DNV·GL

RULES FOR CLASSIFICATION

Ships

Edition July 2016

Part 3 Hull

Chapter 3 Structural design principles

DNV GL AS

FOREWORD

DNV GL rules for classification contain procedural and technical requirements related to obtaining and retaining a class certificate. The rules represent all requirements adopted by the Society as basis for classification.

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

CHANGES – CURRENT

This document supersedes the October 2015 edition.

Changes in this document are highlighted in red colour. However, if the changes involve a whole chapter, section or sub-section, normally only the title will be in red colour.

Main changes July 2016, entering into force as from date of publication

• Sec.1 Materials

— Sec.1 [2.6.2]: Misprint related to material factor for stainless steel is corrected.
— Sec.1 [3.3.3]: The requirements to steering gear is covered by Pt.4 and are removed.

• Sec.3 Corrosion additions

— Sec.3 [1.2.5]: The minimum corrosion addition is removed.
— Sec.3 Table 1: Modified footnotes 1 and 3, and removed compartment type "spaces containing membrane tanks or independent cargo tanks".

• Sec.5 Structural arrangement

— Sec.5 [2.2.3]: The limit for requiring continuous longitudinal stiffeners is changed from 50 m to 65 m.
— Sec.5 [2.3]: The application of this requirement is clarified.

• Sec.6 Detail design

— Sec.6 [3.4.4]: The requirement is corrected.
— Sec.6 [5.1.1]: The minimum permissible corrugation angle is changed from 55° to 45° with 10% increase of requirement for angles less than 55°.
— Sec.6 [6.1.3]: The requirement is modified in line with amendments done to IACS CSR.
— Sec.6 [6.3.5]: Clarification.

• Sec.7 Structural idealisation

— Sec.7 [1.1.3]: The effective bending span of stiffeners with continuous flange along bracket edge is clarified.
— Sec.7 [1.4.3]: Correction of effective shear height for stiffeners with web angle more than 75° is removed.
— Sec.7 [1.4.4]: Correction of elastic section net modulus of stiffeners with web angle more than 75° is removed.

Editorial corrections

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

CONTENTS

SECTION 1 MATERIALS

Symbols

For symbols not defined in this section, refer to Ch.1 Sec.4.

1 General

1.1 Introduction

1.1.1 In this section requirements regarding the application of various structural materials are given.

1.1.2 The requirements for manufacture, condition of supply, heat-treatment, testing, inspection, tolerances, chemical composition, mechanical properties, repair, identification, certification etc. shall in general comply with the requirements given in Pt.2.

1.2 Certification requirements

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

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

2 Rolled steels for structural application

2.1 General

2.1.1 Where the subsequent rules for material grade are dependent on plate thickness, the requirements are based on the thickness as built. For vessels with L < 90 m, where the applied plate thickness is greater than that required by the rules, a lower material grade may be applied, after special consideration.

2.1.2 Young’s modulus and Poisson’s ratio

The Young’s modulus for carbon manganese steel materials and the Poisson’s ratio to be used in the strength assessment are:

E = 206 000 N/mm^2

ν = 0.3

2.1.3 Steel material grades and mechanical properties

Full details for requirements for materials are given in Pt.2.

Steel having a specified minimum yield stress of 235 N/mm^2 is regarded as normal strength hull structural steel. Steel having a specified minimum yield stress (R_{eH}) in the range 235 < R_{eH} ≤ 390 N/mm^2 is regarded as high strength hull structural steel. Steel having R_{eH} > 390 N/mm^2 is regarded as extra high strength structural steel. In the following, material grades of hull structural steels are referred to as follows:

a) A, B, D, E and F denote normal strength steel grades.
b) AH, DH, EH and FH denote high strength and extra high strength steel grades, where ‘H’ indicates the material strength.

Normal strength is denoted ‘NS’ and high strength steel and extra high steel are denoted ‘HT’.

Table 1 gives specified yield stress and tensile strength for rolled steels generally used in construction of ships.

Table 1 Mechanical properties of hull steels

Steel grades for plates with $t_{as\_built} \le 150$ mm	*Specified minimum yield stress R_{eH}, in N/mm^2*	*Specified tensile strength R_m, in N/mm^2*
A-B-D-E	235	400 – 520
A32-D32-E32-F32	315	440 – 570
A36-D36-E36-F36	355	490 – 630
A40-D40-E40-F40	390	510 – 660
A47-D47-E47-F47	460	570 – 720

2.1.4 Extra high strength steel

The application of extra high strength steel with R_{eH} of 460 N/mm^2 is limited to ships with the notation **Container ship** as defined in Pt.5 Ch.2. For other ship types, the application of this steel is considered on a case-by-case basis.

The application of extra high strength steel with R_{eH} greater than 460 N/mm^2, will be considered on a case-by-case basis.

2.1.5 Onboard documents

It is required to keep onboard a plan indicating the steel types and grades adopted for the hull structures. Where steels other than those indicated in Table 1 are used, their mechanical and chemical properties, as well as any workmanship requirements or recommendations, shall be available onboard together with the above plan.

2.2 Material factor, *k*

Unless otherwise specified, the material factor, k, of normal and higher strength steel for hull girder strength and scantling purposes shall be taken as defined in Table 2.

For intermediate values of R_{eH}, k is obtained by linear interpolation.

Table 2 Material factor, *k*

Specified minimum yield stress R_{eH}, in N/mm^2	*k*
235	1.00
315	0.78
355	0.72
390	0.66
460	0.62

2.3 Steel grades

2.3.1 Materials in the various strength members shall not be of lower grade than those corresponding to the material classes and grades specified in Table 3 to Table 10.

General requirements are given in Table 3, while additional minimum requirements are given in the following:

— Table 4: for ships, excluding liquefied gas carriers covered in Table 5, with length exceeding 150 m and single strength deck.
— Table 5: for membrane type liquefied gas carriers with length exceeding 150 m.
— Table 6: for ships with length exceeding 250 m.
— Table 7: for single-side ships, single deck, no longitudinal bulkheads and with length exceeding 150 m.
— Table 8: for ships with ice strengthening.

The material grade requirements for hull members of each class depending on the thickness are defined in Table 9.

Table 3 Minimum material classes and grades

Structural member category		*Material class/grade*
Secondary	A1. Longitudinal bulkhead strakes, other than those belonging to the Primary category A2. Deck plating exposed to weather, other than that belonging to the Primary or Special category A3. Side plating	- Class I within 0.4 *L* amidships - Grade A/AH outside 0.4 *L* amidships
Primary	B1. Bottom plating, including keel plate B2. Strength deck plating, excluding that belonging to the Special category B3. Continuous longitudinal plating of strength members above strength deck, excluding hatch coamings B4. Uppermost strake in longitudinal bulkhead B5. Vertical strake (hatch side girder) and uppermost sloped strake in top wing tank	- Class II within 0.4 *L* amidships - Grade A/AH outside 0.4 *L* amidships
Special	C1. Sheer strake at strength deck [1] C2. Stringer plate in strength deck [1] C3. Deck strake at longitudinal bulkhead, excluding deck plating in way of inner-skin bulkhead of double-hull ships [1]	- Class III within 0.4 *L* amidships - Class II outside 0.4 *L* amidships - Class I outside 0.6 *L* amidships
	C4. Strength deck plating at outboard corners of cargo hatch openings in container ships and other ships with similar hatch opening configuration	- Class III within 0.4 *L* amidships - Class II outside 0.4 *L* amidships - Class I outside 0.6 *L* amidships - Minimum Class III within cargo region
	C5. Strength deck plating at corners of cargo hatch openings in bulk carriers, ore carriers, combination carriers and other ships with similar hatch opening configurations C5.1 Trunk deck and inner deck plating at corners of openings for liquid and gas domes in membrane type liquefied gas carriers.	- Class III within 0.6 *L* amidships - Class II within rest of cargo region
	C6. Bilge strake of ships with double bottom over the full breadth and with length less than 150 m	- Class II within 0.6 *L* amidships - Class I outside 0.6 *L* amidships
	C7. Bilge strake in other ships [1]	- Class III within 0.4 *L* amidships - Class II outside 0.4 *L* amidships - Class I outside 0.6 *L* amidships
	C8. Longitudinal hatch coamings of length greater than 0.15 *L* including coaming top plate and flange C9. End brackets and deckhouse transition of longitudinal cargo hatch coamings	- Class III within 0.4 *L* amidships - Class II outside 0.4 *L* amidships - Class I outside 0.6 *L* amidships - Not to be less than Grade D/DH

1) Single strakes required to be of class III within 0.4 *L* amidships shall have breadths not less than 800 + 5 *L*, in mm, need not be greater than 1800 mm, unless limited by the geometry of the ship's design.

Table 4 Minimum material grades for ships, excluding liquefied gas carriers covered in Table 5, 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 strength members above strength deck	Grade B/AH within 0.4 *L* 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 5 Minimum material grades for membrane type liquefied gas carriers with length exceeding 150 m*)

<table>
<tr><th colspan="2">Structural member category</th><th>Material grade</th></tr>
<tr><td colspan="2">Longitudinal plating of strength deck where contributing to the longitudinal strength</td><td>Grade B/AH within 0.4 L amidships</td></tr>
<tr><td rowspan="2">Continuous longitudinal plating of strength members above the strength deck</td><td>Trunk deck plating</td><td>Class II within 0.4 L midship</td></tr>
<tr><td>— Inner deck plating
— Longitudinal strength member plating between the trunk deck and inner deck</td><td>Grade B/AH within 0.4 L amidships</td></tr>
<tr><td colspan="3">*) Table 3 is applicable to membrane type liquefied gas carriers with deck arrangements as shown in Figure 1. This table may apply to similar ship types with a “double deck” arrangement above the strength deck.</td></tr>
</table>

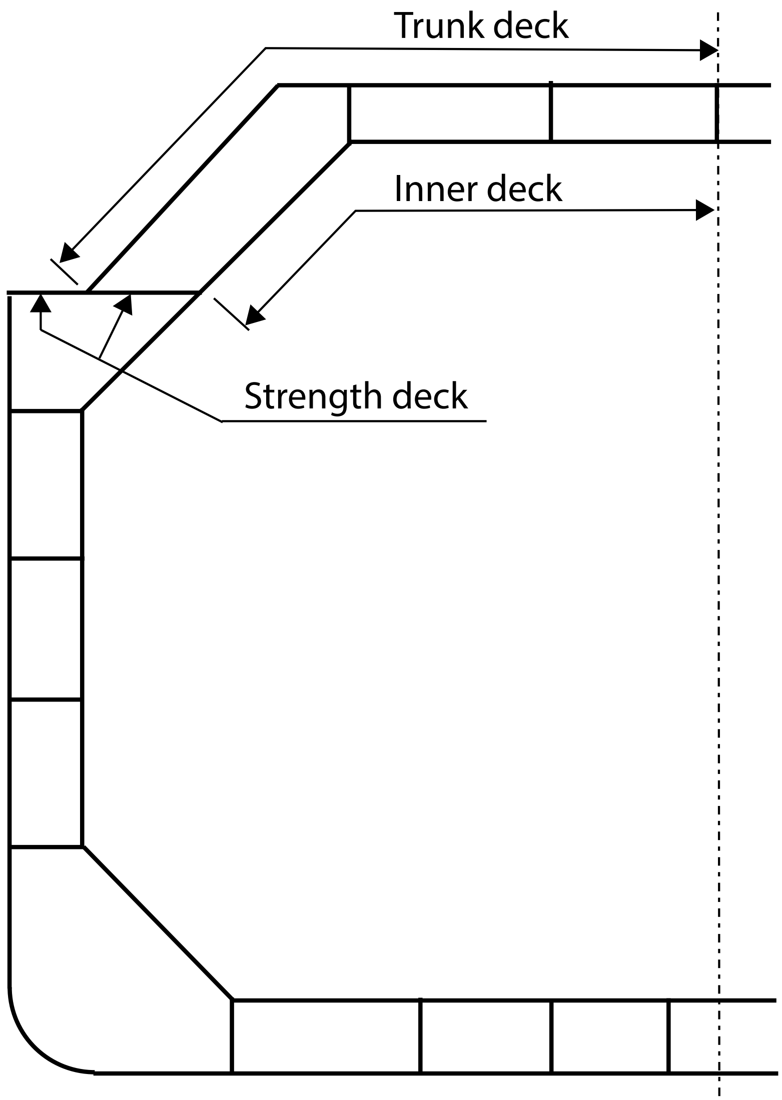

Figure 1 Typical deck arrangement for membrane tank Liquefied Natural Gas Carrier

Table 6 Minimum material grades for ships with length exceeding 250 m

Structural member category *(1)*	*Material grade*
Sheer strake at strength deck	Grade E/EH within 0.4 *L* amidships
Stringer plate in strength deck	Grade E/EH within 0.4 *L* amidships
Bilge strake	Grade D/DH within 0.4 *L* amidships
1) Single strakes required to be of Grade E/EH and within 0.4 *L* amidships shall have breadths, in mm, not less than 800 + 5 *L*, need not be greater than 1800 mm, unless limited by the geometry of the ship's design.	

Table 7 Minimum material grades for ships with single-side skin, single deck, no longitudinal bulkheads and with length exceeding 150 m

Structural member category	*Material grade*
Lower bracket of side frame (1)	Grade D/DH
Side shell strakes included totally or partially between the two points located 0.125ℓ above and below the lower end of side frame (2)	Grade D/DH

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

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

Table 8 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

Table 9 Material grade requirements for classes I, II and III

Class	*I*		*II*		*III*	
As-built thickness, in mm	*NS*	*HT*	*NS*	*HT*	*NS*	*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
$50 < t \leq 150$	D	DH	E	EH	E	EH

2.3.2 Materials in strength members not mentioned in Table 3 to Table 9, shall not be of lower grades than listed in Table 10.

Table 10 Minimum material grade requirements

As-built thickness, in mm	*Minimum*	
	NS	*HT*
t ≤ 40	A	AH
40 < t ≤ 50	B[1)]	AH
50 < t ≤ 150	D[1)]	DH[1)]

1) For heavy foundation plates in engine room:
- Outside 0.6L amidship, grade A/AH is acceptable.
- Within 0.6L amidship, grade B/AH shall be used for plate thickness more than 30mm.

2.3.3 Materials for ship type related special structural members are covered in Pt.5.

2.3.4 Material requirements for heavy machinery, e.g. crane pedestal, rudder, mooring fittings and their supporting structures and other structural elements not covered by above tables are given in Ch.11, Ch.12 and Ch.14.

2.3.5 Plating materials for stern frames and shaft brackets are in general not to be of lower grades than corresponding to Class II.

2.4 Structures exposed to low air temperature

For ships intended to operate in areas with low air temperatures reference is given to Pt.6 Ch.6.

2.5 Through thickness property

Where tee or cruciform connections employ partial or full penetration welds, and the plate material is subject to significant tensile strain in a direction perpendicular to the rolled surfaces, consideration shall be given to the use of special material with specified through thickness properties, in accordance with Pt.2. These steels shall be designated on the plans submitted for approval with the required material grade followed by the letter Z (e.g. E36Z).

2.6 Stainless steel

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

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

2.6.2 For austenitic stainless steel the material factor k can be taken as:

$$k = \left\{\left[\left(3.9 + \frac{T-20}{650}\right)R_{eH} - 4.15\,(T-20) + 220\right]10^{-3}\right\}^{-1}$$

where:

T = cargo temperature in °C, not to be taken less than 20°C.

For end connections of corrugations, girders and stiffeners the factor shall not be taken less than:

$$k = [1.21 - 3.2(T - 20)10^{-3}]^{-1}$$

2.6.3 For clad steel the material factor k can be taken as:

$$k = \left[\frac{1.67 R_{eH} - 1.37 T}{1000} - 41.5 R_{eH\_b}^{-0.7} + 1.6\right]^{-1}$$

where:

R_{eH_b} = specified minimum yield strength in N/mm^2 of base material

k is in no case to be taken smaller than that given for the base material in Table 1.

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

The material factor k of the base material may be used for the minimum thickness requirements as given in Ch.6 Sec.3. The minimum thickness requirements shall be calculated for the base material thickness.

2.6.4 For duplex (ferritic-austenitic) stainless steel the material factor will be specially considered in each case.

Guidance note:

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

k = 0.63 at + 20°C

= 0.74 at + 85°C

For end connection of corrugations, girders and stiffeners the factor should not be taken less than:

k = 0.72 at + 20°C

= 0.85 at + 85°C

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

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

2.7 Cold formed plating

2.7.1 For highly stressed components of the hull girder where notch toughness is of particular concern, e.g. items required to be Class III in Table 3, such as radius gunwales and bilge strakes, the inside bending radius R in mm as shown in Sec.6 Figure 9, in cold formed plating, shall not be less than 10 times the gross plate thickness for carbon-manganese steels (hull structural steels). The allowable inside bending radius may be reduced below 10 times the gross plate thickness, provided that the additional requirements stated in [2.7.3] are complied with.

2.7.2 For important structural members not covered by [2.7.1] e.g. corrugated bulkheads and hopper knuckles, the inside bending radius in cold formed plating shall not be less than 4.5 times the plate thickness for carbon-manganese steels and 2 times the plate thickness for austenitic steel and duplex (ferritic-austenitic) stainless steel, corresponding to 10% and 20% theoretical deformation, respectively.

2.7.3 For carbon-manganese steels the allowable inside bending radius may be reduced below the above values provided the following additional requirements are complied with:

a) The steel is killed and fine grain treated, i.e. grade D/DH or higher.
b) the material is impact tested in the strain-aged condition and satisfies the requirements stated herein. The deformation shall be equal to the maximum deformation in terms of plastic strain to be applied during production, calculated by the formula

$$t_{grs}/\left(2r_{bdg}+t_{grs}\right)$$

where t_{grs} is the gross thickness of the plate material and r_{bdg} is the bending radius. One sample shall be plastically strained at the calculated deformation or 5%, whichever is greater and then artificially aged at 250°C for one hour, and then subject to Charpy V-notch testing. The average impact energy after strain ageing shall meet the impact requirements specified for the grade of steel used.
c) 100% visual inspection of the deformed area shall be carried out. In addition, random check by magnetic particle testing shall be carried out.
d) The bending radius is in no case to be less than 2 times the plate thickness.

3 Steel castings and forgings for structural application

3.1 General

The requirements for manufacture, condition of supply, heat-treatment, testing, inspection, tolerances, chemical composition, mechanical properties, repair, identification, certification etc. for steel castings and forging to be used for structural members are given in Pt.2.

3.2 Rolled bars in lieu of steel forgings

Rolled bars for structural application may be accepted in lieu of forged products, after consideration by the Society on a case-by-case basis. Compliance with applicable requirements for steel forgings given in Pt.2 Ch.2 Sec.6, relevant to the quality and testing of rolled parts accepted in lieu of forged parts, may be required.

3.3 Steel castings for structural application

3.3.1 Cast parts intended for stems and stern frames in general may be made of C and C-Mn weldable steels, having specified minimum tensile strength, $R_m \geq 400$ N/mm^2.

3.3.2 The use of cast parts welded to main plating and contributing to hull strength will be considered on a case-by-case basis.

The Society may require additional properties and tests for such casting, in particular impact properties which are appropriate to those of the steel plating to which the cast parts shall be welded and non-destructive examinations.

4 Aluminium alloys

4.1 General

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

4.1.2 For aluminium alloy subjected to longitudinal stresses, the alloy and the scantlings shall be chosen considering the stress level concerned.

4.1.3 In weld zones of rolled or extruded products (heat affected zones) the mechanical properties given in [4.3] may in general be used as basis for the scantling requirements.

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

4.1.5 Unless otherwise agreed, the Young's modulus for aluminium alloys and the Poisson's ratio to be used in the strength assessment are:

E = 70 000 N/mm^2

ν = 0.33

4.2 Extruded plating

4.2.1 Extrusions with built-in plating and stiffeners, referred to as extruded plating, may be used.

4.2.2 In general, the application of extruded plating is limited to decks, bulkheads, superstructures and deckhouses. Other uses may be permitted by the Society on a case-by-case basis.

4.2.3 Extruded plating shall be oriented so that the stiffeners are parallel to the direction of main stresses.

4.2.4 Connections between extruded plating and primary members shall be given special attention.

4.3 Mechanical properties of weld joints

4.3.1 Welding heat input lowers locally the mechanical strength of aluminium alloys hardened by work hardening (series 5000 other than condition 0 or H111) or by heat treatment (series 6000).

4.3.2 The as-welded properties of aluminium alloys of series 5000 are in general those of condition 0 or H111. Higher mechanical characteristics may be considered, provided they are duly justified.

4.3.3 For the 6000 series alloys the most unfavourable properties corresponding to -T4 condition shall be used.

4.4 Material factor, *k*

4.4.1 The material factor, *k* for aluminium alloys shall be obtained from the following formula:

$$k = \frac{235}{R'_{lim}}$$

where:

R'_{lim} = Minimum guaranteed yield stress of the parent metal in welded condition $R'_{p0.2}$, in N/mm^2, but not to be taken greater than 70% of the minimum guaranteed tensile strength of the parent metal in welded condition R_m', in N/mm^2.

$R'_{p0.2}$ = Minimum guaranteed yield stress, in N/mm^2, of material in welded condition.

$$R'_{p0.2} = \eta_1 R_{p0.2}$$

R_m' = Minimum guaranteed tensile strength, in N/mm^2, of material in welded condition.

$$R'_m = \eta_2 R_m$$

$R_{p0.2}$ = Minimum guaranteed yield stress, in N/mm^2, of the parent metal in delivery condition.

R_m = Minimum guaranteed tensile strength, in N/mm^2, of the parent metal in delivery condition.

η_1, η_2 = Specified in Table 11.

Table 11 Aluminium alloys - Coefficients for welded construction

Aluminium alloy	η_1	η_2
Alloys without work-hardening treatment (series 5000 in annealed condition 0 or annealed flattened condition H111)	1	1
Alloys hardened by work hardening (series 5000 other than condition 0 or H111)	$R'_{p0.2} / R_{p0.2}$	R'_m / R_m
Alloys hardened by heat treatment (series 6000) (1)	$R'_{p0.2} / R_{p0.2}$	0.6
1) When no information is available, coefficient η_1 shall be taken equal to the metallurgical efficiency coefficient β as defined in Table 12.		

Table 12 Aluminium alloys - Metallurgical efficiency coefficient β

Aluminium alloy	*Temper condition*	*As-built thickness, in mm*	*β*
6005A (Open sections)	T5 or T6	$t \leq 6$	0.45
		$t > 6$	0.40
6005A (Closed sections)	T5 or T6	All	0.50
6061 (Sections)	T6	All	0.53
6082 (Sections)	T6	All	0.45

4.4.2 In the case of welding of two different aluminium alloys, the material factor k to be considered for the scantlings is the greater material factor of the aluminium alloys of the assembly.

4.5 Connection between steel and aluminium

4.5.1 Details of the proposed method of joining any aluminium and steel structures shall be submitted for approval.

4.5.2 To prevent galvanic corrosion a non-hygroscopic insulation material shall be applied between steel and aluminium when a bolted connection is used.

4.5.3 Aluminium plating connected to steel boundary bar at deck is as far as possible to be arranged on the side exposed to moisture.

4.5.4 An aluminium-steel transition joint in accordance with the rules Pt.2 Ch.2 Sec.4 may be used in a welded connection after special consideration.

4.5.5 Direct contact between exposed wooden materials, e.g. deck planking, and aluminium shall be avoided.

4.5.6 Bolts with nuts and washers are either to be of stainless steel or cadmium plated or hot galvanized steel. The bolts shall be fitted with sleeves of insulating material. The spacing is normally not to exceed 4 times the bolt diameter.

4.5.7 For earthing of insulated aluminium superstructures, see Pt.4 Ch.8.

4.6 Aluminium fittings

4.6.1 Aluminium fittings in tanks used for the carriage of oil, and in cofferdams and pump rooms shall be avoided. Where fitted, aluminium fittings, units and supports, in tanks used for the carriage of oil, cofferdams and pump rooms shall satisfy the requirements of Sec.4 [2] for aluminium anodes.

4.6.2 The underside of heavy portable aluminium structures such as gangways, shall be protected by means of a hard plastic or wood cover, or other approved means, in order to avoid the creation of smears. Such protection shall be permanently and securely attached to the structures.

5 Steel sandwich panel construction

5.1 Application

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

Guidance note:

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

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

5.1.2 Verification of compliance with the Society's rules shall be demonstrated with method given in the Society's document DNVGL CG 0154, *Steel Sandwich Panel Construction*.

6 Other materials and products

6.1 General

6.1.1 Other materials and products such as parts made of iron castings, where allowed, products made of copper and copper alloys, rivets, anchors, chain cables, cranes, masts, derrick posts, derricks, accessories and wire ropes shall comply with the applicable requirements of the rules for materials as given in Pt.2.

6.1.2 The use of plastics or other special materials not covered by these rules shall be considered by the Society on a case by case basis. In such cases, the requirements for the acceptance of the materials concerned shall be agreed on with the Society.

6.2 Iron cast parts

6.2.1 The use of grey iron, malleable iron or spheroidal graphite cast iron with combined ferritic/perlitic structure is allowed only in low stressed elements of secondary importance.

6.2.2 Ordinary cast iron parts shall not be used for windows or sidescuttles. The use of high grade cast iron parts of a suitable type shall be considered by the Society on a case by case basis.

SECTION 2 NET SCANTLING APPROACH

Symbols

For symbols not defined in this section, refer to Ch.1 Sec.4

t = net required thickness, in mm, as required in [1.3.1]
t_c = corrosion addition in mm
h_{stf} = height of stiffener or primary supporting member in mm
h_w = web height of stiffener or primary supporting member in mm
t_w = web thickness of stiffener or primary supporting member in mm
b_f = face plate width of stiffener or primary supporting member in mm
t_f = face plate thickness of stiffener or primary supporting member in mm
t_p = thickness of the plating attached to a stiffener or to a primary supporting member in mm
d_e = distance in mm, from the upper edge of the web to the top of the flange for L3 profiles, see Figure 2
t_{as_built} = as-built thickness, in mm, taken as the actual thickness provided at the newbuilding stage
t_{gr_off} = gross offered thickness, in mm, as defined in [1.2.2]
t_{gr} = gross required thickness, in mm, as defined in [1.2.1]
t_{off} = net offered thickness, in mm, as defined in [1.2.3]
t_{vol_add} = thickness for voluntary addition, in mm, taken as the thickness voluntarily added as the owner's extra margin or builder's extra margin for corrosion wastage in addition to t_c
t_{res} = reserve thickness, in mm, taken equal to 0.5 mm
t_{c1}, t_{c2} = corrosion addition on one side of the considered structural member, in mm, as defined in Sec.3 Table 1.

1 General

1.1 Application

1.1.1 Net scantling approach

The net scantling approach is the method of obtaining the required thickness in accordance with the rules before adding corrosion margin that is likely to occur during the operation phase of the ship. For corrosion additions, see Sec.3.

No credit is given in the assessment of structural capability for the presence of coatings or similar corrosion protection systems.

1.1.2 Local and global corrosion

The net scantling approach distinguishes between local and global corrosion. Local corrosion is defined as uniform corrosion of local structural elements, such as a single plate or stiffener. Global corrosion is defined as the average corrosion of larger areas, such as primary supporting members and the hull girder.

1.1.3 Exceptions in gross scantling

Items that are directly determined in terms of gross scantlings do not follow the net scantling approach, i.e. they already include additions for corrosion but without any owner's extra margin. Gross scantling requirements are identified by the suffix "gr". Examples of such structures are:

— scantlings of massive pieces made of steel forgings and steel castings.
— rudder
— hatches

— deck equipment.

1.2 Gross and net scantling definitions

1.2.1 Gross required thickness

The gross required thickness, t_{gr}, is the thickness, in mm, obtained by adding the corrosion addition as defined in Sec.3 to the net required thickness, as follows:

$$t_{gr} = t + t_c$$

1.2.2 Gross offered thickness

The gross thickness, i.e. the gross offered thickness, t_{gr_off}, is the gross thickness, in mm, provided at the newbuilding stage, which is obtained by deducting any thickness for voluntary addition from the as-built thickness, as follows:

$$t_{gr\_off} = t_{as\_built} - t_{vol\_add}$$

1.2.3 Net offered thickness

The net offered thickness, t_{off} in mm, is obtained by subtracting the corrosion addition from the gross offered thickness, as follows:

$$t_{off} = t_{gr\_off} - t_c = t_{as\_built} - t_{vol\_add} - t_c$$

1.3 Scantling compliance

1.3.1 The net required thickness, t, is obtained by rounding requirement calculated according to the rules to the nearest half millimetre. For example:

— for $10.75 \le t < 11.25$ mm, the rule required net thickness is 11.0 mm
— for $11.25 \le t < 11.75$ mm, the rule required net thickness is 11.5 mm.

1.3.2 Scantling compliance in relation to the rules is as follow:

— The net offered thickness of plating shall be equal to or greater than the net required thickness of plating.
— The required net section modulus, moment of inertia and shear area properties of local supporting members shall be calculated using the net thickness of the attached plate, web and flange. The net sectional dimensions of local supporting members are defined in Figure 1.
— The offered net sectional properties of primary supporting members and the hull girder shall be equal to or greater than the required net sectional properties which shall be based on the gross offered scantling with a reduction of the applicable corrosion addition, as specified in Table 1, applied to all component structural members.
— The strength assessment methods prescribed shall be assessed by applying the corrosion addition specified in Table 1 to the offered gross scantlings. Half of the applied corrosion addition specified in Table 1 shall be deducted from both sides of the structural members being considered.
— Corrosion additions shall not be taken less than those given in Sec.3 Table 1.

Any additional thickness specified by the owner or the builder shall not be included when considering compliance with the rules.

Table 1 Applied corrosion addition for structural assessment

Structural requirement	*Property/analysis type*	*Applied corrosion addition for structural assessment*
Minimum thickness [1)]	Thickness	t_c
Local strength (plates, stiffeners, and hold frames)	Thickness/sectional properties	t_c
	Proportions / Buckling capacity	t_c
Primary supporting members (prescriptive)	Grillage analysis	$0.5\ t_c$
	Sectional properties	$0.5\ t_c$
	Proportions of web and flange Buckling capacity	t_c
Strength assessment by FEM	Global FE model	$0.5\ t_c$ [2)]
	Cargo tank/cargo hold FE model	$0.5\ t_c$ [2)]
	Buckling capacity	t_c
	Local fine mesh FE model	$0.5\ t_c$ [2)]
Hull girder strength	Sectional properties/yield check Buckling capacity	$0.5\ t_c$ [3)] t_c
Hull girder ultimate strength Hull girder residual strength	Sectional properties	$0.5\ t_c$
	Buckling/collapse capacity	$0.5\ t_c$
Fatigue assessment (simplified stress analysis)	Hull girder section properties Local supporting member	$0.5\ t_c$
Fatigue assessment (FE Stress analysis)	Very fine mesh FE model	$0.5\ t_c$ [2)]

1) Including primary supporting members (PSM)
2) Only applicable for ships with class notation **ESP**. Otherwise, gross offered thickness to be applied.
3) For vertical hull girder bending and shear check gross offered thickness to be applied

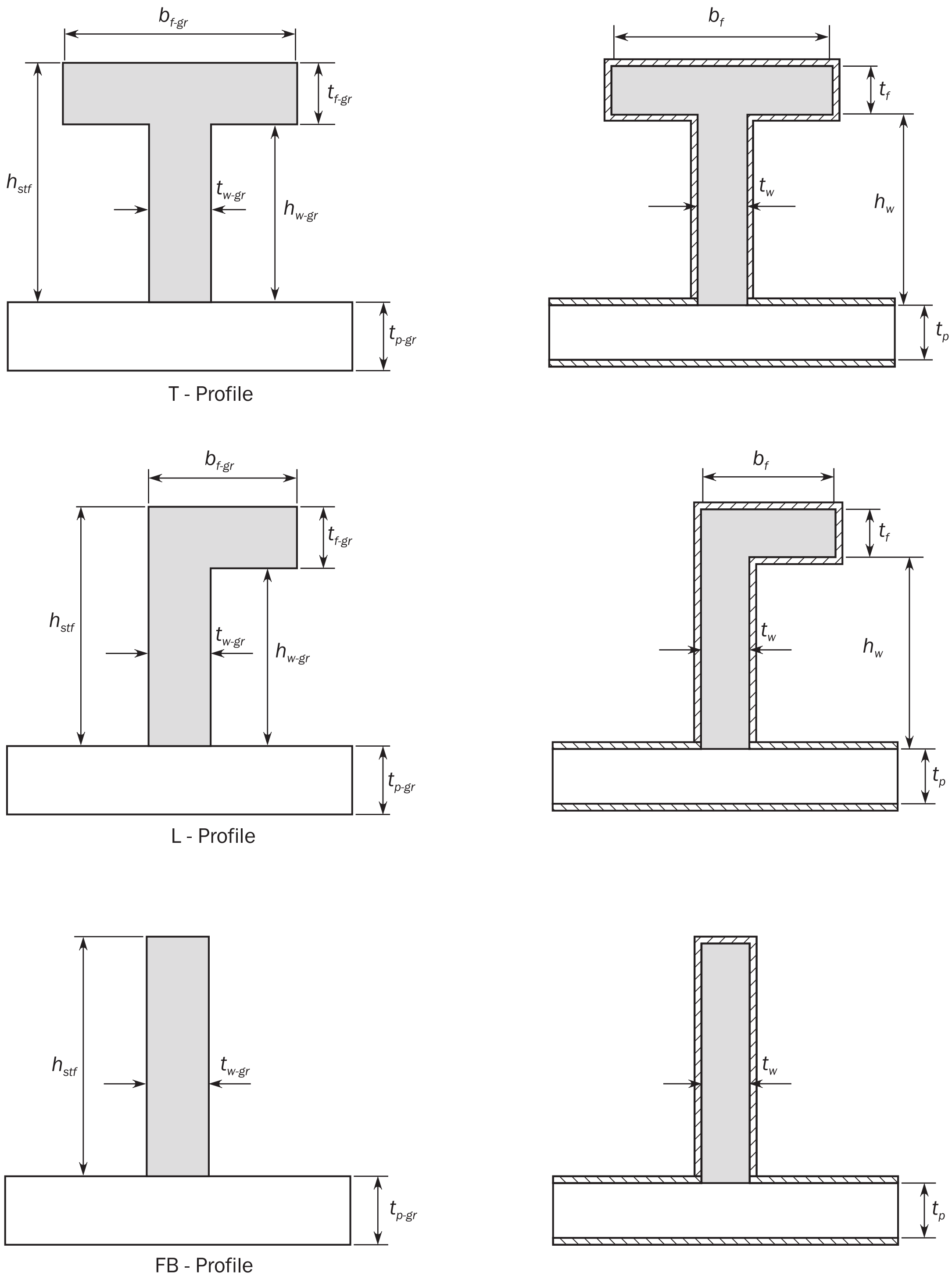

Figure 1 Net sectional properties of local supporting members

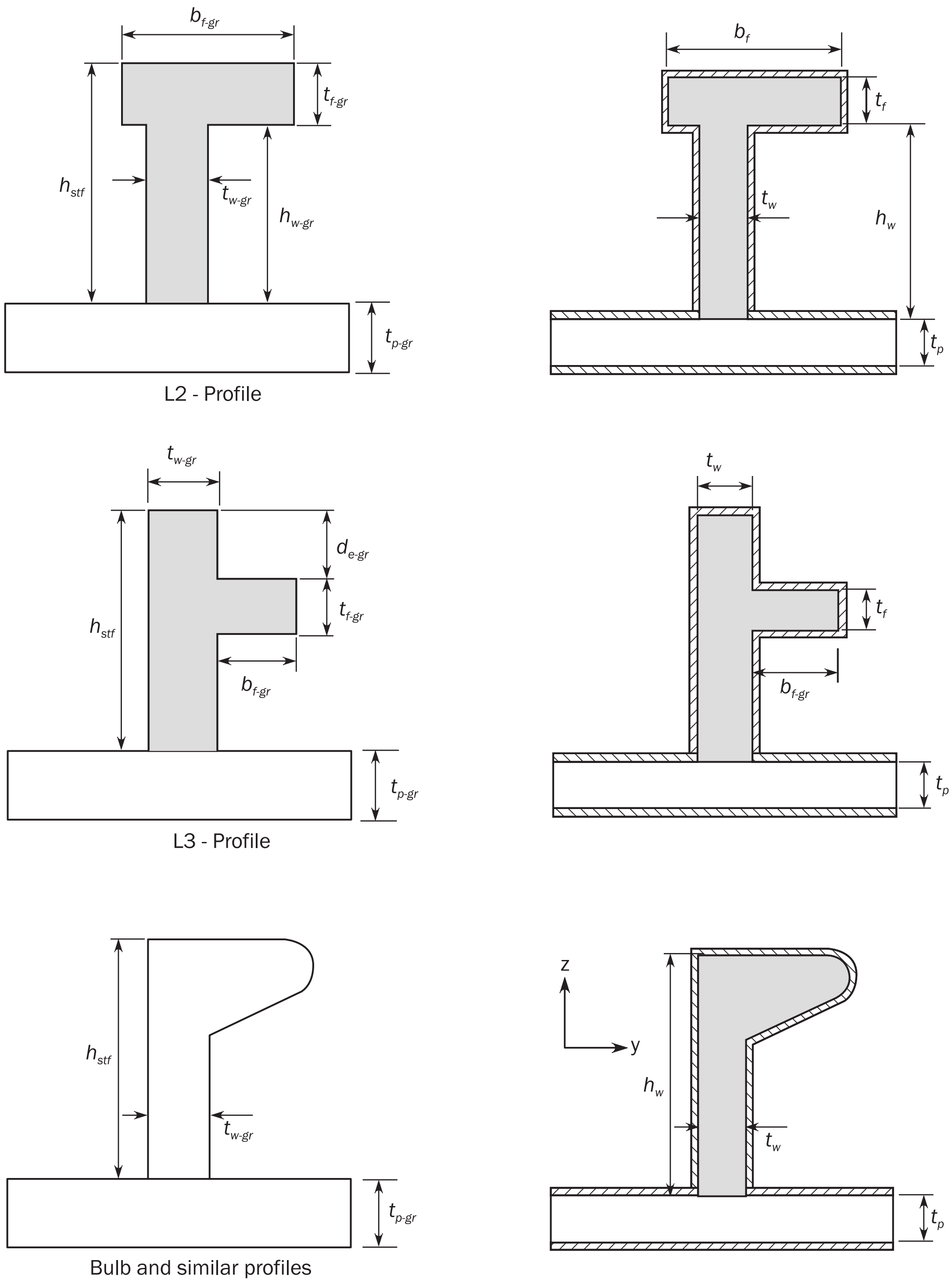

Figure 2 Net sectional properties of local supporting members (continued)

1.3.3 Local supporting members

The net cross-sectional area, the moment of inertia about the y-axis and the associated neutral axis position shall be determined applying a corrosion magnitude of 0.5 t_c deducted from the surface of the profile cross-section.

SECTION 3 CORROSION ADDITIONS

Symbols

For symbols not defined in this section, refer to Ch.1 Sec.4.

t_c = corrosion addition, in mm

t_{c1}, t_{c2} = corrosion addition, in mm, on each of the two sides of the considered structural member, as defined in Table 1

t_{res} = reserve thickness, taken as 0.5 mm.

1 General

1.1 Application

The corrosion additions given in these rules are applicable to carbon-manganese steels, stainless steels, stainless clad steels and aluminium alloys.

1.2 Corrosion addition determination

1.2.1 The total corrosion addition, t_c in mm, for both sides of the structural member is obtained by the following formula:

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

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

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

where t_{c1} is the value specified in Table 1 for one side exposure to that compartment.

1.2.3 The total corrosion addition, t_c in mm, for compartment boundaries and internal members made from stainless steel, or aluminium shall be taken as:

$$t_c = t_{res} = 0.5$$

1.2.4 In case of stainless clad steel, the corrosion additions, t_{c1}, for the carbon steel side and t_{c2}, for the stainless steel side are respectively to be taken as:

t_{c1} = as specified for the corresponding compartment in Table 1

t_{c2} = 0.

1.2.5 Maximum value of corrosion addition

The total corrosion addition, t_c, need not to be taken more than:

$$t_c = t_{c\max} = 0.2t_{gr\_off}$$

where t_{cmax} shall be rounded to the closest half millimetre.

1.2.6 Stiffener

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

1.2.7 When an elementary plate panel or a stiffener are affected by more than one value of corrosion addition, the largest value shall be applied.

Table 1 Corrosion addition for one side of a structural member

Compartment type	*Structural member*	t_{c1} or t_{c2}
Tanks for cargo oil and liquid chemicals	All members	1.0
Dry bulk, container and general cargo holds	Lower part [1] for vessels with **Grab(3-X)** notation	2.5
	Lower part[2] for other vessels	1.0
	Other members	0.5
External surfaces	All members	0.5
Ballast water tank	All members	1.0
Tanks for fresh water, fuel oil, lube oil, RSW, mud[4]	All members	0.5
Tanks for brine, urea, bilge tank, drain storage, chain locker	All members	1.0
Accommodation spaces	All members	0.0
Void, dry spaces and compartment types not mentioned above[3]	Upper surface of decks or bottom plate of the compartment [5]	0.5
	Elsewhere	0.0
Stainless steel and aluminum (independent of compartment type)	All members	0.0

1) Lower part includes the bottom of hold and other structure within a height of 3.0 m above the bottom of hold, e.g. inner bottom. The bottom of hold is defined as the lowest horizontal boundaries of the hold.
2) Lower part includes the bottom of hold and other structure within a height of 1.5 m above the bottom of hold, e.g. inner bottom. The bottom of hold is defined as the lowest horizontal boundaries of the hold.
3) Applicable for the spaces containing membrane or independent cargo tanks of gas carriers. But membrane and independent tank themselves are not covered by this part of the rules, see Pt.5 Ch.7.
4) Applicable also for cargo tanks only intended to carry fresh water, fuel oil, lube oil, RSW or mud.
5) Inclusive upper surface of horizontal stringers in double hull and double bulkhead constructions.

SECTION 4 CORROSION PROTECTION

1 General

1.1 Application

1.1.1 Tanks and holds

Tanks and holds that are exposed to a corrosive environment shall have an efficient corrosion prevention system. For vessels following PSPC requirements, the dedicated seawater ballast tanks shall have an efficient corrosion prevention system in accordance with SOLAS Chapter II-1/3-2 and IMO Resolution MSC.215(82): *"Performance Standard for Protective Coatings (PSPC) for Dedicated Seawater Ballast Tanks in All Types of Ships and Double-Side Skin Spaces of Bulk Carriers"* and cargo oil tanks of crude oil carriers shall have an efficient corrosion prevention in accordance with SOLAS Chapter II-1/3-11 and IMO Resolution MSC.288(87) or MSC.289(87).

1.1.2 Narrow spaces

Narrow spaces are generally to be protected by an efficient protective product, particularly at the ends of the ship where inspections and maintenance are not easily practicable due to their inaccessibility.

2 Sacrificial anodes

2.1 Attachment of anodes to the hull

2.1.1 All anodes shall be attached to the structure in such a way that they remain securely fastened even when it is wasted. The following methods are acceptable:

a) steel core connected to the structure by continuous fillet welds
b) attachment to separate supports by bolting, provided a minimum of two bolts with lock nuts are used. However, other mechanical means of clamping may be accepted.

2.1.2 Anodes shall be attached to stiffeners or aligned in way of stiffeners on plane bulkhead plating, but they shall not be attached to the shell. The two ends shall not be attached to separate members which are capable of relative movement.

2.1.3 Where cores or supports are welded to local supporting members or primary supporting members, they shall be kept clear of end supports, toes of brackets and similar stress raisers. Where they are welded to asymmetrical members, the welding shall be at least 25 mm away from the edge of the web. In the case of stiffeners or girders with symmetrical face plates, the connection may be made to the web or to the centreline of the face plate, but well clear of the free edges.

SECTION 5 STRUCTURAL ARRANGEMENT

Symbols

For symbols not defined in this section, refer to Ch.1 Sec.4.

1 Application

1.1 Introduction

If not specified otherwise, the requirements of this section apply to the hull structure, superstructures and deckhouses for ships with length $L \geq 65$ m. Alternative structural layout to what is specified in this section may be considered based on direct calculations reflecting the actual design.

2 General principles

2.1 Structural continuity

2.1.1 General

Attention shall be paid to the structural continuity, in particular in the following areas:

- in way of changes in the framing system
- at end connections of primary supporting members or stiffeners
- in way of the transition zones between midship area and fore part, aft part and machinery space
- in way of side and end bulkheads of superstructures.

At the termination of a structural member, structural continuity shall be maintained by the fitting of effective supporting structure.

Between the midship region and the end regions there shall be a gradual transition in plate thickness for bottom, shell and strength deck plating.

2.1.2 Longitudinal members

Longitudinal members shall be arranged in such a way that continuity of strength is maintained.

Longitudinal members contributing to the hull girder longitudinal strength shall extend continuously as far as practicable within 0.8 L amidships for vessels with $L < 150$ m and within 0.5 L amidships for ships with $L < 90$ m. Linear interpolation is applicable for vessels with length between 90 m and 150 m. Structural continuity shall be ensured in way of end terminations. For longitudinal bulkheads or deep girders, large transition brackets, fitted in line with the longitudinal member are a possible means to achieve such structural continuity.

2.2 Longitudinal stiffeners

2.2.1 Within 0.8 L for vessels with $L > 150$m , in the area below 0.15 D above the bottom and the area above 0.15 D below strength deck, longitudinal stiffening arrangement shall in general be applied. For ships with length L< 90 m longitudinal stiffening arrangement shall in general be applied within 0.5 L. Linear interpolation is applicable for vessels with length between 90 m and 150 m.

2.2.2 Where stiffeners are terminated in way of large openings, foundations and partial girders, compensation shall be arranged to provide structural continuity in way of the end connection.

2.2.3 When the bottom or inner bottom is longitudinally stiffened, the longitudinals shall in general be continuous through transverse members. For ships with length $L < 65$ m or other ships with low hull girder stresses and not considered prone to fatigue the longitudinals may be non-continuous and welded against the floors.

2.2.4 Deck longitudinals shall in general be continuous at transverse members as given in [2.2.1].

For vessels with more than two decks above 0.7 *D* and $\sigma_{hg} \leq 0.5 \cdot \sigma_{hg\text{-}perm}$ for the deck plating in question, the longitudinals may be terminated at transverse members.

σ_{hg}	=	hull girder longitudinal stress, in N/mm^2, due to bending moments as defined in Ch.5 Sec.3 [2.1] for ships without large deck openings
$\sigma_{hg\text{-}perm}$	=	permissible hull girder stress, in N/mm^2, as given in Ch.5 Sec.3 [2.1] for ships without large deck openings.

For ships with length L < 65 m or other ships with low hull girder stresses and not considered prone to fatigue the longitudinals may be non-continuous and welded against the transverse members/ bulkheads.

In case of deck longitudinals subjected to high tensile hull girder stresses are made non-continous, welding requirements are given in Ch.13 Sec.1 [2.4.5].

2.3 Transverse stiffeners

Transverse and vertical stiffeners shall be continuous through stringers/girders, if provided, or fitted with bracket end connections.

2.4 Plating

Where plates with different thicknesses are joined, a transition plate shall be added if the difference in the as-built plate thickness exceed 50% of larger plate thickness in the load carrying direction. This also applies to the strengthening by local inserts, e.g. insert plates in double bottom girders, floors and inner bottom.

For welding of plates with different thicknesses, see Ch.13 Sec.1 [3.2].

2.5 Sheer strake

2.5.1 Sheer strakes shall have breadths in m not less than $0.8 + L/200$, measured vertically, but need not be greater than 1.8 m.

2.5.2 The thickness of sheer strake shall be increased by 30% on each side of a superstructure end bulkhead located within 0.5 *L* amidships if the superstructure deck is a partial strength deck.

2.5.3 If the sheer strake is rounded by cold forming, its radius shall be in accordance with Sec.1 [2.7].

When it is intended to use hot forming for rounding of the sheer strake, all details of the forming and heat treatment procedures shall be submitted to the Society for approval. Appropriate heat treatment subsequent to the forming operation will normally be required.

Where the rounded sheer strake transforms into a square corner towards the ends of the vessel, line flame heating may be accepted to bend the sheer strake.

2.6 Stringer plate

2.6.1 Stringer plates shall have breadths not less than $0.8 + L/200$ m, measured parallel to the deck, but need not be greater than 1.8 m.

2.6.2 Rounded stringer plates, where adopted, shall comply with the requirements in [2.5.3].

2.7 Connection of deckhouses and superstructures

Connection of deckhouses and superstructures to the strength deck and hatch coamings shall be designed such that loads are transmitted into the under deck supporting structure.

3 Bottom structure

3.1 General

3.1.1 Variation in height of double bottom

Any variation in the height of the double bottom is generally to be made gradually and over an adequate length; the knuckles of inner bottom plating shall be located in way of plate floors or girders. Where such arrangement is not possible, suitable structures such as partial girders, brackets or carlings fitted across the knuckle shall be arranged.

3.1.2 Connection between inner hull and inner bottom plating

Connection between the inner hull plating and the inner bottom plating shall be designed such that stress concentration is minimized. The connection of inner hull plating or hopper plating with inner bottom shall be effectively supported, e.g. by a longitudinal girder or gusset plates.

3.1.3 Striking plate

Striking plates of adequate thickness or other equivalent arrangements shall be provided under sounding pipes to prevent the sounding rod from damaging the plating.

3.1.4 Duct keel

Where a duct keel is arranged, the centre girder may be replaced by two girders spaced no more than 3 m apart. Spacing wider than 3 m will be specially considered.

3.1.5 Keel plating

Keel plating shall extend over the bottom for the full length of the ship.

The width of the keel strake, in m, shall not be less than $0.8 + L/200$, but need not be taken greater than 2.3 m.

3.2 Girders

3.2.1 In double bottoms with transverse stiffening the longitudinal girders shall be stiffened at every transverse frame.

3.2.2 Double bottom girders shall be arranged in line with longitudinal bulkheads arranged from the inner bottom and above.

3.2.3 When fitted, the centre girder shall extend continuously within the full length of the ship, as far as practicable.

3.3 Floors

3.3.1 Plate floors shall be fitted below bulkheads, in way of double bottom structures.

3.3.2 Floors shall be provided with web stiffeners in way of longitudinal stiffeners. Where the web stiffeners are not welded to the longitudinal stiffeners, design standard as given in the Society's document DNVGL CG 0129, *Fatigue assessment of ship structure*, may be applied.

3.4 Docking

3.4.1 Docking of the vessel shall be evaluated and considered at the design stage by the designer. The bottom structure shall withstand the forces imposed by dry docking the ship.

3.4.2 Docking brackets connecting the centreline girder and margin girder to the bottom plating, shall be connected to the adjacent bottom longitudinals.

Docking brackets shall be fitted between floors.

Alternative arrangements require special consideration of local buckling strength of centre girder and local strength of bottom longitudinal in way of docking block.

3.5 Ships touching ground during loading and discharging

The bottom structure of a ship which is expected to frequently touch the ground during loading and discharging will be specially considered.

4 Aft peak

4.1 Application

The area of application is aft of the aft peak bulkhead and below bulkhead deck.

4.2 Structural arrangement

4.2.1 Minimum thickness requirement

The net thickness of the aft peak bulkhead plating in way of the stern tube penetration shall be at least 1.6 times the required thickness for the bulkhead plating itself.

4.2.2 Floors

Floors shall be fitted at every frame in the aft peak and extended to a height at least above the stern tube. Where floors do not extend to flats or decks, they shall be stiffened by flanges at their upper end.

Heavy plate floors shall be fitted in way of the aft face of the rudder horn and in line with the webs in the rudder horn. They may be required to be carried up to the first deck or flat. In this area, cut outs, scallops or other openings shall be kept to a minimum.

4.2.3 Platforms and stringers

Platforms and side girders within the peak shall be arranged in line with those located in the area immediately forward.

Where this arrangement is not possible due to the shape of the hull and access needs, structural continuity between the peak and the structures of the area immediately forward shall be ensured by adopting wide tapering brackets.

Where the aft peak is adjacent to a machinery space with longitudinal framing, the side girders in the aft peak shall be fitted with tapering brackets.

Where the depth from the peak tank top to the weather deck is greater than 2.6 m and the side is transversely framed, one or more side girders shall be fitted, preferably in line with similar structures existing forward.

4.2.4 Longitudinal bulkheads

A longitudinal non-tight bulkhead shall be fitted on the centreline of the ship, in general in the upper part of the peak, and stiffened at each frame spacing.

Where either the stern overhang is very large or when the breadth of the tank is greater than 2/3 of the moulded breadth of the ship, additional longitudinal wash bulkheads may be required.

4.2.5 Stern tube

The stern tube shall be supported by the floor plates or, when the ship's shape is too narrow, to be stiffened by internal rings. Where no sole piece is fitted, the internal rings may be dispensed with.

4.2.6 Alternative design verification

The spacing and arrangement requirements, defined in [4.2.2], [4.2.3] and [4.2.4], may be increased, if verification by means of grillage analysis or FE analysis is performed. The acceptance criteria to be applied for grillage analysis are defined in Ch.6 Sec.6 [2]. A FE analysis shall be performed in accordance with the requirements in Ch.7.

4.3 Stiffening of floors and girders in aft peak

4.3.1 The height of stiffeners, in mm, on the floors and girders shall satisfy:

$h_{stf} \geq 80\ \ell_{stf}$ for flat bar stiffeners.

$h_{stf} \geq 70\ \ell_{stf}$ for bulb profiles and flanged stiffeners.

where:

ℓ_{stf} = Length of stiffener, in m, as shown in Figure 1. For this purpose the length need not be taken greater than 5 m.

4.3.2 Stiffeners on the floors and girders in aft peak ballast or fresh water tanks above the propeller shall be arranged with brackets. This applies for stiffeners located in an area extending longitudinally between the forward edge of the rudder and the aft end of the propeller boss and transversely within the diameter of the propeller. End brackets shall be provided as follows:

— brackets shall be fitted at the lower and upper ends when $\ell_{stf\text{-}t}$ exceeds 4 m

— brackets shall be fitted at the lower end when $\ell_{stf\text{-}t}$ exceeds 2.5 m.

where:

$\ell_{stf\text{-}t}$ = total length of stiffener, in m, as shown in Figure 1.

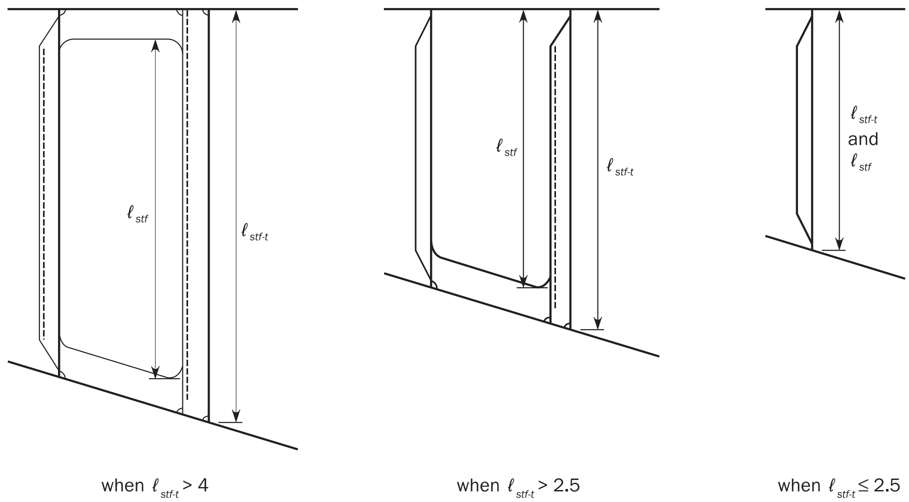

Figure 1 Stiffening of floors and girders in the aft peak tank

5 Engine room

5.1 Bottom structure

5.1.1 Application

The requirements in [5.1.3] to [5.1.8] apply unless verification by means of direct analysis.

5.1.2 Double bottom height

The double bottom height at the centreline shall not be less than the value defined in Ch.2 Sec.3 [2.3]. This depth may need to be considerably increased in relation to the type and depth of main machinery seatings.

The above height shall be increased where the engine room is very large and where there is a considerable variation in draught between light ballast and full load conditions.

Where the double bottom height differs from that in adjacent spaces, structural continuity of longitudinal members shall be provided by sloping the inner bottom over an adequate longitudinal extent. The knuckles in the sloped inner bottom shall be located in way of floors. Lesser double bottom height may be accepted in local areas provided that the overall strength of the double bottom structure is not thereby impaired.

5.1.3 Centreline girder

The double bottom shall be arranged with a centreline girder or side girders adjacent to centreline giving sufficient support for docking loads. Openings for manholes are only permitted where absolutely necessary for double bottom access and maintenance, local strengthening may be required.

5.1.4 Side bottom girders

The number of side bottom girders shall be increased, with respect to the adjacent areas, to provide adequate rigidity of the structure. The side bottom girders in a longitudinal stiffened double bottom, shall be a continuation of any bottom longitudinals in the areas adjacent to the engine room and are generally to have a spacing not greater than 3 times that of longitudinals and in no case greater than 3 m.

5.1.5 Girders in way of machinery seatings

Under the main engine, girders extending from the bottom to the top plate of the engine seating, shall be fitted. The height of the girders shall not be less than that of the floors.

Guidance note:

Side girders under foundation girders shall be extended into the adjacent spaces and to be connected to the bottom structure. This extension abaft and forward of the engine room bulkheads shall be two to four frame spacings, as found practicable.

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

5.1.6 Floors in longitudinally stiffened double bottom

Where the double bottom is longitudinally stiffened, plate floors shall be fitted at every frame under the main engine and thrust bearing. Forward and aft of the engine and bearing seatings, the floors may be fitted with greater spacing if the double bottom is supported by effective longitudinal girders or partial longitudinal bulkheads.

5.1.7 Floors in transversely stiffened double bottom

Where the double bottom in the engine room is transversely stiffened, floors shall be arranged at every frame.

5.1.8 Manholes

The number and size of manholes in floors located in way of seatings and adjacent areas shall be kept to the minimum necessary for double bottom access and maintenance.

5.2 Side structure

In the engine room, web frames shall be spaced not more than 5 times the frame spacing apart. The web frames shall extend to the uppermost continuous deck. Greater web frame spacing may be accepted provided that partial ship structural analysis in accordance with Ch.7 Sec.3 is carried out.

For two-stroke engines, web frames are generally to be fitted at the forward and aft ends of the engine. The web frames shall be evenly distributed along the length of the engine.

6 Fore peak

6.1 Application

The area of application is forward of collision bulkhead and below bulkhead deck.

6.2 Floors and bottom girders

6.2.1 Floors

The minimum depth of the floor at the centreline shall not be less than the required depth of the double bottom, see Ch.2 Sec.3 [2.3].

6.2.2 Bottom girders

A supporting structure shall be provided at the centreline either by extending the centreline girder to the stem or by providing a deep girder or centreline bulkhead.

In areas where the hull shape is very narrow, alternative arrangement, e.g. without centreline girder and with web fitted at every frame, may be accepted.

Where a centreline girder is fitted, the minimum depth and thickness shall not be less than that required for the depth of the double bottom in the neighbouring cargo hold region, and the upper edge shall be stiffened.

6.3 Wash bulkheads

Where a centreline wash bulkhead is fitted, the lowest strake shall have thickness not less than required for a centreline girder.

Where a longitudinal wash bulkhead supports bottom transverses, the details and arrangements of openings in the bulkhead shall be configured to avoid areas of high stresses in way of the connection of the wash bulkhead with bottom transverses.

SECTION 6 DETAIL DESIGN

Symbols

For symbols not defined in this section, refer to Ch.1 Sec.4.

1 Reinforcement of knuckles

1.1 Local reinforcements

1.1.1 Reinforcements at knuckles

a) Knuckles are in general to be stiffened to achieve out-of-plane stiffness by fitting stiffeners or equivalent means in line with the knuckle.

b) Whenever a knuckle in a main member, e.g. shell or longitudinal bulkhead, is arranged, stiffening in the form of webs, brackets or profiles shall be connected to support the knuckle. See example of reinforcement at knuckle in Figure 1.

c) Where stiffeners intersect the knuckle as shown in Figure 1, effective support shall be provided for the stiffeners in way of the knuckle.

d) When the stiffeners of the shell, inner shell or bulkhead intersect a knuckle at a narrow angle, it may be accepted to interrupt the stiffener at the knuckle, provided that proper end support in terms of carling, bracket or equivalent is fitted. Alternative design solution with, e.g. closely spaced carlings fitted across the knuckle between longitudinal members above and below the knuckle may be accepted.

e) For longitudinal shallow knuckles, i.e. angle less than 10 degrees, closely spaced carlings shall be fitted across the knuckle, between longitudinal members above and below the knuckle. Carlings or other types of reinforcement need not be fitted in way of shallow knuckles that are not subject to high lateral loads and/or high in-plane loads across the knuckle, such as deck camber knuckles.

f) Generally, the distance between the knuckle and the support stiffening in line with the knuckle shall not be greater than 50 mm within 0.6 L. For shallow knuckles, i.e. angles less than 10 degrees, the distance of 75 mm is acceptable. Alternative arrangements can be considered based on fatigue analysis in accordance with Ch.9.

g) When a stiffener or primary supporting member is knuckled within the length of the span, effective support shall be provided by fitting tripping bracket or equivalent for the support of the face plate, and tripping bracket or equivalent for supporting the knuckled web section, see Figure 2.

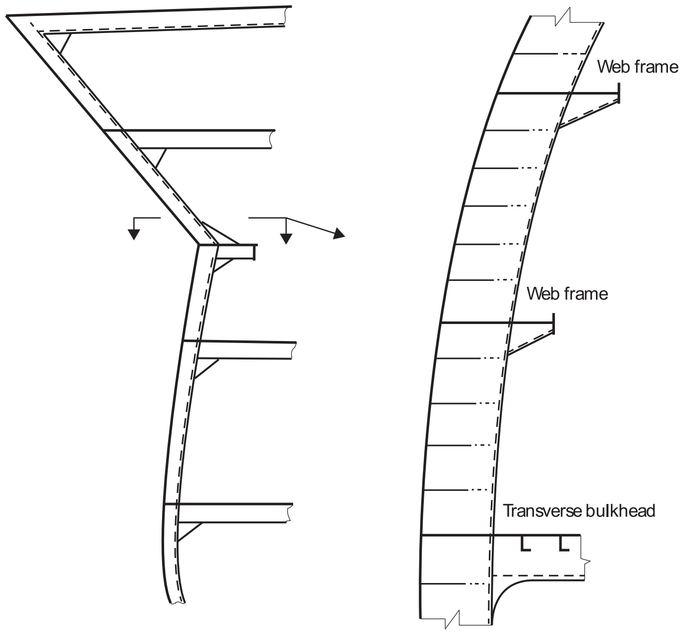

Figure 1 Reinforcement at knuckle

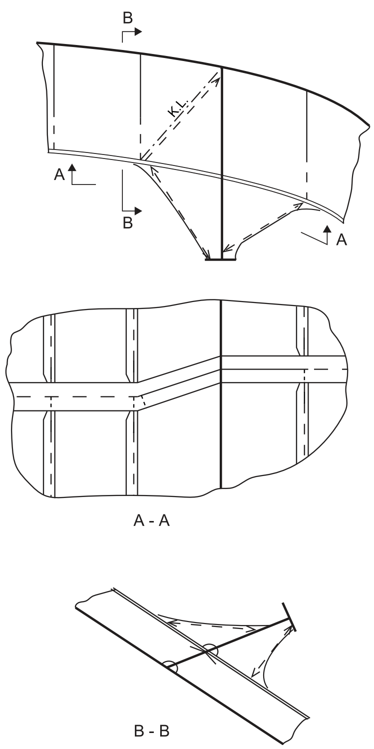

Figure 2 Support arrangement for knuckled stringer

1.1.2 Knuckle support at integral bracket

If the flange transition between the stiffener and an integral bracket is knuckled, the flange shall be effectively supported in way of the knuckle. Alternatively the flange may be curved with radius, in mm, not less than, see Sec.7 Figure 15:

$$r = 1.6 \cdot \frac{b_1^2}{t_f}$$

where:

b_1 = free flange outstand, in mm, as defined in Sec.7 [1.3.4]

t_f = net thickness, in mm, of flange.

Guidance note:

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

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

2 Stiffeners

2.1 General

2.1.1 Stiffeners in local areas are in general to be connected at their ends. However, in special cases sniped ends may be permitted. Requirements for the various types of connections (bracketed, bracketless or sniped ends) are given in [2.2] to [2.4].

2.1.2 Where the angle between the web plate of the stiffener and the attached plating is less than 50 deg, a tripping bracket/carling shall be fitted. If the angle, φ_w, between the web plate of an unsymmetrical stiffener and the attached plating is less than 50 deg, the face plate of the stiffener shall be fitted on the open angle side, Figure 3.

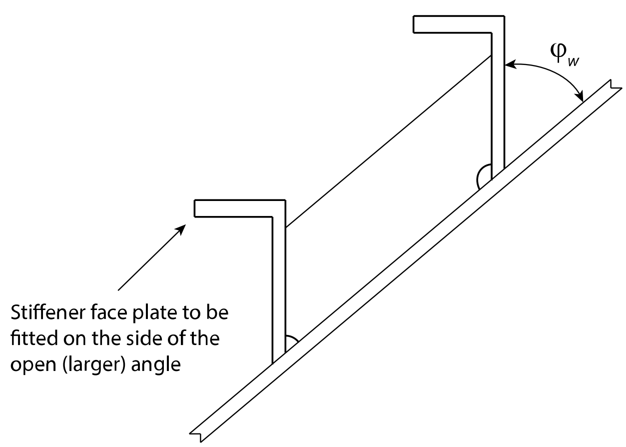

Figure 3 Stiffener on attached plating with an angle less than 50 deg

2.2 Bracketed end connections of non-continuous stiffeners

2.2.1 Where continuity of strength of longitudinal members is provided by brackets, the alignment of the brackets on each side of the primary supporting member shall be ensured, and the scantlings of the brackets shall be such that the combined stiffener/bracket section modulus and effective cross sectional area are not less than those of the member.

Guidance note:

End brackets for stiffeners may, as indicated in item (a) and (b) of Figure 4, be of overlap type. End brackets of this type, however, are only to be applied for locations where the bending moment capacity required for the bracket is reduced compared to the bending moment capacity of the stiffener, e.g. the upper end bracket of vertical stiffeners.

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

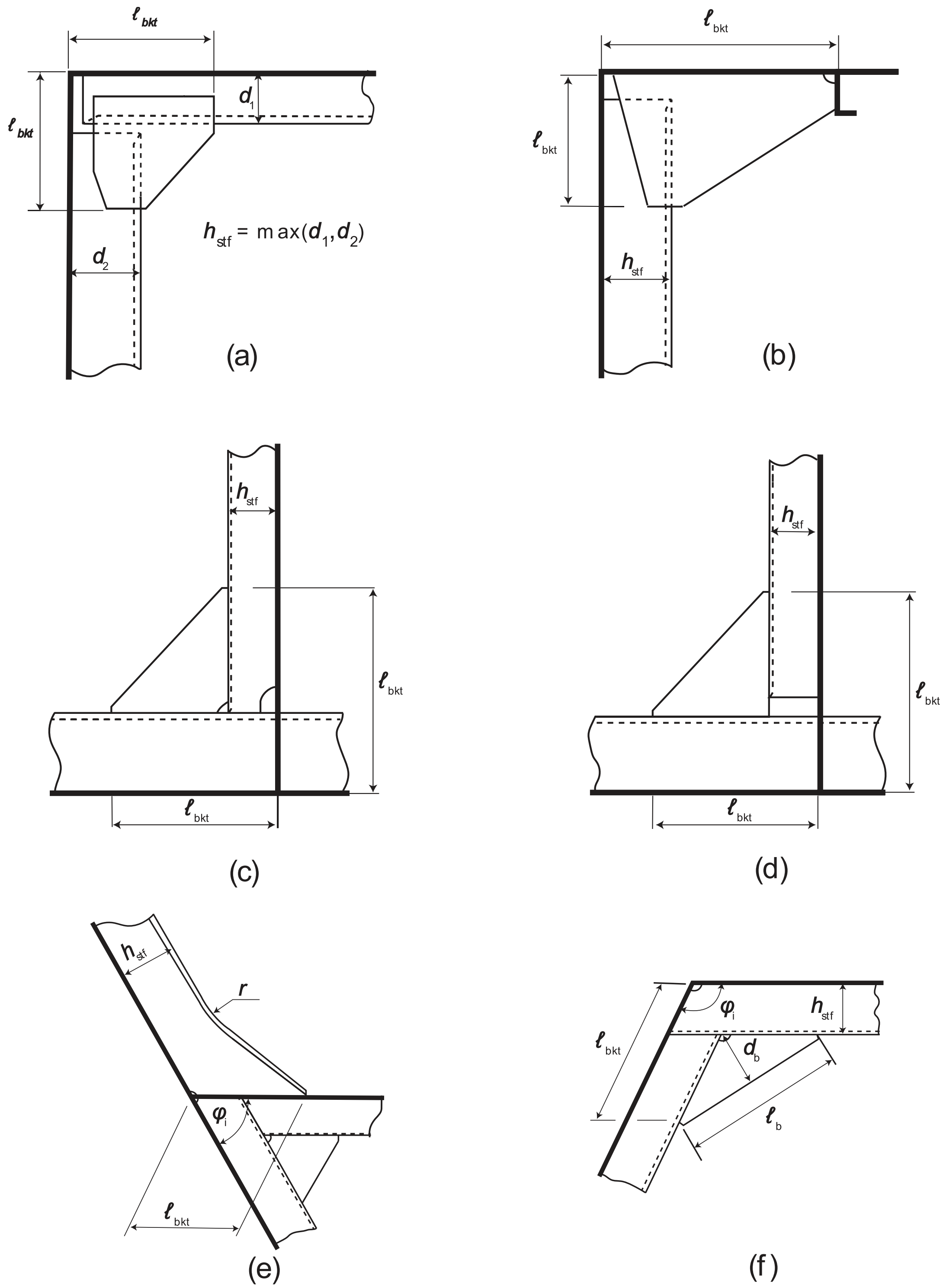

Figure 4 End brackets in way of non-continuous stiffeners

2.2.2 The arrangement of the connection between the stiffener and the bracket shall be such that the section modulus in way of the connection is not less than that required for the stiffener.

2.2.3 Net web thickness

The net bracket web thickness, in mm, shall comply with the following:

$$t_b \geq \min\left(13.5;\ \left(2 + f_{bkt}\sqrt{Z}\right)\sqrt{\frac{R_{eH-stf}}{R_{eH-bkt}}}\right)$$

where:

f_{bkt} = for brackets with flange or edge stiffener, f_{bkt} = 0.2
= for brackets without flange or edge stiffener, f_{bkt} = 0.3
Z = net required section modulus, of the stiffener, in cm^3. In the case of two stiffeners connected, Z is the smallest net required section modulus of the two connected stiffeners
$R_{eH\text{-}stf}$ = specified minimum yield stress of the stiffener material, in N/mm^2
$R_{eH\text{-}bkt}$ = specified minimum yield stress of the bracket material, in N/mm^2.

2.2.4 Brackets size

Brackets shall be fitted at the ends of non-continuous stiffeners. The arm length, in mm, shall satisfy the following:

$$\ell_{bkt} \geq c_{bkt}\sqrt{\frac{Z}{t_b}}$$

and the minimum requirement:

- $\ell_{bkt} \geq 1.8\ h_{stf}$ for connections where the end of the stiffener web is supported and the bracket is welded in line with the stiffener web or with offset necessary to enable welding, see items (c), (e) and (f) in Figure 4.
- $\ell_{bkt} \geq 2.0\ h_{stf}$ for other cases, see items (a), (b) and (d) in Figure 4.

where:

c_{bkt} = for brackets with flange or edge stiffener, c_{bkt} = 65
= for brackets without flange or edge stiffener, c_{bkt} = 70
Z = net required section modulus, for the stiffener, in cm^3
t_b = minimum net bracket thickness, in mm.

For connections similar to item (b) in Figure 4, but not lapped, the bracket arm length shall comply with $\ell_{bkt} \geq h_{stf}$.

For connections similar to items (c) and (d) in Figure 4 where the smaller stiffener is connected to a primary supporting member or bulkhead, the bracket arm length shall not be less than $2h_{stf}$.

2.2.5 Edge stiffening of bracket

Where an edge stiffener is required, the web height of the edge stiffener, in mm, shall not be less than:

$$h_w = 45\left(1 + \frac{Z}{2000}\right) \quad \text{but not less than 50 mm}$$

where:

Z = net section modulus, of the stiffener, in cm^3, as defined in [2.2.3].

For buckling requirement, reference is made to Ch.8 Sec.2 [5.3.1].

2.3 Connection of continuous stiffeners

Connections for longitudinals and other stiffeners running continuously through girders (web frames, transverses, stringers, bulkheads etc.), may be without end brackets provided sufficient connection area is arranged for.

Bracketed end connections are in general to be provided between non-continuous stiffeners on tight boundaries designed for tank pressure or flooding pressure and continuous stiffeners on adjacent boundaries.

2.4 Sniped ends

2.4.1 Sniped ends may be used where dynamic pressures are moderate, provided the net thickness of plating supported by the stiffener, in mm, is not less than:

$$t_p = c_1 \sqrt{\left(1000\ell - \frac{s}{2}\right)\frac{s \cdot P \cdot k}{10^6}}$$

where:

P = design pressure for the stiffener for the design load set being considered, in kN/m^2

c_1 = coefficient taken as:

c_1 = 1.2 for AC-I

c_1 = 1.0 for AC-II and AC-III

For sniped stiffeners fitted between stiffeners, the spacing s, in mm, need not to be taken greater than 1000ℓ, where ℓ is the span, in m, of the sniped stiffener.

In general, sniped stiffeners shall not be used:

— on structures in the vicinity of engines or generators or propeller impulse zone

— at boundaries of sea chest.

2.4.2 Bracket toes and sniped stiffeners ends shall be terminated close to the adjacent member. The distance shall not exceed 40 mm unless the bracket or member is supported by another member on the opposite side of the plating. Tapering of the sniped end shall not be more than 30 degin way of the toe. The depth of toe or sniped end is, generally, not to exceed the thickness of the bracket toe or sniped end member, but need not be less than 15 mm.

2.5 Stiffeners on watertight bulkheads

Bulkhead stiffeners cut in way of watertight doors shall be supported by carlings or stiffeners.

3 Primary supporting members (PSM)

3.1 General

3.1.1 Primary supporting members web stiffeners, tripping brackets and end brackets shall comply with [3.2] to [3.4].

3.1.2 Abrupt changes of web height or cross section shall be avoided. Smooth transitions shall be provided.

3.2 Web stiffening arrangement

Web stiffeners arranged on primary supporting members shall comply with the requirements for scantlings of such stiffeners given in Ch.8 Sec.2 [4.2].

3.3 Tripping bracket arrangement

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

3.3.2 Tripping brackets (see Figure 5) are generally to be fitted:

- at positions along the member span such that it satisfies the criteria of Ch.8 Sec.2 [5.1] for tripping bracket spacing and flange slenderness
- at the termination of end brackets
- at ends of continuous curved face plates
- in way of concentrated loads
- near a change of section
- in line with a longitudinal stiffener
- at knuckles.

3.3.3 For a flange with a breadth, b_f, of 200 mm or more, the flange shall be connected to the tripping bracket, see Figure 5.

3.3.4 For a free flange outstand, $b_{f\text{-}out}$, as defined in Ch.8 Sec.2, of 200 mm or more, the flange outstand shall be connected to the tripping bracket.

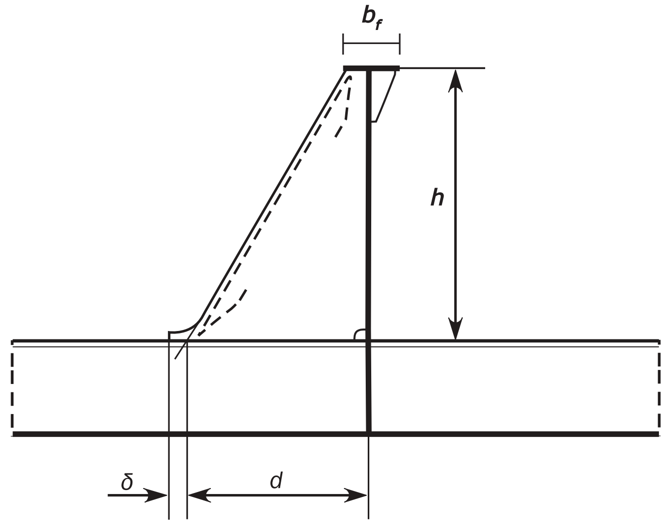

Figure 5 Tripping bracket arrangement for primary supporting members

3.3.5 Arm length

The arm length of tripping brackets shall not be less than the greater of the following values, in m:

$$d = 0.38h$$

and

$$d = 0.85h\sqrt{\frac{s_t}{t_b}}$$

where:

h = height, in m, of tripping brackets, shown in Figure 5
s_t = spacing, in m, of tripping brackets
t_b = net thickness, in mm, of tripping brackets.

3.4 End connections

3.4.1 General

Brackets or equivalent structure shall be provided at ends of primary supporting members.

End brackets are generally to be made with soft toe in areas considered critical with respect to fatigue.

Bracketless connections may be applied provided that there is adequate support of adjoining face plates, ref. [3.4.4].

3.4.2 Scantling of end brackets

In general, the arm lengths of brackets connecting PSMs, as shown in Figure 6 shall not be less than the web depth of the member, and need not be taken greater than 1.5 times the web depth. Direct strength calculations by means of grillage analysis or FE analysis will be considered as alternative basis for the scantlings. The acceptance criteria to be applied for grillage analysis are defined in Ch.6 Sec.6 [2]. A FE analysis shall be performed in accordance with the requirements given in Ch.7.

The thickness of the bracket is, in general, not to be less than that of the PSM web plate.

Scantlings of the end brackets shall be such that the section modulus of the PSM with end bracket, excluding face plate where it is sniped, shall not be less than that of the primary supporting member at mid-span.

The net cross sectional area, in cm^2, of face plates of brackets shall not be less than:

$$A_f = \ell_b \cdot t_b$$

where:

ℓ_b = length of bracket edge, in m, see Figure 6. For brackets that are curved, the length of the bracket edge may be taken as the length of the tangent at the midpoint of the edge

t_b = minimum net bracket thickness, in mm, as defined in [2.2.4].

Moreover, the net thickness of the face plate shall be not less than that of the bracket web.

Additional requirements with respect to buckling are given in Ch.8 Sec.2 [5.2].

3.4.3 Arrangement of end brackets

Where the length of free edge of bracket, ℓ_b, is greater than 1.5 m, the web of the bracket shall be stiffened as follows:

— the net sectional area, in cm^2, of web stiffeners shall be not less than 16.5 ℓ, where ℓ is the span, in m, of the stiffener

— tripping flat bars shall be fitted. Where the width of the symmetrical face plate is greater than 400 mm, additional backing brackets shall be fitted.

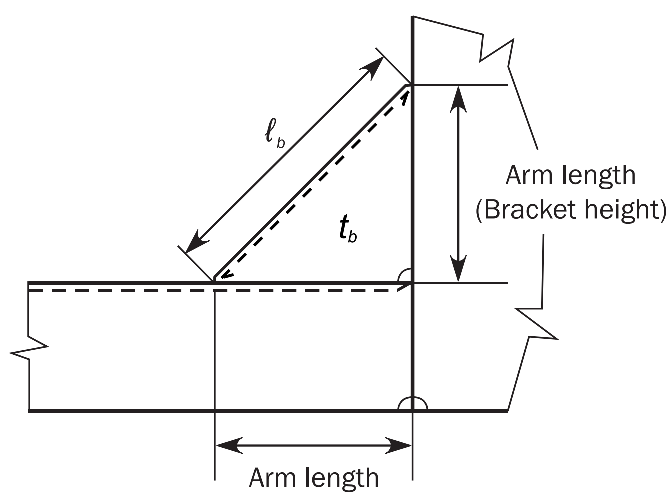

Figure 6 Dimension of brackets

For a ring system where the end bracket is integral with the webs of the members and the face plate is carried continuously along the edges of the members and the bracket, the full area of the largest face plate shall be maintained close to the mid-point of the bracket and gradually tapered to the smaller face plates. Butts in face plates shall be kept well clear of the bracket toes.

Where a wide face plate abuts a narrower one, the taper shall not be greater than 1 to 4.

The toes of brackets shall not end on unstiffened plating. The toe height shall not be greater than the thickness of the bracket toe, but need not be less than 15 mm. In general, the end brackets of primary supporting members shall be soft-toed. Where primary supporting members are constructed of higher strength steel, particular attention shall be paid to the design of the end bracket toes in order to minimise stress concentrations.

Where a face plate is welded onto the edge or welded adjacent to the edge of the end bracket, see Figure 7, the face plate shall be sniped and tapered at an angle not greater than 30°.

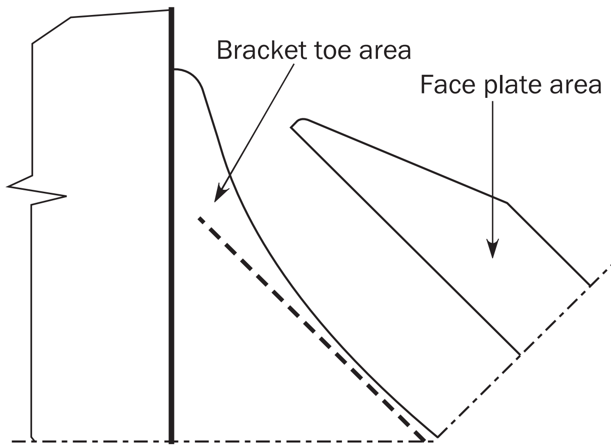

Figure 7 Bracket face plate adjacent to the edge

The details shown in Figure 7 are only used to illustrate items described in the text and are not intended to represent design guidance or recommendations.

3.4.4 Bracketless connections

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

The net thickness of the web plate at the cross joint of bracketless connection (between girder 1 and 2), in mm, shall satisfy the following (see Figure 8):

$$t_{3-n50} \geq \max\left(\frac{100\sigma_1 A_{1-n50} - \tau_2 h_2 t_{2-n50}}{C_t \tau_{eH} h_2}; \frac{100\sigma_2 A_{2-n50} - \tau_1 h_1 t_{1-n50}}{C_t \tau_{eH} h_1}\right)$$

The thickness of the web plate at the cross joint, $t_{3\text{-}n50}$, shall not be less than the greater of $t_{1\text{-}n50}$ and $t_{2\text{-}n50}$ unless verified by direct strength analysis.

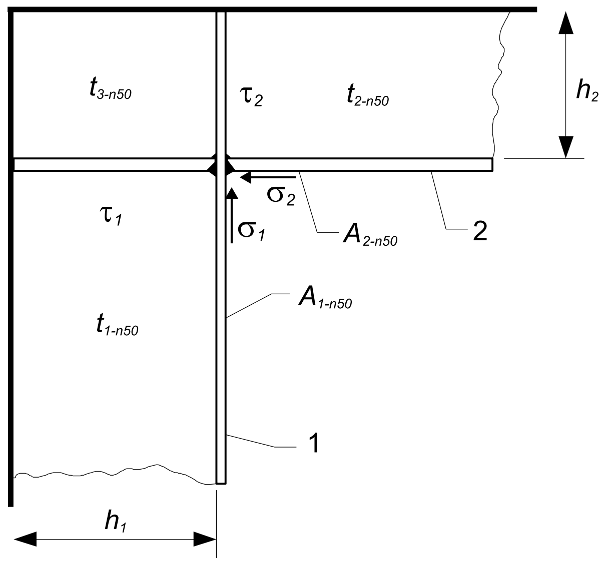

Figure 8 Bracketless joint

$A_{1\text{-}n50}$, $A_{2\text{-}n50}$	=	net flange area in cm^2 of girder 1 and 2
h_1, h_2	=	height in mm of girder 1 and 2
$t_{1\text{-}n50}$, $t_{2\text{-}n50}$	=	net thickness (outside the cross-joint) in mm of girder 1 and 2
τ_1, τ_2	=	shear stress in N/mm^2 in girder 1 and 2
σ_1, σ_2	=	bending stress in N/mm^2 in girder 1 and 2
C_t	=	permissible shear stress coefficient for the design load set being considered, as given in Ch.6 Sec.6 [2.2].

4 Pillars

4.1 General

4.1.1 Rows of pillars shall be fitted in the same vertical line wherever possible. If not possible, effective means shall be provided for transmitting their loads to the supports below.

4.1.2 Effective arrangements shall be made to distribute the load at the heads and heels of all pillars.

4.1.3 Where pillars support eccentric loads, they shall be strengthened for the additional bending moment imposed upon them.

4.1.4 Pillars shall be provided in line with double bottom girders and /or floors or as close thereto as practicable, and the structure above and below the pillars shall be of sufficient strength to provide effective distribution of the load. Where pillars connected to the inner bottom are not located in way of the intersection of floors and girders, partial floors or girders or equivalent structures shall be fitted as necessary to support the pillars.

4.1.5 Pillars in tanks shall be of solid or open section type.

4.2 Connections

4.2.1 Heads and heels of pillars shall be supported to transmit the pillar force into the surrounding structures. Where pillars are likely to be subjected to tensile loads, the head and heel of pillars shall be efficiently secured to withstand the tensile loads, e.g. by fitting end brackets.

4.2.2 In general, the net thickness of doubling plates shall be not less than 1.5 times the net thickness of the pillar. Pillars shall be attached at their heads and heels by continuous welding.

5 Corrugated bulkheads

5.1 Corrugated bulkheads

5.1.1 Construction

The main dimensions a, R, c, d, t_f, t_w, s_C of corrugated bulkheads are defined in Figure 9.

The corrugation angle φ shall generally not be less than 55°. Corrugation angle between 45° and 55° may be accepted provided that the permissible stress/permissible utilization factor for overall bending is reduced by 10%, see Ch.6 Sec.4 [1.2.3] for section modulus, Ch.7 Sec.3 [4.2.4] for yield check and Ch.8 Sec.1 [3.4] for buckling assessment.

When welds in a direction parallel to the bend axis are provided in the zone of the bend, the welding procedures shall be submitted for approval.

For requirements to inside bending radius, R in mm, for cold formed plating, see Sec.1 [2.7].

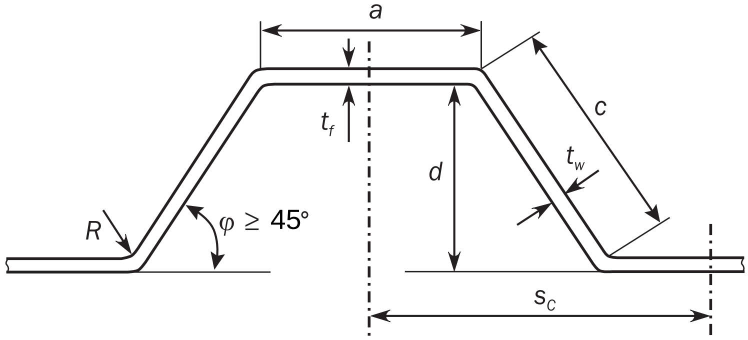

Figure 9 Dimensions of a corrugated bulkhead

5.1.2 Corrugated bulkhead depth

The depth of the corrugation, in mm, shall satisfy:

$$d \geq \frac{1000\ell_c}{C}$$

where:

ℓ_c = mean length of considered corrugation, in m, as defined in [5.1.4]
C = coefficient to be taken as:
C = 15 for tank and water ballast cargo hold bulkheads.
C = 18 for dry cargo hold bulkheads.

5.1.3 Actual section modulus of corrugations

The net section modulus of a corrugation shall be obtained, in cm^3, from the following formula:

$$Z = \left[\frac{d\left(3 \cdot a \cdot t_f + c \cdot t_w\right)}{6}\right]10^{-3}$$

where:

t_f, t_w = net thickness of the plating of the corrugation, in mm, shown in Figure 9
a, d and c = dimensions of the corrugation, in mm, shown in Figure 9.

Where the web continuity is not ensured at ends of the bulkhead, the net section modulus of a corrugation shall be obtained, in cm^3, from the following formula:

$$Z = 0.5 \cdot a \cdot t_f \cdot d \cdot 10^{-3}$$

5.1.4 Span of corrugations

The length ℓ_C of the corrugations shall be taken as the distance shown in Figure 10.

For the definition of ℓ_C, the bottom of the upper stool shall not be taken more than a distance from the deck at the centre line equal to:

— 3 times the depth of corrugation, for non rectangular stool.
— 2 times the depth of corrugation, for rectangular stool.

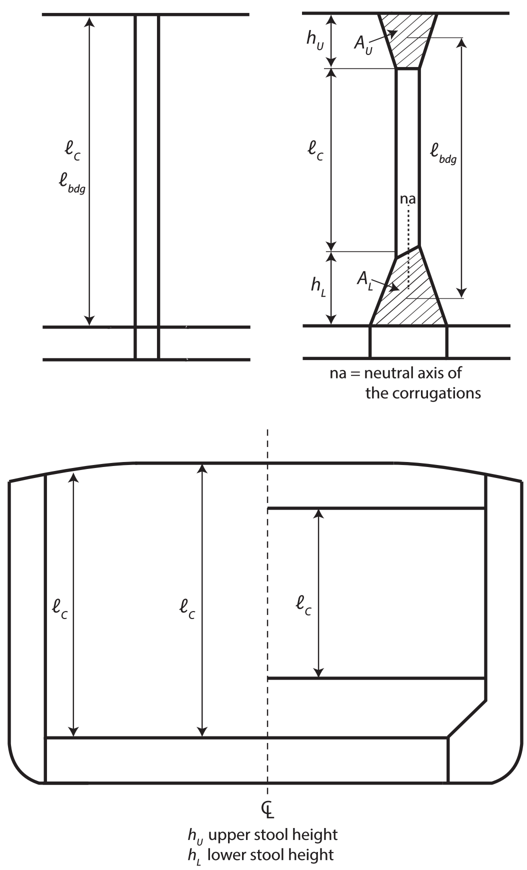

Figure 10 Span of the corrugations

ℓ_{bdg} = effective bending span taken as the distance between supports, ℓin m. For vertically corrugated bulkheads with stool tanks taken as the distance between the area centre of the upper stool A_U and the area centre of the lower stool A_L as shown in Figure 17.

5.1.5 Structural arrangements

Where corrugated bulkheads are cut in way of primary supporting members, corrugations on each side of the primary member shall be aligned with each other.

5.1.6 Bulkhead end supports

The strength continuity of corrugated bulkheads shall be maintained at the ends of corrugations.

Where a bulkhead is provided with a lower stool, floors or girders shall be fitted in line with both sides of the lower stool. Where a bulkhead is not provided with a lower stool, floors or girders shall be fitted in line with both flanges of the vertically corrugated transverse bulkhead.

The supporting floors or girders shall be connected to each other by suitably designed shear plates.

At deck, if no upper stool is fitted, transverse or longitudinal members shall be fitted in line with the corrugation flanges.

When the corrugation flange connected to the adjoining boundary structures, i.e. inner hull, side shell, longitudinal bulkhead, trunk, etc., is smaller than 50% of the width of the typical corrugation flange, an assessment of the stresses due to relative deformation between the adjoining boundary structure and the first corrugation is required.

Guidance note:

An assessment method acceptable to the Society may be to carry out a beam analysis representing a section perpendicular to the corrugation knuckles in way of mid span of corrugations with a cross sectional area of t x t extending over minimum 2 s_c, with boundary conditions from the cargo hold analysis and subjected to lateral pressure. The bending stress in way of the mid of the corrugation flange width shall comply with acceptance criteria given in Ch.6 Sec.4 [1.2.1]. In way of the connection to the adjoining structure the bending stress shall not exceed $\gamma_f R_y$, where γ_f is permissible fine mesh utilization factor as given in Ch.7 Sec.4 [4.2.2].

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

5.1.7 Corrugation web support

For boundaries of tanks, brackets shall be provided in line with the corrugation webs at lower end of vertical corrugations and at both ends for horizontal corrugations. Alternatively, supporting brackets in way of every knuckle of corrugation web may be fitted.

5.1.8 Bulkhead stool

Stool side plating shall be aligned with the corrugation flanges.

6 Openings

6.1 Openings and scallops in stiffeners

6.1.1 Figure 11 shows examples of air holes, drain holes and scallops. In general, the ratio of a/b, as defined in Figure 11, shall be between 0.5 and 1.0. In fatigue sensitive areas further consideration may be required with respect to the details and arrangements of openings and scallops.

6.1.2 Openings and scallops shall be kept at least 200 mm clear of the toes of end brackets, end connections and other areas of high stress concentration, measured along the length of the stiffener toward the mid-span and 50 mm measured along the length in the opposite direction, see Figure 12. In areas where the shear stress is less than 60 percent of the permissible stress, alternative arrangements may be accepted.

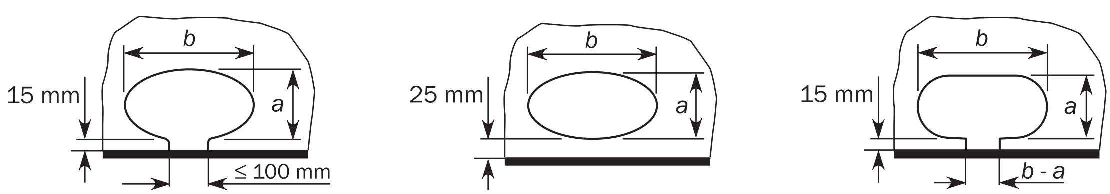

Figure 11 Examples of air holes, drain holes and scallops

The details shown in Figure 11 are for guidance and illustration only.

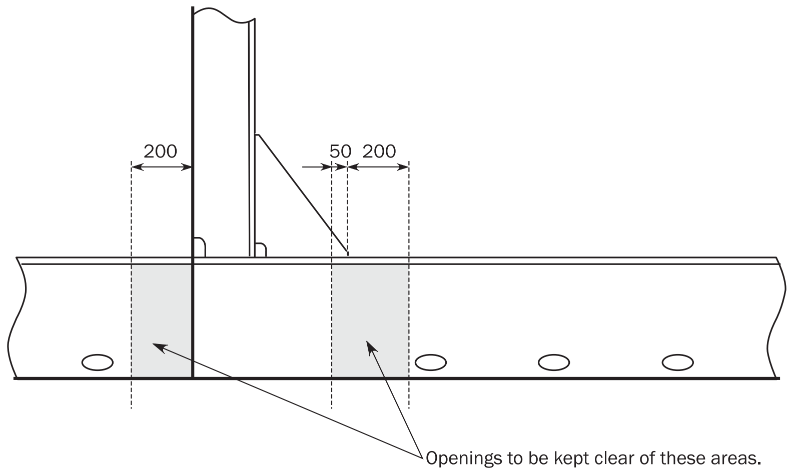

Figure 12 Location of air and drain holes

6.1.3 Closely spaced scallops or drain holes, i.e. where the distance between scallops/drain holes is less than twice the width *b* as shown in Figure 11, are not permitted in stiffeners contributing to the longitudinal strength. For other stiffeners, closely spaced scallops/drain holes are not permitted within 20% of the stiffener span measured from the end of the stiffener. Widely spaced air or drain holes may be permitted provided that they are of elliptical shape or equivalent to minimise stress concentration and are cut clear of the welds.

6.2 Openings in primary supporting members

6.2.1 General

Manholes, lightening holes and other similar openings shall be avoided in way of concentrated loads and areas of high shear.

Examples of high stress areas include:

- Vertical or horizontal diaphragm plates in narrow cofferdams/double plate bulkheads within one-sixth of their length from either end.
- Floors or double bottom girders close to their span ends.
- Primary supporting member webs in way of end bracket toes.
- Above the heads and below the heels of pillars.

Where openings are arranged, the shape of openings shall be such that the stress concentration remains within acceptable limits.

Openings shall be well rounded with smooth edges.

6.2.2 Scallops, air- and drain holes

Requirements given in [6.1] applies.

Scallops shall be avoided in way of fatigue sensitive areas.

Examples of fatigue sensitive areas include:

- Connections of transverse webs in double side or double bottom tanks to hopper tanks.
- Connections at horizontal stringer heel.
- Connections of vertically corrugated bulkhead to lower and upper stool diaphragms.
- Connections of vertically corrugated bulkhead without stool to inner bottom/hopper supporting structures.
- Connections of plain cofferdam bulkhead vertical frames to inner bottom longitudinal girders.

6.2.3 Manholes and lightening holes

Web openings as indicated below do not require reinforcement

— In single skin sections, having depth not exceeding 40% of the web depth and located so that the edges are not less than 20% of the web depth from the faceplate.
— In double skin sections, having depth not exceeding 50% of the web depth and located so that the edges are well clear of cut outs for the passage of stiffeners.

For web openings without reinforcements of free edges, the length of openings shall not be greater than:

— At the mid-span of primary supporting members: the distance between adjacent openings.
— At the ends of the span: 25% of the distance between adjacent openings.

For openings cut in single skin sections, the length of opening shall not be greater than the web depth or 60% of the stiffener spacing, whichever is greater.

Where lightening holes are cut in the brackets, the distance from the circumference of the hole to the free flange of brackets shall not be less than the diameter of the lightening hole.

The diameter of the lightening holes in the bracket floors shall not be greater than 1/3 of the breadth of the brackets.

Openings which require reinforcement shall be stiffened according to [6.2.4]. Where larger openings are proposed, the arrangements and compensation required will be considered on a case by case basis.

6.2.4 Reinforcements around openings

Manholes and lightening holes shall be stiffened according to this requirement, except where alternative arrangements are demonstrated as satisfactory, i.e. the stresses in the plating and the panel buckling characteristics shall be calculated and proofed to be satisfactory.

On members contributing to longitudinal strength, stiffeners shall be fitted along the free edges of the openings parallel to the vertical and horizontal axis of the opening. Stiffeners may be omitted in the direction of the shortest axis. Edge reinforcement may be used as an alternative to stiffeners, see Figure 13.

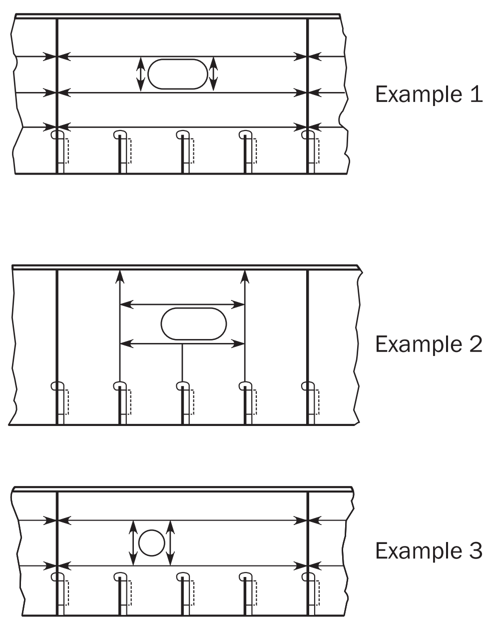

Figure 13 Web plate with openings and stiffeners

In the case of large openings in the web, e.g. where a pipe tunnel is fitted in the double bottom, the secondary stresses in PSMs shall be considered for the reinforcement of these openings.

6.3 Openings in strength deck, side shell, and longitudinal bulkheads

6.3.1 Strength deck

All openings in the strength deck shall have well rounded corners.

Openings in strength deck within 0.6 L amidships (for «open» ships within cargo hold region) are as far as practicable to be located inside the outer line of large hatch openings. Necessary openings outside this line shall be kept well clear of ship's side and hatch corners. Openings in lower decks shall be kept clear of main hatch corners and other areas with high stresses.

Circular openings in strength deck within 0.6 L amidships and for «open» ships within cargo hold region shall have edge reinforcement. The cross-sectional area of edge reinforcements, in cm^2, shall not be less than:

A = $2.5\, d \cdot t$

d = diameter, in m, of opening

t = net plate thickness of strength deck, in mm.

The edge reinforcement of circular openings may be dispensed with, where the opening diameter is less than 300 mm and the smallest distance from another opening is not less than 5 times the diameter of the smaller opening. The distance between the outer edge of openings for pipes etc. and the ship's side shall not be less than the opening diameter.

Rectangular and approximately rectangular openings in areas specified above shall have a breadth not less than 0.4 m. For corners of circular shape the radius shall in general not be less than:

R = $0.2\, b$

b = breadth of opening, in m.

Special considerations with respect to longitudinal stresses and fatigue will be required in case of $R < 0.2b$

The edges of such rectangular openings shall be reinforced as required above for circular openings. For corners of streamlined shape see [6.3.5].

6.3.2 Side shell, longitudinal bulkheads and girders

Openings in side shell, longitudinal bulkheads and longitudinal girders shall be located not less than twice the opening breadth below strength deck or termination of rounded deck corner.

Where openings are cut in the shell plating for windows or side scuttles, hawses, scuppers, sea valves etc., they shall have well rounded corners. If they exceed 700 mm, the openings shall be reinforced by framing, a thicker plate or a ring.

Openings in side shell in areas subjected to large shear stresses shall be of circular shape and shall have edge reinforcement as given in [6.2.4] irrespective of size of opening.

6.3.3 Moonpool corners

For ships having length, L <150 m, moonpool openings in strength deck and bottom shall have corners with rounded or streamline shape. For corners of streamlined shape requirements are given in [6.3.5].

For corners with rounded shape the radius, in m, shall not be taken less than:

$$r = \max(0.025B;\ 0.1b)$$

where:

b = breadth of the opening, in m.

Moonpool corners with smaller radius than required above may be accepted on the results of a direct strength assessment according to Ch.7, including buckling check and fatigue strength assessment of hatch corners according to Ch.8 and Ch.9, respectively. The corner radius shall not in any case be less than 300 mm.

Longitudinal strength members along the hatch openings shall be extended continuously beyond the openings to avoid stress concentrations if terminated at corner.

6.3.4 Large openings and hatchways

For hatchways located within the cargo area, radiused insert plates with thickness not less than determined according to the formula given below, shall be fitted in way of corners.

The radius of circular corners shall not be less than 5% of the hatch width, where a continuous longitudinal deck girder is fitted below the hatch coaming.

Corner radius, in the case of the arrangement of two or more hatchways athwartship, is considered by the Society on a case-by-case basis.

For hatchways located within the cargo area, insert plates are, in general, not required in way of corners where the plating cut-out has an elliptical or parabolic profile and the half axes of elliptical openings, or the half lengths of the parabolic arch, are not less than:

— 1/20 of the hatchway width or 600 mm, whichever is the lesser, in the transverse direction
— twice the transverse dimension, in the fore and aft direction.

Where insert plates are required, their net thickness shall be obtained, in mm, from the following formula:

$$t_{INS} = \left(0.8 + 0.4\frac{b}{\ell}\right) \cdot t_{off}$$

without being taken less than t_{off} or greater than 1.6 t_{off}.

where:

t_{off} = offered net thickness, in mm, of the deck at the side of the hatchways
b = width, in m, of the hatchway considered, measured in the transverse direction
ℓ = length, in m, in way of the corner considered, of the cross deck strip between two consecutive hatchways, measured in the longitudinal direction.

For the extreme corners of end hatchways, insert plates are required.

Where insert plates are required, the arrangement is shown in Figure 14 which d_1, d_2, d_3 and d_4 shall be greater than the stiffener spacing.

For hatchways located outside the cargo area, a reduction in the thickness of the insert plates in way of corners may be considered by the Society on a case-by-case basis.

For ships having length, L, of 150 m or above, the corner radius, the thickness and the extent of insert plate may be determined by the results of a direct strength assessment according to Ch.7, including buckling check and fatigue strength assessment of hatch corners according to Ch.8 and Ch.9 respectively.

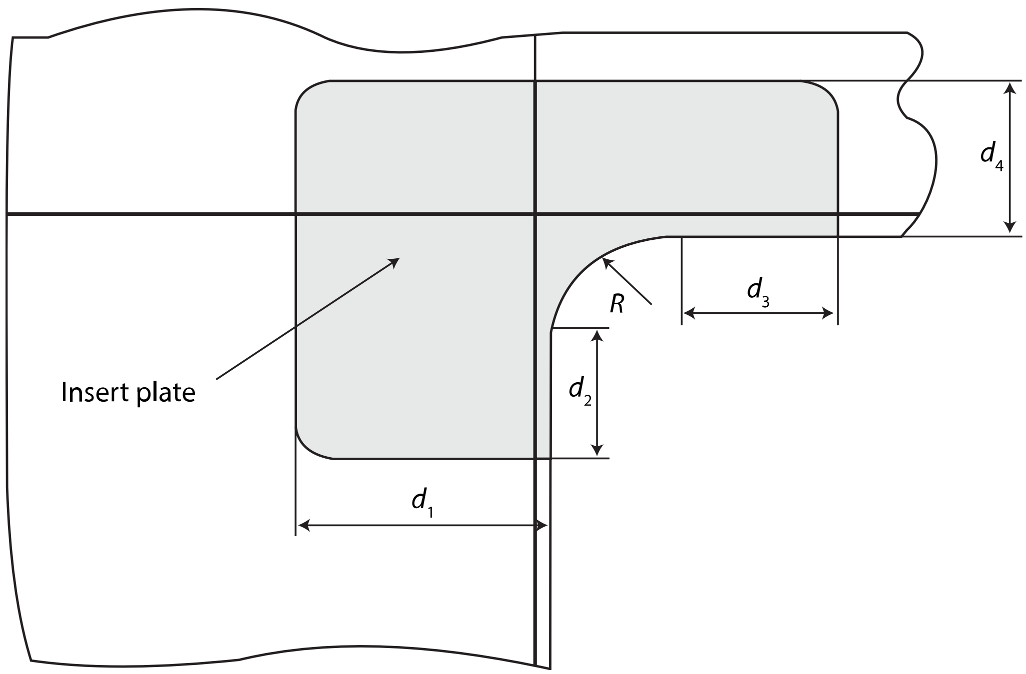

Figure 14 Hatch corner insert plate

6.3.5 Streamlined corner shapes

For corners of streamlined shape of smaller openings, as given by Figure 15 and Table 1, the transverse extension of the curvature, in mm, shall not be less than:

$$a = 0.15\,b$$

Edge reinforcement will then generally not be required. For large hatch openings, see [6.3.6].

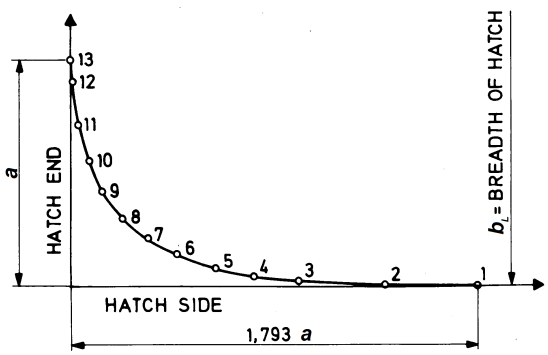

Figure 15 Streamlined deck corner

Table 1 Ordinates of streamlined corner

Point	*Abscissa x*	*Ordinate y*
1	1.793 *a*	0
2	1.381 *a*	0.002 *a*
3	0.987 *a*	0.021 *a*
4	0.802 *a*	0.044 *a*
5	0.631 *a*	0.079 *a*
6	0.467 *a*	0.131 *a*
7	0.339 *a*	0.201 *a*
8	0.224 *a*	0.293 *a*
9	0.132 *a*	0.408 *a*
10	0.065 *a*	0.548 *a*
11	0.022 *a*	0.712 *a*
12	0.002 *a*	0.899 *a*
13	0	1.000 *a*

Alternative hatch corner designs, e.g. key hole type, may be accepted subject to special consideration in each case.

6.3.6 Hatch corners of ships with large deck openings

For cargo hatchways the corners will be specially considered on the basis of the stresses due to longitudinal hull girder bending, torsion and transverse loads.

The following formula shall be used to determine the radii in m, of the hatchway corners:

$$r \geq c_1 \cdot c_2 \text{ with } r \geq r_{min}$$

where:

r_{min} = minimum radius, in m, of the hatchway corner, defined as:
r_{min} = 0.15 for hatchway corners in the strength deck
r_{min} = 0.10 in all other locations

c_1 = coefficient, defined as:

$$c_1 = \left(f_D + \frac{\ell}{750}\right) \cdot b_L$$

for hatchway corners between longitudinal deck strips and a closed area, see HC1 in Figure 16

$$c_1 = 0.4 \cdot b_Q$$

for hatchway corners between transverse deck strips and a closed area, see HC2 in Figure 16

$$c_1 = \left(f_D + \frac{\ell}{750}\right) \cdot \sqrt{\frac{b_L^2 \cdot b_Q^2}{b_L^2 + b_Q^2}}$$ for hatchway corners between two deck strips, see HC3 in Figure 16

f_D = Coefficient for deck configuration, defined as:

$$f_D = 0.25 + \frac{L_{13}}{2000}$$ for hatchway corners of the strength deck and for decks and coamings above strength deck

$$f_D = 0.20 + \frac{L_{13}}{1800}$$ for the strength deck, decks and coamings above strength deck and for decks within the distance of maximum b_L below the strength deck, if a further deck with the same hatchway corner radius is arranged in a distance of less than b_L below the strength deck

$$f_D = 0.10$$ for lower decks where the distance from the strength deck exceeds b_L

ℓ = relevant length, in m, of large deck openings forward and/or aft of superstructure

b_L = breadth, in m, of deck girder alongside the hatchway

b_Q = breadth, in m, of cross deck strip between hatchway

For all hatchway corners, b_L and b_Q shall be taken as the breadths of the longitudinal or transverse structural members adjacent to the hatchway corners

L_{13} = rule length, L, But not to be taken less than 100 m and not greater than 300 m

c_2 = coefficient, defined as:

$$c_2 = \frac{M_T \cdot (z_D - z_0)}{I_{y-gr} \cdot 175 \cdot 10^3 \cdot c_s} \cdot \frac{t_D}{t_i} \cdot \sqrt[4]{k_i}$$

M_T = total longitudinal bending moment, in kNm, according to at the forward or aft edge of the relevant cross deck strip or relevant closed area

z_D = distance, in m, of the relevant hatchway corner from baseline

z_0 = distance, in m, of neutral axis of the hull section from the baseline

t_i = gross thickness, in mm, of the hatchway corner plate, with:

$$1.0 \geq \frac{t_D}{t_i} \geq 0.65$$

t_D = gross plate thickness, in mm, of the longitudinal structural member

$I_{y\text{-}gr}$ = gross moment of inertia, in m^4, of the section in the hatchway corner without insert plate

c_s = distribution factor, defined as:

for the strength deck:

$$c_s = 0.5 + \frac{5}{3} \cdot \frac{x}{L} \quad \text{for} \quad 0 \le \frac{x}{L} < 0.3$$

$$c_s = 1.0 \quad \text{for} \quad 0.3 \le \frac{x}{L} < 0.7$$

$$c_s = 0.5 + \frac{5}{3} \cdot \frac{x}{L} \quad \text{for} \quad 0.7 \le \frac{x}{L} < 1.0$$

for the lower deck:

$$c_s = 1.0$$

k_i = material factor of the relevant hatchway corner.

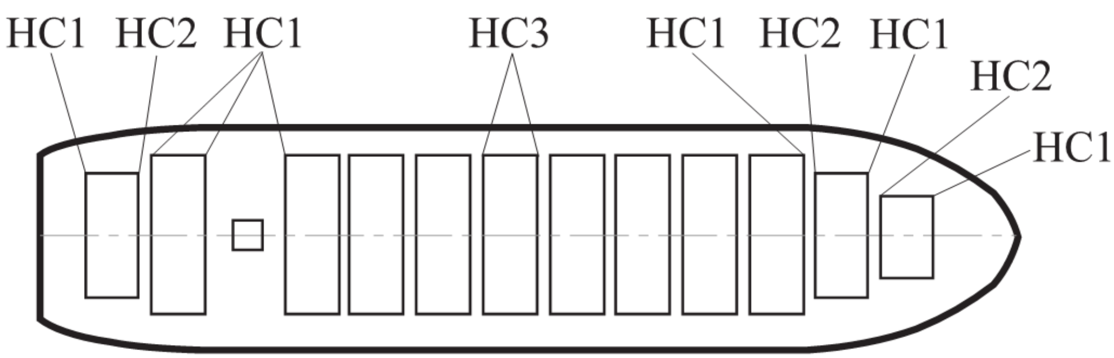

Figure 16 Positions of hatch corners

Where required by above calculation or on the basis of direct fatigue assessment, hatchway corners shall be strengthened by insert plates with minimum size *a* and *b*, in mm, see Figure 17:

$$a = 3 \cdot (t_i - t_{gr}) + 300 \quad \text{with} \quad a \ge a_{min}$$

$$b = r + 3r \cdot (t_i - t_{gr}) + 125$$

where:

a_{min} = minimum distance, in mm, defined as:
a_{min} = 350

Openings in way of hatchway corners shall not be located within the following minimum distances, see Figure 17.

Openings outside of insert plate:

c = distance, in mm, of opening from butt seam, defined as:

$$c = 2 \cdot t_{gr} + h + 50$$ for strength deck

$$b = 2 \cdot t_{gr} + \frac{h}{2} + 50$$ for lower decks

Openings inside of insert plate:

e = distance, in mm, of opening from longitudinal bulkhead, defined as:

$$e = 2 \cdot r + \frac{h}{2}$$ for strength deck

$$e = 1.5 \cdot r + \frac{h}{2}$$ for lower decks

where:

t_{gr} = gross thickness, in mm, of the deck plate

h = diameter, in mm, of opening.

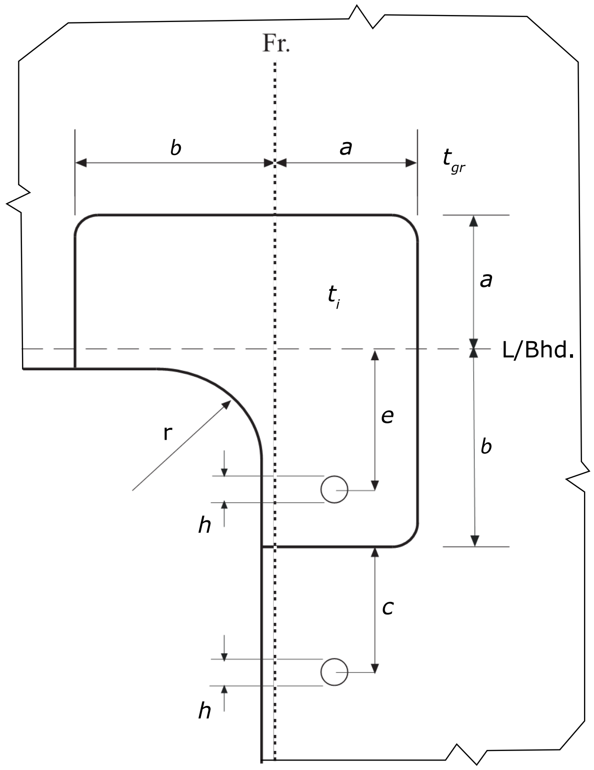

Figure 17 Insert plate, parameter definition

On the basis of direct calculations, other minimum distances may be accepted on a case by case basis by the Society.

Outside 0.5 *L* amidships the net thickness of the insert plate shall not exceed 1.6 times the thickness of the deck plating abreast the hatchway.

SECTION 7 STRUCTURAL IDEALISATION

Symbols

For symbols not defined in this section, refer to Ch.1 Sec.4.

PSM = primary Supporting Member
EPP = elementary Plate Panel
LCP = load Calculation Point
φ_w = angle, in deg, between the stiffener or PSM web and the attached plating, see Figure 11. φ_w shall be taken equal to 90 deg if the angle is greater than or equal to 75 deg
ℓ_{bdg} = effective bending span, in m, as defined in [1.1.2] for stiffeners and [1.1.8] for PSM
ℓ_{shr} = effective shear span, in m, as defined in [1.1.4] for stiffeners and [1.1.9] for PSM
ℓ = full length of stiffener or of PSM, in m, between their supports
s = stiffener spacing, in mm, as defined in [1.2]
S = PSM spacing, in m, as defined in [1.2]
a = length, in mm, of EPP as defined in [2.1.1]
b = breadth, in mm, of EPP as defined in [2.1.1]
h_{stf} = stiffener height, including the face plate, in mm
t_p = net thickness of attached plate, in mm
t_w = net web thickness, in mm
b_f = breadth of flange, in mm, see Sec.2 Figure 1. For bulb profiles, see Table 1 and Table 2
t_f = net thickness of flange, in mm.

1 Structural idealisation of stiffeners and primary supporting members

1.1 Effective spans

1.1.1 General

Where arrangements differ from those defined in this article, span definition may be specially considered.

1.1.2 Effective bending span of stiffeners

The effective bending span ℓ_{bdg} of stiffeners shall be measured as shown in Figure 1 for single skin structures and Figure 2 for double skin structures.

If the web stiffener is sniped at the end or not attached to the stiffener under consideration, the effective bending span shall be taken as the full length between PSMs unless a backing bracket is fitted.

The effective bending span may be reduced where brackets are fitted to the flange or free edge of the stiffener. The effective bending span shall not be reduced for brackets fitted to the attached plating on the opposite side to that of the stiffener.

In single skin structures, the effective bending span of a stiffener supported by a bracket or by a web stiffener on one side only of the primary supporting member web, shall be taken as the total span between primary supporting members as shown in item (a) of Figure 1. If brackets are fitted on both sides of the primary supporting member, the effective bending span shall be taken as in items (b), (c) and (d) of Figure 1.

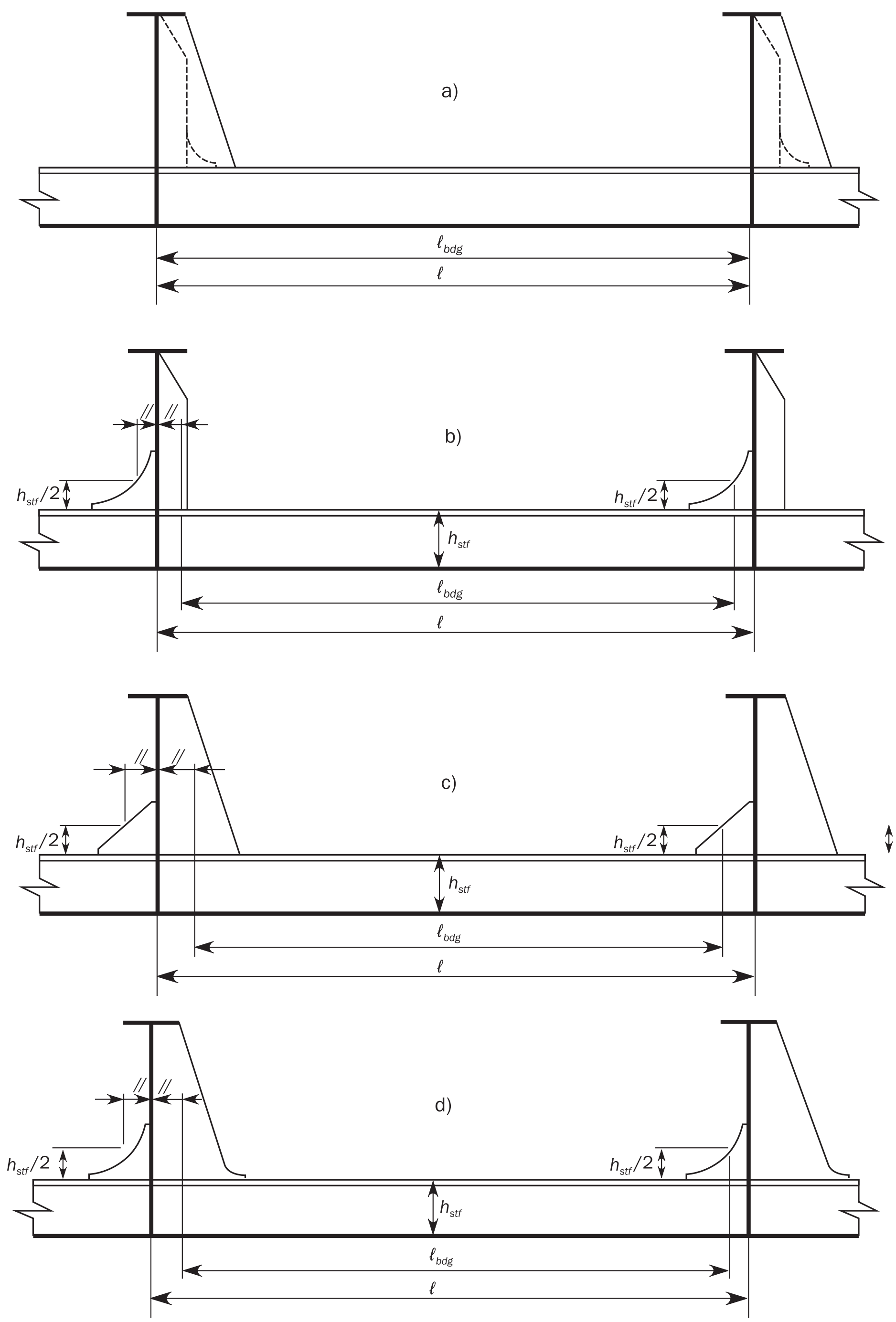

Figure 1 Effective bending span of stiffeners supported by web stiffeners (single skin construction)

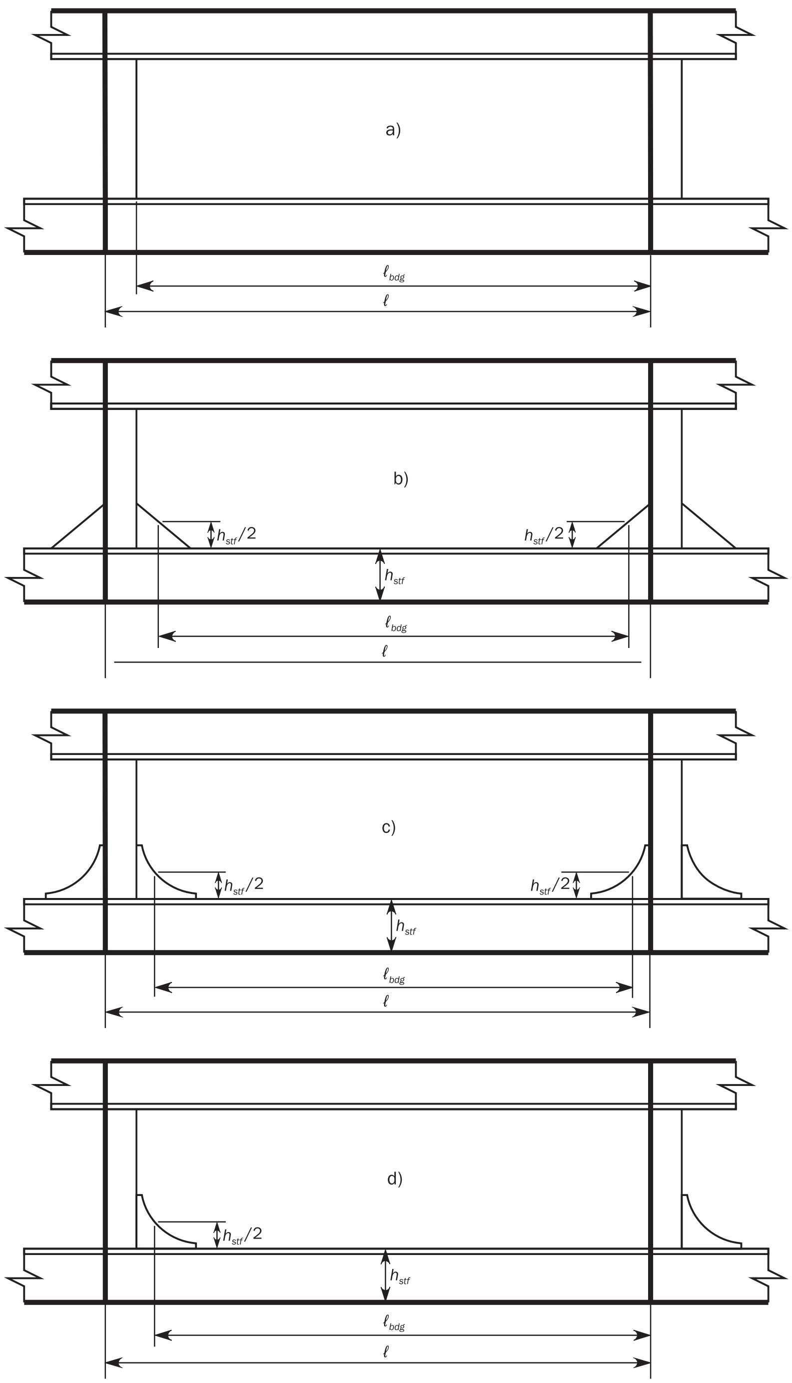

Figure 2 Effective bending span of stiffeners supported by web stiffeners (double skin construction)

1.1.3 Effective bending span of stiffeners with continuous flange along bracket edge

Where the flange of the stiffener is continuous along the edge of the bracket, the effective bending span shall be taken to the position where the depth of the bracket is equal to one quarter of the depth of the stiffener, see Figure 3.

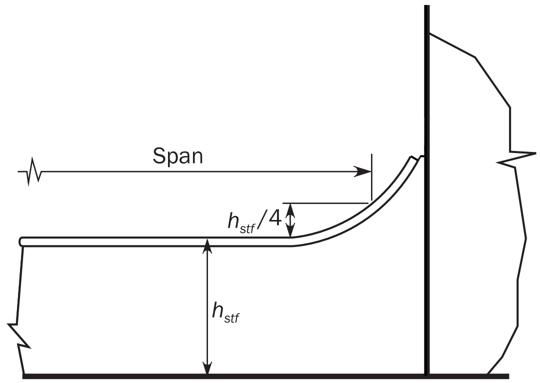

Figure 3 Effective bending span of stiffener with continuous flange along bracket edge

1.1.4 Effective shear span of stiffeners

The effective shear span, ℓ_{shr} in m, of stiffeners shall be measured as shown in Figure 4 for single skin structures and Figure 5 for double skin structures.

Regardless of support detail, the full length of the stiffener shall be reduced by a minimum of s/4000 m at each end of the member, hence the effective shear span ℓ_{shr}, shall not be taken greater than:

$$\ell_{shr} \leq \ell - \frac{s}{2000}$$

The effective shear span may be reduced for brackets fitted on either the flange or the free edge of the stiffener, or for brackets fitted to the attached plating on the side opposite to that of the stiffener.

If brackets are fitted at both the flange or free edge of the stiffener, and to the attached plating on the side opposite to the stiffener the effective shear span may be reduced using the longer effective bracket arm.

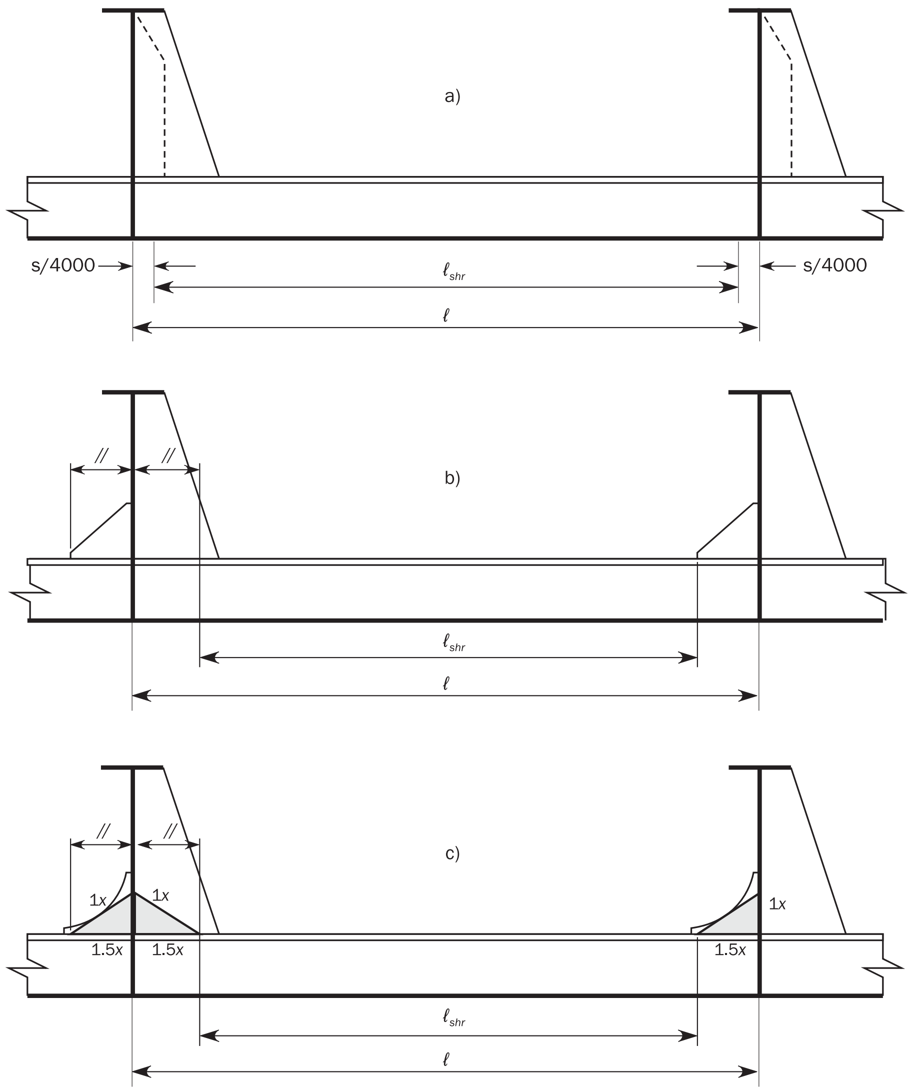

Figure 4 Effective shear span of stiffeners supported by web stiffeners (single skin construction)

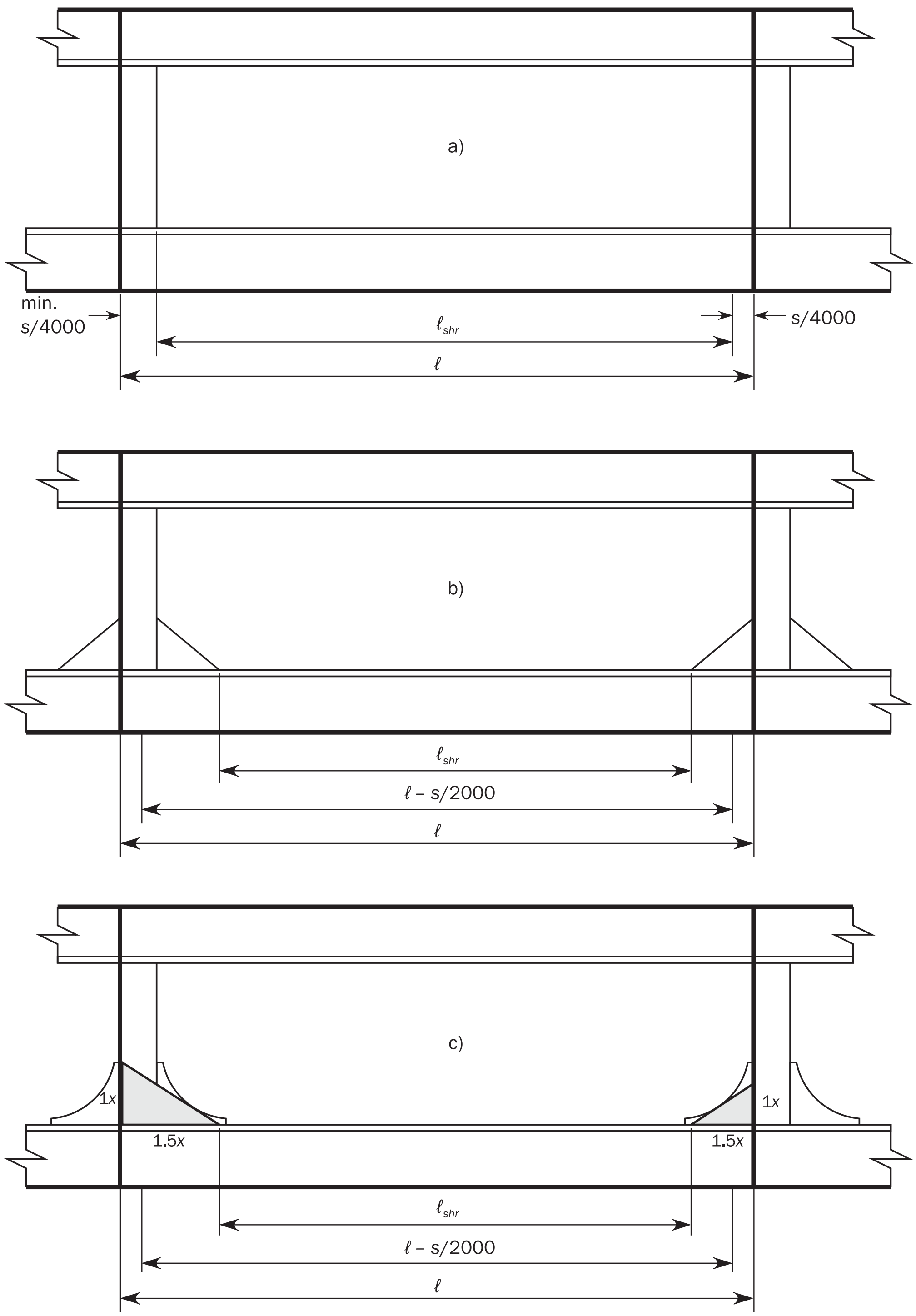

Figure 5 Effective shear span of stiffeners supported by web stiffeners (double skin construction)

1.1.5 Effective shear span of stiffeners with continuous flange along bracket edge

For curved and/or long brackets (high length/height ratio), the effective bracket length shall be taken as the maximum inscribed 1:1.5 triangle as shown in item (c) of both Figure 4 and Figure 5.

Where the flange of the stiffener is continuous along the curved edge of the bracket, the bracket length to be considered for determination of the shear span shall not be taken greater than 1.5 times the length of the bracket arm as shown in Figure 6.

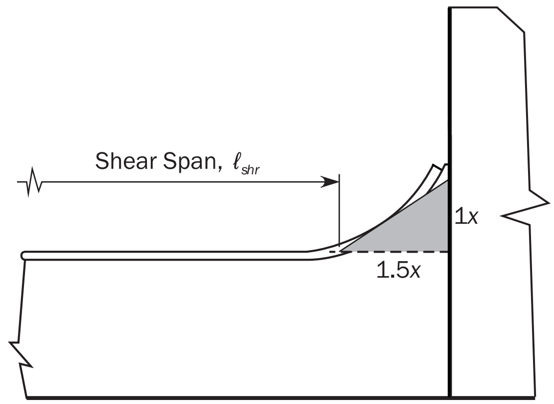

Figure 6 Effective shear span of stiffener with continuous flange along bracket edge

1.1.6 Effective span of stiffeners supported by struts

Stiffeners supported by struts are not allowed in way of boundaries to cargo tanks or fuel oil tanks.

The bending- and shear span, ℓ_{bdg} and ℓ_{shr}, of stiffeners supported by one strut fitted at mid distance of the primary supporting members shall be taken as 0.8ℓ, see Figure 7.

In case where two struts are fitted at 1/3 and 2/3 length between primary supporting members, the bending- and shear span, ℓ_{bdg} and ℓ_{shr}, of stiffeners shall be taken as 0.7ℓ, see Figure 8.

When the ratio between the net section modulus of the larger stiffeners and the smaller stiffeners connected by strut(s) exceeds 1.5, the above reduction in the bending span is not applicable.

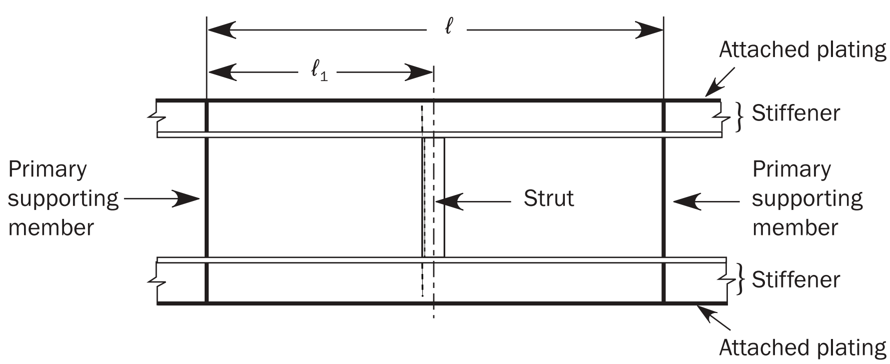

Figure 7 Span of stiffeners with one strut

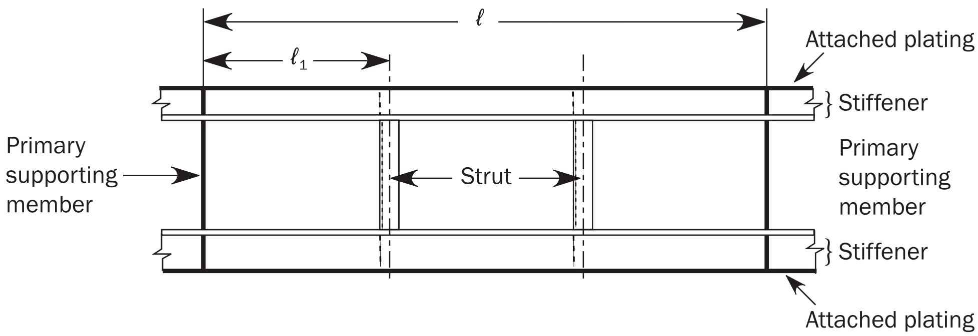

Figure 8 Span of stiffeners with two struts

1.1.7 Effect of hull form shape on span of stiffeners

For curved stiffeners, the span is defined as the chord length between span points to be measured at the flange for stiffeners with a flange, and at the free edge for flat bar stiffeners, see Figure 9. The calculation of the effective span shall be in accordance with requirements given in [1.1.2] and [1.1.4].

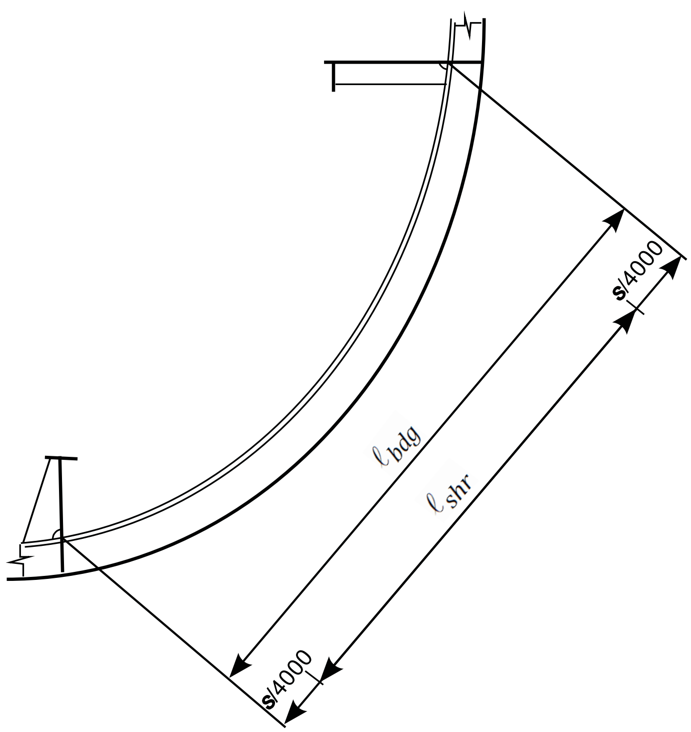

Figure 9 Effective span of curved stiffener

1.1.8 Effective bending span of primary supporting members

The effective bending span, ℓ_{bdg}, in m, of a primary supporting member without end bracket shall be taken as the length of the member between supports.

The effective bending span, ℓ_{bdg}, of a primary supporting member may be taken as less than the full length of the member between supports provided that suitable end brackets are fitted.

The effective bending span ℓ_{bdg}, in m, of a primary supporting member with end brackets is taken between points where the depth of the bracket is equal to half the web height of the primary supporting member as shown in item (b) of Figure 10. The effective bracket used to define these span points shall be taken as given in [1.1.11].

In case of brackets where the face plate of the member is continuous along the face of the bracket, as shown in items (a), (c) and (d) of Figure 10, the effective bending span ℓ_{bdg}, in m, is taken between points where the depth of the bracket is equal to one quarter the web height of the primary supporting member. The effective bracket used to define these span points shall be taken as given in [1.1.11].

For straight brackets with a length to height ratio greater than 1.5, the span point shall be taken to the effective bracket; otherwise the span point shall be taken to the fitted bracket.

For curved brackets, for span positions above the tangent point between fitted bracket and effective bracket, the span point shall be taken to the fitted bracket; otherwise, the span point shall be taken to the effective bracket.

For arrangements where the primary supporting member face plate is carried on to the bracket and backing brackets are fitted, the span point need not be taken greater than to the position where the total depth reaches twice the depth of the primary supporting member. Arrangements with small and large backing brackets are shown in items (e) and (f) of Figure 10.

For arrangements where the height of the primary supporting member is maintained and the face plate width is increased towards the support; the effective bending span may be taken to a position where the face plate breadth reaches twice the nominal breadth.

1.1.9 Effective shear span of primary supporting members

The effective shear span of the primary supporting member may be reduced compared to effective bending span, and taken between the toes of the effective brackets supporting the member, where the toes of effective brackets are as shown in Figure 11. The effective bracket used to define the toe point is given in [1.1.11].

For arrangements where the effective backing bracket is larger than the effective bracket in way of face plate, the shear span shall be taken as the mean distance between toes of the effective brackets as shown in item (f) of Figure 11.

1.1.10 Effect of hull form shape on span of primary supporting members

For curved primary supporting members, the span is defined as the cord length between span points. The calculation of the effective span shall be in accordance with requirements given in [1.1.9].

1.1.11 Effective bracket definition

The effective bracket is defined as the maximum size of triangular bracket with a length to height ratio of 1.5 that fits inside the fitted bracket. See Figure 10 for examples.

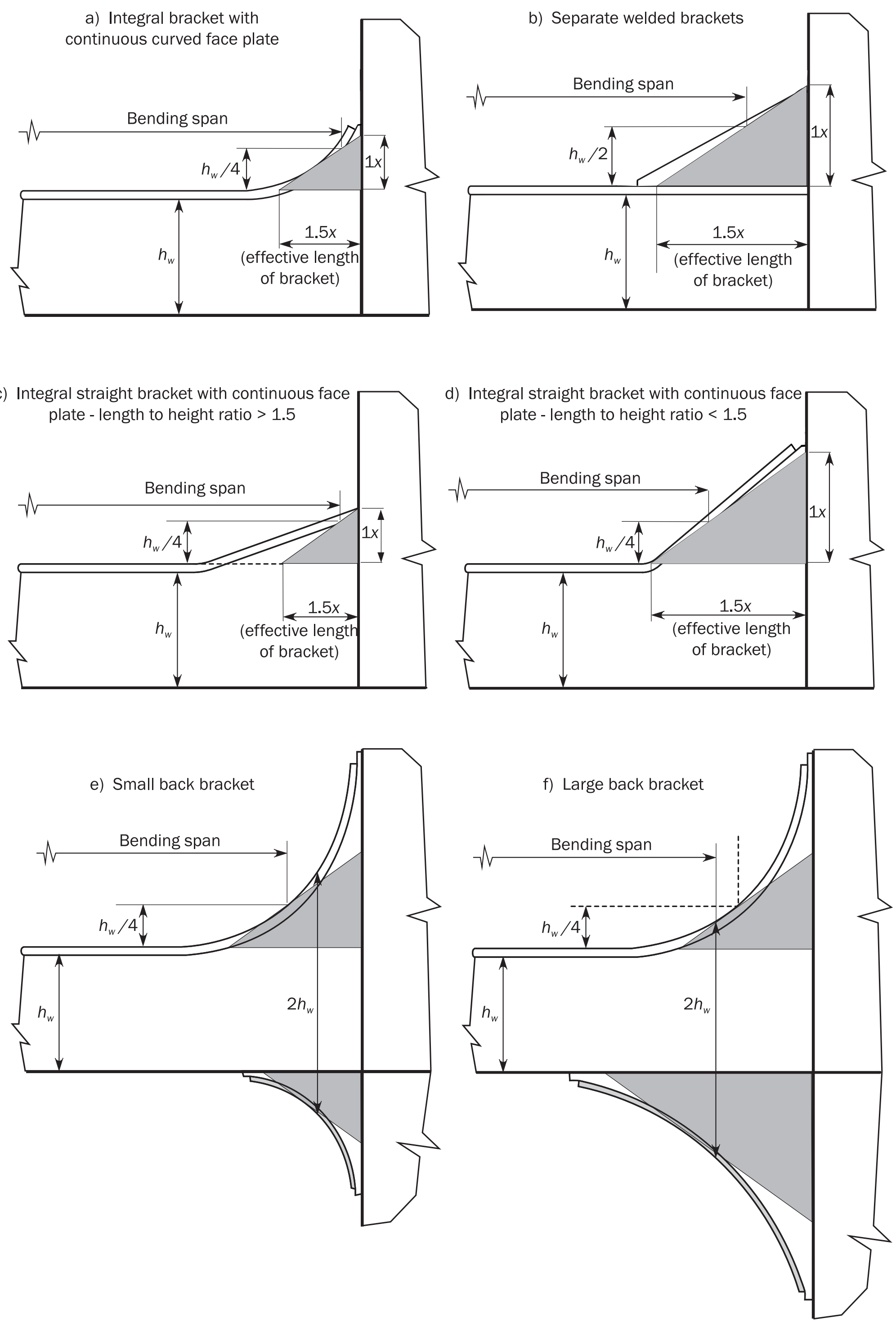

Figure 10 Effective bending span of primary supporting member

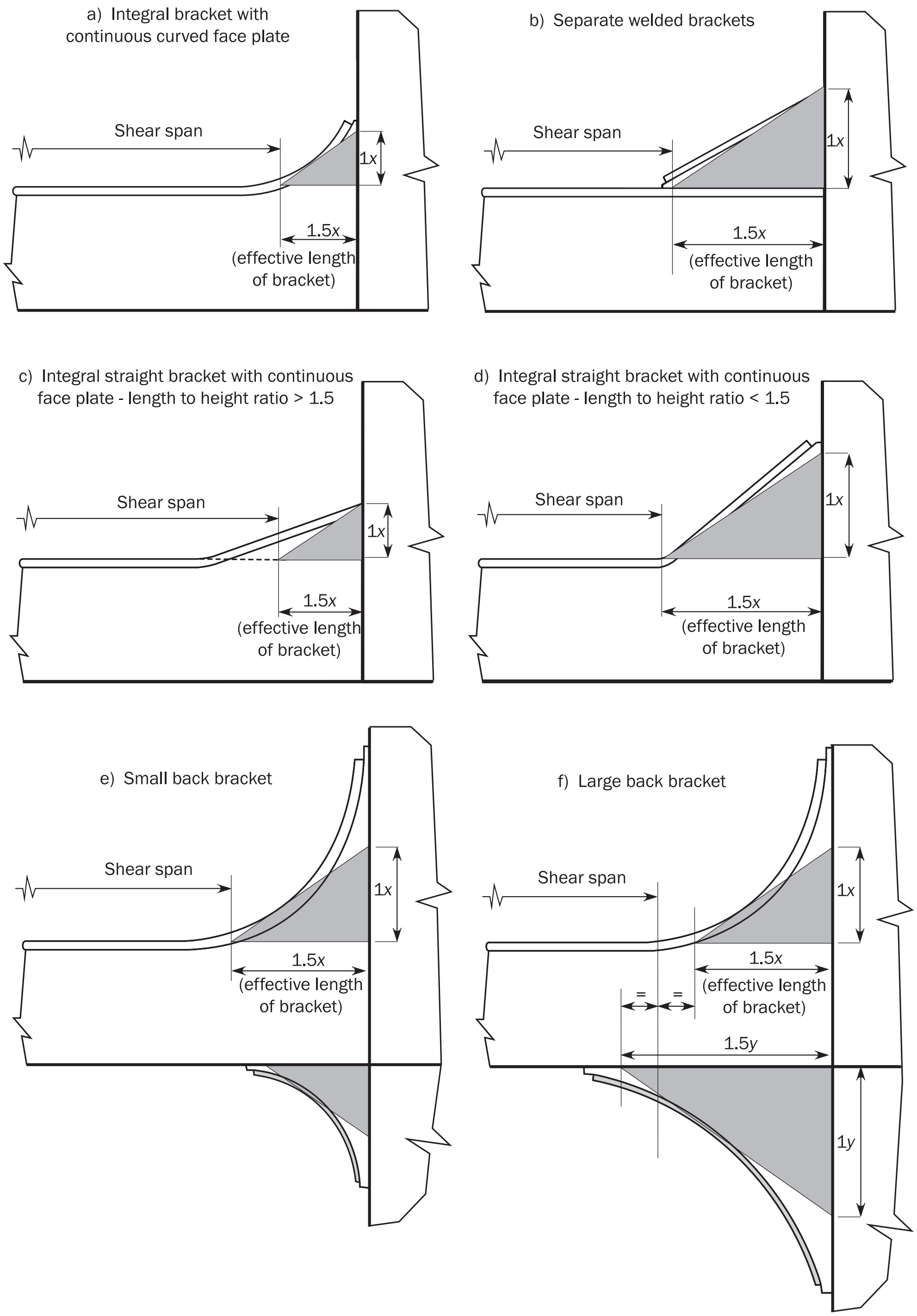

Figure 11 Effective shear span of primary supporting member

1.2 Spacing and load supporting breadth

1.2.1 Stiffeners

Stiffener spacing, *s*, in mm, for the calculation of the effective attached plating of stiffeners shall be taken as the mean spacing between stiffeners, see Figure 12:

$$s = \frac{b_1 + b_2 + b_3 + b_4}{4}$$

where:

b_1, b_2, b_3, b_4 = spacings between stiffeners at ends measured along plating, in mm.

In general, the loading breadth supported by stiffener shall be taken equal to *s*.

1.2.2 Primary supporting member

Primary supporting member spacing, *S*, for the calculation of the effective attached plating of primary supporting members shall be taken as the mean spacing between adjacent primary supporting members, and taken equal to, see Figure 12.

$$S = \frac{b_1 + b_2 + b_3 + b_4}{4}$$

where:

b_1, b_2, b_3, b_4 = spacings between primary supporting members at ends measured along plating, in m.

In general, the loading breadth supported by a primary supporting member shall be taken equal to *S*.

1.2.3 Spacing of curved plating

For curved plating, the stiffener spacing, *s* or the primary supporting member spacing, *S* shall be measured on the mean chord between members.

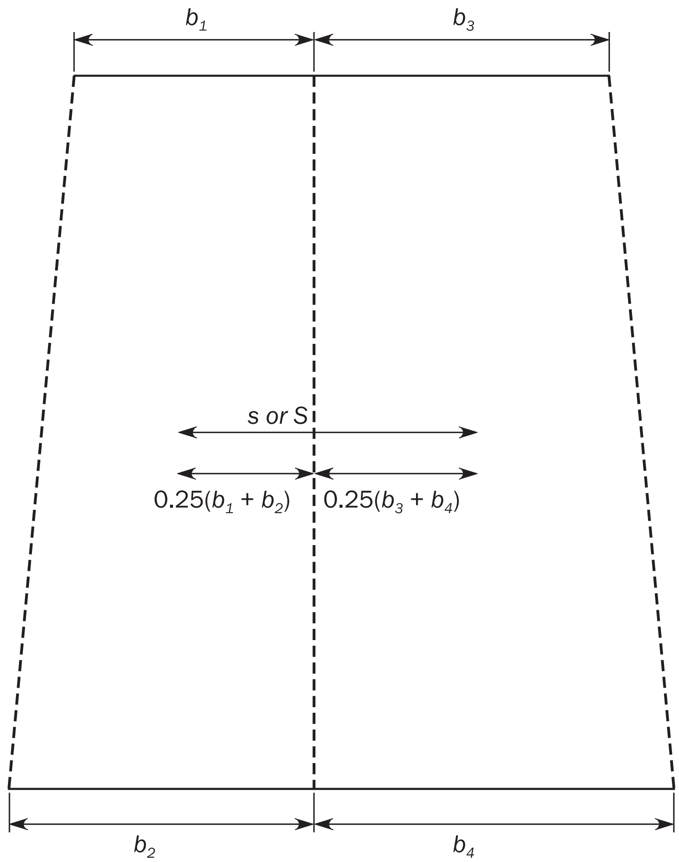

Figure 12 Spacing of plating

1.3 Effective breadth

1.3.1 Stiffeners

The effective breadth, b_{eff}, in mm, of the attached plating to be considered in the actual net section modulus for the yielding check of stiffeners shall be obtained from the following formulae:

— where the plating extends on both sides of the stiffener:

$b_{eff} = 200 \cdot \ell$, or

$b_{eff} = s$

whichever is lesser.

— where the plating extends on one side of the stiffener, i.e. stiffeners bounding openings:

$b_{eff} = 100 \cdot \ell$, or

$b_{eff} = 0.5\ s$

whichever is lesser.

However, where the attached plate net thickness is less than 8 mm, the effective breadth shall not be taken greater than 600 mm.

The effective breadth, b_{eff}, in mm, of the attached plating to be considered for the buckling check of stiffeners is given in the Society's document DNVGL CG 0128, *Buckling*.

1.3.2 Primary supporting members

The effective breadth of attached plating, b_{eff} in m, for calculating the section modulus and/or moment of inertia of a primary supporting member with uniform load shall be taken as:

$$b_{eff} = S \cdot min\left[\frac{1.12}{1 + 1.75 \Big/ \left(\frac{\ell_{bdg}}{S\sqrt{3}}\right)^{1.6}} ; 1.0\right] \qquad for \qquad \frac{\ell_{bdg}}{S\sqrt{3}} \geq 1.0$$

$$b_{eff} = 0.407\left(\frac{\ell_{bdg}}{\sqrt{3}}\right) \qquad for \qquad \frac{\ell_{bdg}}{S\sqrt{3}} < 1.0$$

For double skin sections such as double bottom or double side structures with uniform load, full flange effectivity may normally be assumed for the members representing the floors or web frames. The effective breadth of attached plating, b_{eff} in m, shall be taken as:

$$b_{eff} = S$$

Within $0.1\ell_{bdg}$ from the end of bending span or in way of concentrated point loads, the effective breadth b_{eff}^{*} in m of the attached plating shall be taken as:

$$b_{eff^*} = 0.5 \cdot b_{eff}$$

1.3.3 Primary supporting members in way of cargo area

In way of cargo area where significant in plane stresses may occur, the effective breadth of attached plating, b'_{eff} in m, for calculating section modulus, moment of inertia and effective cross section area of a primary supporting member (PSM) shall be taken as:

$b'_{eff} = n_1 \cdot b_m$ for stiffening parallel to web of PSM

$b'_{eff} = \min(n_2 \cdot C_y \cdot S;\ b_{eff})$ for stiffening perpendicular to web of PSM

where:

n_1 = integer number of stiffeners inside the effective breadth b_{eff}, defined as:

$$n_1 = \mathrm{int}\left(\frac{1000 \cdot b_{eff}}{s}\right)$$

n_2 = coefficient defined as:

$$n_2 = \min\left(\frac{2.7 \cdot b_{eff}}{S}; 1.0\right)$$

b_{eff} = effective breadth of attached plating of PSM according to [1.3.2], in m

b_m = effective width of plating for stiffeners parallel to web of PSM see Figure 14, in m:

$$b_m = \frac{\min\left(\frac{C_{x1}b_1 + C_{x2}b_2}{2}; \chi_s s\right)}{1000}$$

b_1, b_2 = breadth of plating at each side of the considered stiffener, in mm, see Figure 14

C_{x1}, C_{x2} = reduction factor for plating at each side of the considered stiffener, calculated with edge stress ratio ψ = 1.0 for Case 1 in DNVGL CG 0128 Sec.3 Table 3

χ_s = effective width coefficient for the stiffener considered according to DNVGL CG 0128 Sec.3 [2.3.5]

C_y = reduction factor for plating calculated with edge stress ratio ψ = 1.0 for Case 2 in DNVGL CG 0128 Sec.3 Table 3.

For calculation of properties of primary supporting members with the stiffeners parallel to the web, the stiffener area within b_{eff} may be included provided that the actual geometry of the stiffeners, e.g. centre of area, is correctly represented, see Figure 13.

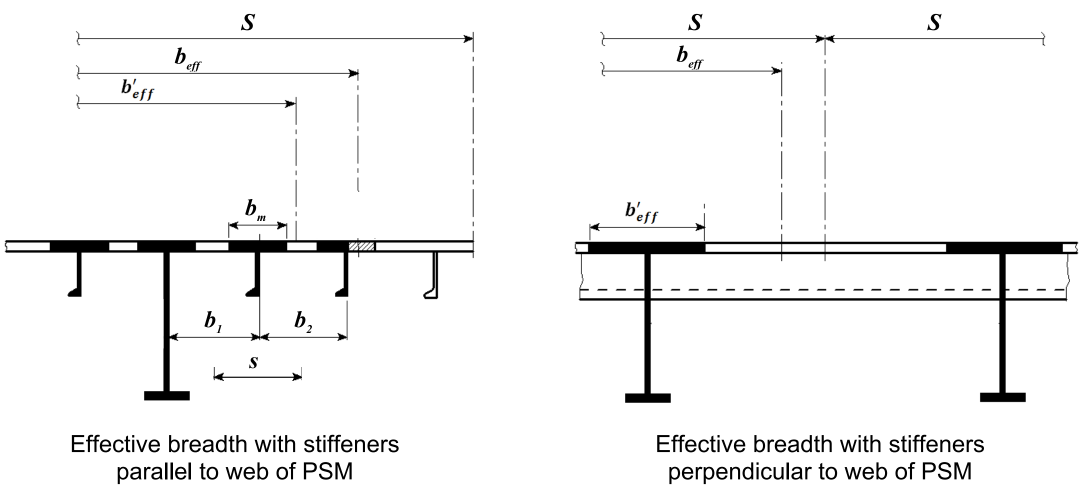

Figure 13 Effective breadth b'_{eff} of a primary supporting member

1.3.4 Effective area of curved face plate and attached plating of primary supporting members

The effective net area given in (a) and (b) below is only applicable to curved face plates and curved attached plating of primary supporting members. It is not applicable for the area of web stiffeners parallel to the face plate.

The effective net area is applicable to primary supporting members for the following calculations:

— actual net section modulus used for comparison with the scantling requirements given in Ch.6
— actual effective net area of curved face plates, modelled by beam elements, used in Ch.7.

a) The effective net area, in mm^2, shall be taken as:

$$A_{eff-n50} = C_f \cdot t_{f-n50} \cdot b_f$$

where:

C_f = flange efficiency coefficient taken equal to, see Figure 15:

$$C_f = C_{f1}\frac{\sqrt{r_f\, t_{f-n50}}}{b_1}$$ but not to be taken greater than 1.0.

C_{f1} = coefficient taken equal to:
For symmetrical and unsymmetrical face plates,

$$C_{f1} = \frac{0.643\ (\sinh\beta\ \cosh\beta + \sin\beta\ \cos\beta)}{(\sinh\beta)^2 + \sin^2\beta}$$

For attached plating of box girders with two webs,

$$C_{f1} = \frac{0.78\ (\sinh\beta + \sin\beta)\ (\cosh\beta - \cos\beta)}{(\sinh\beta)^2 + \sin^2\beta}$$

For attached plating of box girders with multiple webs,

$$C_{f1} = \frac{1.56\ (\cosh\beta - \cos\beta)}{\sinh\beta + \sin\beta}$$

β = coefficient calculated as:

$$\beta = \frac{1.285\ b_1}{\sqrt{r_f\, t_{f-n50}}}$$, in rad.

b_1 = breadth, in mm, to be taken equal to:
- for symmetrical face plates, $b_1 = 0.5\ (b_f - t_{w-n50})$
- for unsymmetrical face plates, $b_1 = b_f$
- for attached plating of box girders, $b_1 = s_w - t_{w-n50}$

s_w = spacing of supporting webs for box girders, in mm
t_{f-n50} = net flange thickness, in mm. For calculation of C_f and β of unsymmetrical face plates, t_{f-n50} shall not be taken greater than t_{w-n50}
t_{w-n50} = net web plate thickness, in mm
r_f = radius of curved face plate or attached plating, in mm, see Figure 14 at mid thickness
b_f = breadth of face plate or attached plating, in mm, see Figure 14.

b) The effective net area, in mm^2, of curved face plates supported by radial brackets, or attached plating supported by stiffeners, is given by:

$$A_{eff-n50} = \left(\frac{3r_f t_{f-n50} + C_f s_r^2}{3r_f t_{f-n50} + s_r^2}\right) t_{f-n50} b_f$$

where:

s_r = spacing of tripping brackets or web stiffeners or stiffeners normal to the web plating, in mm, see Figure 14.

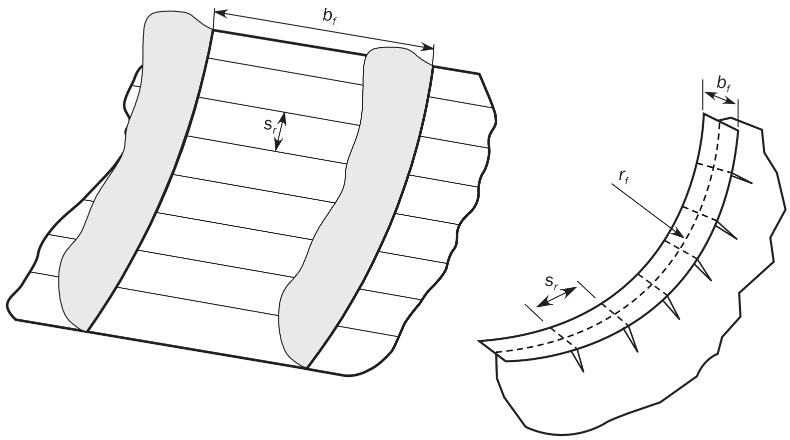

Figure 14 Curved shell panel and face plate

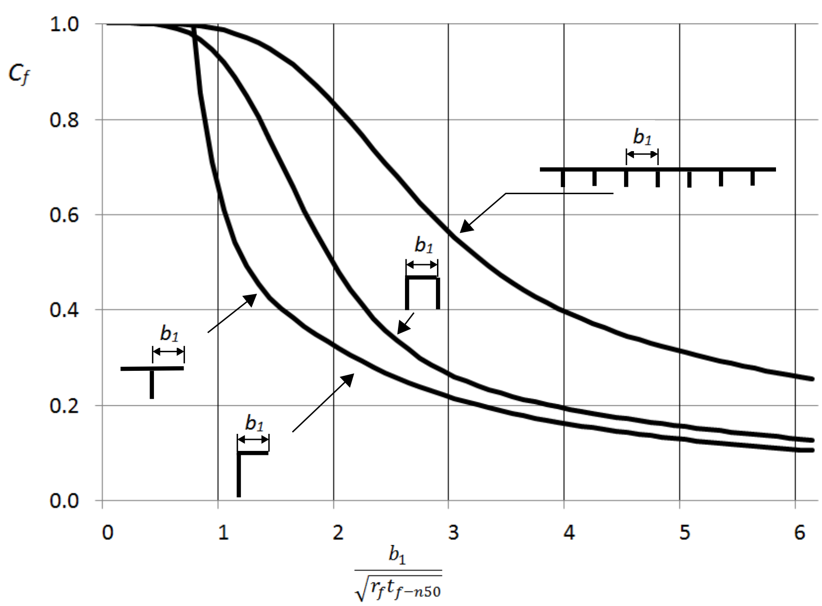

Figure 15 Flange efficiency coefficient for curved face plates

1.4 Geometrical properties of stiffeners and primary supporting members

1.4.1 Stiffener profile with a bulb section

The properties of bulb profile sections shall be determined by direct calculations.

Where direct calculation of properties is not possible, a bulb section may be taken equivalent to an angle section. The net dimensions of the equivalent angle section shall 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 net thickness of a bulb section, in mm, as shown in Figure 16

α = coefficient equal to:

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

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

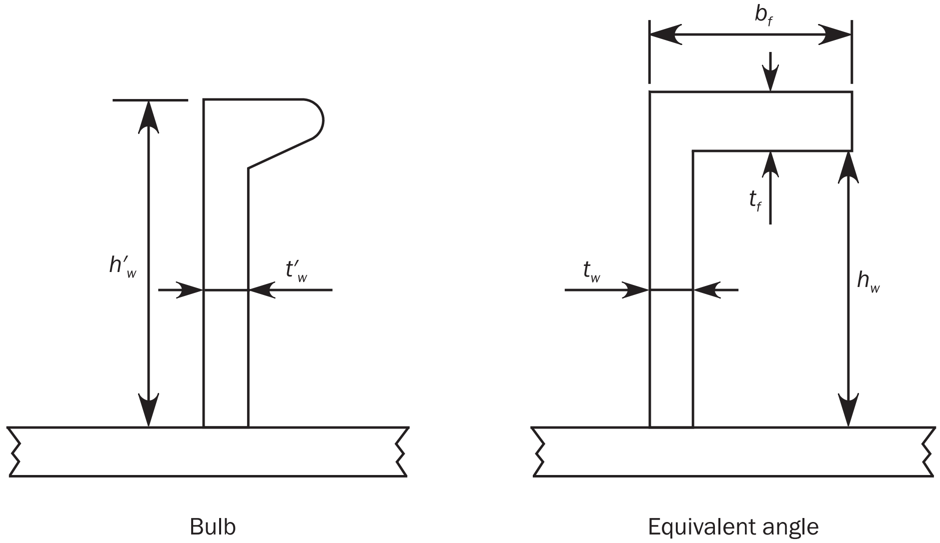

Figure 16 Dimensions of stiffeners

1.4.2 Net shear area of stiffeners

The net shear area, in cm^2, of stiffeners shall be taken as:

$$A_s = d_{shr} t_w 10^{-2}$$

d_{shr} = effective shear depth of stiffener, in mm, as defined in [1.4.3]
t_w = net web thickness of the stiffener, in mm, as defined in Sec.2 Figure 1.

1.4.3 Effective shear depth of stiffeners

The effective shear depth of stiffeners, in mm, shall be taken as:

$$d_{shr} = h_{stf} + t_p \quad \text{for } 75° \le \varphi_w \le 90°$$

$$d_{shr} = (h_{stf} + t_p) \sin \varphi_w \quad \text{for } \varphi_w < 75°$$

where:

h_{stf} = height of stiffener, in mm, as defined in Sec.2 Figure 1
t_p = net thickness of the attached plating, in mm, as defined in Sec.2 Figure 1
φ_w = angle, in deg, as defined in Figure 17.

1.4.4 Elastic net section modulus of stiffeners

The elastic net section modulus of stiffeners, in cm^3, shall be taken as:

$$Z = Z_{stf} \quad \text{for } 75° \le \varphi_w \le 90°$$

$$Z = Z_{stf} \cdot \sin \varphi_w \quad \text{for } \varphi_w < 75°$$

where:

Z_{stf} = net section modulus of the stiffener, in cm^3, considered perpendicular to its attached plate, i.e. with φ_w = 90 deg.

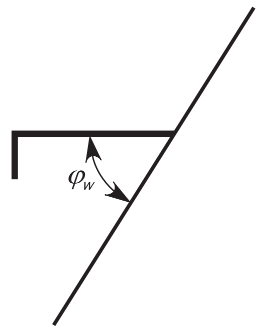

Figure 17 Angle between stiffener web and attached plating

1.4.5 Effective net plastic section modulus of stiffeners

The effective net plastic section modulus of stiffeners, in cm^3, which is used for assessment against impact loads, shall be taken as:

$$Z_{pl} = \frac{h_w t_w (h_w + t_p)}{2000} + \frac{(2\gamma - 1) A_f (h_{f-ctr} + t_p/2)}{1000} \qquad \text{for } 75° \le \varphi_w \le 90°$$

$$Z_{pl} = \frac{h_w t_w (h_w + t_p) \sin\varphi_w}{2000} + \frac{(2\gamma - 1) A_f [(h_{f-ctr} + t_p/2)\sin\varphi_w - b_{f-ctr}\cos\varphi_w]}{1000} \qquad \text{for } \varphi_w < 75°$$

where:

t_p = net thickness of stiffener attached plating as defined in Sec.2 Figure 1

h_w = depth of stiffener web, in mm, taken equal to:

For T, L (rolled and built-up) and flat bar profiles, as defined in Sec.2 Figure 1,

For L2, L3 and bulb profiles as defined in Sec.2 Figure 2,

γ = coefficient equal to:

$$\gamma = \frac{1 + \sqrt{3 + 12\beta}}{4}$$

β = coefficient equal to:

$$\beta = \frac{t_w^2 \; \ell_{bdg}^2}{80 b_f^2 \; t_f \, h_{f-ctr}} 10^6 + \frac{t_w}{2 b_f} \qquad \text{for L profiles without a mid-span tripping bracket,}$$

but not to be taken greater than 0.5.

β = 0.5 for other cases.

A_f = net cross sectional area of flange, in mm^2:

— A_f = 0 for flat bar stiffeners.
— $A_f = b_f \cdot t_f$ for other stiffeners.

$b_{f\text{-}ctr}$ = distance from mid thickness of stiffener web to the centre of the flange area, in mm:

— $b_{f\text{-}ctr} = 0.5\ (b_f - t_{w\text{-}gr})$ for rolled angle profiles.
— $b_{f\text{-}ctr}$ = 0 for T profiles.
— for bulb profiles as given in Table 1 and Table 2.

h = height of stiffener measured to the mid thickness of the flange, in mm:

— $h_{f\text{-}ctr} = h_{stf} - 0.5\ t_f$ for profiles with flange of rectangular shape except for L3 profiles.
— $h_{f\text{-}ctr} = h_{stf} - d_{e\text{-}gr} - 0.5\ t_f$ for L3 profiles as defined in Sec.2 Figure 2.
— for bulb profiles as given in Table 1 and Table 2.

$d_{e\text{-}gr}$ = distance from upper edge of web to the top of the flange, in mm, for L3 profiles, see Sec.2 Figure 1

t_f = net flange thickness, in mm

t_f = 0 for flat bar stiffeners.

for bulb profiles as given in Table 1 and Table 2.

Table 1 Characteristic flange data for HP bulb profiles, see Figure 18

h_{stf} (mm)	d_w (mm)	$b_{f\text{-}gr}$ (mm)	$t_{f\text{-}gr}$ (mm)	$b_{f\text{-}ctr}$ (mm)	$h_{f\text{-}ctr}$ (mm)
200	171	40	14.4	10.9	188
220	188	44	16.2	12.1	206
240	205	49	17.7	13.3	225
260	221	53	19.5	14.5	244
280	238	57	21.3	15.8	263
300	255	62	22.8	16.9	281
320	271	65	25.0	18.1	300
340	288	70	26.4	19.3	318
370	313	77	28.8	21.1	346
400	338	83	31.5	22.9	374
430	363	90	33.9	24.7	402

Characteristic flange data converted to net scantlings are given as:
$b_f = b_{f\text{-}gr} + 2\ t_w$
$t_f = t_{f\text{-}gr} - t_c$
$t_w = t_{w\text{-}gr} - t_c$

Table 2 Characteristic flange data for Japanese bulb profiles, see Figure 18

h_{stf} (mm)	d_w (mm)	$b_{f\text{-}gr}$ (mm)	$t_{f\text{-}gr}$ (mm)	$b_{f\text{-}ctr}$ (mm)	$h_{f\text{-}ctr}$ (mm)
180	156	34	11.9	9.0	170
200	172	39	13.7	10.4	188
230	198	45	15.2	11.7	217

h_{stf} (mm)	d_w (mm)	$b_{f\text{-}gr}$ (mm)	$t_{f\text{-}gr}$ (mm)	$b_{f\text{-}ctr}$ (mm)	$h_{f\text{-}ctr}$ (mm)
250	215	49	17.1	12.9	235
Characteristic flange data converted to net scantlings are given as: $b_f = b_{f\text{-}gr} + 2\ t_w$ $t_f = t_{f\text{-}gr} - t_c$ $t_w = t_{w\text{-}gr} - t_c$					

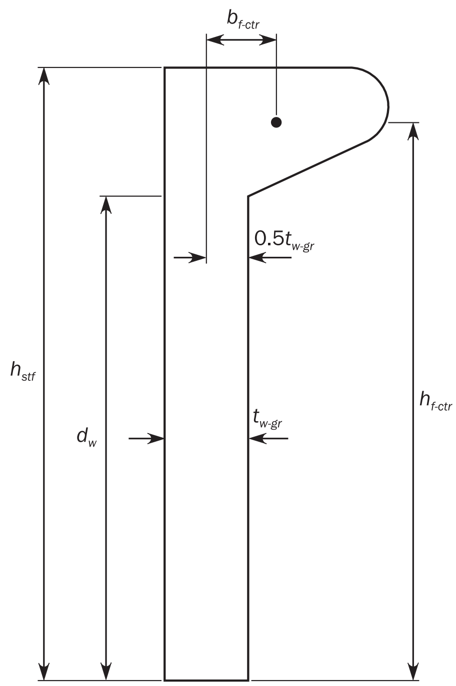

Figure 18 Characteristic data for bulb profiles

1.4.6 Primary supporting member web not perpendicular to attached plating

Where the primary supporting member web is not perpendicular to the attached plating, the actual net shear area, in cm^2, and the actual net section modulus, in cm^3, can be obtained from the following formulae:

— actual net shear area:

$A_{sh\text{-}n50} = A_{sh\text{-}0\text{-}n50} \sin \varphi_w$ for $\varphi_w < 75°$

$A_{sh\text{-}n50} = A_{sh\text{-}0\text{-}n50}$ for $75° \le \varphi_w \le 90°$

— actual net section modulus:

$Z_{n50} = Z_{perp\text{-}n50} \sin \varphi_w$ for $\varphi_w < 75°$

$Z_{n50} = Z_{perp\text{-}n50}$ for $75° \le \varphi_w \le 90°$

where:

$A_{sh\text{-}0\text{-}n50}$ = actual net shear area, in cm^2, of the primary supporting member assumed to be perpendicular to the attached plating, to be taken equal to:

$$A_{sh-0-n50} = (h_w + t_{f-n50} + t_{p-n50})\, t_{w-n50}\, 10^{-2}$$

$Z_{perp\text{-}n50}$ = actual section modulus, in cm^3, with its attached plating of the primary supporting member assumed to be perpendicular to the attached plating.

φ_w = angle, in degrees, between web and attached plating, see Figure 19

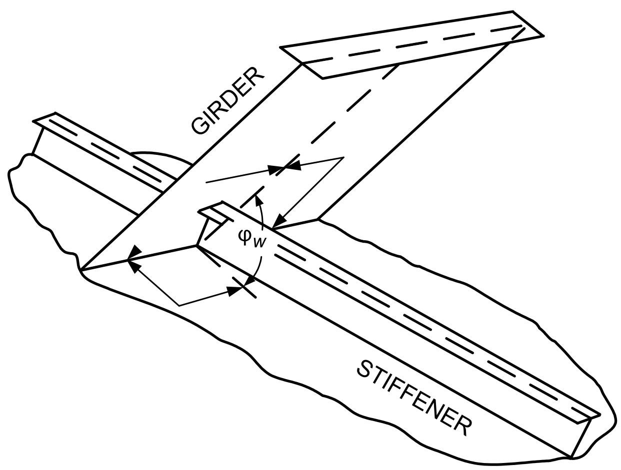

Figure 19 The web angle φ_w of primary supporting members

1.4.7 Shear area of primary supporting members with web openings

The effective web height, in mm, to be considered for calculating the effective net shear area, $A_{sh\text{-}n50}$ shall be taken as the lesser of:

$h_{eff} = h_w$

$h_{eff} = h_{w3} + h_{w4}$

$h_{eff} = h_{w1} + h_{w2} + h_{w4}$

where:

h_w = web height of primary supporting member, in mm

$h_{w1}, h_{w2}, h_{w3}, h_{w4}$ = dimensions as shown in Figure 20.

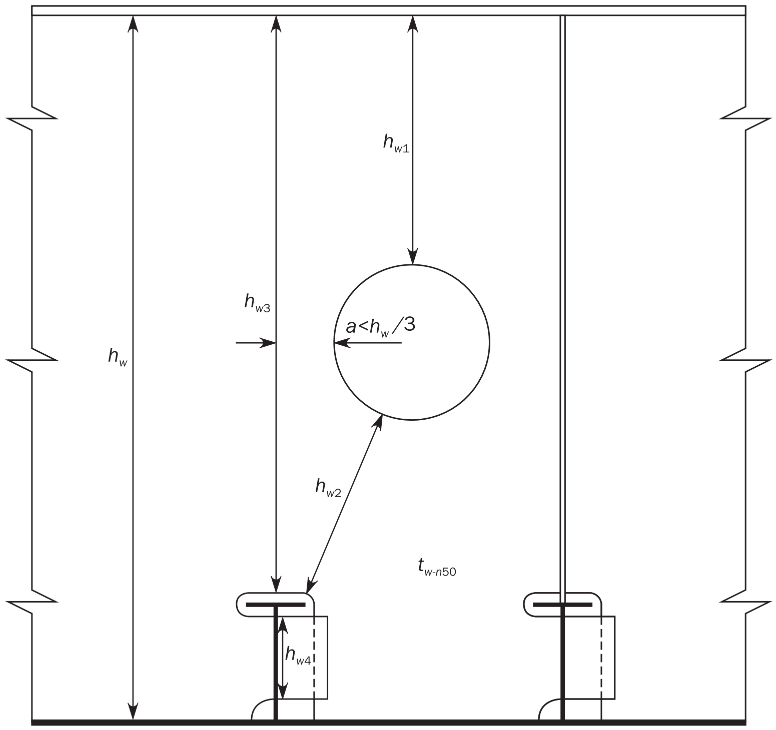

Figure 20 Effective shear area in way of web openings

1.4.8 Where the PSM flange is not parallel to the attached plate, the effective web area, in cm^2, shall be taken as:

$$A_{W-n50} = 0.01h_n \cdot t_{w-n50} + 1.3A_{F-n50} \cdot sin2\theta sin\theta$$

where:

h_n = web height, in mm, at the considered section.
$A_{F\text{-}n50}$ = net flange area, in cm^2
θ = angle of slope of continuous flange in deg
$t_{w\text{-}n50}$ = net web thickness, in mm.

See Figure 21.

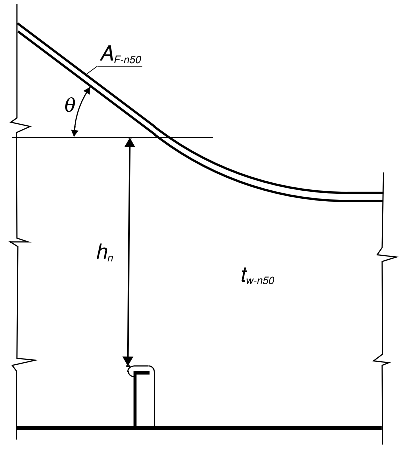

Figure 21 Effective web area in way of brackets

2 Plates

2.1 Idealisation of EPP

2.1.1 EPP

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 as the longest and shortest plate edges, respectively, as shown in Figure 22.

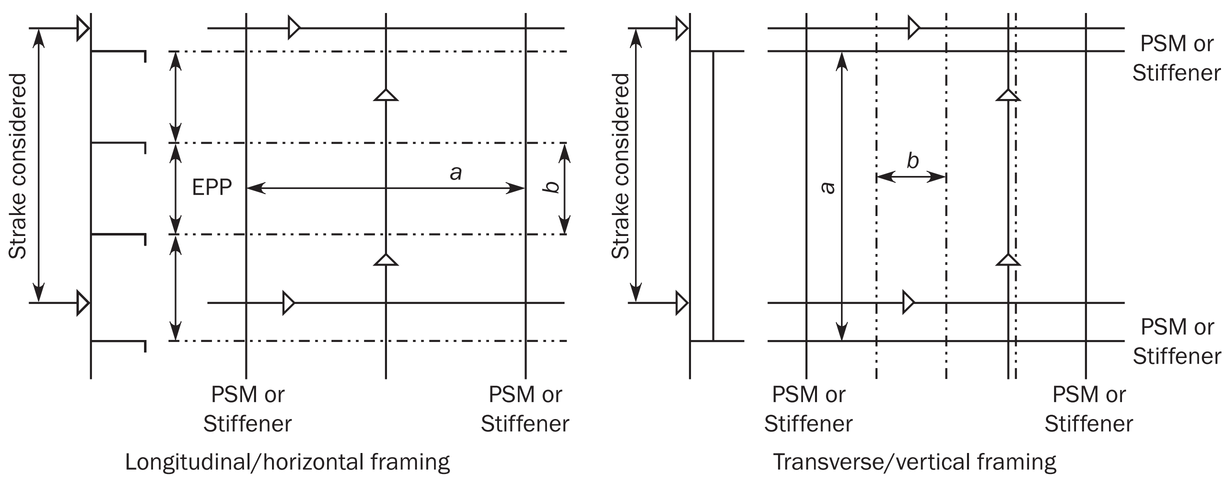

Figure 22 Elementary Plate Panel (EPP) definition

2.1.2 Strake required thickness

The required thickness of a plate strake shall be taken as the greatest value required for each EPP within that strake. The requirements given in Table 3 shall be applied for the selection of strakes to be considered as shown in Figure 23.

The maximum corrosion addition within an EPP shall be applied according to Sec.3.

Table 3 Strake considered in a given EPP

	a/b > 2	*a/b* ≤ 2
$a_1 > b/2$	All strakes (St1, St2, St3, St4)	All strakes (St1, St2, St3, St4)
$a_1 \le b/2$	Strakes St2 and St4	All strakes (St1, St2, St3, St4)

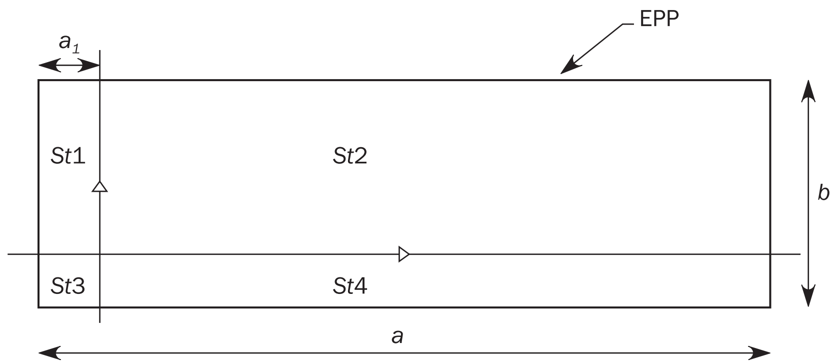

Figure 23 Strake considered in a given EPP

where:

a_1 = Distance, in mm, measured inside the considered strake in the direction of the long edge of the EPP, between the strake boundary weld seam and the EPP edge.

2.1.3 For direct strength assessment, the EPP shall be idealised with the mesh arrangement in the finite element model.

2.2 Load calculation point

2.2.1 Yielding

For the yielding check, the local pressure and hull girder stress, used for the calculation of the local scantling requirements shall be taken at the Load Calculation Point (LCP) having coordinates *x*, *y* and *z* as defined in Table 4.

Table 4 LCP coordinates for yielding

LCP coordinates	*General* (1)		*Horizontal plating*		*Vertical transverse structure and transverse stool plating*	
	Longitudinal framing (*Figure 24*)	*Transverse framing* (*Figure 25*)	*Longitudinal framing*	*Transverse framing*	*Horizontal framing* (*Figure 26*)	*Vertical framing* (*Figure 27*)
x coordinate	Mid-length of the EPP		Mid-length of the EPP		Corresponding to *y* and *z* values	
y coordinate	Corresponding to *x* and *z* coordinates		Outboard *y* value of the EPP		Outboard *y* value of the EPP, taken at *z* level	
z coordinate	Lower edge of the EPP	The greater of lower edge of the EPP or lower edge of the strake	Corresponding to *x* and *y* values		Lower edge of the EPP	The greater of lower edge of the EPP or lower edge of the strake
1) All structures other than horizontal platings or vertical transverse structures.						

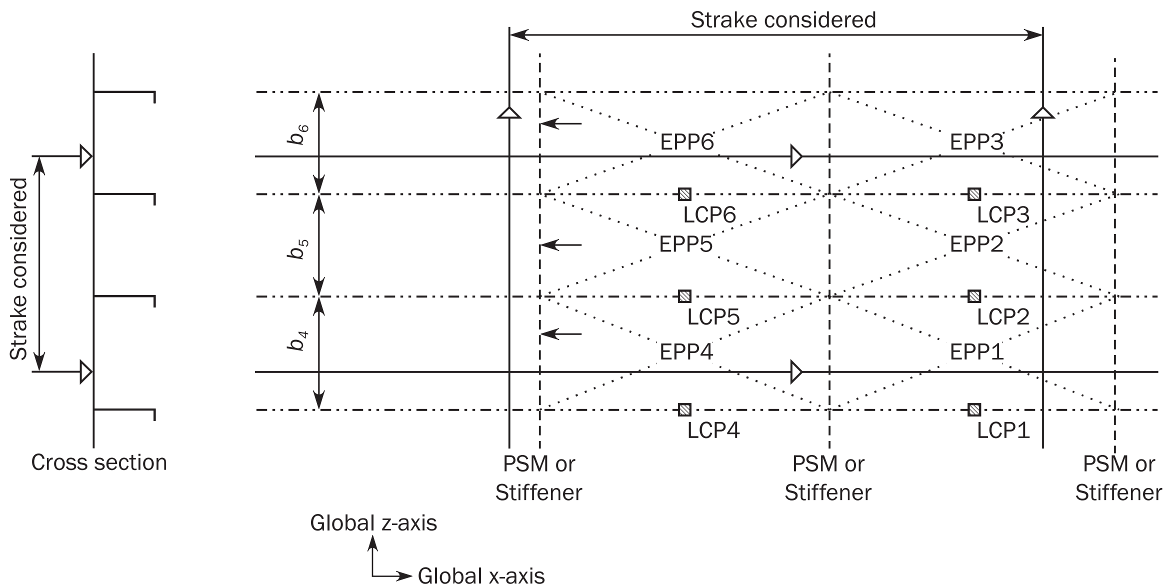

Figure 24 LCP for longitudinal framing at longitudinal plating

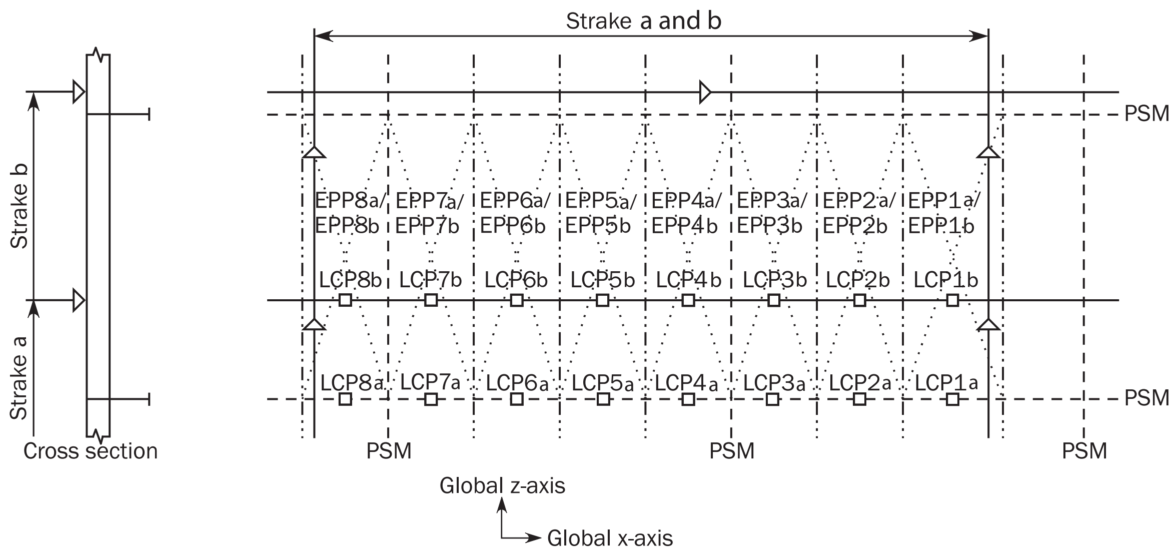

Figure 25 LCP for transverse framing at longitudinal plating

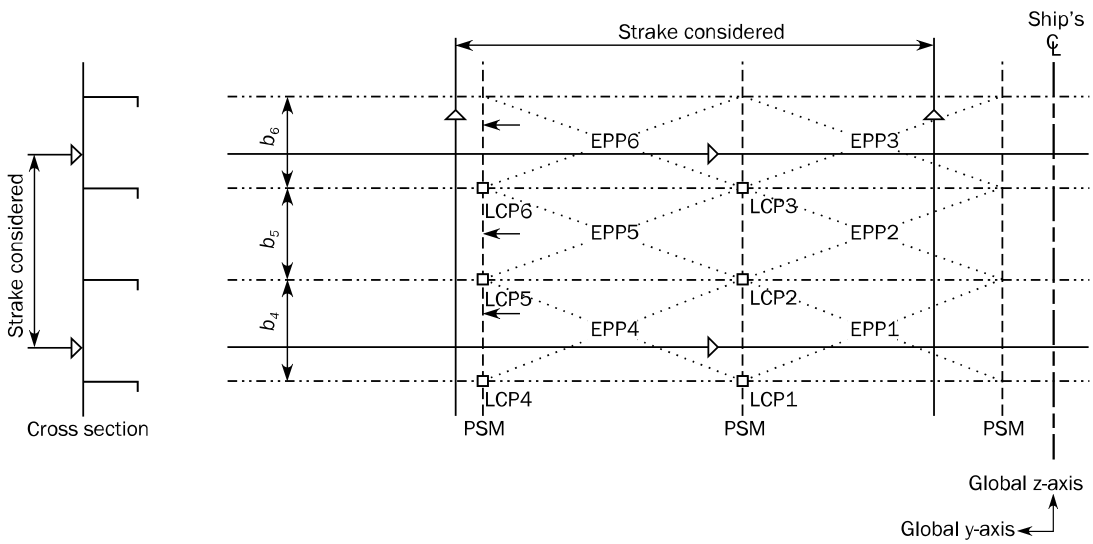

Figure 26 LCP for horizontal framing on transverse vertical structure

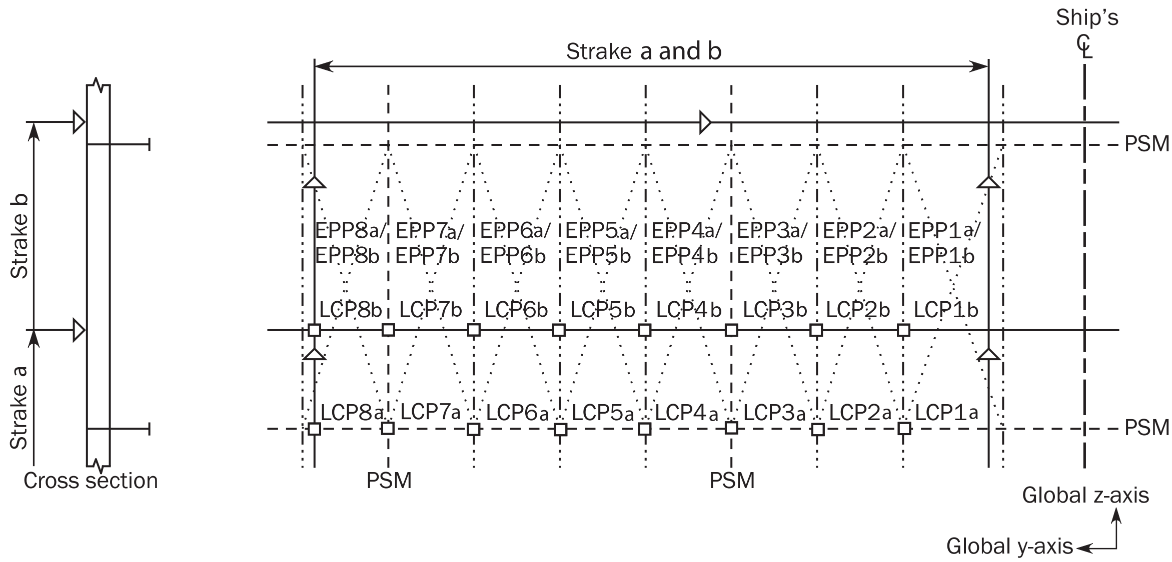

Figure 27 LCP for vertical framing on transverse vertical structure

2.2.2 Buckling

For the prescriptive buckling check of the EPP according to Ch.8 Sec.3, the LCP for the pressure and for the hull girder stresses are defined in Table 5.

For the FE buckling check, Ch.8 Sec.4 is applicable.

Table 5 LCP coordinates for plate buckling check

LCP coordinates	*LCP for pressure*	*LCP for hull girder stresses (Figure 28)*		
		Bending stresses		*Shear stresses*
		Non horizontal plate	*Horizontal plate*	
x coordinate	Same coordinates as LCP for yielding. See Table 4	Mid-length of the EPP		
y coordinate		Both upper and lower ends of the EPP (points A1 and A2)	Outboard and inboard ends of the EPP (points A1 and A2)	Mid-point of EPP (point B)
z coordinate		Corresponding to *x* and *y* values		

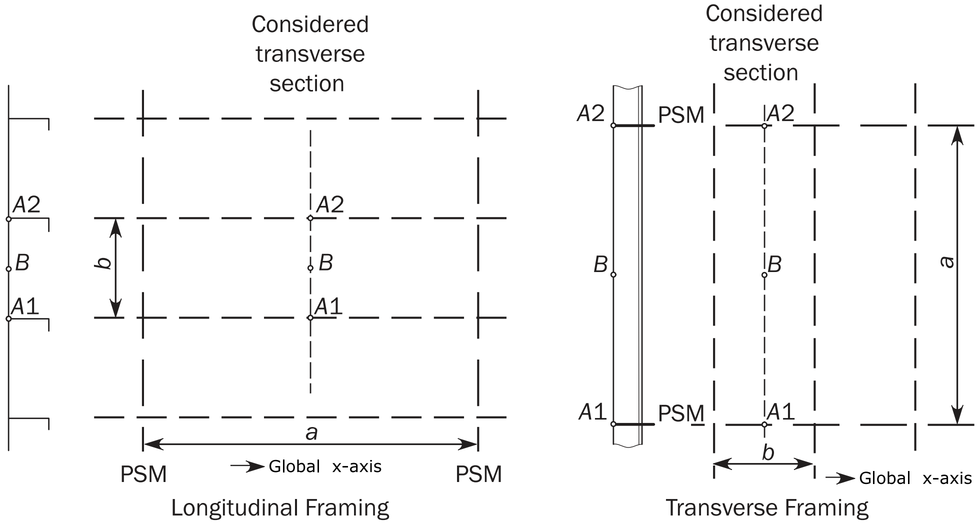

Figure 28 LCP for plate buckling – hull girder stresses

3 Stiffeners

3.1 Reference point

3.1.1 The requirements for section modulus for stiffeners relate to the reference point giving the minimum section modulus. This reference point is generally located as shown in Figure 29 for typical profiles.

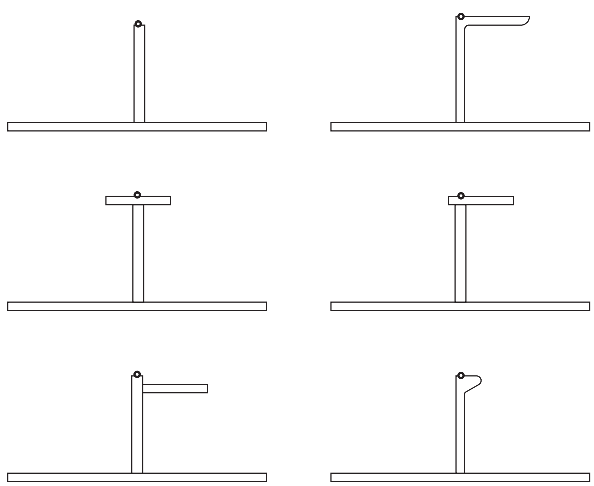

Figure 29 Reference point for calculation of section modulus and hull girder stress for local scantling assessment

3.2 Load calculation points

3.2.1 LCP for Pressure

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.

3.2.2 LCP for hull girder bending stress

The load calculation point for the hull girder bending stresses is defined as follows:

— for yielding check according Ch.6:
  — at the middle of the full length, ℓ, of the considered stiffener
  — at the reference point given in Figure 29.
— for prescriptive buckling check according to Ch.8:
  — at the middle of the full length, ℓ, of the considered stiffener
  — at the intersection point between the stiffener and its attached plate.

3.2.3 Non-horizontal stiffeners

The lateral pressure, P shall be calculated as the maximum between the value obtained at middle of the full length, ℓ, and the value obtained from the following formulae:

$P = \frac{P_U + P_L}{2}$ when the upper end of the vertical stiffener is below the lowest zero pressure level.

$P = \frac{\ell_1}{\ell} \frac{P_L}{2}$ when the upper end of the vertical stiffener is at or above the lowest zero pressure level, see Figure 30.

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.

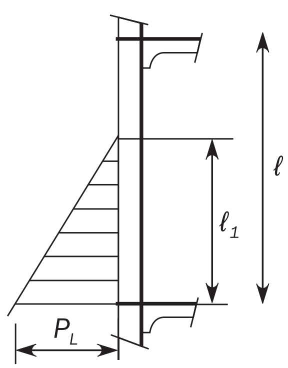

Figure 30 Definition of pressure for vertical stiffeners

4 Primary supporting members

4.1 Load calculation point

The load calculation point is located at the middle of the full length, ℓ, at the attachment point of the primary supporting member with its attached plate.

CHANGES – HISTORIC

October 2015 edition

This is a new document.
The rules enter into force 1 January 2016.

Amendments January 2016

• Sec.3 Corrosion additions

— Sec.3 Table 1: Modified footnotes 1 and 3

• Sec.7 Structural idealisation

— Sec.7 [1.1.3]: New and additional definition of effective flange PSM.

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