
- UP-B: an unstiffened panel with application of Method B.

3.2 Buckling Utilisation Factor

3.2.1 The utilisation factor, η , is defined as the ratio between the applied loads and the corresponding buckling capacity.

3.2.2 For combined loads, the utilisation factor, η_{act} , is to be defined as the ratio of the applied equivalent stress and the corresponding buckling capacity, as shown in Figure 5, and is to be taken as:

$$\eta_{act} = \frac{W_{act}}{W_U} = \frac{1}{\gamma_c}$$

S35 (cont)

where:

W_{act} Equivalent applied stress. The actual applied stresses are given in Sec 3 and Sec 4 respectively for buckling assessment by prescriptive and direct strength analysis.

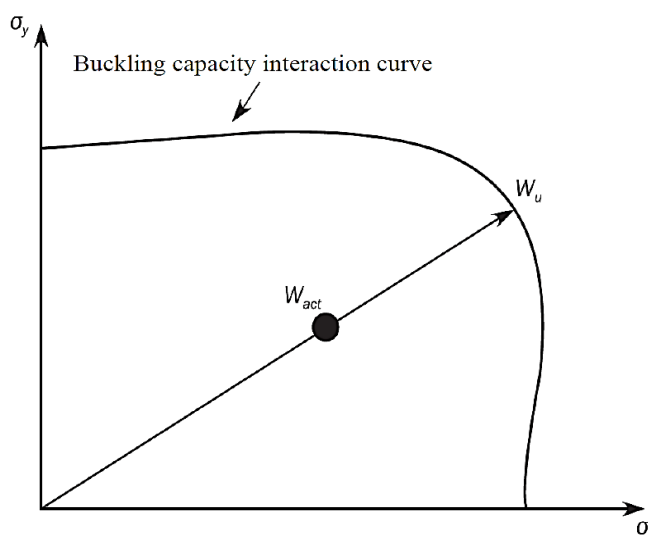
W_U Equivalent buckling capacity. For plates and stiffeners, their respective buckling or ultimate capacities are given in Sec 5.

γ_c Stress multiplier factor at failure.

For each typical failure mode, the corresponding buckling capacity of the panel is calculated by applying the actual stress combination and then increasing or decreasing the stresses proportionally until collapse occurs, i.e., when the increased or decreased stresses are on a buckling strength interaction curve or surface.

Figure 5 illustrates the buckling capacity and the buckling utilisation factor of a structural member subject to σ_x and σ_y stresses.

Figure 5: Illustration of buckling capacity and buckling utilisation factor



3.3 Allowable Buckling Utilisation Factor

3.3.1 The allowable buckling utilisation factor η_{all} is to be taken according to the Relevant UR-S.

3.4 Buckling Acceptance Criteria

3.4.1 A structural member is considered to have an acceptable buckling strength if it satisfies the following criterion:

$$\eta_{act} \leq \eta_{all}$$

where:

η_{act} Buckling utilisation factor based on the applied stress, defined in [3.2.2].

η_{all} Allowable buckling utilisation factor as defined in [3.3.1].

S35

(cont)

SECTION 2 SLENDERNESS REQUIREMENTS

Symbols

For symbols not defined in this section, refer to Sec 1, [2.3.2].

R_{eH} Specified minimum yield stress of the structural member being considered, in N/mm².

1. General

1.1 Introduction

1.1.1 The stiffener elements except for U-type stiffeners are to comply with the applicable slenderness and proportion requirements given in [2].

2. Stiffeners

2.1 Proportions of Stiffeners

2.1.1 Net thickness of all stiffener types

The net thickness of stiffeners is to satisfy the following criteria:

a) Stiffener web plate:

$$t_w \geq \frac{h_w}{C_w} \sqrt{\frac{R_{eH}}{235}}$$

b) Flange:

$$t_f \geq \frac{b_{f-out}}{C_f} \sqrt{\frac{R_{eH}}{235}}$$

where:

C_w, C_f : Slenderness coefficients given in Table 1.

If requirement b) is not fulfilled, the effective free flange outstand, in mm, used in strength assessment including the calculation of actual net section modulus, is to be taken as:

$$b_{f-out-max} = C_f t_f \sqrt{\frac{235}{R_{eH}}}$$

Table 1: Slenderness coefficients

Type of Stiffener	C_w	C_f
Angle and L2 bars	75	12
T-bars	75	12
Bulb flats	45	-
Flat bars	22	-

S35
(cont)

For built-up profile where the relevant yielding strength for the web of built-up profile without the edge stiffener is acceptable, as an alternative the web can be assessed according to the web requirements of Angle and L2 bars in Table 1, and the edge stiffener can be assessed as a flat bar stiffener according to [2.1.1]. The requirement to flange in [2.1.2] shall still apply.

2.1.2 Net dimensions of angle and T-bars

The total flange breadth b_f , in mm, for angle and T-bars is to satisfy the following criterion:

$$b_f \geq 0.2h_w$$

3. Primary Supporting Members**3.1 Proportions and Stiffness****3.1.1 Proportions of web plate and flange**

The scantlings of webs and flanges of primary supporting members are to comply with the Rules of the Classification Society.

S35

(cont)

SECTION 3 BUCKLING REQUIREMENTS FOR HULL GIRDER PRESCRIPTIVE ANALYSIS

Symbols

η_{all} Allowable buckling utilisation factor, as defined in Sec 1, [3.3.1].

LCP Load Calculation Point, as defined in [1.2.1].

1. General

1.1 Introduction

1.1.1 This section applies to plate panels including plane and curved plate panels, stiffeners and corrugation of longitudinal corrugated bulkheads subject to hull girder compression and shear stresses.

1.1.2 The ship longitudinal extent where the buckling check is performed for structural elements subject to hull girder stresses is to be in accordance with the Relevant UR-S.

1.1.3 Design load sets: The buckling check is to be performed for all design load sets corresponding to the design loading conditions defined in the Relevant UR-S with the most unfavourable pressure combinations.

For each design load set, for all static and dynamic load cases, the lateral pressure is to be determined at the load calculation point defined in [1.2.1], and is to be applied together with the hull girder stress combinations defined in the Relevant UR-S.

1.2 Definitions

1.2.1 Load calculation point

The load calculation points (LCP) for both elementary plate panels (EPP) and stiffeners are defined as follows:

a) LCP for hull girder stresses of EPP

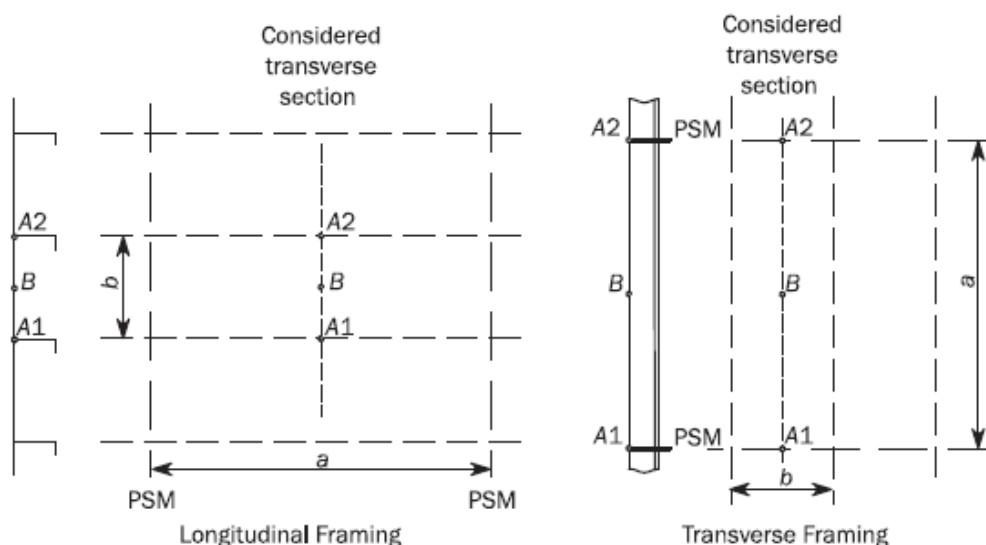
The hull girder stresses for EPP are to be calculated at the load calculation points defined in Table 1.

Table 1: 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 1)	Outboard and inboard ends of the EPP (points A1 and A2 in Figure 1)	Mid-point of EPP (point B in Figure 1)
z coordinate	Corresponding to x and y values		

S35 (cont)

Figure 1: LCP for plate buckling assessment



b) LCP for hull girder stresses of longitudinal stiffeners

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.

c) LCP for pressure of horizontal stiffeners

The load calculation point for the pressure is located at:

- Middle of the full length, l , of the considered stiffener.
- The intersection point between the stiffener and its attached plate.

d) LCP for pressure of non-horizontal stiffeners

The lateral pressure, P is to be calculated as the maximum between the value obtained at middle of the full length, l , and the value obtained from the following formulae:

$$P = \frac{p_U + p_L}{2} \quad \text{when the upper end of the vertical stiffener is below the lowest zero pressure level.}$$

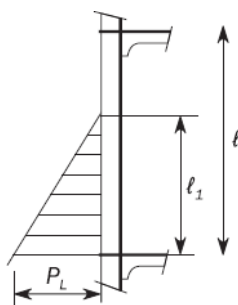
$$P = \frac{l_1}{l} \frac{p_L}{2} \quad \text{when the upper end of the vertical stiffener is at or above the lowest zero pressure level, see Figure 2.}$$

where:

l_1 Distance, in m, between the lower end of vertical stiffener and the lowest zero pressure level.

p_U, p_L Lateral pressures at the upper and lower end of the vertical stiffener span l , respectively.

Figure 2: Definition of pressure for vertical stiffeners



1.3 Assumptions for Equivalent Plate Panels

1.3.1 Longitudinal stiffening with varying plate thickness

In longitudinal stiffening arrangement, when the plate thickness varies over the width b , of a plate panel, the buckling check is to be performed for an equivalent plate panel width, combined with the smaller plate thickness, t_1 . The width of this equivalent plate panel, b_{eq} , in mm, is defined by the following formula:

$$b_{eq} = l_1 + l_2 \left(\frac{t_1}{t_2} \right)^{1.5}$$

where:

- l_1 Width of the part of the plate panel with the smaller plate thickness, t_1 , in mm, as defined in Figure 3.
- l_2 Width of the part of the plate panel with the greater plate thickness, t_2 , in mm, as defined in Figure 3.

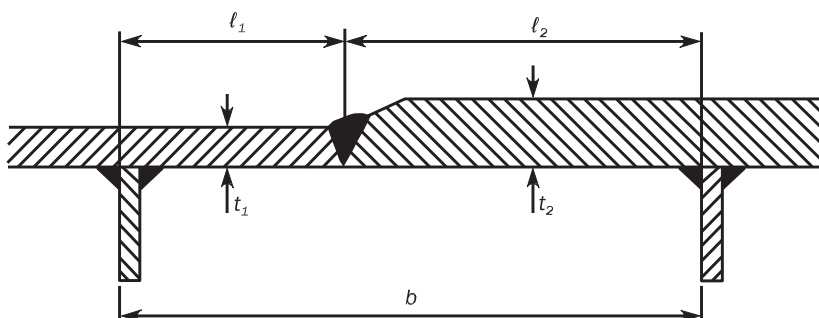
1.3.2 Transverse stiffening with varying plate thickness

In transverse stiffening arrangement, when an EPP is made with different thicknesses, the buckling check of the plate and stiffeners is to be made for each thickness considered constant on the EPP, the stresses and pressures being estimated for the EPP at the LCP.

1.3.3 Plate panel with different materials

When the plate panel is made of different materials, the minimum yield strength is to be used for the buckling assessment.

Figure 3: Plate thickness change over the width



S35

(cont)

2. Buckling Criteria

2.1 Overall Stiffened Panel

2.1.1 The buckling strength of overall stiffened panels is to satisfy the following criterion:

$$\eta_{overall} \leq \eta_{all}$$

where:

$\eta_{overall}$ Maximum overall buckling utilisation factor as defined in Sec 5, [2.1].

2.2 Plates

2.2.1 The buckling strength of elementary plate panels is to satisfy the following criterion:

$$\eta_{plate} \leq \eta_{all}$$

where:

η_{plate} Maximum plate buckling utilisation factor as defined in Sec 5, [2.2] where SP-A model is to be used.

For the determination of η_{plate} of the vertically stiffened side shell plating of single side skin bulk carrier between hopper and topside tanks, the cases 12 and 16 of Sec 5, Table 3 corresponding to the shorter edge of the plate panel clamped are to be considered together with a mean σ_y stress and $\psi_y = 1$.

2.3 Stiffeners

2.3.1 The buckling strength of stiffeners or of side frames of single side skin bulk carriers is to satisfy the following criterion:

$$\eta_{stiffener} \leq \eta_{all}$$

where:

$\eta_{stiffener}$ Maximum stiffener buckling utilisation factor as defined in Sec 5, [2.3].

Note 1: This buckling check can only be fulfilled when the overall stiffened panel buckling check, as defined in [2.1], is satisfied.

Note 2: The buckling check of the stiffeners is only applicable to the stiffeners fitted along the long edge of the buckling panel.

2.4 Vertically Corrugated Longitudinal Bulkheads

The shear buckling strength of vertically corrugated longitudinal bulkheads is to satisfy the following criterion:

$$\eta_{shear} \leq \eta_{all}$$

where:

η_{shear} Maximum shear buckling utilisation factor, defined as

$$\eta_{shear} = \frac{\tau_{bhd}}{\tau_c}$$

S35

(cont)

τ_{bhd}	Shear stress, in N/mm ² , in the bulkhead taken as the hull girder shear stress defined in the Relevant UR-S
τ_c	Shear critical stress, in N/mm ² , as defined in Sec 5, [2.2.3].

2.5 Horizontally Corrugated Longitudinal Bulkheads

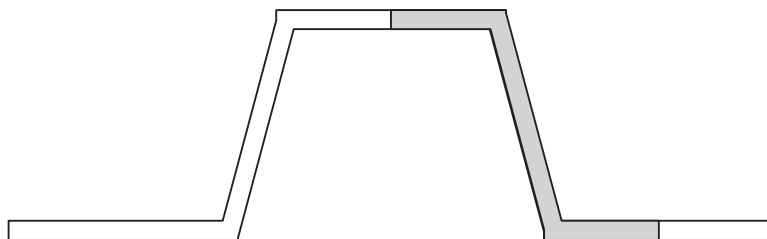
2.5.1 Each corrugation unit within the extension of half flange, web and half flange (i.e. single corrugation as shown in grey in Figure 4) is to satisfy the following criterion:

$$\eta_{column} \leq \eta_{all}$$

where:

η_{column} Overall column buckling utilisation factor, as defined in Sec 5, [3.1].

Figure 4: Single corrugation



S35

(cont)

SECTION 4 BUCKLING REQUIREMENTS FOR DIRECT STRENGTH ANALYSIS OF HATCH COVERS

Symbols

R_{eH_P}	Yield stress of the plate panel, as defined in [2.1.3].
R_{eH_S}	Yield stress of the stiffener, as defined in [2.1.3].
α	Aspect ratio of the plate panel, as defined in the Symbol list of Sec 5.
η_{all}	Allowable buckling utilisation factor, as defined in Sec 1, [3.3.1].

1. General

1.1 Introduction

1.1.1 The requirements of this Section apply to the buckling assessment of hatch cover structural members based on direct strength analysis (usually by finite element method) and subjected to normal stress, shear stress and lateral pressure.

1.1.2 All structural elements in the direct strength analysis carried out according to the Relevant UR-S are to be assessed individually. The buckling checks are to be performed for the following structural elements:

- Stiffened and unstiffened panels.
- Web plate in way of openings.

2. Stiffened and Unstiffened Panels

2.1 General

2.1.1 The plate panel of a hatch cover structure is to be modelled as stiffened panel (SP) or unstiffened panel (UP), with either Method A or Method B as defined in Sec 1, [3.1.1] to be used for the calculation of the plate buckling capacity, which in combination is also equivalent to use the buckling assessment models defined in Sec 1, [3.1.2].

2.1.2 Average thickness of plate panel

For FE analysis, where the plate thickness along a plate panel is not constant, the panel used for the buckling assessment is to be modelled with a weighted average thickness taken as:

$$t_{avr} = \frac{\sum_1^n A_i t_i}{\sum_1^n A_i}$$

where:

A_i : Area of the i -th plate element.

t_i : Net thickness of the i -th plate element.

n : Number of finite elements defining the buckling plate panel.

S35

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2.1.3 Yield stress of the plate panel and stiffener

The panel yield stress R_{eH_P} is taken as the minimum value of the specified yield stresses of the elements within the plate panel.

The stiffener yield stress R_{eH_S} is taken as the minimum value of the specified yield stresses of the elements within the stiffener.

2.2 Stiffened Panels

2.2.1 For a stiffened panel (SP), each stiffener with attached plate is to be idealized as a stiffened panel model of the extent defined in the Relevant UR-S.

2.2.2 If the stiffener properties or stiffener spacing varies within the stiffened panel, the calculations are to be performed separately for all configurations of the panels, i.e. for each stiffener and plate between the stiffeners. Plate thickness, stiffener properties and stiffener spacing at the considered location are to be assumed for the whole panel.

2.3.1 The buckling check of the stiffeners of stiffened panels is only applicable to the stiffeners fitted along the longer side edges of the buckling panel.

2.3 Unstiffened Panels

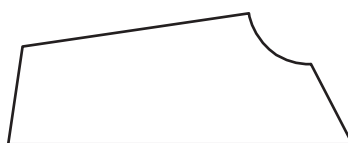
2.3.1 Irregular plate panel

In way of web frames and brackets, the geometry of the panel (i.e. plate bounded by web stiffeners/face plate) may not have a rectangular shape. In this case, for FE analysis, an equivalent rectangular panel is to be defined according to [2.3.2] for irregular geometry and [2.3.3] for triangular geometry and to comply with buckling assessment.

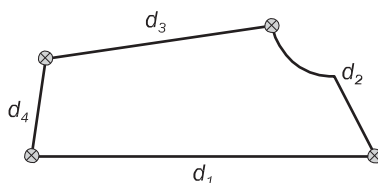
2.3.2 Equivalent EPP of an unstiffened panel with irregular geometry

Unstiffened panels with irregular geometry are to be idealised to equivalent panels for plate buckling assessment according to the following procedure:

- The four corners closest to a right angle, 90 deg, in the bounding polygon for the plate are identified.

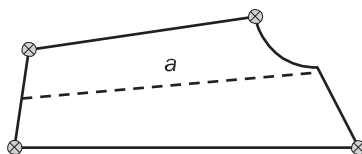


- The distances along the plate bounding polygon between the corners are calculated, i.e. the sum of all the straight-line segments between the end points.



S35 (cont)

- c) The pair of opposite edges with the smallest total length is identified, i.e. minimum of $d_1 + d_3$ and $d_2 + d_4$.



- d) A line joins the middle points of the chosen opposite edges (i.e. a mid-point is defined as the point at half the distance from one end). This line defines the longitudinal direction for the capacity model. The length of the line defines the length of the capacity model, a , measured from one end point.

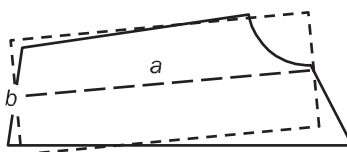
- e) The length of shorter side, b , in mm, is to be taken as:

$$b = \frac{A}{a}$$

where:

A : Area of the plate, in mm²

a : Length defined in (d), in mm.

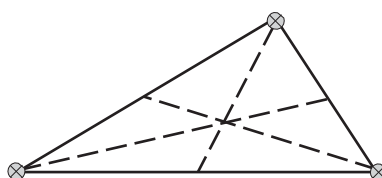


- f) The stresses from the direct strength analysis are to be transformed into the local coordinate system of the equivalent rectangular panel. These stresses are to be used for the buckling assessment.

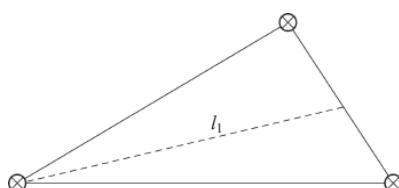
2.3.3 Modelling of an unstiffened plate panel with triangular geometry

Unstiffened panels with triangular geometry are to be idealised to equivalent panels for plate buckling assessment according to the following procedure:

- a) Medians are constructed as shown below.



- b) The longest median is identified. This median the length of which is l_1 , in mm, defines the longitudinal direction for the capacity model.



S35

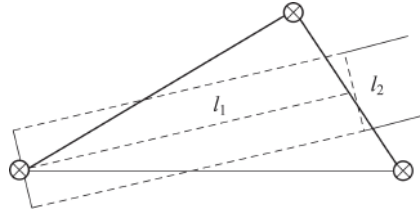
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- c) The width of the model, l_2 , in mm, is to be taken as:

$$l_2 = \frac{A}{l_1}$$

where:

A Area of the plate, in mm²



- d) The lengths of shorter side, b , and of the longer side, a , in mm, of the equivalent rectangular plate panel are to be taken as:

$$b = \frac{l_2}{C_{tri}}$$

$$a = l_1 C_{tri}$$

where:

$$C_{tri} = 0.4 \frac{l_2}{l_1} + 0.6$$

- e) The stresses from the direct strength analysis are to be transformed into the local coordinate system of the equivalent rectangular panel and are to be used for the buckling assessment of the equivalent rectangular panel.

2.4 Reference Stress

2.4.1 The stress distribution is to be taken from the direct strength analysis according to the Relevant UR-S and applied to the buckling model.

2.4.2 For FE analysis, the reference stresses are to be calculated using the stress-based reference stresses as defined in Appendix 1.

2.5 Lateral Pressure

2.5.1 The lateral pressure applied to the direct strength analysis is also to be applied to the buckling assessment.

For FE analysis, where the lateral pressure is not constant over a buckling panel defined by a number of finite plate elements, an average lateral pressure, N/mm², is calculated using the following formula:

$$P_{avr} = \frac{\sum_1^n A_i P_i}{\sum_1^n A_i}$$

where:

A_i : Area of the i -th plate element, in mm².

P_i : Lateral pressure of the i -th plate element, in N/mm².

S35 (cont)

n : Number of finite elements in the buckling panel.

2.6 Buckling Criteria

2.6.1 UP-A

The compressive buckling strength of UP-A is to satisfy the following criterion:

$$\eta_{UP-A} \leq \eta_{all}$$

where:

η_{UP-A} Plate buckling utilisation factor, equal to η_{plate} as defined in Sec 5, [2.2] where UP-A model is to be used.

2.6.2 UP-B

The compressive buckling strength of UP-B is to satisfy the following criterion:

$$\eta_{UP-B} \leq \eta_{all}$$

where:

η_{UP-B} Plate buckling utilisation factor, equal to η_{plate} as defined in Sec 5, [2.2] where UP-B model is to be used.

2.6.3 SP-A

The compressive buckling strength of SP-A is to satisfy the following criterion:

$$\eta_{SP-A} \leq \eta_{all}$$

where:

η_{SP-A} Buckling utilisation factor of the stiffened panel, taken as the maximum of the buckling utilisation factors calculated as below:

- The overall stiffened panel buckling utilisation factor $\eta_{overall}$ as defined in Sec 5, [2.1].
- The plate buckling utilisation factor η_{plate} as defined in Sec 5, [2.2] where SP-A model is to be used.
- The stiffener buckling utilisation factor $\eta_{stiffener}$ as defined in Sec 5, [2.3] considering separately the properties (thickness, dimensions), the pressures defined in [2.5.2] and the reference stresses of each EPP at both sides of the stiffener.

Note 1: The stiffener buckling strength check can only be fulfilled when the overall stiffened panel capacity check, as defined in Sec 5, [2.1], is satisfied.

S35 (cont)

2.6.4 SP-B

The compressive buckling strength of SP-B is to satisfy the following criterion:

$$\eta_{SP-B} \leq \eta_{all}$$

where:

η_{SP-B} Buckling utilisation factor of the stiffened panel, taken as the maximum of the buckling utilisation factors calculated as below:

- The overall stiffened panel buckling utilisation factor $\eta_{overall}$ as defined in Sec 5, [2.1].
- The plate buckling utilisation factor η_{plate} as defined in Sec 5, [2.2] where SP-B model is to be used.
- The stiffener buckling utilisation factor $\eta_{stiffener}$ as defined in Sec 5, [2.3] considering separately the properties (thickness, dimensions), the pressures defined in [2.5.2] and the reference stresses of each EPP at both sides of the stiffener.

Note 1: The stiffener buckling strength check can only be fulfilled when the overall stiffened panel capacity check, as defined in Sec 5, [2.1], is satisfied.

2.6.5 Web plate in way of openings

The web plate of primary supporting members with openings is to satisfy the following criterion:

$$\eta_{opening} \leq \eta_{all}$$

where:

$\eta_{opening}$ Maximum web plate utilisation factor in way of openings, calculated with the definition in Sec 1, [3.2.2] and the stress multiplier factor at failure γ_c which can be calculated following the requirements in Sec 5, [2.4].

S35

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SECTION 5 BUCKLING CAPACITY

Symbols

A_p	Net sectional area of the stiffener attached plating, in mm ² , taken as: $A_p = st_p$
A_s	Net sectional area of the stiffener without attached plating, in mm ² .
a	Length of the longer side of the plate panel, in mm.
b	Length of the shorter side of the plate panel, in mm.
b_{eff}	Effective width of the attached plating of a stiffener, in mm, as defined in [2.3.5].
b_{eff1}	Effective width of the attached plating of a stiffener, in mm, without the shear lag effect taken as: - For $\sigma_x > 0$ - For prescriptive assessment: $b_{eff1} = \frac{C_{x1}b_1 + C_{x2}b_2}{2}$ - For FE analysis: $b_{eff1} = C_x b$ - For $\sigma_x \leq 0$ $b_{eff1} = b$
b_f	Breadth of the stiffener flange, in mm.
b_1, b_2	Width of plate panel on each side of the considered stiffener, in mm. For stiffened panels fitted with U-type stiffeners, b_1 and b_2 are as defined in Sec 1, Figure 4.
C_{x1}, C_{x2}	Reduction factor defined in Table 3 calculated for the EPP1 and EPP2 on each side of the considered stiffener according to case 1.
d	Length of the side parallel to the cylindrical axis of the cylinder corresponding to the curved plate panel as shown in Table 4, in mm.
d_f	Breadth of the extended part of the flange for L2 profiles, in mm, as shown in Sec 1, Figure 3.
e_f	Distance from attached plating to centre of flange, in mm, as shown in Sec 1, Figure 3 to be taken as: $e_f = h_w$ for flat bar profile. $e_f = h_w - 0.5t_f$ for bulb profile. $e_f = h_w + 0.5t_f$ for angle, L2 and T profiles.
F_{long}	Coefficient defined in [2.2.4].
F_{tran}	Coefficient defined in [2.2.5].
h_w	Depth of stiffener web, in mm, as shown in Sec 1, Figure 3.

S35

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l	Span, in mm, of stiffener equal to spacing between primary supporting members or span of side frame equal to the distance between the hopper tank and top wing tank in way of the side shell.
R	Radius of curved plate panel, in mm.
R_{eH_P}	Specified minimum yield stress of the plate in N/mm ² .
R_{eH_S}	Specified minimum yield stress of the stiffener in N/mm ² .
S	Partial safety factor, unless otherwise specified in the Relevant UR-S, to be taken as 1.0.
t_p	Net thickness of plate panel, in mm.
t_w	Net stiffener web thickness, in mm.
t_f	Net flange thickness, in mm.
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.
α	Aspect ratio of the plate panel, defined in Table 3 to be taken as: $\alpha = \frac{a}{b}$
β	Coefficient taken as: $\beta = \frac{1-\psi}{\alpha}$
ω	Coefficient taken as: $\omega = \min(3, \alpha)$
σ_x	Normal stress applied on the edge along x -axis of the buckling panel, in N/mm ² .
σ_y	Normal stress applied on the edge along y -axis of the buckling panel, in N/mm ² .
σ_1	Maximum normal stress along a panel edge, in N/mm ² .
σ_2	Minimum normal stress along a panel edge, in N/mm ² .
σ_E	Elastic buckling reference stress, in N/mm ² to be taken as: - For the application of the limit state of plane plate panels according to [2.2.1]: $\sigma_E = \frac{\pi^2 E}{12(1 - \nu^2)} \left(\frac{t_p}{b} \right)^2$ - For the application of the limit state of curved plate panels according to [2.2.6]: $\sigma_E = \frac{\pi^2 E}{12(1 - \nu^2)} \left(\frac{t_p}{d} \right)^2$
τ	Applied shear stress, in N/mm ² .
τ_c	Buckling strength in shear, in N/mm ² , as defined in [2.2.3].
ψ	Edge stress ratio to be taken as: $\psi = \frac{\sigma_2}{\sigma_1}$
γ	Stress multiplier factor acting on loads. When the factor is such that the loads reach the interaction formulae, $\gamma = \gamma_c$.
γ_c	Stress multiplier factor at failure.
γ_{GEB}	Stress multiplier factor of global elastic buckling capacity.

S35

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1. General

1.1 Introduction

1.1.1 This section contains the methods for determination of the buckling capacities of plate panels, stiffeners, primary supporting members and columns.

1.1.2 For the application of this section, the stresses σ_x , σ_y and τ applied on the structural members are defined in:

- Sec 3 for hull girder prescriptive buckling requirements.
- Sec 4 for direct strength analysis buckling requirements of hatch covers.

1.1.3 Buckling capacity

The buckling capacity is calculated by applying the actual stress combination and then increasing or decreasing the stresses proportionally until the interaction formulae defined in [2.1.1], [2.2.1] and [2.3.4] are equal to 1.0, respectively.

1.1.4 Buckling utilisation factor

The buckling utilisation factor of the structural member is equal to the highest utilisation factor obtained for the different buckling modes.

1.1.5 Lateral pressure

The lateral pressure is to be applied and considered as constant for the calculation of buckling capacities as defined in [1.1.3].

2. Buckling Capacity of Plate Panels

2.1 Overall Stiffened Panels

2.1.1 The elastic stiffened panel limit state is based on the following interaction formula, which sets a precondition for the buckling check of stiffeners in accordance with [2.3.4]:

$$\frac{\gamma_c}{\gamma_{GEB}} = 1$$

with the corresponding buckling utilization factor defined as

$$\eta_{overall} = \frac{1}{\gamma_c}$$

where the stress multiplier factors of global elastic buckling capacity, γ_{GEB} , are to be calculated based on the following formulae:

$$\gamma_{GEB} = \gamma_{GEB,bi+\tau} \quad \text{for } \tau \neq 0 \text{ and } (\sigma_x > 0 \text{ or } \sigma_y > 0)$$

$$\gamma_{GEB} = \gamma_{GEB,bi} \quad \text{for } \tau = 0 \text{ and } (\sigma_x > 0 \text{ or } \sigma_y > 0)$$

$$\gamma_{GEB} = \gamma_{GEB,\tau} \quad \text{for } \tau \neq 0 \text{ and } (\sigma_x \leq 0 \text{ and } \sigma_y \leq 0)$$

S35

(cont)

where $\gamma_{GEB,bi+\tau}$, $\gamma_{GEB,bi}$ and $\gamma_{GEB,\tau}$ are stress multiplier factors of the global elastic buckling capacity for different load combinations as defined in [2.1.2], [2.1.3] and [2.1.4], respectively. For the calculation of $\gamma_{GEB,bi+\tau}$, $\gamma_{GEB,bi}$ and $\gamma_{GEB,\tau}$, neither σ_x nor σ_y shall be taken less than 0.

σ_x, σ_y Applied normal stress to the plate panel, in N/mm², to be taken as defined in [2.2.7].

τ Applied shear stress, in N/mm², to be taken as defined in [2.2.7].

2.1.2 The stress multiplier factor $\gamma_{GEB,bi}$ for the stiffened panel subjected to biaxial loads is taken as:

$$\gamma_{GEB,bi} = \frac{\pi^2}{L_{B1}^2 L_{B2}^2} \frac{[D_{11}L_{B2}^4 + 2(D_{12} + D_{33})n^2 L_{B1}^2 L_{B2}^2 + n^4 D_{22}L_{B1}^4]}{L_{B2}^2 N_x + n^2 L_{B1}^2 N_y}$$

where:

N_x Load per unit length applied on the edge along x -axis of the stiffened panel, in N/mm, taken as

$$N_x = \sigma_{x,av}(A_p + A_s)/s$$

For stiffened panels fitted with U-type stiffeners, stiffener spacing s is taken as:

$$s = b_1 + b_2$$

where b_1 and b_2 are as defined in Sec 1, Figure 4.

N_y Load per unit length applied on the edge along y axis of the stiffened panel, in N/mm, taken as $N_y = c\sigma_y t_p$

L_{B1} Stiffener span, in mm, distance between primary supporting members, i.e. $L_{B1} = l$. Specially, for vertically stiffened side shell of single side skin bulk carriers, $L_{B1} = 0.8l$.

L_{B2} Total width of stiffened panel between lateral supports, in mm, taken as 6 times of the stiffener spacing, i.e. $6s$.

n Number of half waves along the direction perpendicular to the stiffener axis. The factor $\gamma_{GEB,bi}$ is to be minimized with respect to the wave parameters n , i.e. to be taken as the smallest value larger than zero.

c Factor taking into account the normal stress distribution in the attached plating acting perpendicular to the stiffener's axis:

$$c = 0.5(1 + \psi) \quad \text{for } 0 \leq \psi \leq 1$$

$$c = \frac{1}{2(1 - \psi)} \quad \text{for } \psi < 0$$

ψ Edge stress ratio for case 2 according to Table 3.

$\sigma_{x,av}$ Average stress for both plate and stiffener, taken as:

$$\begin{aligned} \sigma_{x,av} &= \sigma_x - \nu c \sigma_y A_s / (A_p + A_s) \geq 0 & \text{for } \sigma_x > 0 \text{ and } \sigma_y > 0 \\ \sigma_{x,av} &= \sigma_x & \text{for } \sigma_x \leq 0 \text{ or } \sigma_y \leq 0 \end{aligned}$$

S35

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$D_{11}, D_{12}, D_{22}, D_{33}$ Bending stiffness coefficients, in Nmm, of the stiffened panel, defined in general as:

$$\left. \begin{aligned} D_{11} &= \frac{EI_{eff} 10^4}{s} \\ D_{12} &= \frac{Et_p^3 \nu}{12(1 - \nu^2)} \\ D_{22} &= \frac{Et_p^3}{12(1 - \nu^2)} \\ D_{33} &= \frac{Et_p^3}{12(1 + \nu)} \end{aligned} \right\}$$

For stiffened panels fitted with U-type stiffeners, D_{12} and D_{22} are defined as:

$$D_{22} = \frac{Et_p^3}{12(1 - \nu^2)} \left[1.2 + 4.8 \times \text{Min} \left(1.0, \frac{b_1^2}{h_w(b_1 + b_2)} \right) \times \text{Min} \left(1.0, \left(\frac{t_w}{t_p} \right)^3 \right) \right]$$

$$D_{12} = \nu D_{22}$$

h_w is the breadth of U-type stiffener web as defined in Sec 1, Figure 4.

I_{eff} Moment of inertia, in cm^4 , of the stiffener including the effective width of the attached plating, same as I defined in [2.3.4].

2.1.3 The stress multiplier factor $\gamma_{GEB,\tau}$ for the stiffened panel subjected to pure shear load is taken as:

$$\gamma_{GEB,\tau} = \frac{\sqrt[4]{D_{11}^3 D_{22}}}{(L_{B1}/2)^2 N_{xy}} \left[8.125 + 5.64 \sqrt{\frac{(D_{12} + D_{33})^2}{D_{11} D_{22}}} - 0.6 \frac{(D_{12} + D_{33})^2}{D_{11} D_{22}} \right] \text{ for } D_{11} D_{22} \geq (D_{12} + D_{33})^2$$

$$\gamma_{GEB,\tau} = \frac{\sqrt{2 D_{11} (D_{12} + D_{33})}}{(L_{B1}/2)^2 N_{xy}} \left[8.3 + 1.525 \frac{D_{11} D_{22}}{(D_{12} + D_{33})^2} - 0.493 \frac{D_{11}^2 D_{22}^2}{(D_{12} + D_{33})^4} \right] \text{ for } D_{11} D_{22} < (D_{12} + D_{33})^2$$

where:

$$N_{xy} = \tau t_p$$

2.1.4 The stress multiplier factor $\gamma_{GEB,bi+\tau}$ for the stiffened panel subjected to combined loads is taken as:

$$\gamma_{GEB,bi+\tau} = \frac{1}{2} \gamma_{GEB,\tau}^2 \left[-\frac{1}{\gamma_{GEB,bi}} + \sqrt{\frac{1}{\gamma_{GEB,bi}^2} + 4 \frac{1}{\gamma_{GEB,\tau}^2}} \right]$$

where $\gamma_{GEB,bi}$ and $\gamma_{GEB,\tau}$ are as defined in [2.1.2] and [2.1.3], respectively.

S35

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2.2 Plates

2.2.1 Plate limit state

The plate limit state is based on the following interaction formulae:

$$\left(\frac{\gamma_{c1}\sigma_x S}{\sigma_{cx}}\right)^{e_0} - B \left(\frac{\gamma_{c1}\sigma_x S}{\sigma_{cx}}\right)^{\frac{e_0}{2}} \left(\frac{\gamma_{c1}\sigma_y S}{\sigma_{cy}}\right)^{\frac{e_0}{2}} + \left(\frac{\gamma_{c1}\sigma_y S}{\sigma_{cy}}\right)^{e_0} + \left(\frac{\gamma_{c1}|\tau|S}{\tau_c}\right)^{e_0} = 1$$

$$\left(\frac{\gamma_{c2}\sigma_x S}{\sigma_{cx}}\right)^{\frac{2}{\beta_p^{0.25}}} + \left(\frac{\gamma_{c2}|\tau|S}{\tau_c}\right)^{\frac{2}{\beta_p^{0.25}}} = 1 \text{ for } \sigma_x \geq 0$$

$$\left(\frac{\gamma_{c3}\sigma_y S}{\sigma_{cy}}\right)^{\frac{2}{\beta_p^{0.25}}} + \left(\frac{\gamma_{c3}|\tau|S}{\tau_c}\right)^{\frac{2}{\beta_p^{0.25}}} = 1 \text{ for } \sigma_y \geq 0$$

$$\frac{\gamma_{c4}|\tau|S}{\tau_c} = 1$$

with

$$\gamma_c = \text{Min}(\gamma_{c1}, \gamma_{c2}, \gamma_{c3}, \gamma_{c4})$$

and the corresponding buckling utilization factor defined as

$$\eta_{plate} = \frac{1}{\gamma_c}$$

where:

σ_x, σ_y Applied normal stress to the plate panel, in N/mm², to be taken as defined in [2.2.7].

τ Applied shear stress to the plate panel, in N/mm².

σ_{cx} Ultimate buckling stress, in N/mm², in direction parallel to the longer edge of the buckling panel as defined in [2.2.3].

σ_{cy} Ultimate buckling stress, in N/mm², in direction parallel to the shorter edge of the buckling panel as defined in [2.2.3].

τ_c Ultimate buckling shear stress, in N/mm², as defined in [2.2.3].

$\gamma_{c1}, \gamma_{c2}, \gamma_{c3}, \gamma_{c4}$: Stress multiplier factors at failure for each of the above different limit states. γ_{c2} and γ_{c3} are only to be considered when $\sigma_x \geq 0$ and $\sigma_y \geq 0$ respectively.

B Coefficient given in Table 1

e_0 Coefficient given in Table 1

β_p Plate slenderness parameter taken as:

$$\beta_p = \frac{b}{t_p} \sqrt{\frac{R_{eH_P}}{E}}$$

Table 1: Definition of coefficients B and e_0

Applied stress	B	e_0
$\sigma_x \geq 0$ and $\sigma_y \geq 0$	$0.7 - 0.3 \beta_p / \alpha^2$	$2 / \beta_p^{0.25}$
$\sigma_x < 0$ or $\sigma_y < 0$	1.0	2.0

S35

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2.2.2 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 3 and Table 4.

2.2.3 Ultimate buckling stresses

The ultimate buckling stresses of plate panels, in N/mm², are 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_τ Reduction factors, as defined in Table 3

- For the 1st Equation of [2.2.1], when $\sigma_x < 0$ or $\sigma_y < 0$, the reduction factors are to be taken as:

$$C_x = C_y = C_\tau = 1.$$

- For other cases:

- For SP-A and UP-A, C_y is calculated according to Table 3 by using

$$c_1 = \left(1 - \frac{1}{\alpha}\right) \geq 0$$

- For SP-B and UP-B, C_y is calculated according to Table 3 by using

$$c_1 = 1$$

- For vertically stiffened single side skin of bulk carrier, C_y is calculated according to Table 3 by using

$$c_1 = \left(1 - \frac{1}{\alpha}\right) \geq 0$$

- For corrugation of corrugated bulkheads, C_y is calculated according to Table 3 by using

$$c_1 = \left(1 - \frac{1}{\alpha}\right) \geq 0$$

The boundary conditions for plates are to be considered as simply supported, see cases 1, 2 and 15 of Table 3. If the boundary conditions differ significantly from simple support, a more appropriate boundary condition can be applied according to the different cases of Table 3 subject to the agreement of the Society.

S35

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2.2.4 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 2. 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 2, the value of c is to be agreed by the Society. In such a case, value of c higher than those mentioned in Table 2 can be used, provided it is verified by buckling strength check of panel using non-linear FE analysis and deemed appropriate by the Society.

Table 2: Correction factor F_{long}

Structural element types			F_{long}	c
Unstiffened Panel			1.0	N/A
Stiffened Panel	Stiffener not fixed at both ends		1.0	N/A
	Stiffener fixed at both ends	Flat bar ⁽¹⁾	$F_{long} = c + 1 \text{ for } \frac{t_w}{t_p} > 1$ $F_{long} = c \left(\frac{t_w}{t_p} \right)^3 + 1 \text{ for } \frac{t_w}{t_p} \leq 1$	0.10
		Bulb profile		0.30
		Angle and L2 profiles		0.40
		T profile		0.30
		Girder of high rigidity (e.g. bottom transverse)	1.4	N/A
		U-type profile fitted on hatch cover ⁽²⁾	- Plate on which the U-type profile is fitted, including EPP b_1 and EPP b_2 - For $b_2 < b_1$: $F_{long} = 1$ - For $b_2 \geq b_1$: $F_{long} = \left(1.55 - 0.55 \frac{b_1}{b_2} \right) \left[1 + c \left(\frac{t_w}{t_p} \right)^3 \right]$ - Other plates of the U-type profile: $F_{long} = 1$	0.2

(1) t_w is the net web thickness, in mm, without the correction defined in [2.3.2].

(2) b_1, b_2 and t_w are defined in Sec.1, Figure 4.

2.2.5 Correction factor F_{tran}

The correction factor F_{tran} is to be taken as:

- For transversely framed EPP of single side skin bulk carrier, between the hopper and top wing tank:
 - $F_{tran} = 1.25$ when the two adjacent frames are supported by one tripping bracket fitted in way of the adjacent plate panels.
 - $F_{tran} = 1.33$ when the two adjacent frames are supported by two tripping brackets each fitted in way of the adjacent plate panels.
 - $F_{tran} = 1.15$ elsewhere.

S35

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- For the attached plate of a U-type stiffener fitted on a hatch cover:

$$F_{tran} = \text{Max}(3 - 0.08(F_{tran0} - 6)^2, 1.0) \leq 2.25$$

where:

$$F_{tran0} = \text{Min}\left(\frac{b_2}{b_1} + \frac{6b_2^2}{\pi^2 h_w(b_1 + b_2)} \left(\frac{t_w}{t_p}\right)^3, 6\right) \text{ for EPP } b_2$$

$$F_{tran0} = \text{Min}\left(\frac{b_1}{b_2} + \frac{6b_1^2}{\pi^2 h_w(b_2 + b_1)} \left(\frac{t_w}{t_p}\right)^3, 6\right) \text{ for EPP } b_1$$

with b_1, b_2 and h_w as defined in Sec.1, Figure 4.

Coefficient F defined in Case 2 of Table 3 is to be replaced by the following formula:

$$F = \left[1 - \left(\frac{K_y}{0.91F_{tran}} - 1\right)/\lambda_p^2\right] c_1 \geq 0$$

- For other cases: $F_{tran} = 1$.

2.2.6 Curved plate panels

This requirement for curved plate limit state is applicable when $R/t_p \leq 2500$. Otherwise, the requirement for plate limit state given in [2.2.1] is applicable.

The curved plate limit state is based on the following interaction formula:

$$\left(\frac{\gamma_c \sigma_{ax} S}{C_{ax} R_{eH_P}}\right)^{1.25} - 0.5 \left(\frac{\gamma_c \sigma_{ax} S}{C_{ax} R_{eH_P}}\right) \left(\frac{\gamma_c \sigma_{tg} S}{C_{tg} R_{eH_P}}\right) + \left(\frac{\gamma_c \sigma_{tg} S}{C_{tg} R_{eH_P}}\right)^{1.25} + \left(\frac{\gamma_c \tau \sqrt{3} S}{C_\tau R_{eH_P}}\right)^2 = 1.0$$

with the corresponding buckling utilization factor defined as

$$\eta_{curved_plate} = \frac{1}{\gamma_c}$$

where:

σ_{ax} Applied axial stress to the cylinder corresponding to the curved plate panel, in N/mm². In case of tensile axial stresses, $\sigma_{ax} = 0$.

σ_{tg} Applied tangential stress to the cylinder corresponding to the curved plate panel, in N/mm². In case of tensile tangential stresses, $\sigma_{tg} = 0$.

C_{ax}, C_{tg}, C_τ Buckling reduction factor of the curved plate panel, as defined in Table 4.

The stress multiplier factor, γ_c , of the curved plate panel need not be taken less than the stress multiplier factor, γ_c , for the expanded plane panel according to [2.2.1].

Figure 1: Transverse stiffened bilge plating

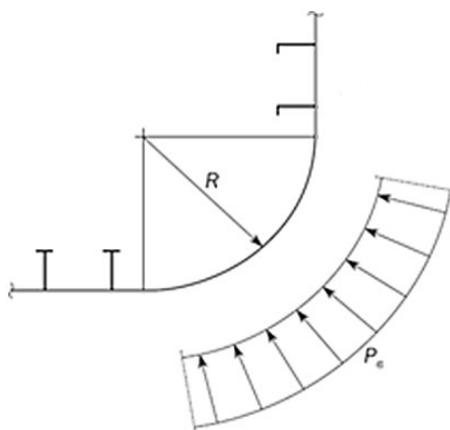


Table 3: Buckling factor and reduction factor for plane plate panels

Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
1	$1 \geq \psi \geq 0$		$K_x = F_{long} \frac{8.4}{\psi + 1.1}$	When $\sigma_x \leq 0$, $C_x = 1$
	$0 > \psi > -1$		$K_x = F_{long} [7.63 - \psi(6.26 - 10\psi)]$	When $\sigma_x > 0$, $C_x = 1$ for $\lambda \leq \lambda_c$ $C_x = c \left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2} \right)$ for $\lambda > \lambda_c$
	$\psi \leq -1$		$K_x = F_{long} [5.975(1 - \psi)^2]$	where: $c = (1.25 - 0.12\psi) \leq 1.25$ $\lambda_c = \frac{c}{2} \left(1 + \sqrt{1 - \frac{0.88}{c}} \right)$
2	$1 \geq \psi \geq 0$		$K_y = \frac{F_{tran} \cdot 2 \left(1 + \frac{1}{\alpha^2} \right)^2}{1 + \psi + \frac{(1 - \psi)}{100} \left(\frac{2.4}{\alpha^2} + 6.9f_1 \right)}$	When $\sigma_y \leq 0$, $C_y = 1$
		$\alpha \leq 6$	$f_1 = (1 - \psi)(\alpha - 1)$	When $\sigma_y > 0$
		$\alpha > 6$	$f_1 = 0.6 \left(1 - \frac{6\psi}{\alpha} \right) \left(\alpha + \frac{14}{\alpha} \right)$ but not greater than $14.5 - \frac{0.35}{\alpha^2}$	$C_y = c \left(\frac{1}{\lambda} - \frac{R + F^2(H - R)}{\lambda^2} \right)$
	$1 - \frac{4\alpha}{3} \leq \psi < 0$		$K_y = \frac{200F_{tran}(1 + \beta^2)^2}{(1 - f_3)(100 + 2.4\beta^2 + 6.9f_1 + 23f_2)}$	where: $c = (1.25 - 0.12\psi) \leq 1.25$
		$\alpha > 6(1 - \psi)$	$f_1 = 0.6 \left(\frac{1}{\beta} + 14\beta \right)$ but not greater than $14.5 - 0.35\beta^2$ $f_2 = f_3 = 0$	$R = \lambda \left(1 - \frac{\lambda}{c} \right)$ for $\lambda < \lambda_c$ $R = 0.22$ for $\lambda \geq \lambda_c$ $\lambda_c = 0.5c \left(1 + \sqrt{1 - \frac{0.88}{c}} \right)$

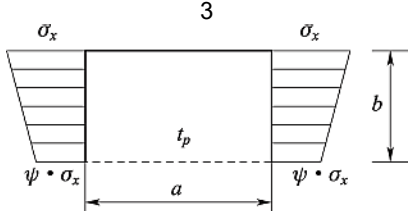
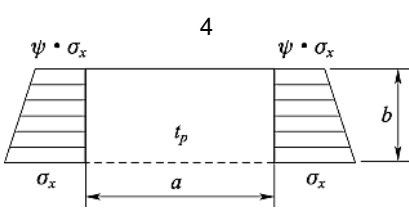
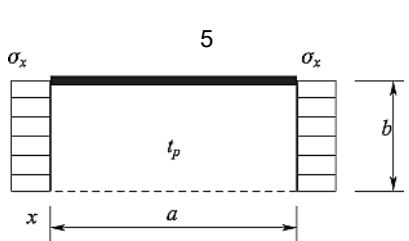
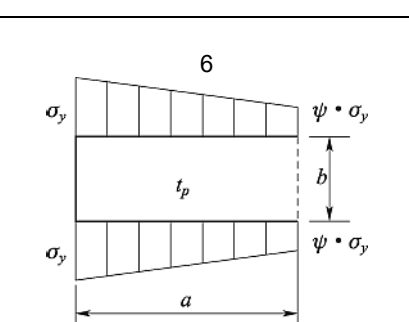
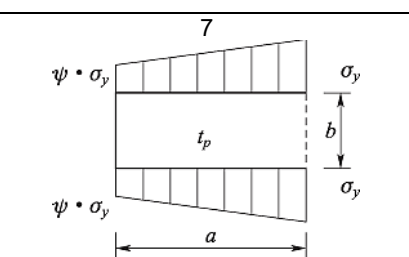
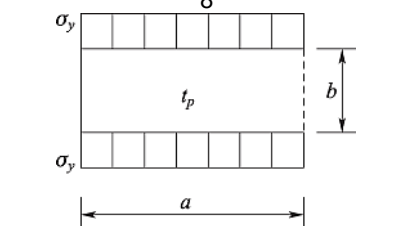
S35

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		$3(1-\psi) \leq \alpha \leq 6(1-\psi)$	$f_1 = \frac{1}{\beta} - 1$ $f_2 = f_3 = 0$	$F = \left(1 - \frac{\left(\frac{K}{0.91} - 1\right)}{\lambda_p^2}\right) c_1 \geq 0$ $\lambda_p^2 = \lambda^2 - 0.5$ for $1 \leq \lambda_p^2 \leq 3$ c_1 as defined in [2.2.3] $H = \lambda - \frac{2\lambda}{c(T + \sqrt{T^2 - 4})} \geq R$ $T = \lambda + \frac{14}{15\lambda} + \frac{1}{3}$
		$1.5(1-\psi) \leq \alpha < 3(1-\psi)$	$f_1 = \frac{1}{\beta} - (2 - \omega\beta)^4$ $-9(\omega\beta - 1)\left(\frac{2}{3} - \beta\right)$ $f_2 = f_3 = 0$	
		$1 - \psi \leq \alpha < 1.5(1-\psi)$	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 $\alpha \leq 1.5$ $f_1 = 2\left(\frac{1.5}{1-\psi} - 1\right)\left(\frac{1}{\beta} - 1\right)$ $f_2 = \frac{\psi(1 - 16f_4^2)}{1 - \alpha}$ $f_3 = 0$ $f_4 = (1.5 - \text{Min}(1.5, \alpha))^2$	
		$0.75(1-\psi) \leq \alpha < 1 - \psi$	$f_1 = 0$ $f_2 = 1 + 2.31(\beta - 1)$ $-48\left(\frac{4}{3} - \beta\right)f_4^2$ $f_3 = 3f_4(\beta - 1) - \left(\frac{f_4}{1.81} - \frac{\alpha - 1}{1.31}\right)$ $f_4 = (1.5 - \text{Min}(1.5, \alpha))^2$	
	$\psi < 1 - \frac{4\alpha}{3}$		$K_y = 5.972F_{tran} \frac{\beta^2}{1 - f_3}$ where $f_3 = f_5 \left(\frac{f_5}{1.81} + \frac{1 + 3\psi}{5.24} \right)$ $f_5 = \frac{9}{16} (1 + \text{Max}(-1, \psi))^2$	

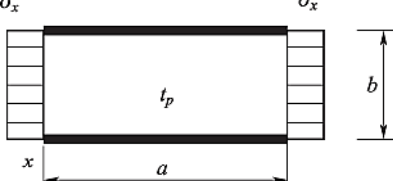
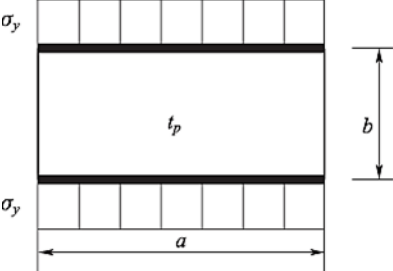
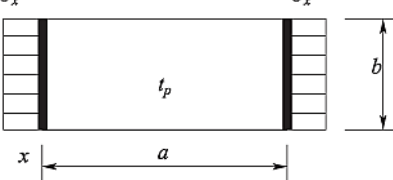
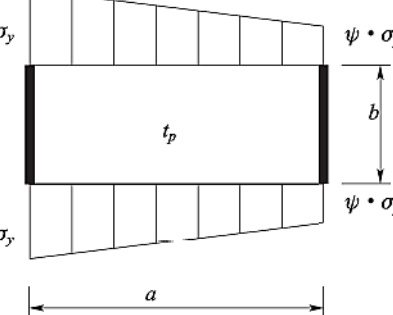
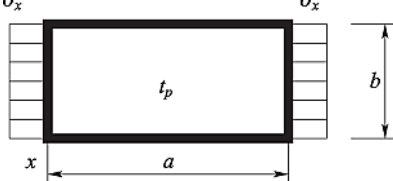
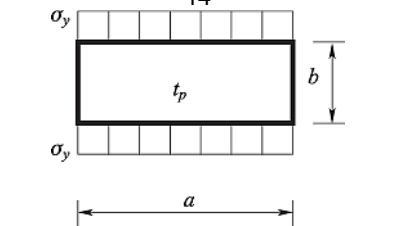
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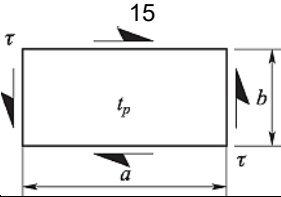
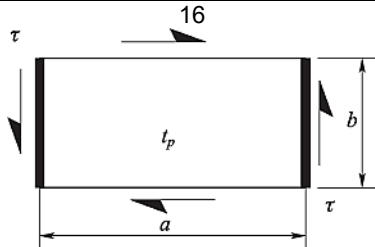
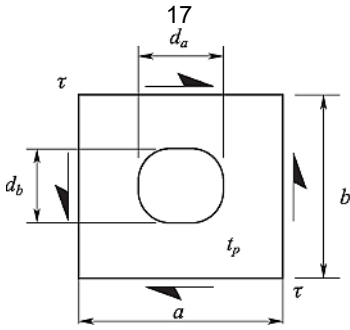
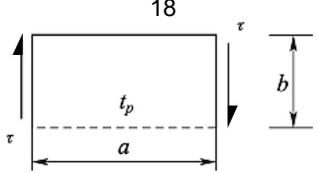
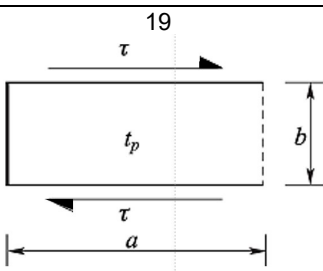
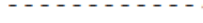
Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
	$0 \leq \psi \leq 1$	$\alpha \geq 1$	$K_x = \frac{4(0.425 + 1/\alpha^2)}{3\psi + 1}$	For UP-A: $C_x = 1$ for $\lambda \leq 0.75$ $C_x = \frac{0.75}{\lambda}$ for $\lambda > 0.75$ For UP-B: $C_x = 1$ for $\lambda \leq 0.7$ $C_x = \frac{1}{\lambda^2 + 0.51}$ for $\lambda > 0.7$
	$0 > \psi > -1$		$K_x = 4 \left(0.425 + \frac{1}{\alpha^2} \right) (1 + \psi) - 5\psi(1 - 3.42\psi)$	
	$1 \leq \psi \leq -1$	$\alpha \geq 1.64$	$K_x = \left(0.425 + \frac{1}{\alpha^2} \right) \frac{3 - \psi}{2}$	
	—		$K_x = 1.28$	
	$\alpha < 1.64$	$K_x = \frac{1}{\alpha^2} + 0.56 + 0.13\alpha^2$		
	$1 \leq \psi \leq 0$	$\alpha \geq 1$	$K_y = \frac{4(0.425 + \alpha^2)}{(3\psi + 1)\alpha^2}$	For UP-A: $C_y = 1$ for $\lambda \leq 0.75$ $C_y = \frac{0.75}{\lambda}$ for $\lambda > 0.75$ For UP-B: $C_y = 1$ for $\lambda \leq 0.7$ $C_y = \frac{1}{\lambda^2 + 0.51}$ for $\lambda > 0.7$
	$0 > \psi > -1$		$K_y = 4(0.425 + \alpha^2)(1 + \psi) \frac{1}{\alpha^2} - 5\psi(1 - 3.42\psi) \frac{1}{\alpha^2}$	
	$1 \leq \psi \leq -1$	$\alpha \geq 1.64$	$K_y = (0.425 + \alpha^2) \frac{(3 - \psi)}{2\alpha^2}$	
	—		$K_y = 1 + \frac{0.56}{\alpha^2} + \frac{0.13}{\alpha^4}$	
	$\alpha < 1.64$	$K_y = 1 + \frac{0.56}{\alpha^2} + \frac{0.13}{\alpha^4}$		

S35

(cont)

Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
9 	—	$K_x = 6.97$	$C_x = 1$ for $\lambda \leq 0.83$ $C_x = 1.13 \left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2} \right)$ for $\lambda > 0.83$	
10 	—	$K_y = 4 + \frac{2.07}{\alpha^2} + \frac{0.67}{\alpha^4}$	$C_y = 1$ for $\lambda \leq 0.83$ $C_y = 1.13 \left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2} \right)$ for $\lambda > 0.83$	
11 	—	$\alpha \geq 4$ $\alpha < 4$	$K_x = 4$ $K_x = 4 + 2.74 \left(\frac{4 - \alpha}{3} \right)^4$	$C_x = 1$ for $\lambda \leq 0.83$ $C_x = 1.13 \left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2} \right)$ for $\lambda > 0.83$
12 	—	$K_y = K_y$ determined as per case 2		For $\alpha < 2$ $C_y = C_{y2}$ For $\alpha \geq 2$ $C_y = \left(1.06 + \frac{1}{10\alpha} \right) C_{y2}$ where: $C_{y2} : C_y$ determined as per case 2
13 	—	$\alpha \geq 4$ $\alpha < 4$	$K_x = 6.97$ $K_x = 6.97 + 3.1 \left(\frac{4 - \alpha}{3} \right)^4$	$C_x = 1$ for $\lambda \leq 0.83$ $C_x = 1.13 \left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2} \right)$ for $\lambda > 0.83$
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 $\lambda \leq 0.83$ $C_y = 1.13 \left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2} \right)$ for $\lambda > 0.83$

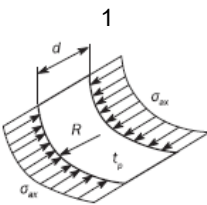
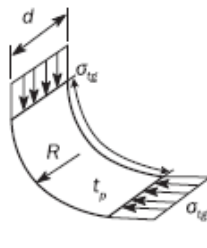
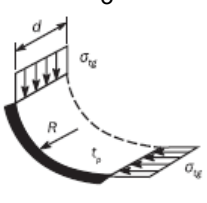
S35 (cont)

Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
	—		$K_\tau = \sqrt{3} \left(5.34 + \frac{4}{\alpha^2} \right)$	$C_\tau = 1$ for $\lambda \leq 0.84$ $C_\tau = \frac{0.84}{\lambda}$ for $\lambda > 0.84$
	—		$K_\tau = \sqrt{3} \left[5.34 + \text{Max} \left(\frac{4}{\alpha^2}, \frac{7.15}{\alpha^{2.5}} \right) \right]$	
	—		$K_\tau = K_{\tau \text{ case } 15} r$ $K_{\tau \text{ case } 15}$: K_τ 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 $\frac{d_a}{a} \leq 0.7$ and $\frac{d_b}{b} \leq 0.7$	
	—		$K_\tau = \sqrt{3} \left(0.6 + \frac{4}{\alpha^2} \right)$	
	—		$K_\tau = 8$	
Edge boundary conditions:  Plate edge free  Plate edge simply supported  Plate edge clamped				
Note 1: Cases listed are general cases. Each stress component (σ_x , σ_y) is to be understood in local coordinates.				

S35

(cont)

Table 4: Buckling factor and reduction factor for curved plate panel with $R/t_p \leq 2500$

Case	Aspect ratio	Buckling factor K	Reduction factor C
	$\frac{d}{R} \leq 0.5 \sqrt{\frac{R}{t_p}}$	$K = 1 + \frac{2}{3} \frac{d^2}{R t_p}$	For general application: $C_{ax} = 1$ for $\lambda \leq 0.25$ $C_{ax} = 1.233 - 0.933\lambda$ for $0.25 < \lambda \leq 1$ $C_{ax} = 0.3/\lambda^3$ for $1 < \lambda \leq 1.5$ $C_{ax} = 0.2/\lambda^2$ for $\lambda > 1.5$ For curved single fields, e.g. bilge strake, which are bounded by plane panels as shown in Figure 1: $C_{ax} = \frac{0.65}{\lambda^2} \leq 1.0$
	$\frac{d}{R} > 0.5 \sqrt{\frac{R}{t_p}}$	$K = 0.267 \frac{d^2}{R t_p} \left[3 - \frac{d}{R} \sqrt{\frac{t_p}{R}} \right] \geq 0.4 \frac{d^2}{R t_p}$	
	$\frac{d}{R} \leq 1.63 \sqrt{\frac{R}{t_p}}$	$K = \frac{d}{\sqrt{R t_p}} + 3 \frac{(R t_p)^{0.175}}{d^{0.35}}$	For general application: $C_{tg} = 1$ for $\lambda \leq 0.4$ $C_{tg} = 1.274 - 0.686\lambda$ for $0.4 < \lambda \leq 1.2$ $C_{tg} = \frac{0.65}{\lambda^2}$ for $\lambda > 1.2$ For curved single fields, e.g. bilge strake, which are bounded by plane panels as shown in Figure 1: $C_{tg} = \frac{0.8}{\lambda^2} \leq 1.0$
	$\frac{d}{R} > 1.63 \sqrt{\frac{R}{t_p}}$	$K = 0.3 \frac{d^2}{R^2} + 2.25 \left(\frac{R^2}{d t_p} \right)^2$	
	$\frac{d}{R} \leq \sqrt{\frac{R}{t_p}}$	$K = \frac{0.6d}{\sqrt{R t_p}} + \frac{\sqrt{R t_p}}{d} - 0.3 \frac{R t_p}{d^2}$	As in load case 2.
	$\frac{d}{R} > \sqrt{\frac{R}{t_p}}$	$K = 0.3 \frac{d^2}{R^2} + 0.291 \left(\frac{R^2}{d t_p} \right)^2$	
	$\frac{d}{R} \leq 8.7 \sqrt{\frac{R}{t_p}}$	$K = \sqrt{3} \sqrt{28.3 + \frac{0.67 d^3}{R^{1.5} t_p^{1.5}}}$	$C_\tau = 1$ for $\lambda \leq 0.4$ $C_\tau = 1.274 - 0.686\lambda$ for $0.4 < \lambda \leq 1.2$ $C_\tau = \frac{0.65}{\lambda^2}$ for $\lambda > 1.2$
	$\frac{d}{R} > 8.7 \sqrt{\frac{R}{t_p}}$	$K = \sqrt{3} \frac{0.28 d^2}{R \sqrt{R t_p}}$	
Explanations for boundary conditions:			
----- Plate edge free.			
———— Plate edge simply supported.			
———— Plate edge clamped.			

S35 (cont)

2.2.7 Applied normal and shear stresses to plate panels

The normal stress, σ_x and σ_y , in N/mm², to be applied for the overall stiffened panel capacity and the plate panel capacity calculations as given in [2.1.1] and [2.2.1] respectively, are to be taken as follows:

- For FE analysis, the reference stresses as defined in Sec.4 [2.4].
- For prescriptive assessment of the overall stiffened panel capacity and the plate panel capacity, the axial or transverse compressive stresses calculated according to the Relevant UR-S, at load calculation points of the considered stiffener or the considered elementary plate panel, as defined in item a) and item b) of Sec 3, [1.2.1] respectively. However, in case of transverse stiffening arrangement, the transverse compressive stress used for the assessment of the overall stiffened panel capacity is to be taken as the compressive stress calculated at load calculation points of the stiffener attached plating, as defined in item a) of Sec 3, [1.2.1].
- For grillage analysis where the stresses are obtained based on beam theory, the stresses taken as:

$$\sigma_x = \frac{\sigma_{xb} + \nu\sigma_{yb}}{1 - \nu^2}$$

$$\sigma_y = \frac{\sigma_{yb} + \nu\sigma_{xb}}{1 - \nu^2}$$

Where

σ_{xb}, σ_{yb} Stress, in N/mm², from grillage beam analysis respectively along x or y axis of the plate attached to the PSM web.

The shear stress τ , in N/mm², to be applied for the overall stiffened panel capacity and the plate panel capacity calculations as given in [2.1.1] and [2.2.1] respectively, are to be taken as follows:

- For FE analysis, the reference shear stresses as defined in Sec 4, [2.4].
- For prescriptive assessment of the plate panel capacity, the shear stresses calculated according to the Relevant UR-S, at load calculation points of the considered elementary plate panel, as defined in item a) of Sec 3, [1.2.1].
- For prescriptive assessment of the overall stiffened panel capacity, the shear stresses calculated according to the Relevant UR-S, at the following load calculation point:
 - At the middle of the full span, l , of the considered stiffener.
 - At the intersection point between the stiffener and its attached plating.
- For grillage beam analysis, $\tau = 0$ in the plate attached to the PSM web.

2.3 Stiffeners

2.3.1 Buckling modes

The following buckling modes are to be checked:

- Stiffener induced failure (S/I).
- Associated plate induced failure (P/I).

S35

(cont)

2.3.2 Web thickness of flat bar

For accounting the decrease of the stiffness due to local lateral deformation, the effective web thickness of flat bar stiffener, in mm, is to be used in [2.1] and [2.3.4] 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:

$$t_{w_red} = t_w \left(1 - \frac{2\pi^2}{3} \left(\frac{h_w}{s} \right)^2 \left(1 - \frac{b_{eff1}}{s} \right) \right)$$

2.3.3 Idealisation of bulb profile

Bulb profiles are to 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.

$$h_w = h'_w - \frac{h'_w}{9.2} + 2$$

$$b_f = \alpha \left(t'_w + \frac{h'_w}{6.7} - 2 \right)$$

$$t_f = \frac{h'_w}{9.2} - 2$$

$$t_w = t'_w$$

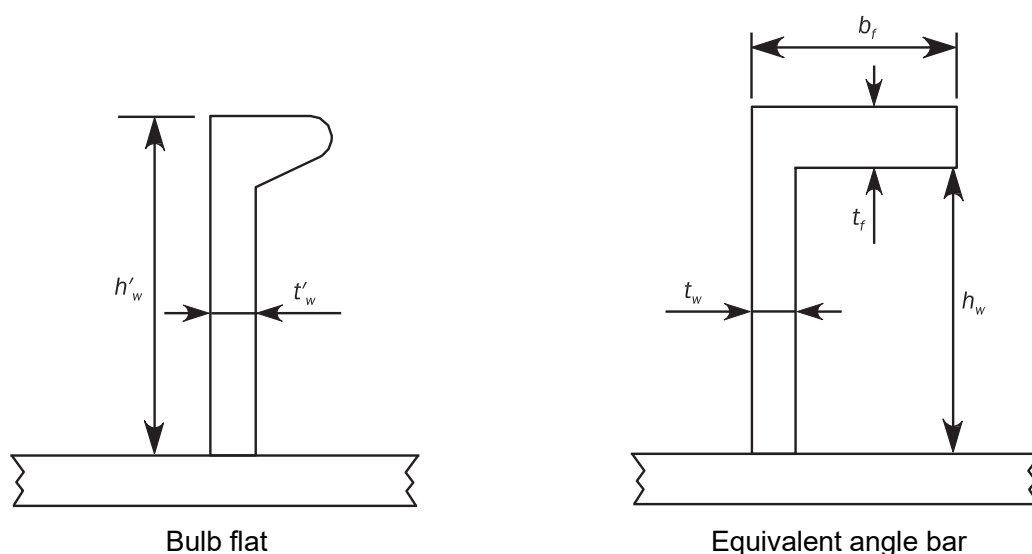
where:

h'_w, t'_w Net height and thickness of a bulb section, in mm, as shown in Figure 2.

α Coefficient equal to $\alpha = 1.1 + \frac{(120-h'_w)^2}{3000}$ for $h'_w \leq 120$

$\alpha = 1.0$ for $h'_w > 120$

Figure 2: Idealisation of bulb stiffener



S35

(cont)

2.3.4 Ultimate buckling capacity

When $\sigma_a + \sigma_b + \sigma_w > 0$ while initially setting $\gamma = 1$, the ultimate buckling capacity for stiffeners is to be checked according to the following interaction formula:

$$\frac{\gamma_c \sigma_a + \sigma_b + \sigma_w}{R_{eH}} S = 1$$

with the corresponding buckling utilization factor defined as

$$\eta_{stiffener} = \frac{1}{\gamma_c}$$

where:

σ_a Effective axial stress, in N/mm², at mid span of the stiffener, acting on the stiffener with its attached plating.

$$\sigma_a = \sigma_x \frac{st_p + A_s}{b_{eff1}t_p + A_s}$$

σ_x Nominal axial stress, in N/mm², acting on the stiffener with its attached plating.

- For FE analysis, σ_x is the FE corrected stress as defined in [2.3.6] in the attached plating in the direction of the stiffener axis.
- For prescriptive assessment, σ_x is the axial stress calculated according to Sec 3, [2.2.1] at load calculation point of the stiffener, as defined in Sec 3, [1.2.1].
- For grillage beam analysis, σ_x is the stress acting along the x -axis of the attached buckling panel.

R_{eH} Specified minimum yield stress of the material, in N/mm²

- $R_{eH} = R_{eH_S}$ for stiffener induced failure (SI).
- $R_{eH} = R_{eH_P}$ for plate induced failure (PI).

σ_b Bending stress in the stiffener, in N/mm²:

$$\sigma_b = \frac{M_0 + M_1 + M_2}{1000Z}$$

Z Net section modulus of stiffener, in cm³, including effective width of plating according to [2.3.5], to be taken as:

- 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).

M_2 Bending moment, in Nmm, due to eccentricity of sniped stiffeners, to be taken as

- $M_2 = 0$ for continuous stiffeners
- $M_2 = C_{snip} w_{na} \gamma \sigma_x (A_p + A_s)$ for stiffeners sniped at one or both ends.

C_{snip} Coefficient to account for the end effect of the stiffener sniped at one or both ends, to be taken as

- $C_{snip} = -1.2$ for stiffener induced failure (SI)
- $C_{snip} = 1.2$ for plate induced failure (PI).

S35 (cont)

- M_1 Bending moment, in Nmm, due to the lateral load P :
- $M_1 = C_i \frac{|P|sl^2}{24 \times 10^3}$ for continuous stiffener
 - $M_1 = C_i \frac{|P|sl^2}{8 \times 10^3}$ for sniped stiffener
 - $M_1 = C_i \frac{|P|sl^2}{14.2 \times 10^3}$ for stiffener sniped at one end and continuous at the other end
- P Lateral load, in kN/m².
- For FE analysis, P is the average pressure as defined in Sec 4, [2.5.2] in the attached plating.
 - For prescriptive assessment, P is the pressure calculated at load calculation point of the stiffener, as defined in Sec 3, [1.2.1].
- 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 Nmm, due to the lateral deformation w of stiffener:
- $$M_0 = F_E C_{sl} \frac{\gamma}{\gamma_{GEB} - \gamma} w_0 \text{ with precondition } \gamma_{GEB} - \gamma > 0$$
- γ_{GEB} Stress multiplier factor of global elastic buckling capacity as defined in [2.1].
- F_E Ideal elastic buckling force of the stiffener, in N.
- $$F_E = \left(\frac{\pi}{l}\right)^2 EI \cdot 10^4$$
- I Moment of inertia, in cm⁴, of the stiffener including effective width of attached plating according to [2.3.5]. I is to comply with the following requirement:
- $$I \geq \frac{st_p^3}{12 \cdot 10^4}$$
- t_p Net thickness of plate, in mm, to be taken as
- For prescriptive requirements: the mean thickness of the two attached plating panels,
 - For FE analysis: the thickness of the considered EPP on one side of the stiffener.
- C_{sl} Deformation reduction factor to account for global slenderness, to be taken as:
- $C_{sl} = 1 - \frac{1}{12} \lambda_G^4$ for $\lambda_G \leq 1.56$
 - $C_{sl} = 3 / \lambda_G^4$ for $\lambda_G > 1.56$

S35

(cont)

λ_G The reference degree of global slenderness of the stiffened panel, to be taken as

$$\lambda_G = \sqrt{\frac{\gamma_{ReH}}{\gamma_{GEB}}} \text{ with } \gamma_{ReH} = \frac{\text{Min}(ReH_P, ReH_S)}{\sqrt{\sigma_{x,av}^2 + \sigma_y^2 - \sigma_{x,av}\sigma_y + 3\tau^2}}$$

$\sigma_{x,av}$ Average stress for both plate and stiffener as defined in [2.1.2].

σ_y Applied transverse stress to the plate panel as defined in [2.1.1].

τ Applied shear stress to the plate panel as defined in [2.1.1].

w_0 Assumed imperfection, in mm, to be taken as:

$$w_0 = l / 1000.$$

σ_w Stress due to torsional deformation, in N/mm², to be taken as:

- For stiffener induced failure (S/)

- For $\sigma_a > 0$

$$\sigma_w = E\gamma_w e_f \Phi_0 \left(\frac{m_{tor}\pi}{l_{tor}} \right)^2 \left(\frac{1}{1 - \frac{\gamma\sigma_a}{\sigma_{ET}}} - 1 \right) \text{ with precondition } \sigma_{ET} - \gamma\sigma_a > 0$$

- For $\sigma_a \leq 0$

$$\sigma_w = 0$$

- For plate induced failure (P/)

$$\sigma_w = 0$$

y_w Distance, in mm, from centroid of stiffener cross section to the free edge of stiffener flange, to be taken as:

- $y_w = \frac{t_w}{2}$ for flat bar

- $y_w = b_f - \frac{h_w t_w^2 + t_f b_f^2}{2A_s}$ for angle and bulb profiles

- $y_w = b_{f-out} + 0.5t_w - \frac{h_w t_w^2 + t_f (b_f^2 - 2b_f d_f)}{2A_s}$ for L2 profile

- $y_w = \frac{b_f}{2}$ for T profile.

Φ_0 Coefficient taken as:

$$\Phi_0 = \frac{l_{tor}}{m_{tor} h_w} 10^{-4}$$

σ_{ET} : Reference stress for torsional buckling, in N/mm², to be taken as:

$$\sigma_{ET} = \frac{E}{I_p} \left[\left(\frac{m_{tor}\pi}{l_{tor}} \right)^2 I_\omega \cdot 10^2 + \frac{1}{2(1+\nu)} I_T + \left(\frac{l_{tor}}{m_{tor}\pi} \right)^2 \varepsilon \cdot 10^{-4} \right]$$

I_p Net polar moment of inertia of the stiffener, in cm⁴, about point C as shown in Sec 1, Figure 3, as defined in Table 5.

I_T Net St. Venant's moment of inertia of the stiffener, in cm⁴, as defined in Table 5.

S35

(cont)

- I_ω Net sectorial moment of inertia of the stiffener, in cm^6 , about point C as shown in Sec 1, Figure 3, as defined in Table 5.
- l_{tor} Stiffener span, distance equal to spacing between primary supporting members, i.e. $l_{tor} = l$. When the stiffener is supported by tripping brackets, l_{tor} should be taken as the maximum spacing between the adjacent primary supporting members and fitted tripping brackets.
- m_{tor} Number of half waves, taken as a positive integer so as to give smallest reference stress for torsional buckling.
- ε Degree of fixation, in mm^2 , to be taken as:
- $\varepsilon = \left(\frac{3b}{t_p^3} + \frac{2h_w}{t_w^3} \right)^{-1}$ for bulb, angle, L2 and T profiles;
 - $\varepsilon = \left(\frac{t_p^3}{3b} \right)$ for flat bars.
- A_w : Net web area, in mm^2 .
- A_f : Net flange area, in mm^2 .

Table 5: Moments of inertia

	Flat bars ⁽¹⁾	Bulb, angle, L2 and T profiles
I_p	$\frac{h_w^3 t_w}{3 \cdot 10^4}$	$\left(\frac{A_w (e_f - 0.5 t_f)^2}{3} + A_f e_f^2 \right) 10^{-4}$
I_T	$\frac{h_w t_w^3}{3 \cdot 10^4} \left(1 - 0.63 \frac{t_w}{h_w} \right)$	$\frac{(e_f - 0.5 t_f) t_w^3}{3 \cdot 10^4} \left(1 - 0.63 \frac{t_w}{e_f - 0.5 t_f} \right) + \frac{b_f t_f^3}{3 \cdot 10^4} \left(1 - 0.63 \frac{t_f}{b_f} \right)$
I_ω	$\frac{h_w^3 t_w^3}{36 \cdot 10^6}$	For bulb, angle and L2 profiles⁽²⁾: $\frac{A_f^3 + A_w^3}{36 \cdot 10^6} + \frac{e_f^2}{10^6} \left(\frac{A_f b_f^2 + A_w t_w^2}{3} - \frac{(A_f (b_f - 2d_f) + A_w t_w)^2}{4(A_f + A_w)} - A_f d_f (b_f - d_f) \right)$ For T profile: $\frac{b_f^3 t_f e_f^2}{12 \cdot 10^6}$
(1) t_w is the net web thickness, in mm. t_{w_red} as defined in [2.3.2] is not to be used in this table. (2) d_f is to be taken as 0 for bulb and angle profiles.		

S35

(cont)

2.3.5 Effective width of attached plating

The effective width of attached plating of stiffeners, b_{eff} , in mm, is to be taken as:

- For $\sigma_x > 0$:
 - For FE analysis,

$$b_{eff} = \text{Min}(C_x b, \chi_s s)$$
 - For prescriptive assessment,

$$b_{eff} = \text{Min}\left(\frac{C_{x1}b_1 + C_{x2}b_2}{2}, \chi_s s\right)$$
- For $\sigma_x \leq 0$:

$$b_{eff} = \chi_s s$$

where:

χ_s : Effective width coefficient to be taken as:

$$\chi_s = \frac{1.12}{1 + \frac{1.75}{\left(\frac{\ell_{eff}}{s}\right)^{1.6}}} \leq 1.0 \quad \text{for} \quad \frac{\ell_{eff}}{s} \geq 1$$

$$\chi_s = 0.407 \frac{\ell_{eff}}{s} \quad \text{for} \quad \frac{\ell_{eff}}{s} < 1$$

ℓ_{eff} : Effective length of the stiffener, in mm, taken as:

$$\ell_{eff} = \frac{l}{\sqrt{3}} \quad \text{for stiffener fixed at both ends.}$$

$$\ell_{eff} = 0.75l \quad \text{for stiffener simply supported at one end and fixed at the other.}$$

$$\ell_{eff} = l \quad \text{for stiffener simply supported at both ends.}$$

2.3.6 FE corrected stresses for stiffener capacity

When the reference stresses σ_x and σ_y obtained by FE analysis according to Sec 4, [2.4] are both compressive, σ_x is to be corrected according to the following formulae:

- If $\sigma_x < \nu \sigma_y$

$$\sigma_{xcor} = 0$$
- If $\sigma_x \geq \nu \sigma_y$

$$\sigma_{xcor} = \sigma_x - \nu \sigma_y$$

S35

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2.4 Primary Supporting Members

2.4.1 Web plate in way of openings

The web plate of primary supporting members with openings is to be assessed for buckling based on the combined axial compressive and shear stresses.

The web plate adjacent to the opening on both sides is to be considered as individual unstiffened plate panels as shown in Table 6.

The interaction formulae of [2.2.1] are to be used with:

$$\sigma_x = \sigma_{av}$$

$$\sigma_y = 0$$

$$\tau = \tau_{av}$$

where:

σ_{av} Weighted average compressive stress, in N/mm^2 , in the area of web plate being considered, i.e. $P1$, $P2$, or $P3$ as shown in Table 6.

For the application of Table 6, the weighted average shear stress is to be taken as:

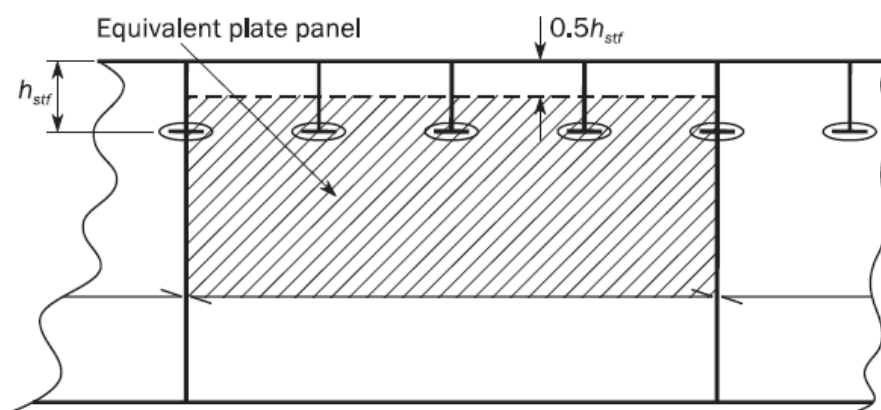
- Opening modelled in primary supporting members:
 τ_{av} Weighted average shear stress, in N/mm^2 , in the area of web plate being considered, i.e. $P1$, $P2$, or $P3$ as shown in Table 6.
- Opening not modelled in primary supporting members:
 τ_{av} Weighted average shear stress, in N/mm^2 , given in Table 6.

2.4.2 Reduction factors of web plate in way of openings

The reduction factors, C_x or C_y in combination with, C_τ of the plate panel(s) of the web adjacent to the opening is to be taken as shown in Table 6.

2.4.3 The equivalent plate panel of web plate of primary supporting members crossed by perpendicular stiffeners is to be idealised as shown in Figure 3.

Figure 3: Web plate idealization

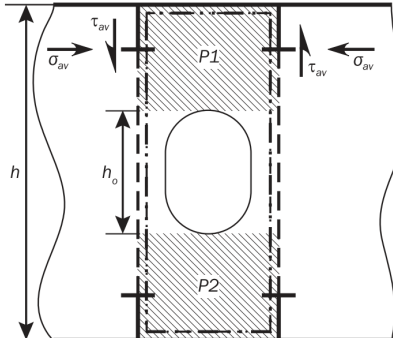
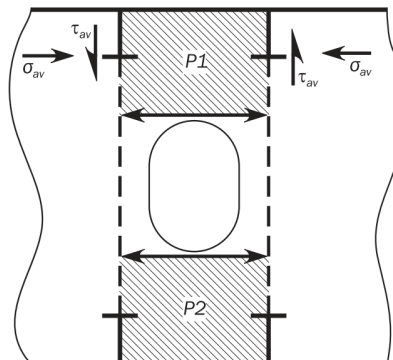
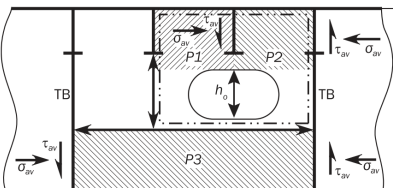


S35

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The correction of panel breadth is applicable also for other slot configurations provided that the web or collar plate is attached to at least one side of the passing stiffener.

Table 6: Reduction factors

Configuration ⁽¹⁾	C_x, C_y	C_τ	
		Opening modelled in PSM	Opening not modelled in PSM
(a) Without edge reinforcements:⁽²⁾ 	Separate reduction factors are to be applied to areas <i>P1</i> and <i>P2</i> using case 3 or case 6 in Table 3, with edge stress ratio: $\psi = 1.0$	Separate reduction factors are to be applied to areas <i>P1</i> and <i>P2</i> using case 18 or case 19 in Table 3.	When case 17 of Table 3 is applicable: A common reduction factor is to be applied to areas <i>P1</i> and <i>P2</i> using case 17 in Table 3 with: $\tau_{av} = \tau_{av} (web)$ When case 17 of Table 3 is not applicable: Separate reduction factors are to be applied to areas <i>P1</i> and <i>P2</i> using case 18 or case 19 in Table 3 with: $\tau_{av} = \tau_{av} (web) h / (h - h_o)$
(b) With edge reinforcements: 	Separate reduction factors are to be applied for areas <i>P1</i> and <i>P2</i> using C_x for case 1 or C_y for case 2 in Table 3 with stress ratio: $\psi = 1.0$	Separate reduction factors are to be applied for areas <i>P1</i> and <i>P2</i> using case 15 in Table 3.	Separate reduction factors are to be applied to areas <i>P1</i> and <i>P2</i> using case 15 in Table 3 with: $\tau_{av} = \tau_{av} (web) h / (h - h_o)$
(c) Example of hole in web: 	Panels <i>P1</i> and <i>P2</i> are to be evaluated in accordance with (a). Panel <i>P3</i> is to be evaluated in accordance with (b).		
Where: <i>h</i> Height, in m, of the web of the primary supporting member in way of the opening.			

S35

(cont)

h_o	Height in m, of the opening measured in the depth of the web.
$\tau_{av} (web)$	Weighted average shear stress, in N/mm ² , over the web height h of the primary supporting member.
Note (1)	Web panels to be considered for buckling in way of openings are shown shaded and numbered P1, P2, etc.
Note (2)	For a PSM web panel with opening and without edge reinforcements as shown in configuration (a), the applicable buckling assessment method depends on its specific boundary conditions. If one of the long edges along the face plate or along the attached plating is not subject to "inline support", i.e. the edge is free to pull in, Method B should be applied. In other cases, typically such as when the short plate edge is attached to the plate flanges, Method A is applicable.

2.5 Stiffened Panels with U-type Stiffeners

2.5.1 Local plate buckling

For stiffened panels with U-type stiffeners, local plate buckling is to be checked for each of the plate panels EPP b_1, b_2, b_f and h_w (see Sec 1, Figure 4) separately as follows:

- The attached plate panels EPP b_1 and b_2 are to be assessed using SP-A model, where in the calculation of buckling factors K_x as defined in Case 1 of Table 3, the correction factor F_{long} for U-type stiffeners as defined in Table 2 is to be used; and in the calculation of K_y as defined in Case 2 of Table 3, the F_{tran} for U-type stiffeners as defined in [2.2.5] is to be used.
- The face plate and web plate panels b_f and h_w are to be assessed using UP-B model with $F_{long} = 1$ and $F_{tran} = 1$.

2.5.2 Overall stiffened panel buckling and stiffener buckling

For a stiffened panel with U-type stiffeners, the overall buckling capacity and ultimate capacity of the stiffeners are to be checked with warping stress $\sigma_w = 0$, and with bending moment of inertia including effective width of attached plating being calculated based on the following assumptions:

- The two web panels of a U-type stiffener are to be taken as perpendicular to the attached plate with thickness equal to t_w and height equal to the distance between the attached plate and the face plate of the stiffener.
- Effective width of the attached plating, b_{eff} , taken as the sum of the b_{eff} calculated for the EPP b_1 and b_2 respectively according to SP-A model.
- Effective width of the attached plating of a stiffener without shear lag effect, b_{eff1} , taken as the sum of the b_{eff1} calculated for the EPP b_1 and b_2 respectively.

S35

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3. Buckling capacity of column structures

3.1 Column Buckling of Corrugations

3.1.1 Buckling utilisation factor

The column buckling utilisation factor, η , for axially compressed corrugations is to be taken as:

$$\eta_{column} = \frac{\sigma_{av}}{\sigma_{cr}}$$

where:

σ_{av} Average axial compressive stress in the member, in N/mm².

σ_{cr} Minimum critical buckling stress, in N/mm², taken as:

- $\sigma_{cr} = \sigma_E$ for $\sigma_E \leq 0.5R_{eH_S}$
- $\sigma_{cr} = \left(1 - \frac{R_{eH_S}}{4\sigma_E}\right) R_{eH_S}$ for $\sigma_E > 0.5R_{eH_S}$

σ_E Elastic column compressive buckling stress, in N/mm², according to [3.1.2].

R_{eH_S} Specified minimum yield stress of the considered member, in N/mm². For built-up members, the lowest specified minimum yield stress is to be used.

3.1.2 Elastic column buckling stress

The elastic compressive column buckling stress, σ_E in N/mm² of members subject to axial compression is to be taken as:

$$\sigma_E = \pi^2 E f_{end} \frac{I}{A l_{pill}^2} 10^{-4}$$

where:

I Net moment of inertia about the weakest axis of the cross section, in cm⁴.

A Net cross-sectional area of the member, in cm².

l_{pill} Unsupported length of the member, in m.

f_{end} End constraint factor, corresponding to simply supported ends is to be applied except for fixed end support to be used in way of stool with width exceeding 2 times the depth of the corrugation, taken as:

- $f_{end} = 1.0$ where both ends are simply supported.
- $f_{end} = 2.0$ where one end is simply supported and the other end is fixed.
- $f_{end} = 4.0$ where both ends are fixed.

S35

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APPENDIX 1 STRESS BASED REFERENCE STRESSES

Symbols

- a Length, in mm, of the longer side of the plate panel as defined in Sec 5.
- b Length, in mm, of the shorter side of the plate panel as defined in Sec 5.
- A_i Area, in mm², of the i -th plate element of the buckling panel.
- n Number of plate elements in the buckling panel.
- σ_{xi} Actual stress, in N/mm², at the centroid of the i -th plate element in x direction, applied along the shorter edge of the buckling panel.
- σ_{yi} Actual stress, in N/mm², at the centroid of the i -th plate element in y direction, applied along the longer edge of the buckling panel.
- ψ Edge stress ratio as defined in Sec 5.
- τ_i Actual membrane shear stress, in N/mm², at the centroid of the i -th plate element of the buckling panel.

1. Stress Based Method

1.1 Introduction

1.1.1 This section provides a method to determine stress distribution along edges of the considered buckling panel by second-order polynomial curve, by linear distribution using least square method and by weighted average approach. This method is called Stress based Method. The reference stress is the stress components at centre of plate element transferred into the local system of the considered buckling panel.

1.1.2 Definition: A regular panel is a plate panel of rectangular shape. An irregular panel is plate panel which is not regular, as detailed in Sec 4, [2.3.1].

1.2 Stress Application

1.2.1 Regular panel

The reference stresses are to be taken as defined in [2.1] for a regular panel when the following conditions are satisfied:

- At least, one plate element centre is located in each third part of the long edge a of a regular panel and
- This element centre is located at a distance in the panel local x direction not less than $a/4$ to at least one of the element centres in the adjacent third part of the panel.

Otherwise, the reference stresses are to be taken as defined in [2.2] for an irregular panel.

1.2.2 Irregular panel and curved panel

The reference stresses of an irregular panel or of a curved panel are to be taken as defined in [2.2].

S35

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2. Reference Stresses

2.1 Regular Panel

2.1.1 Longitudinal stress

The longitudinal stress σ_x applied on the shorter edge of the buckling panel is to be calculated as follows:

- For plate buckling assessment, the distribution of $\sigma_x(x)$ is assumed as second order polynomial curve as:

$$\sigma_x = Cx^2 + Dx + E$$

The best fitting curve $\sigma_x(x)$ is to be obtained by minimising the square error Π considering the area of each element as a weighting factor.

$$\Pi = \sum_{i=1}^n A_i [\sigma_{xi} - (Cx_i^2 + Dx_i + E)]^2$$

The unknown coefficients C , D and E must yield zero first derivatives, $\partial\Pi$ with respect to C , D and E , respectively.

$$\begin{cases} \frac{\partial\Pi}{\partial C} = 2 \sum_{i=1}^n A_i x_i^2 [\sigma_{xi} - (Cx_i^2 + Dx_i + E)] = 0 \\ \frac{\partial\Pi}{\partial D} = 2 \sum_{i=1}^n A_i x_i [\sigma_{xi} - (Cx_i^2 + Dx_i + E)] = 0 \\ \frac{\partial\Pi}{\partial E} = 2 \sum_{i=1}^n A_i [\sigma_{xi} - (Cx_i^2 + Dx_i + E)] = 0 \end{cases}$$

The unknown coefficients C , D and E can be obtained by solving the 3 above equations.

$$\sigma_{x1} = \frac{1}{b} \int_0^b \sigma_x(x) dx = \frac{b^2}{3} C + \frac{b}{2} D + E$$

$$\sigma_{x2} = \frac{1}{b} \int_{a-b}^a \sigma_x(x) dx = \left(a^2 - ab + \frac{b^2}{3}\right) C + \left(a - \frac{b}{2}\right) D + E$$

If $-\frac{D}{2C} < \frac{b}{2}$ or $-\frac{D}{2C} > a - \frac{b}{2}$, σ_{x3} is to be ignored. Otherwise, σ_{x3} is taken as:

$$\sigma_{x3} = \frac{1}{b} \int_{x_{min}}^{x_{max}} \sigma_x(x) dx = \frac{b^2}{12} C - \frac{D^2}{4C} + E$$

where:

$$x_{min} = -\frac{b}{2} - \frac{D}{2C}$$

$$x_{max} = \frac{b}{2} - \frac{D}{2C}$$

$$\sigma_x = \text{Max}(\sigma_{x1}, \sigma_{x2}, \sigma_{x3})$$
$$\psi_x = 1$$

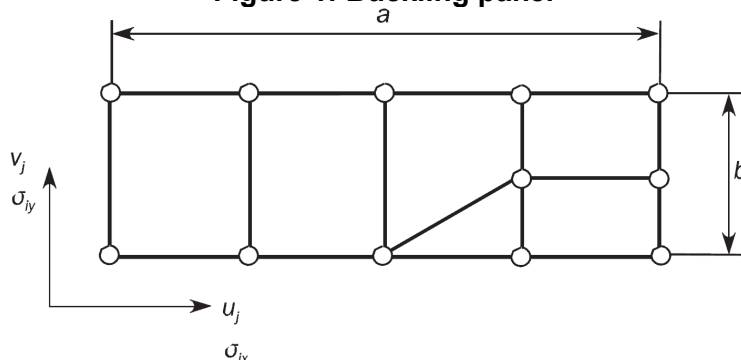
- For overall stiffened panel buckling and stiffener buckling assessments, the longitudinal stress σ_x applied on the shorter edge of the attached plate is to be taken as:

$$\sigma_x = \frac{\sum_{i=1}^n A_i \sigma_{xi}}{\sum_{i=1}^n A_i}$$

2.1.2 Transverse stress

The transverse stress σ_y applied along the longer edges of the buckling panel is to be calculated by extrapolation of the transverse stresses of all elements up to the shorter edges of the considered buckling panel.

Figure 1: Buckling panel



The distribution of $\sigma_v(x)$ is assumed as straight line. Therefore: $\sigma_v(x) = A + Bx$

The best fitting curve $\sigma_y(x)$ is to be obtained by the least square method minimising the square error Π considering area of each element as a weighting factor.

$$P = \sum_{i=1}^n A_i [\sigma_{yi} - (A + Bx_i)]^2$$

The unknown coefficients C and D must yield zero first partial derivatives, $\partial \Pi$ with respect to C and D , respectively.

$$\frac{\partial \Pi}{\partial A} = 2 \sum_{i=1}^n A_i [\sigma_{yi} - (A + Bx_i)] = 0$$

$$\frac{\partial \Pi}{\partial B} = 2 \sum_{i=1}^n A_i x_i [\sigma_{yi} - (A + Bx_i)] = 0$$

The unknown coefficients A and B are obtained by solving the 2 above equations and are given as follow:

$$A = \frac{(\sum_{i=1}^n A_i \sigma_{yi})(\sum_{i=1}^n A_i x_i^2) - (\sum_{i=1}^n A_i x_i)(\sum_{i=1}^n A_i x_i \sigma_{yi})}{(\sum_{i=1}^n A_i)(\sum_{i=1}^n A_i x_i^2) - (\sum_{i=1}^n A_i x_i)^2}$$

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$$B = \frac{(\sum_{i=1}^n A_i)(\sum_{i=1}^n A_i x_i \sigma_{yi}) - (\sum_{i=1}^n A_i x_i)(\sum_{i=1}^n A_i \sigma_{yi})}{(\sum_{i=1}^n A_i)(\sum_{i=1}^n A_i x_i^2) - (\sum_{i=1}^n A_i x_i)^2}$$

The transverse stress is to be taken as:

$$\sigma_y = \max(A, A + Ba)$$

The edge stress ratio is to be taken as:

$$\psi_y = \frac{\min(A, A + Ba)}{\max(A, A + Ba)} \text{ for } \sigma_y > 0$$

$$\psi_y = 1 \text{ for } \sigma_y \leq 0.$$

2.1.3 Shear stress

The shear stress τ is to be calculated using a weighted average approach, and is to be taken as:

$$\tau = \frac{\sum_{i=1}^n A_i \tau_i}{\sum_{i=1}^n A_i}$$

2.2 Irregular Panel and Curved Panel

2.2.1 Reference stresses

The longitudinal, transverse and shear stresses are to be calculated using a weighted average approach. They are to be taken as:

$$\sigma_x = \frac{\sum_{i=1}^n A_i \sigma_{xi}}{\sum_{i=1}^n A_i}$$

$$\sigma_y = \frac{\sum_{i=1}^n A_i \sigma_{yi}}{\sum_{i=1}^n A_i}$$

$$\tau = \frac{\sum_{i=1}^n A_i \tau_i}{\sum_{i=1}^n A_i}$$

The edge stress ratios are to be taken as

$$\psi_x = 1$$

$$\psi_y = 1$$

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