HULL IN ALUMINIUM ALLOYS

BUREAU VERITAS

BUREAU VERITAS
MARINE & OFFSHORE
RULE NOTE

NR561 R05 DECEMBER 2025

NR561 DT R05 December 2025 replaces former edition November 2022.

The PDF electronic version of this document available on the Bureau Veritas Marine & Offshore website **https://marine-offshore.bureauveritas.com/** is the official version and shall prevail if there are any inconsistencies between the PDF version and any other available version.

These rules are provided within the scope of the Bureau Veritas Marine & Offshore General Conditions, enclosed at the end of Part A of NR467, Rules for the Classification of Steel Ships. The latest version of these General Conditions is available on the Bureau Veritas Marine & Offshore website.

Rule Note
NR561

HULL IN ALUMINIUM ALLOYS

Table of Content

Table of Content

Table of Content

Table of Content

Section 1 General Requirements

1 General

1.1 Application

1.1.1 General scope of application
The requirements of this Rule Note are applicable to ships having their hull and superstructure totally made of aluminium alloy.

The purpose of this Rule Note is to define the general requirements for hull scantling and arrangements, with respect to:
- material
- hull structure and welding calculation approach
- classification and /or certification process.

1.1.2 Other applicable Rules
The requirements of this Rule Note apply in addition to the following Society Rules for the classification and/or certification of ships, in particular the requirements concerning:

a) Classification:

NR467, Part A: Rules for the Classification of Steel Ships, Classification and Surveys.

b) Loading cases, permissible stresses and/or safety coefficients, as applicable:
- NR600, Hull Structure and Arrangement for the Classification of Cargo Ships less than 65 m and Non Cargo Ships less than 90 m
- NR500, Rules for the Classification and the Certification of Yachts
- NR217, Rules for the Inland Navigation Vessels.

c) Subdivision, compartment and access arrangements and arrangement of hull openings, as applicable:
- NR600, Hull Structure and Arrangement for the Classification of Cargo Ships less than 65 m and Non Cargo Ships less than 90 m, or
- NR566, Hull arrangement, Stability and Systems for ships less than 500 GT
- NR500, Rules for the Classification and the Certification of Yachts
- NR217, Rules for the Inland Navigation Vessels.

Other Rule Notes may be considered by the Society on a case by case basis in accordance with the service notations and additional service features considered for the classification (see NR467, Part A).

1.1.3 Structural scopes not covered by Rules
The following structural aspects are not covered by the present Rules:
- structure deflection under loads
- structural response to vibrations induced by engines, propeller blades or water jet.

The scantling of superstructures built in aluminium alloy and fitted on board a steel ship are to be checked according to NR467, Rules for Steel Ships.

1.2 Exceptions

1.2.1 Ships with unusual design, speed or service, or intended to carry special cargoes not provided by the Rules, are examined on a case-by-case basis.

1.3 Drawings and documents to be submitted

1.3.1 As a rule, the drawings and documents to be submitted for hull structure review are listed in the Society Rules for the classification and/or certification of ships (see [1.1.2]).
Weld and welding booklets as requested in Sec 3, [1.2] are also to be submitted for review.

1.3.2 Builder's quality systems checking the general production fabrication and process are to be submitted for review (see Sec 9).

1.4 Working process and inspection at works

1.4.1 Inspections needed by the Society during ship hull construction within the scope of the classification and/or certification of ships built in unit production or in mass production are defined in Sec 9.

Section 2   Materials

Symbols

E   :   Young's modulus of aluminium, equal to 70000 N/mm^2

ν   :   Poisson ratio of aluminium, equal to 0,33

R_m :   Tensile strength, in N/mm^2, of the parent metal in delivery condition, as specified

$R_{p0,2}$:   Proof stress (yield strength), in N/mm^2, of the parent metal in delivery condition, as specified

R'_m :   Tensile strength, in N/mm^2, of the parent metal in as-welded condition, as defined in [2.1.3] or [2.1.4]

$R'_{p0,2}$:   Proof stress (yield strength), in N/mm^2, of the parent metal in as-welded condition, as defined in Article [2].

1   General

1.1   Application

1.1.1 As a rule, the aluminium alloys used for the construction of aluminium ships are as follows:
- for rolled or extruded products:
    - series 5000: aluminium-magnesium alloy
    - series 6000: aluminium-magnesium-silicon alloy.
- for cast products:
    - aluminium-magnesium alloy
    - aluminium-silicon alloy
    - aluminium-magnesium-silicon alloy.

In the early stages of the project, the shipyard is to submit to the Society the characteristics of the materials they intend to use for the construction of the hull and of the structures. In particular, the temper of parent metal is to be indicated.

1.1.2   Manufacture, inspection and certification

The general requirements relevant to the manufacture, inspection and certification of aluminium alloy products entering in the hull construction are given in NR216 Rules on Materials and Welding for the Classification of Marine Units.

1.1.3   Aluminium alloy characteristics

The characteristics of aluminium alloy to be used in the construction are to comply with the applicable requirements of NR216 Materials and Welding, Chapter 9, Section 2.

Materials with different characteristics may be considered provided their specification (manufacture, chemical composition, mechanical properties, welding, etc.) is submitted to the Society for approval.

1.1.4 In the case of structures subjected to low service temperatures or intended for other specific applications, the alloys to be employed are to be agreed by the Society.

2   Aluminium structure

2.1   Influence of welding on mechanical characteristics

2.1.1 Welding heat input lowers locally the mechanical characteristics $R_{p0,2}$ and R_m of aluminium alloys hardened by work hardening (series 5000 other than condition O) or by heat treatment (series 6000).

2.1.2 Consequently, where necessary, a drop in the mechanical characteristics of welded structures, with respect to those of the parent material, is to be considered for the structure calculation.

As a general rule, the heat affected zone (HAZ) is to be taken extending over 25 mm on each side of the weld axis.

2.1.3   Aluminium alloys of series 5000 (rolled and extruded)

Aluminium alloys of series 5000 in O condition (annealed)   are not subject to a drop in mechanical strength in the welded areas.

Aluminium alloys of series 5000 other than condition O are subject to a drop in mechanical strength in the welded areas. The mechanical characteristics to be considered are normally those of condition O.

Note 1: Higher mechanical characteristics may be taken into account, provided they are duly justified.

Table 1 : Aluminium alloys as welded mechanical characteristics

Aluminium alloy	Temper condition	$R'_{p0,2}$	R'_m
5000 series	0	$R_{p0,2}$	R_m
5000 series	other	values of 0 condition	
6005 A (open sections)	T5 or T6	0,45 $R_{p0,2}$	0,6 R_m
6005 A (closed sections)	T5 or T6	0,50 $R_{p0,2}$	0,6 R_m
6060 (sections) **(1)**	T5	0,43 $R_{p0,2}$	0,5 R_m
6061 (sections)	T6	0,53 $R_{p0,2}$	0,6 R_m
6082 (sections)	T6	0,45 $R_{p0,2}$	0,6 R_m
6106 (sections)	T5	0,33 $R_{p0,2}$	0,54 R_m
(1) 6060 alloy is not to be used for structural members sustaining dynamic loads (slamming and impact loads). The use of 6106 alloy is recommended in that case.			

2.1.4 Aluminium alloys of series 6000

Aluminium alloys of series 6000 are subject to a drop in mechanical strength in the vicinity of the welded areas.

The mechanical characteristics to be considered in this HAZ are normally indicated by the supplier.

When no information is provided by the supplier, the values given in Tab 1 may be used.

Note 1: Higher mechanical characteristics may be taken into account, provided they are duly justified.

2.1.5 Hardened aluminium alloys

For welded constructions in hardened aluminium alloys (series 5000 other than condition O and series 6000), higher characteristics than those in welded condition may be considered, provided that welded connections are located in areas where stress levels are acceptable for the alloy considered in annealed or as-welded condition.

2.1.6 Young's modulus and Poisson ratio

Unless otherwise specified, the Young's modulus and the Poisson ratio are to be taken, for aluminium alloy, respectively equal to 70000 N/mm² and 0,33.

2.2 Extruded plating

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

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

2.2.2 Extruded plating is preferably to be oriented so that the stiffeners are parallel to the direction of main stresses.

2.2.3 The structure continuity of plates and stiffeners is to be ensured in way of weld end extruded panels. The end weld preparation and joints of extruded plating ends are to be submitted for examination.

The crossing of extruded plating stiffeners with transverse primary structure is to be submitted for examination, in particular the connection of the secondary stiffeners to the primary web transverse, and the connection of the primary web transverse to the extruded plating.

2.3 Minimum yield stress for scantling criteria of hull structure

2.3.1 The minimum yield stress of aluminium R_y, in N/mm², used for the scantling criteria of the hull structure is to be taken, unless otherwise specified, equal to:

$$R_y = R'_{lim}$$

where:

R'_{lim} : Minimum yield stress of the aluminium alloys considered, to be taken equal to the minimum value, in welded condition, between $R'_{p0,2}$ (proof stress) and 0,7 R'_m (tensile strength).

2.4 Material factor k

2.4.1 To take into account the minimum yield stress of the aluminium alloy in welded condition, the material factor k used in the scantling formulae is to be taken equal to:

k = 100 / R'_{lim}

2.4.2 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.

2.5 Aluminium properties

2.5.1 Mechanical properties of aluminium alloys are to comply with the applicable requirements of NR216 Materials and Welding.

For information only, these properties are reminded in App 1.

2.6 Tolerances on dimensions

2.6.1 The minimum requirements for the under thickness tolerances for rolled products are given in NR216 Materials, Ch 9, Sec 2, [1.7].

The tolerances for extruded products are to be in accordance with the requirements of recognized standards (EN 755-9 or equivalent).

Section 3   Joint Design, Weld and Riveting Scantling

1 General

1.1 Application

1.1.1 The requirements of this Section apply to the scantling and joint design of welded connections or riveting connections in aluminium alloy hull structures.

Other equivalent standards may be accepted by the Society, on a case-by-case basis.

Note 1: Welding processes and inspection are dealt with in Sec 9.

1.1.2 Welding of various types of aluminium alloys is to be carried out by means of welding procedures approved for the purpose (see Sec 9, [3.4]).

1.1.3 The requirements of this Section apply also to heterogeneous connection of aluminium alloy members with steel members by riveting, bi-metallic transition joints or other means.

1.1.4 Weld connections are to be executed according to:
- the approved hull construction plans, and
- the weld and welding booklets submitted to the Society.

Any details not specifically represented in the plans are, in any case, to comply with the applicable requirements of the Society.

1.1.5 The method used to prepare the parts to be welded is left to the discretion of each shipbuilder, according to its own technology and experience.

These methods are to be reviewed during the qualification of welding procedure, as defined in [1.2.2].

1.2 Weld and welding booklets

1.2.1 Weld booklet

A weld booklet, including the weld scantling such as throat thickness, pitch, design of joints, is to be submitted to the Society for examination.

The weld booklet is not required if the structure drawings submitted to the Society contain the necessary relevant data defining the weld scantling.

1.2.2 Welding booklet

A welding booklet including the welding procedures and the criteria for the acceptance of weld imperfections is to be submitted to the Surveyor for examination (see Sec 9).

2 Scantling of welds

2.1 Butt welds

2.1.1 As a rule, butt welding is to be used for plate and stiffener butts and is mandatory for heavily stressed butts such as those of the bottom, keel, side shell, sheerstrake and strength deck plating, and bulkheads (in particular bulkheads located in areas where vibrations occur).

2.1.2 All structural butt joints are to be full penetration welds completed by a backing run weld.

2.2 Butt welds on permanent backing

2.2.1 Butt weld on permanent backing may be accepted where a backing run is not feasible.

In this case, the type of bevel and the gap between the members to be assembled are to be such as to ensure a proper penetration of the weld on its backing.

2.3 Fillet welds in a lap joint

2.3.1 Fillet weld in a lap joint may be used only for members submitted to moderate stresses, taking into account the throat thicknesses as defined in Fig 1 or Fig 2.

2.3.2 The width b, in mm, of overlapping is to be such that:

$b \geq 1{,}5 \, (t_1 + t_2) + 20$.

Figure 1 : Fillet weld in lap joint

$a = 0,5 \, t_2$

t_1 b t_2

$a = 0,5 \, t_2$

$t_1 \, {}^3 \, t_2$
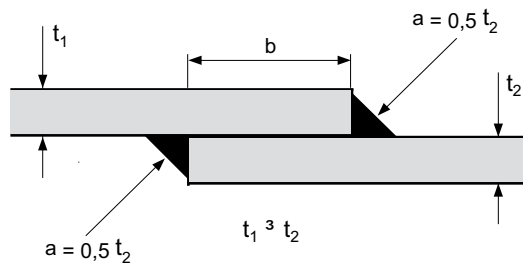
Figure 2 : Fillet weld in joggled lap joint

$a = 0,5 \, t_2$

t_1 b t_2

$2 \, t_1$ minimum

$a = 0,5 \, t_1$
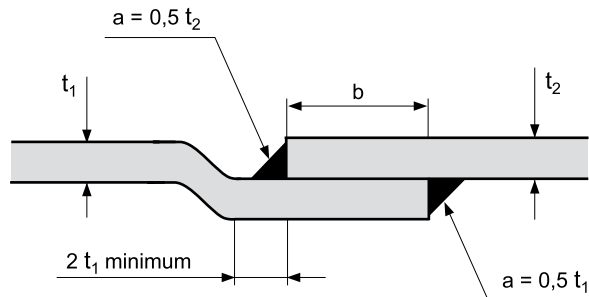
2.3.3 The ends are to be watertight, as far as practicable.

2.3.4 The weld closest to the shoulder may be intermittent except in liquid compartments and exposed areas.

2.4 Slot welds

2.4.1 Slot welding may be used where fillet welding is not possible. The shape is shown in Fig 3 and Fig 4, depending on the plate thickness.

Slot welds are to be, as far as practicable, parallel to the direction of main stresses.

Figure 3 : Slot welding for t $\leq$ 12 mm

$t \leq 12$

a

25

80
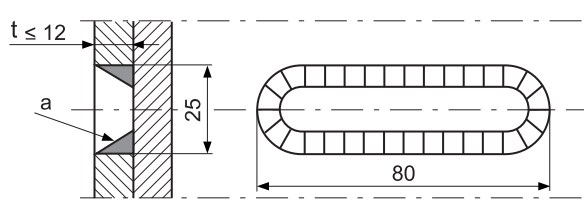
Figure 4 : Slot welding for t > 12 mm

$t > 12$

a

3 t

100
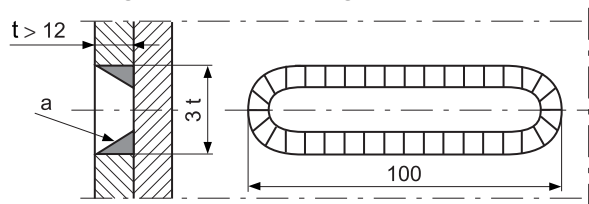
2.4.2 Slot welding is not to be completely filled by the weld, and the width of the opening is to be such as to allow easy fillet weld along its perimeter.

2.4.3 The distance L between extremities of two consecutive slot welds, as shown in Fig 5, is to be such that:

$10 \, t \leq L \leq 200$

where "t" is the plate thickness, in mm.

The maximum distance of L depends on the stresses of the members.

Figure 5 : Distance between slot welds

ℓ L
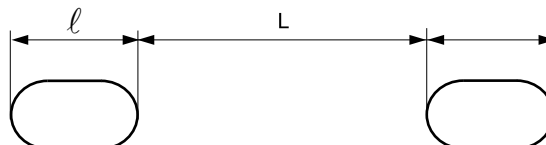
2.5 Plug welding

2.5.1 Plug welding is to be used exceptionally, as a substitute to slot welding.

Plug welding is to be completely filled by the welding.

2.6 Fillet weld

2.6.1 Double continuous fillet weld location

As a general rule, double continuous fillet weld is to be required in the following locations, as appropriate:

a) watertight and oiltight connections

b) main engine and auxiliary machinery seatings

c) bottom structure of high speed ship in way of jet room spaces

d) structure in way of bilge keel, stabiliser, bow thruster, cranes, etc.

e) bottom structure in the vicinity of propeller blade

f) primary and secondary stiffener web to attached plating or flange at ends, over a distance d at least equal to:

- • For secondary stiffeners:
  - general: the depth h of the stiffeners, with 300 mm ≥ d ≥ 75 mm. Where end brackets are fitted, the length in way of brackets and at least 50 mm beyond the bracket toes
  - floors web stiffeners: 20% of the span from span ends
  - bulkhead stiffeners: 25% of the span from span ends
- • For primary stiffeners:
  - 20% of the span from the span ends. Where end brackets are fitted, the length in way of brackets and at least 100 mm beyond the bracket toes.

  Note 1: Where direct calculations according to [2.6.5] and [2.6.6] or equivalent are carried out, discontinuous fillet weld may be considered on a case-by-case basis.

g) stiffeners in tanks intended for the carriage of ballast or fresh water

h) secondary stiffeners of deck plating subjected to wheel loads.

Continuous fillet weld may also be adopted in lieu of intermittent welding wherever deemed suitable, and is recommended where the length p, defined according to [2.6.6], is low.

2.6.2 Intermittent fillet weld

Where intermittent fillet welds are provided in area subjected to high dynamic loads of vibrations, staggered welds may be accepted with overlap in compliance with Tab 2 case 2.

2.6.3 Efficient length of fillet weld

The efficient length, in mm, of the lines of welding is given by:

$d_e = d - 20$

where:

d   :   Actual length, in mm, of the line of welding.

2.6.4 Throat thickness of double continuous fillet weld

a) General:

The minimum throat thickness t_T of a double continuous fillet weld, in mm, is to be obtained from the following formula:

$t_T = w_F \, t$

where:

w_F :   Welding factor for the various hull structural connections, defined in Tab 1

t   :   Actual thickness, in mm, of the thinner plate of the assembly.

b) Particular cases:

The throat thickness t_T may be increased when deemed necessary in high stress level areas.

In case of automatic welding with deep penetration, or in case of TIG welding, a reduction in the throat t_T may be accepted, subject to qualification of the welding procedure.

c) Specific requirements:

- As a rule, the actual throat thickness is to be not less than 4 mm. Lower value may be taken into account provided that a direct calculation of the throat thickness scantling is carried out and that welding procedures and welders are specially qualified for welding having throat thickness less than 4 mm.
- The maximum throat thickness is not to be greater than 1,5 t to limit the welding energy content and to avoid the deterioration of the elements to weld.

Table 1 : Welding factor w_F for the various hull structural connections

Hull area	Connection			w_F (1)
	of	to		
General, unless otherwise specified in the Table	watertight plates	boundaries		0,35
	non-tight plates	boundaries		0,20
	strength decks	side shell		0,45
	webs of ordinary stiffeners	plating		0,13
		plating at ends (2)		0,20
		web of primary stiffener		see [2.7]
	web of primary stiffeners	plating and flange		0,20
		plating and flange at ends (2)		0,30 (3)
		bottom and inner bottom (in way of transversal and/or longitudinal bulkhead supported on tank top)		0,45
		deck (for cantilever deck beam)		0,45
		web of primary stiffeners		0,35 (3)
Structures located abaft 0,25 L from the fore end	ordinary stiffeners	bottom and side shell plating		0,20
	primary stiffeners	bottom, inner bottom and side shell plating		0,25
Structures located in bottom slamming area or in the first third of underside of cross deck of catamaran	ordinary stiffeners	bottom plating		0,20
	primary stiffeners	bottom plating		0,25
Machinery space	girders	bottom and inner bottom plating	in way of main engine foundations	0,45
			in way of seating of auxiliary machinery	0,35
			elsewhere	0,25
	floors (except in way of main engine foundations)	bottom and inner bottom plating	in way of seating of auxiliary machinery	0,35
			elsewhere	0,25
	floors in way of main engine foundations	bottom plating		0,35
		foundation plates		0,45
	floors	centre girder	single bottom	0,45
			double bottom	0,25
Superstructures and deckhouses	external bulkheads	deck		0,35
	internal bulkheads	deck		0,13
	ordinary stiffeners	external and internal bulkhead plating		0,13
Pillars	pillars	deck	pillars in compression	0,35
			pillars in tension	full penetration welding
Rudders	primary element directly connected to solid parts or rudder stock	solid part or rudder stock		0,45
	other webs	each other		0,20
	webs	plating	in general	0,20
			top and bottom plates of rudder plating	0,35

(1) For connections where w_F ≥ 0,35, continuous fillet welding is to be adopted. See also [2.6.1].
(2) See [2.6.1], item f)
(3) Full penetration welding may be required, depending on the structural design and loads.

2.6.5 Direct calculation of double continuous fillet weld

Where deemed necessary, the minimum throat thickness t_T of a double continuous fillet weld between stiffener web and associated plating and/or flange, in mm, may be determined as follows:

$$t_T \geq \frac{T \cdot m}{2 \cdot I \cdot \tau}$$

where:

T   :   Shear force, in N, in the considered section of the stiffener

I   :   Inertia, in mm^4, of the stiffener

τ :   Permissible shear stress, in N/mm^2, as defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2])

m   :   Value, in mm^3, calculated as follows (see Fig 6):

- for weld between flange and web: $m = t_f \cdot b_f \cdot v_f$

- for weld between associated plate and web: $m = t_p \cdot b_p \cdot v_p$

Figure 6 : Direct calculation of double continuous fillet weld
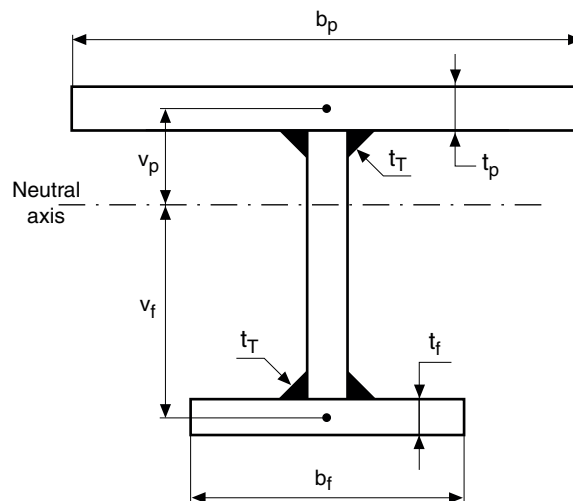
2.6.6 Throat thickness of intermittent weld

The throat thickness t_{IT}, in mm, of intermittent welds is to be not less than:

$$t_{IT} = t_T \frac{p}{d_e} \leq 1{,}5\,t$$

where:

t_T :   Throat, in mm, of the double continuous fillet weld, obtained as defined in [2.6.4] or [2.6.5]

p   :   Pitch, in mm, of the fillet welds positioned on the same side, measured as indicated in Tab 2

d_e :   Efficient length, in mm, of the fillet welds, as defined in [2.6.3]

t   :   Actual thickness, in mm, of the thinner plate of the assembly.

2.6.7 Fillet weld in way of cut-outs

In way of cut-outs for the passage of stiffeners, the throat thickness t_{IT} of the fillet welds located between cut-outs is to be such that:

$$t_{IT} \geq t_T \frac{p}{d_e}$$

where:

d_e :   Efficient length, defined in [2.6.3]

p   :   As shown in Fig 7

t_T :   Throat, in mm, of the double continuous fillet weld, obtained as defined in [2.6.4] or [2.6.5]

Table 2 : Pitch on intermittent fillet weld
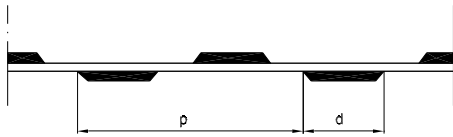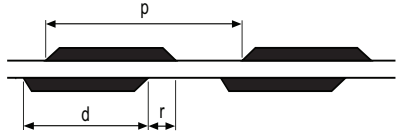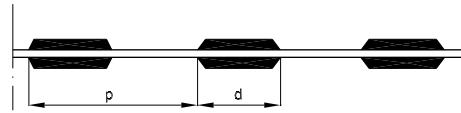
Type of intermittent fillet weld	Pitch requirements
Case 1: Staggered welds 	d ≥ 75 mm **(1)** p ≤ 4 d
Case 2: Staggered welds subjected to dynamic loads 	d ≥ 75 mm r ≥ 20 mm p ≤ 3 d
Case 3: Chain welds 	d ≥ 75 mm p − d ≤ 200mm
(1) To reduce deformations, it is recommended to choose the values of d according to the thickness.	

Figure 7 : Fillet weld in way of cut-outs
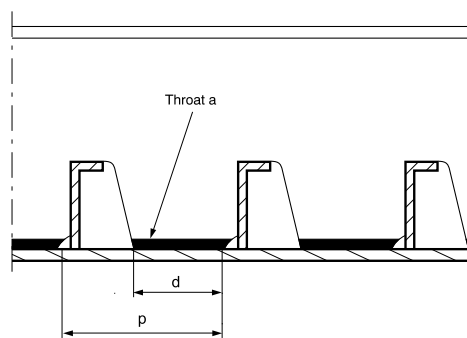
2.7 Welding between secondary and primary stiffeners

2.7.1 Continuous secondary stiffeners

As a general rule, the total resistant weld section A_W, in cm², connecting the continuous secondary stiffeners to the web of primary members, is to be such that:

a) General case:

$$A_W \geq \varphi p s \ell \left(1 - \frac{s}{2\ell}\right) k 10^{-3}$$

where:

A_W : Total resistant weld section A_W, in cm², to be determined taking into account the efficient length of the welding d_e defined in [2.6.3]

φ : Coefficient to be taken equal to:
  • 200 when the weld is parallel to the reaction exerted on primary members
  • 160 when the weld is perpendicular to the reaction exerted on primary members

p : Design pressure, in kN/m², acting on the secondary stiffeners, as defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2])

s : Spacing of the secondary stiffeners, in m

ℓ : Span of the secondary stiffeners, in m

k : Greater value of the material factors for the secondary stiffeners, primary members and welding consumable as defined in Sec 2, [2.4].

b) Case of side shell impact:

$$A_W \geq \varphi sp\left(0, 6 - \frac{s}{4}\right) k 10^{-3}$$

where:

A_W : Total resistant weld section A_W, in cm², to be determined taking into account the efficient length of the welding d_e defined in [2.6.3]

s : Spacing of secondary stiffeners, in m, without being taken greater than 0,6 m

p : Pressure, in kN/m², to be taken equal to: $P = C_p P_{ssmin}$

C_p : Pressure coefficient equal to: $C_p = -0,98s^2 + 0,3s + 0,95 \geq 0,8$

p_{ssmin} : Impact pressure, in kN/m², acting on the secondary stiffeners as defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

φ, k : Coefficients defined in a).

c) Case of wheeled loads:

$$A_W \geq \varphi p_w k 10^{-3}$$

where:

A_W : Total resistant weld section A_W, in cm², to be determined taking into account the efficient length of the welding d_e defined in [2.6.3]

p_w : Maximum shear force reaction in way of the connection with the primary stiffener, in kN, induced by wheeled load applied on the secondary stiffener

φ, k : Coefficients defined in item a).

The actual total resistant weld section A_W is to be calculated taking into account the efficient length of the line of weld, connecting the continuous secondary stiffener to the web of primary member, as defined in [2.6.3].

2.8 Particular conditions applying to bilge keels

2.8.1 Connection of the bilge keel (as defined in Sec 7, [5.5.1]) to the intermediate flat is to be made by continuous welds, with a throat not less than, or equal to, the one of the continuous welds connecting the intermediate flat to the bilge strake.

Butt welds of the shell plating, intermediate flat and bilge keel are to be suitably staggered.

To avoid shell plating being damaged, butt welds of the intermediate flat are to be made on a backing.

Butt welds of the bilge keel are not to extend up to the intermediate flat but are to stop on a scallop. The weld is to be free from imperfections in way of the scallop and, where necessary, the imperfections are to be ground.

3 Typical joint preparation

3.1 Butt weld

3.1.1 In case of assembly of two plates of different thicknesses, a taper x, having a minimum slope as shown on Fig 8 or Fig 9, is to be adopted where:

* $t_1 \leq 10$ mm and $t_2 - t_1 \geq 3$ mm, or

* $t_1 > 10$ mm and $t_2 - t_1 \geq 4$ mm

Note 1: For connection of platings parallel to the direction of the main stresses, a minimum taper length x, such that x > 3 b, may be permitted.

Figure 8 : Tapering on one face
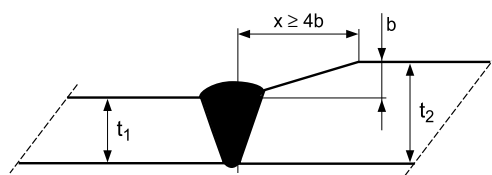
Figure 9 : Tapering on both faces
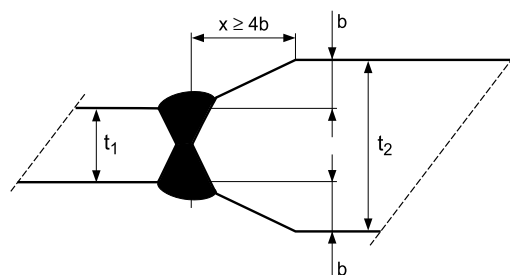
3.2 Butt welding on backing

3.2.1 For butt welding on permanent or temporary backing, the edge preparations and gap are to be defined by the shipyard, taking into account the type of backing plate.

3.2.2 For extruded sections with an integrated melting bath for backing, preparation before welding is defined during the qualification of welding procedures.

3.3 Sections, bulb and flat bars

3.3.1 Stiffeners contributing to the longitudinal or transversal strength, or elements in general subjected to high stresses, are to be connected together by butt joints with full penetration weld. Other solutions may be adopted if deemed acceptable by the Society on a case-by-case basis.

The work is to be done in accordance with an approved procedure, in particular for work done on board or in conditions of difficult access to the welded connection, where special measures may be required by the Society.

3.4 Fillet weld

3.4.1 Preparation

A preparation with a single or double bevel butt with a root face device of 3 mm minimum is recommended:

- where the thickness of the abutting plate exceeds 8 mm
- where partial or full penetration welding is required.

4 Riveting

4.1 General

4.1.1 This Article defines the conditions of riveting of hulls and structures made of aluminium alloy.

Riveting strength data sheets are to be submitted to the Society. Additional sample tests of riveted joints representative of the hull construction may be required, if deemed necessary by the Society. As a general rule, the samples are tested under tensile, compressive and shear forces (see also NR216 Materials and welding).

4.2 Choice of rivets

4.2.1 For the riveting of series 5000 aluminium-magnesium alloys, the grade of the rivet is to have magnesium content not exceeding 3,5%.

4.3 Shape of aluminium-alloy rivets

4.3.1 Diameters of rivets (versus the thickness of the thinner member to be riveted), diameters of hole perforations, manufacturing tolerances and shape of the heads of rivets are given in Tab 3 and Tab 4 (see also Fig 10 and Fig 11).

Slight departure from the above dimensions may be accepted, to the satisfaction of the Surveyor.

4.3.2 For riveting of massive parts and accessories, the hole diameter may be increased by 2 mm.

Table 3 : Rivets in aluminium alloy

Diameter of the rivets, in mm			Reaming of rivet holes, in mm		Thickness of plates and sections, in mm	Radius r, in mm
Nominal value d	Minimum value	Maximum value	Minimum value	Maximum value		
4	3,9	4,0	4,1	4,2	from 1,5 to 2,0	0,2
5	4,9	5,0	5,1	5,2	from 2,0 to 2,5	0,2
6	5,9	6,0	6,1	6,2	from 2,5 to 3,0	0,3
8	7,8	8,0	8,1	8,2	from 3,0 to 4,0	0,4
10	9,8	10,0	10,1	10,2	from 4,0 to 6,0	0,4
12	11,8	12,0	12,1	12,2	from 5,0 to 8,0	0,5
14 **(1)**	13,8	14,0	14,1	14,2	from 6,0 to 10,0	0,6
16	15,8	16,0	16,1	16,2	from 7,0 to 12,0	0,05 d
18	17,8	18,0	18,1	18,2	from 9,0 to 14,0	0,05 d
20	19,8	20,0	20,2	20,3	from 10,0 to 15,0	0,05 d
22	21,8	22,0	22,2	22,3	from 11,0 to 16,0	0,05 d
24	23,8	24,0	24,2	24,3	from 12,0 to 17,0	0,05 d
(1) Maximal diameter of rivet recommended for cold use.						

Table 4 : Value of r of riveted heads

Diameter d, in mm	4 and 5	6	8 and 10	12	14	16 and over
Value of r, in mm	0,2	0,3	0,4	0,5	0,6	0,05 d

Note 1: A manufactured head may be associated with different types of riveted heads.
Type C rivets of diameter 10 mm or more may have flat points.

Figure 10 : Manufactured heads

TYPE A   TYPE B   TYPE C

$\alpha = 120°$ (d ≥ 4)
$\alpha = 90°$ (d = 5,6 and 8)
$\alpha = 60°$ (d ≤ 10)
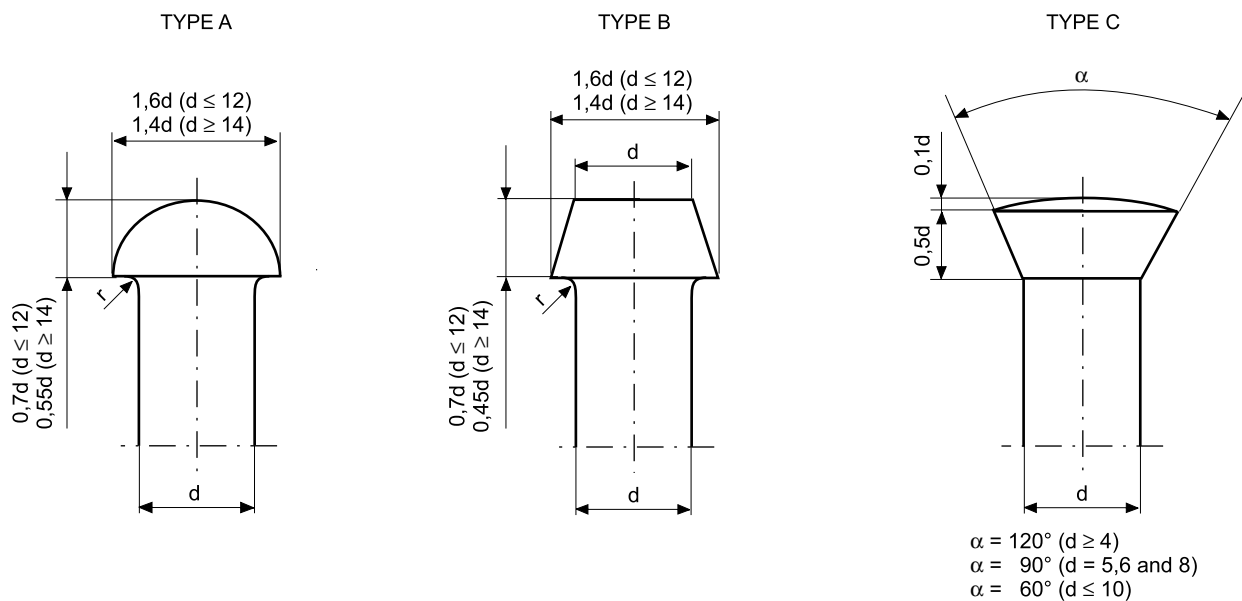
Figure 11 : Riveted heads

TYPE D   TYPE E   TYPE F
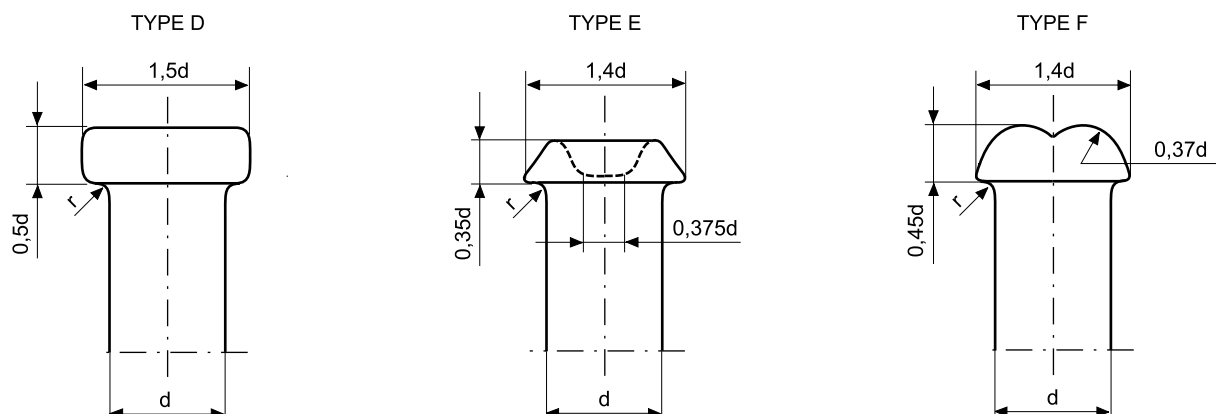
4.4 Execution of riveting

4.4.1 The rivet holes are to be spaced regularly with a very low tolerance (0,1 to 0,2 mm). Holes are to be drilled.

4.4.2 The number of rows of rivets and the pitch between rivets depend on the relative strength required for the joint.

The pitch is to be such that:

2,5 d ≤ pitch ≤ 6 d, where d is the rivet diameter.

For riveting with several rows, the row spacing is to be, as a rule, equal to:

- the pitch for chain-riveting, and
- 0,75 time the pitch for staggered riveting.

4.4.3 Cold-riveting may be performed with well annealed rivets up to 14 mm in diameter for grade 5052 rivets. For larger diameters, hot-riveting is to be used (at 400°C ± 25°C). In some special cases, large diameter AlSiMg rivets may be used directly after hardening.

The holding dolly is to be heavier than that used for a steel rivet of the same diameter.

5 Heterogeneous assembly steel / aluminium alloy

5.1 General

5.1.1 This Article defines the conditions for heterogeneous assembly for hulls and structures made of aluminium alloys and steel.

5.2 Riveting of members in aluminium alloy onto steel members

5.2.1 Correct insulation between steel and aluminium is to be ensured by means of joints, washers and plastic or rubber tubes, or any other equivalent solution.

5.2.2 As far as practicable, the rivet is to be of the same composition as the aluminium alloy used for the structure.

5.2.3 Requirements of [4.3] apply. Diameters of rivets are given in Tab 3 according to the thickness of the member in aluminium alloy.

5.2.4 Requirements of [4.4] apply otherwise.

5.3 Jointing systems other than classical riveting

5.3.1 Any jointing system other than classical riveting (high performance fixation, etc.) may be used with the Society's agreement.

5.4 Transition joints by aluminium / steel cladded plates

5.4.1 The use of transition joints made of aluminium / steel cladded plates or profiles may be considered with the Society's agreement.

5.4.2 The requirements defined in NR216 Materials, Ch 9, Sec 4 are applicable.

6 Construction deformations

6.1 General

6.1.1 Shrinkage heats to reduce hull construction deformation are not advisable for 5000 series alloy with metallurgical temper other than O-H111 and for 6000 series alloy.

Section 4   Calculation Principles of Hull Structure

Symbols

b_f : Breath of the flange or the bulb, in mm

h_w : Height of the web, in mm. For bulb sections, the height is to be measured without the bulb

k : Material factor defined in Sec 2, [2.4]

t_w : Thickness of the web, in mm

t_f : Thickness of the flange or the bulb, in mm.

1 General

1.1 Application

1.1.1 Hull structural members are to be examined under the effect of global hull girder loads (forces and moments which result from effects of local loads acting on the ship as a whole and considered as a beam), and the effect of local loads (pressure and forces directly applied to the individual structural members).

1.1.2 The purpose of the present Section is to define the calculation principles of hull structural members.

The global hull girder scantling and the local hull scantling are defined in Sec 5 and Sec 6, respectively.

1.1.3 Global hull girder and local strength

As a rule, the global hull girder strength and the local strength are examined independently, as follows:

- the global scantling of the hull girder and of the platform of multihull is examined on the basis of a maximum permissible stress at deck and bottom and a buckling check of elements contributing to the global hull girder strength

- the local scantling is examined on the basis of local permissible stresses defined in relation to the type of local loads applied and the type of structure element.

A combination between the global hull girder stresses and the local stresses analysis may be carried out when deemed necessary by the Society (see applicable Society Rules defined in Sec 1, [1.1.2]).

1.2 Definitions

1.2.1 Framing system

The requirements of the present Section are provided for longitudinal and transverse framing systems, according to the following definitions:

- secondary supporting members: members straight supporting plates

- primary supporting members: members supporting secondary members.

Note 1: Other types of framing systems are to be examined on a case-by-case basis by the Society.

1.2.2 Platform of multihull

A platform of multihull is a strength structure connecting the hulls by primary cross transverse structure elements. These transverse elements may be cross beams or cross bulkheads.

The part of the platform directly exposed to sea effect is designed as platform bottom.

The upper part of the platform and the upper decks are defined as platform deck.

2 Calculation principles for plating

2.1 General

2.1.1 The scantling of plating is to be such as to satisfy the required strength under the local loads and under the hull girder loads as follow:

a) Scantling under local loads:

The scantlings under local loads are to be determined as defined in Sec 6.

b) Scantling under global hull girder loads:

The scantlings under global hull girder loads are to be defined such as to satisfy the rules criteria of:

- the actual overall bending stress check as defined in Sec 5, and

- the buckling check as defined in App 2, [2].

2.2 Plate buckling analysis

2.2.1 General
The plate panels to be checked under buckling criteria are mainly:
- Under compression due to global hull bending:
  - bottom and/or deck plating
  - side shell plating, in the upper area below strength deck
  - side shell plating, in the lower area above bottom
  - superstructure contributing to the longitudinal or transversal global strength.
- Under compression on one side and/or under two sides due to transverse global bending of catamaran induced by torsion:
  - platings of platform deck and platform bottom of catamarans, in way of the primary cross transverse structure elements of the platform.
- Under shear:
  - side shell plating
  - primary cross transverse structure elements of the platform of catamarans.
  - superstructure contributing to the longitudinal or transversal global strength.

Other hull areas may be checked under buckling on a case by case basis when deemed necessary by the Society.

3 Calculation principles for secondary supporting members

3.1 General

3.1.1 The scantling of secondary supporting members (section modulus and shear area) is to be such as to satisfy the required strength under the local loads and, when the stiffener is submitted to overall bending and/or to global strength of catamaran, under the hull girder loads as follow:

a) Scantling under local loads:

   The scantlings under local loads are to be determined as defined in Sec 6, [3].

b) Scantling under global hull girder loads:

   The scantling under hull global girder loads are to be defined such as to satisfy the rules criteria of:
   - the actual overall bending stress as defined in Sec 5, and
   - the buckling check as defined in App 2, [3.2].

3.1.2 Geometric properties and attached plating width
As a rule, the geometric properties of secondary supporting members (inertia, section modulus and shear section) are to be determined by direct approach.

The width b_p, in m, of the attached plating to take into account for the inertia and section modulus calculations are to be taken equal to the spacing between stiffeners, or half of the spacing between stiffeners when the plating extends on one side only.

3.1.3 Recommended proportions of stiffeners
As a rule, the proportions of stiffeners are to be as defined in App 2, [3.1].

3.2 Secondary stiffener buckling analysis

3.2.1 General
The secondary stiffeners to be checked under buckling criteria are mainly:
- bottom and/or deck stiffeners
- side shell stiffener in the upper area below the strength deck
- side shell stiffener in the lower area above bottom
- superstructure stiffener contributing to the longitudinal or transversal global strength.
- platform of multihull
- bulkhead stiffener acting as pillar.

4 Calculation principles for primary supporting members

4.1 Scantling

4.1.1 The section modulus and the shear area of primary supporting members are to be defined by the same approach than for the secondary supporting members defined in Article [3], taking into account the requirements of the present Article.

4.1.2 Geometric properties and attached plating width

As a rule, the geometric properties of primary supporting members (inertia, section modulus and shear section) are to be determined by direct approach, taking into consideration item a) and/or item b):

a) Web of primary member directly welded on the attached plating:

The width b_P, in m, of the attached plating to take into account for the inertia and section modulus calculations   for primary supporting members analysed through beam structural models is to be taken equal to:

- where the plating extends on both sides of the primary supporting member:

b_P = min (s; 0,2ℓ)

- where the plating extends on one side of the primary supporting member (i.e. primary supporting member bounding an opening):

b_P = min (0,5 s; 0,1ℓ)

where:

s   :   Spacing, in m, of primary supporting member

ℓ :   Span, in m, of primary supporting member

b) Web of primary member not directly welded on the attached plating (floating frame):

As a rule, the attached plating is normally to be disregarded for the calculation of the primary supporting member geometric properties.

4.1.3 Recommended proportions of stiffeners

As a rule, the proportions of stiffeners are to be as defined in App 2, [3.1].

4.2 Cut-outs and large openings

4.2.1 General

Cut-outs and large openings in primary supporting member webs may be taken into account as defined in the present [4.2], when deemed necessary.

4.2.2 Cut-outs in web

The web shear area of primary supporting members is to take into account the section reduction due to cut-outs provided for secondary stiffeners, if relevant.

Cut-outs for the passage of secondary stiffeners are to be as small as possible and well rounded with smooth edges.

In general, the height of cut-outs is to be not greater than 50% of the height of the primary supporting member.

4.2.3 Location of cut-outs in web

As a general rule, where openings such as lightening holes or duct routing for pipes, electrical cables, etc. are cut in primary supporting members, they are to be equidistant from the face plate and the attached plate. Their height is not to be greater than 20% of the primary supporting member web height.

The length of openings is to be not greater than:

- at the end of primary member span: 25% of the distance between adjacent openings

- elsewhere: the distance between adjacent openings.

Openings may not be fitted in way of toes of end brackets.

4.2.4 Large openings

In case of large openings as shown in Fig 1, the secondary stresses in primary supporting members are to be considered for the reinforcement of the openings, where deemed necessary.

The secondary stresses may be calculated in accordance with the following procedure.

Members (1) and (2) are subjected to the following forces, moments and stresses:

$$F = \frac{M_A + M_B}{2\,d}$$

$$m_1 = \left|\frac{M_A - M_B}{2}\right| K_1$$

$$m_2 = \left|\frac{M_A - M_B}{2}\right| K_2$$

$$\sigma_{F1} = 10\frac{F}{S_1}$$

$$\sigma_{F2} = 10\frac{F}{S_2}$$

$$\sigma_{m1} = \frac{m_1}{w_1}10^3$$

$$\sigma_{m2} = \frac{m_2}{w_2}10^3$$

$$\tau_1 = 10\frac{K_1 Q_T}{S_{w1}}$$

$$\tau_2 = 10\frac{K_2 Q_T}{S_{w2}}$$

where:

M_A, M_B : Bending moments, in kN.m, in sections A and B of the primary supporting member

m_1, m_2 : Bending moments, in kN.m, in (1) and (2)

d : Distance, in m, between the neutral axes of (1) and (2)

σ_{F1}, σ_{F2} : Axial stresses, in N/mm², in (1) and (2)

σ_{m1}, σ_{m2} : Bending stresses, in N/mm², in (1) and (2)

Q_T : Shear force, in kN, equal to Q_A or Q_B, whichever is greater

τ_1, τ_2 : Shear stresses, in N/mm², in (1) and (2)

w_1, w_2 : Net section moduli, in cm³, of (1) and (2)

S_1, S_2 : Net sectional areas, in cm², of (1) and (2)

S_{w1}, S_{w2} : Net sectional areas, in cm², of webs in (1) and (2)

I_1, I_2 : Net moments of inertia, in cm⁴, of (1) and (2) with attached plating

**Figure 1 : Large openings in primary supporting members
Secondary stresses**
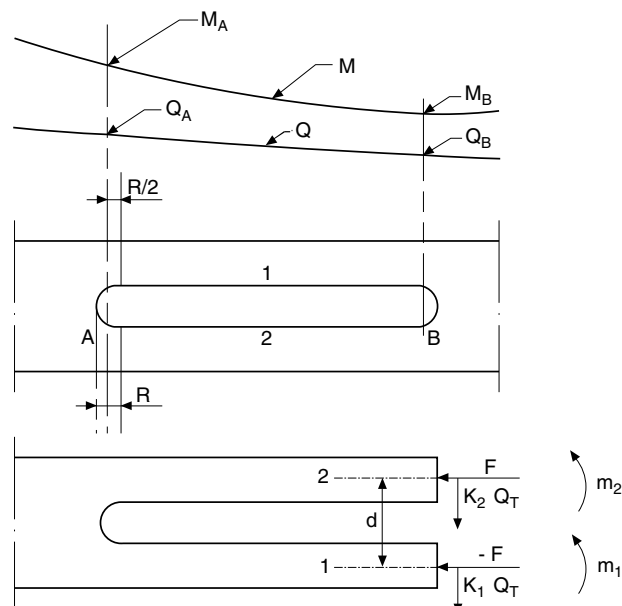
$$K_1 = \frac{I_1}{I_1 + I_2}$$

$$K_2 = \frac{I_2}{I_1 + I_2}$$

The combined stress σ_C calculated at the ends of members (1) and (2) is to be obtained from the following formula:

$$\sigma_C = \sqrt{(\sigma_F + \sigma_m)^2 + 3\tau^2}$$

The combined stress σ_C is to comply with the checking criteria defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]). Where these checking criteria are not complied with, the cut-out is to be reinforced by:

• continuous face plate (see Fig 2), or
• straight face plate (see Fig 3), or
• compensation of the opening by increase of the web thickness t_1 (see Fig 4).

Other arrangements may be accepted provided they are supported by direct calculations submitted to the Society for review.

Figure 2 : Stiffening of large openings in primary supporting members
Solution 1
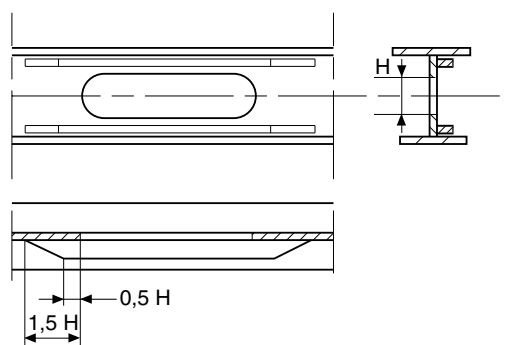
Figure 3 : Stiffening of large openings in primary supporting members
Solution 2
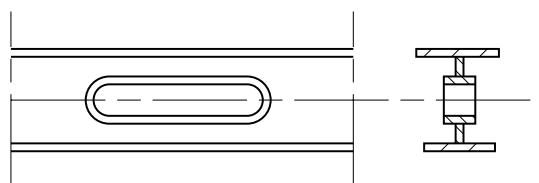
Figure 4 : Stiffening of large openings in primary supporting members
Solution 3
Inserted plate
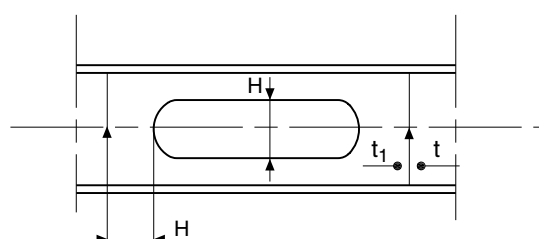
Section 5   Global Strength Analysis of Hull Girder and Cross Deck

Symbols

σ_A, τ_A : Actual normal and shear stresses, in N/mm², as defined in the applicable Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]) and calculated taking into account:
- the global hull bending moments and shear forces, and
- the strength characteristics of the hull transverse section and the platform section of catamaran.

1   General

1.1   Global strength approach

1.1.1 As a rule, the global hull girder strength is to be examined regardless of local hull strength.

a) General approach:

The global hull girder strength and the global strength of catamaran are to be examined on the basis of:
- global hull girder loads, and
- geometrical characteristics of the main structure elements

according to the methodology defined in the applicable Society Rules (see Sec 1, [1.1.2]).

b) Finite element calculation approach:

The global strength analysis may also be examined with a Finite Element Analysis submitted by the designer according to the requirements defined in the applicable Society Rules (see Sec 1, [1.1.2]).

1.2   Application

1.2.1   Global hull longitudinal girder strength

As a rule, for monohull ships and for floats of catamarans, the global hull girder longitudinal strength is to be examined in the following cases:
- ships with length greater than 40 m, or
- ships having large openings in decks or significant geometrical structure discontinuity at bottom or deck, or
- ships with transverse framing systems, or
- ships with deck structure made of small plate thicknesses and large spacing of secondary stiffeners, or
- ships with important deadweight, or
- where deemed appropriate by the Society.

Note 1: For ships not covered by the above cases, the hull girder strength is considered satisfied when local scantlings are in accordance with requirements defined in Sec 6.

1.2.2   Global transverse strength of catamaran

As a rule, the global transverse strength of catamaran is to be examined for all types of catamaran.

2   Global strength check

2.1   General

2.1.1 The global analysis check is to be successively carried out taking into account the scantling criteria based on:
- maximum stress check as defined in [2.2]
- buckling check as defined in App 2.

The global analysis check is to be carried out in the following areas of the hull:
- in head sea condition (for monohull and multihull):
  Along the ship from 0,3L to 0,7L from the aft end
- in quartering sea (for multihull only):
  Along the float from aft to fore end, and in way of each primary transverse cross structure of the platform.

Note 1: As a rule, the distribution of hull girder loads from the aft perpendicular to 0,3 L and from 0,7 L to the fore perpendicular are overlooked and considered as equal to zero.

2.2 Stress check

2.2.1 General approach

a) Maximum stress check:

It is to be checked that the actual normal stresses σ_A and the actual shear stresses τ_A, in N/mm^2, are in compliance with the following criteria:

$|\sigma_A| \leq \sigma_{glam}$

$|\tau_A| \leq \tau_{glam}$

where:

$\sigma_{glam}, \tau_{glam}$: Global bending and shear permissible stresses, in N/mm^2, as defined in the applicable Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

b) Buckling stress check:

It is to be checked that the actual stresses are in compliance with the buckling criteria and buckling safety factors defined in App 2.

2.2.2 Stress check using Finite element calculation

The stresses and buckling analysis, and the scantling criteria are to be checked as defined in the applicable Society Rules (see Sec 1, [1.1.2]).

Section 6   Hull Local Strength Analysis

1 General

1.1 Local scantling

1.1.1 The present Section deals with the local scantling of platings, secondary and primary stiffeners under local lateral pressures.

1.1.2 The scantling of platings, secondary and primary stiffeners contributing to the overall longitudinal strength of the hull girder and to the overall transverse strength of platform of catamaran are also to be checked as defined in Sec 5.

1.2 Local loads

1.2.1 Local loads

The local lateral pressures to take into account for the scantling are those defined in the Society Rules for the classification and/ or certification of ships (see Sec 1, [1.1.2]), i.e.:

a) Sea pressure

   Still water loads (due to hydrostatic external sea pressure in still water), and wave loads (due to wave pressure and ship motions).

b) Dynamic sea pressures

   The dynamic sea pressures are loads which have a duration shorter than the period of wave loads and are constituted by:

   - side shell impacts and, for multihull, platform bottom impact: to be calculated for the plating and the secondary stiffeners only

   - bottom impact pressure on flat bottom forward area: to be calculated for the structural elements of forward bottom, where applicable

   - bottom slamming pressure: to be calculated for the structural elements of the bottom of planing hull   where slamming may occur.

Note 1: Side shell primary stiffeners and cross deck primary stiffeners are, as a general rule, examined with sea pressures only, without taking into account the side shell and cross deck impacts.

c) Local internal pressure

   Local internal pressures are loads induced by liquid cargoes, dry cargoes, accommodations, testing loads and flooding loads.

d) Wheel loads on deck, when applicable.

1.2.2 Local loads point location

Unless otherwise specified, the local loads are to be calculated at the following point location:

a) General case:

   - for plate panels:

     at the lower edge of the plate panels

   - for longitudinal stiffeners:

     at mid-span of the stiffeners

   - for transverse stiffeners:

     at the lower ($p_{S\ lower}$) and upper ($p_{S\ upper}$) points of the stiffeners.

b) Dynamic loads:

   - for plate panels:

     at mid-edge of the plate panels

   - for longitudinal and transverse stiffeners:

     at mid-span of the stiffeners.

2 Plating scantling

2.1 General

2.1.1 Loading cases

Local scantlings of platings are to be checked under the following loads:

- for bottom platings: wave loads and bottom slamming pressures (when slamming may occur)

- for side shell and platform bottom platings: wave loads and side shell impacts

- for deck platings: the greater value between wave loads and minimum loads, and, when applicable, wheeled loads

- for superstructure platings: the greater value between wave loads and minimum loads.

- for all hull plating, when applicable: exceptional damage loads and testing loads.

2.2 Plating scantling

2.2.1 Theoretical scantling approach

The plating scantling under lateral pressure is based on an elastic scantling approach.

2.2.2 Plating scantling

The thickness, in mm, is obtained considering successively the different loads sustained by the plate (defined in [2.1.1]) and the:

- scantling formulae, and

- relevant associated permissible stresses

defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

3 Secondary stiffener scantlings

3.1 General

3.1.1 Loading cases

Local scantlings of secondary stiffeners are to be checked under the following loading cases:

- for bottom secondary stiffeners: wave loads and bottom slamming pressures (when slamming may occur)

- for side shell and platform bottom secondary stiffeners: wave loads and side shell impacts

- for deck secondary stiffeners: the greater value between wave loads and minimum loads, and, when applicable, wheeled loads

- for superstructure secondary stiffeners: the greater value between wave loads and minimum loads.

- for all hull secondary stiffeners, when applicable: exceptional damage loads and testing loads.

3.1.2 End stiffener conditions

The connection of secondary stiffeners with surrounding supporting structure is to be taken into account in the calculation of the rule stiffener section moduli.

The following three hypotheses on end stiffener conditions are taken into consideration in the scantling formulae, using a coefficient m equal, successively, to:

- for fixed end condition: m = 12

  The cross-section at the ends of the stiffener cannot rotate under the effect of the lateral loads (as a rule, the secondary stiffeners are considered with fixed ends).

- for simply supported end condition: m = 8

  The cross-section at the ends of the stiffener can rotate freely under the effect of the lateral loads.

- for intermediate conditions: m = 10

  The cross-section at the ends of the stiffener is in an intermediate condition between fixed end condition and simply supported end condition.

3.2 Span of stiffener

3.2.1 The span ℓ of the stiffeners considered in the scantling formulae is to be measured as shown in Fig 1 to Fig 3.

Figure 1 : Stiffener without brackets
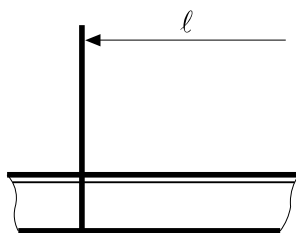
Figure 2 : Stiffener with a stiffener at one end
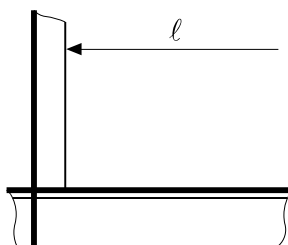
Figure 3 : Stiffener with a bracket and a stiffener at one end
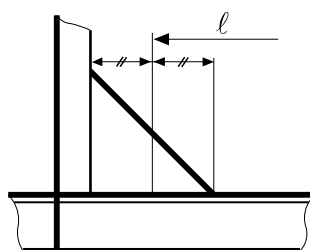
3.2.2 For open floors, when a direct beam calculation taking into account all the elements of the open floor is not carried out, the span ℓ of the upper and lower secondary stiffeners connected by one or two strut(s) is to be taken equal to $0,7\,\ell_2$ instead of ℓ_1 (see Fig 4).

Figure 4 : Span of stiffeners in case of open floors
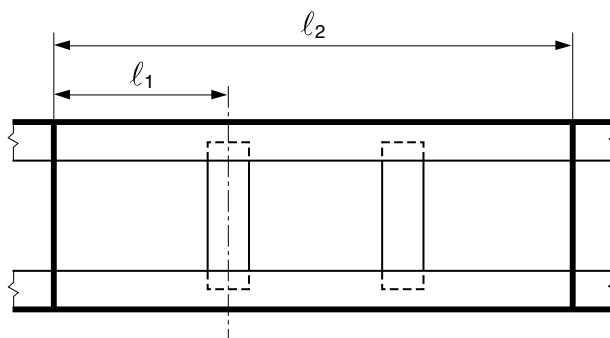
3.3   Secondary stiffener scantling

3.3.1 The section modulus, in cm^3 and the shear area, in cm^2, are obtained considering successively the different loads sustained by the secondary stiffeners (defined in [3.1.1]) and the:

• scantling formulae, and

• relevant associated permissible stresses

defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

As a rule, the thicknesses (web and flange) of stiffeners are to be as defined in [3.3.2]. Other thicknesses may be considered if the buckling assessment under axial loads or under local loads is carried out according to App 2, [3].

3.3.2   Recommended proportions of stiffeners

As a rule, the thicknesses (web and flange) of stiffeners are to satisfy the following criteria:

a) Stiffener web plate:

$$t_w \geq \frac{h_w}{C_w} \sqrt{\frac{R_y}{100}}$$

b) Stiffener flange:

$$t_f \geq \frac{b_{f\text{-}out}}{C_f} \sqrt{\frac{R_y}{100}}$$

$$b_f \geq 0{,}25 \, h_w$$

where:

C_w, C_f : Slenderness coefficients given in Tab 1.

Note 1: For stiffened web, h_w may be replaced by the spacing between web stiffeners, in mm, if smaller.

Table 1 : Slenderness coefficients

Type of stiffeners	C_w	C_f
Angle bars	50	8
T-bars	50	8
Bulb bars	30	–
Flat bars	15	–

Figure 5 : Stiffener scantling parameters
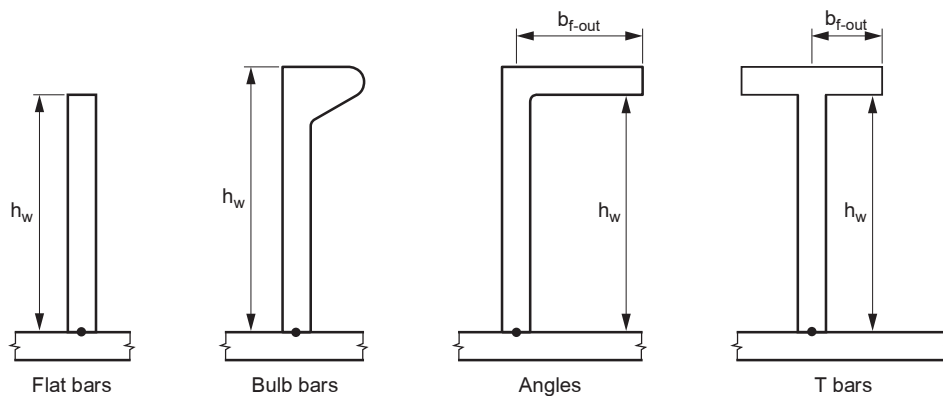
4 Primary stiffener scantling

4.1 General

4.1.1 Loading cases

Scantlings of primary stiffeners are to be checked under the following local loading cases:

- for bottom primary stiffeners: wave loads and bottom slamming pressures (when slamming may occur)
- for side shell and platform bottom primary stiffeners: wave loads
- for deck primary stiffeners: the greater value between wave loads and minimum loads, and, when applicable, wheel loads
- for superstructure primary stiffeners: the greater value between wave loads and minimum loads.
- for all hull primary stiffeners, when applicable: exceptional damage loads and testing loads.

4.2 Primary stiffener scantling

4.2.1 Scantling approach

a) General case: Isolated beam model

As a rule, the requirements for the scantling of the primary stiffener scantling are defined for isolated beam model.

b) 2D or 3D beam model:

When an isolated beam calculation of the primary structure is not sufficient due to an interaction of the primary stiffeners, a two or three-dimensional structural model analysis including the different primary stiffeners is to be carried out as defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

c) Finite element calculation:

The primary stiffener scantling strength under local loads may also be examined with a Finite Elements Analysis submitted by the designer according to the requirements defined in the applicable Society Rules (see Sec 1, [1.1.2]).

4.2.2   Primary stiffener scantling

a) General case: Isolated beam model

The section modulus, in cm³ and the shear area, in cm², are obtained considering successively the different loads sustained by the primary stiffener (defined in [4.1.1]) and the:

- structural isolated beam model, and
- relevant associated permissible stresses

defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

b) 2D or 3D beam model:

It is to be checked that the actual combined stresses σ_{VM} calculated according to Von Mises criteria are in compliance with:

$\sigma_{VM} \leq \sigma_{vmam}$

where:

σ_{vmam} :   Rule permissible combined stress value defined in the applicable Society Rules (see Sec 1, [1.1.2]).

c) Finite element calculation:

The maximum actual stresses and buckling stresses together with specific permissible stresses and buckling criteria are to be calculated according to the applicable Society Rules (see Sec 1, [1.1.2]).

4.2.3   Recommended stiffener scantling

As a rule, the proportions of stiffeners are to be as defined in [3.3].

4.2.4   Attached plating buckling

Depending on the compression stress level in the attached plating induced by the bending of primary stiffener under the local loads, it may be necessary to check the buckling of the attached plating along the primary stiffener span.

The buckling of the attached plating is to be checked according to the criteria defined App 2.

4.3   Curved primary stiffeners

4.3.1 The curvature of primary supporting members may be taken into account by direct analysis.

In case of 2-D or 3-D beam structural model, the curved primary supporting members may be represented by a number N of straight beams, N being adequately selected to minimize the spring effect in way of knuckles.

The stiffness of knuckle equivalent springs is considered as minor from the point of view of the local bending moment and the shear force distribution when the angle between two successive beams is not more than 3°.

5   General arrangement of brackets for secondary and primary stiffeners

5.1   General requirements

5.1.1 As a general rule, brackets are to be provided at the stiffener ends when the continuity of the web or the flange of the stiffeners is not ensured in way of their supports.

5.1.2 Arm lengths of end brackets are to be equal, as far as practicable.

5.1.3 The section of the end bracket web is generally to be not less than that of the supported stiffener web.

5.1.4 The section modulus of the end bracket is to be at least equal to the section modulus of the stiffener supported by the bracket.

When the bracket is flanged, the section modulus is to be examined in way of the flange as well as in way of the end of the flange.

5.1.5   Bracket flanges

Aluminium brackets having a thickness, in mm, less than 22 L_b are to be flanged or stiffened with a welded face plate, such that:

- the sectional area, in cm², of the flanged edge or the face plate is at least equal to 10 L_b
- the thickness of the bracket flange is not less than that of the bracket web

where:

L_b :   Length, in m, of the free edge of the bracket.

5.1.6 When a face plate is welded on end brackets to be strengthened, this face plate is to be symmetrical.

In such a case, the following arrangements are to be complied with, as a rule:

- the face plates are to be snipped at the ends, with a total angle not greater than 30°
- the width of the face plates at ends is not to exceed 25 mm
- the face plates being 20 mm thick or above are to be tapered at ends over half the thickness
- the radius of the curved face plates is to be as large as possible
- a collar plate is to be fitted in way of the bracket toes
- the fillet weld throat is to be not less than t/2, where t is the thickness of the bracket toe.

5.2 Brackets for connection of perpendicular stiffeners

5.2.1 Typical brackets for connection of perpendicular stiffeners are shown from Fig 6 to Fig 11.

As a general rule, brackets are to be in accordance with the requirements given in [5.1].

In addition, and where no direct calculation is carried out, the length d, in mm, as defined from Fig 6 to Fig 11, is to be not less than:

$$d = \varphi \sqrt{\frac{w + 30}{t}}$$

where:

φ : Coefficient equal to:
- for unflanged brackets: $\varphi = 48,0$
- for flanged brackets: $\varphi = 43,5$

w : Required section modulus of the supported stiffener, in cm^3

t : Bracket thickness, in mm.

When a bracket is provided to ensure the simultaneous continuity of two (or three) stiffeners of equivalent stiffness, the bracket scantling is to be examined by direct calculation, taking into account the balanced bending moment in the connection of the two (or three) stiffeners.

Figure 6 : Bracket at upper end of secondary stiffeners on plane bulkhead
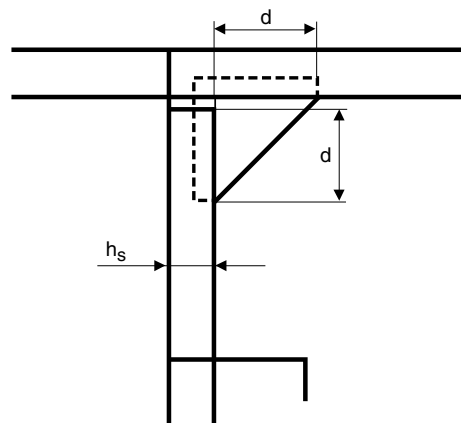
Figure 7 : Bracket at lower end of secondary stiffeners on plane bulkhead
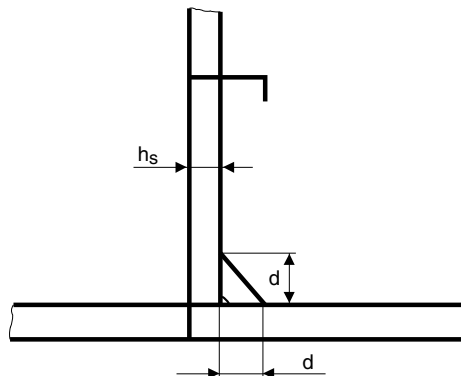
Figure 8 : Other bracket arrangement at lower end of secondary stiffeners on plane bulkhead

Section A-A
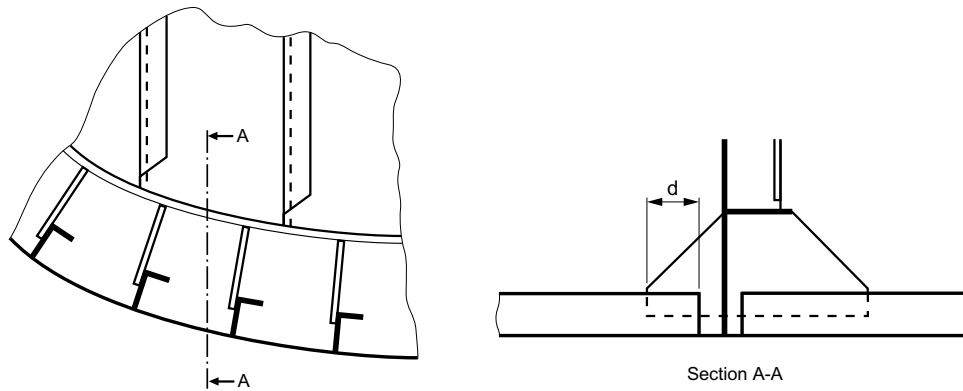
Figure 9 : Connection of perpendicular stiffeners in the same plane
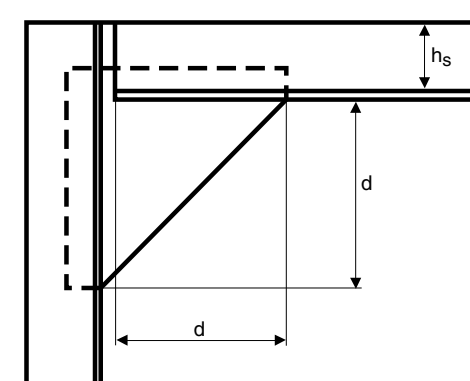
Figure 10 : Connection of stiffeners located in perpendicular planes
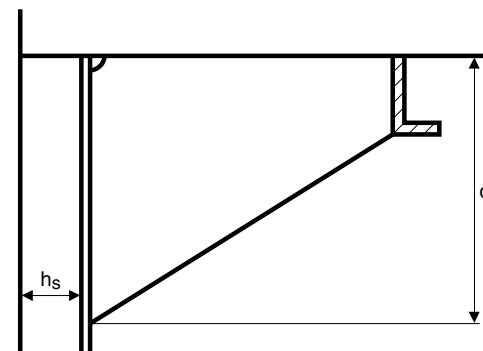
Figure 11 : Lower bracket of main frames
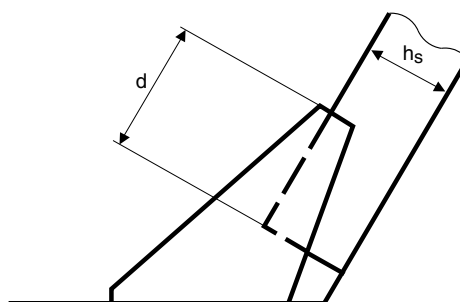
5.3 Brackets ensuring continuity of secondary stiffeners

5.3.1 Where secondary stiffeners are cut in way of the primary supporting members, brackets (or equivalent arrangements) are to be fitted to ensure the structural continuity as shown in Fig 12. Their section moduli and their sectional areas are to be not less than those of the secondary stiffeners.

The bracket thickness is to be not less than that of the secondary stiffeners and dimension d of each bracket is to be as a rule not less than the value defined in [5.2.1].

Figure 12 : End connection of secondary stiffeners - Backing bracket
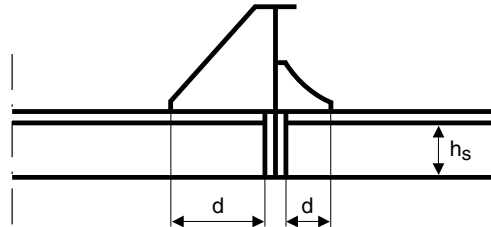
5.4 Bracketless end stiffener connections

5.4.1 Case of two stiffeners

In the case of bracketless crossing between two primary supporting members (see Fig 13), the thickness t_b of the common part of the webs, in mm, is to be not less than the greater value obtained from the following formulae:

$$t_b = \frac{Sf_1 \sigma_1}{0,4 h_2 R'_{p0,2}}$$

$$t_b = \frac{Sf_2 \sigma_2}{0,4 h_1 R'_{p0,2}}$$

$$t_b = \max(t_1, t_2)$$

where:

Sf_1, Sf_2 : Flange sections, in mm^2, of member 1 and member 2, respectively

σ_1, σ_2 : Actual normal stresses, in N/mm^2, in flanges of member 1 and member 2, respectively.

Figure 13 : Bracketless connections between two primary supporting members
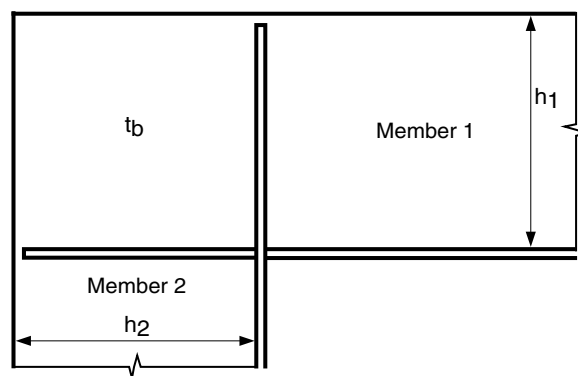
5.4.2 Case of three stiffeners

In the case of bracketless crossing between three primary supporting members (see Fig 14) and when the flange continuity is ensured between member 2 and member 3, the thickness t_b of the common part of the webs, in mm, is to be not less than:

$$t_b = \frac{Sf_1 \sigma_1}{0,4 h_2 R'_{p0,2}}$$

When the flanges of member 2 and member 3 are not continuous, the thickness of the common part of the webs is to be as defined in [5.4.1].

Figure 14 : Bracketless connections between three primary supporting members
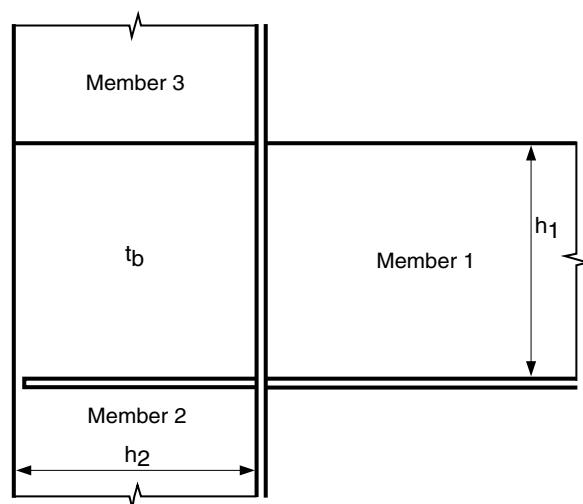
5.4.3 Stiffening of common part of webs

When the minimum value of heights h_1 and h_2 of member 1 and member 2 is greater than 60 t_b, the common part of the webs is generally to be stiffened.

5.4.4 Lamellar tearing in way of flanges

When lamellar tearing of flanges is likely to occur, a 100% ultrasonic testing of the flanges in way of the weld may be required after welding.

5.5 Other type of end connections

5.5.1 Where end connections are made according to Fig 15, a stiffener with sniped ends is to be fitted on connection web, when:

$a > 60 \ t$

where:

a : Dimension, in mm, measured as shown on Fig 15

t : Web thickness, in mm.

Figure 15 : End connection with stiffener
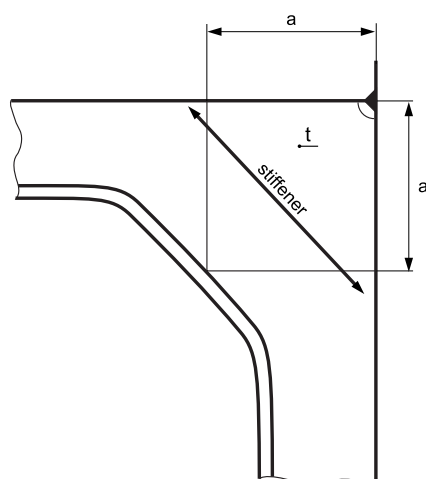
Section 7   Structural Arrangements and Special Features

1   General

1.1   Application

1.1.1 The requirements of the present Section apply to longitudinally and transversely frame structure arrangements of ships built in aluminium alloy for:

- structural continuity of hull
- single and double bottoms
- sides and decks
- transverse and longitudinal structures
- superstructures and deckhouses
- special features.

Any other arrangement may be considered on a case-by-case basis.

Additional specific structure arrangements in relation to the service notation of the ship are to comply with the applicable requirements defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

2   Structural continuity of hull girder

2.1   General principles for longitudinal hull girder

2.1.1 Attention is to be paid to the structural continuity:
- in way of changes in the framing system
- at the connections of primary and secondary stiffeners.

2.1.2 Longitudinal members contributing to the hull girder longitudinal strength are to extend continuously over a sufficient distance towards the ends of the ship.

Secondary stiffeners contributing to the hull girder longitudinal strength are generally to be continuous when crossing primary supporting members. Otherwise, the detail of connections is considered by the Society on a case-by-case basis.

2.1.3 Where stress concentrations may occur in way of structural discontinuity, adequate compensation and reinforcements are to be provided.

2.1.4 Openings are to be avoided, as far as practicable, in way of highly stressed areas.

Where necessary, the shape of openings is to be specially designed to reduce the stress concentration factors.

Openings are to be generally well rounded with smooth edges.

2.1.5 Primary supporting members are to be arranged in such a way that they ensure adequate continuity of strength. Abrupt changes in height or in cross-section are to be avoided.

2.2   General principles for platform of multihull

2.2.1 Attention is to be paid to the structural continuity of the primary transverse cross structure of the platform ensuring the global transversal resistance of the multihull.

The primary transverse cross structure of catamaran are generally to be continuous when crossing float structures.

The connection between the transverse cross structure of swath and struts are to be examined by direct calculation.

The general continuity principles defined in [2.1] also apply for the primary transverse cross structure of the platform.

2.3   Insert plates and doublers

2.3.1 A local increase in plating thickness is generally to be achieved through insert plates. Local doublers, which are normally only allowed for temporary repair, may however be accepted by the Society on a case-by-case basis.

In any case, doublers and insert plates are to be made of materials of a quality at least equal to that of the plates on which they are welded.

2.3.2 Doublers having width, in mm, greater than:

• 20 times their thickness, for thicknesses equal to or less than 15 mm

• 25 times their thickness, for thicknesses greater than 15 mm,

are to be fitted with slot welds, to be effected according to Sec 3.

2.3.3 When doublers fitted on the outer shell and strength deck within 0,6 L amidships are accepted by the Society, their width and thickness are to be such that slot welds are not necessary according to the requirements in [2.3.2]. Outside this area, the possibility of fitting doublers requiring slot welds will be considered by the Society on a case-by-case basis.

3 Subdivision, compartment and access arrangements

3.1 General

3.1.1 Subdivision, compartment and access arrangements are to comply with the applicable requirements defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

4 Arrangement of hull openings

4.1 General

4.1.1 Arrangement of hull openings is to comply with the applicable requirements defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

5 Bottom structure arrangements

5.1 General arrangement

5.1.1 The bottom structure is to be checked by the Designer to make sure that it withstands the loads resulting from the dry-docking of the ship or the lifting by crane. These loading cases are not within the scope of the classification and/or certification.

5.1.2 Provision is to be made for the free passage of water from all the areas of the bottom to the suctions, by means of scallops in floors and bottom girders.

5.1.3 Additional girders and floors may be fitted in the engine room to ensure adequate rigidity of the structure, according to the recommendations of the engine supplier.

5.1.4 If fitted, solid ballast is to be securely positioned. If necessary, intermediate girders and floors may be required. The builder is to check that solid ballast material is compatible with the aluminium alloys used.

5.1.5 Where face plates of floors and bottom girders are at the same level, the face plate of the stiffer member is generally to be continuous. Butt welds of face plates are to provide strength continuity.

5.1.6 As a rule, bottom girders are to be fitted in way of each line of pillars. If it is not the case, local longitudinal members are to be provided.

5.2 Longitudinal framing arrangement of single bottom

5.2.1 As a general rule, hull with a longitudinally framed single bottom are to be fitted with a continuous or intercostal centre girder welded to the floors.

5.2.2 Where side girders are fitted locally in lieu of the centre girder, they are to be extended over a sufficient distance beyond the ends of the existing centre girder and an additional stiffening of the bottom in the centreline area may be required.

5.2.3 Centre and side bottom girders are to be extended as far as possible towards the ends of the hull.

5.2.4 Cut-outs fitted in the web of floors for the crossing of bottom longitudinals are to be taken into account for the shear analysis of floors.

5.3 Transverse framing arrangement of single bottom

5.3.1 In general, the height, in m, of floors at the centreline should not be less than B/16. In the case of ships with considerable rise of floors, this height may be required to be increased so as to ensure a satisfactory connection to the frames.

5.3.2 The ends of floors at side are to be located in line with side transverse members.

It may be accepted, on a case-by-case basis that floor ends at side be welded on a primary longitudinal member of the side shell or of the bottom.

5.3.3 Openings and cut-outs in the web of bottom girders for the crossing of floors are to be taken into account for the girder shear analysis.

5.4 Double bottom arrangements

5.4.1 Double bottom height

As a general rule, the double bottom height is to be:

- sufficient to ensure access to any part of the bottom, and

- not less than 0,76 m in way of the centre girder.

5.4.2 Where the height of the double bottom varies, the variation is generally to be made gradually and over an adequate length.

The knuckles of inner bottom plating are to be located in way of floors

Where such arrangements are not possible, suitable longitudinal structures such as partial girders, longitudinal brackets etc., fitted across the knuckle, are to be fitted.

5.4.3 Adequate continuity is to be provided between double bottom area and single bottom area.

5.4.4 Floors are to be provided:

- watertight in way of watertight transverse bulkheads

- reinforced in way of double bottom steps.

5.4.5 Where the double bottom height exceeds 0,9 m, web of floors and girders are to be strengthened by vertical stiffeners spaced not more than 1 m apart.

These stiffeners may consist of:

- either bottom girders welded to the floors, or

- flat bars with, as a rule, a width equal to one tenth of the floor depth and a thickness equal to the floor thickness.

5.4.6 Watertight floors are to be fitted with stiffeners having a section modulus not less than that required for tank bulkhead vertical stiffeners.

5.4.7 In case of open floors consisting in a frame connected to the bottom plating and a reverse frame connected to the inner bottom plating, the construction principle is to be as shown on Fig 1.

Figure 1 : Open floor - Transverse framing system
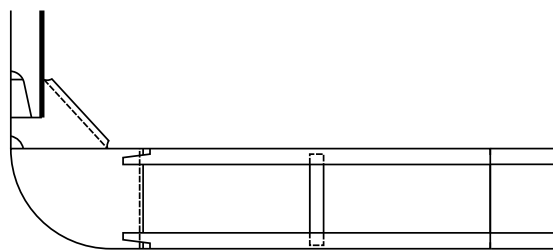
5.4.8 Double bottom compartment

Double bottom compartment arrangements are to be in accordance with the applicable requirements defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

5.4.9 Duct keel

Where a duct keel is arranged, the strength continuity of the structure of the floors is to be ensured.

5.5 Arrangement, scantling and connections of bilge keel

5.5.1 Arrangement

Bilge keels may not be welded directly on the shell plating. An intermediate flat, or doubler, is required on the shell plating.

The thickness of the intermediate flat is to be equal to that of the bilge strake.

The ends of the bilge keels are to be sniped at an angle of 15° or rounded with a large radius. They are to be located in way of a transverse bilge stiffener. The ends of the intermediate flat are to be sniped at an angle of 15°.

The arrangement shown in Fig 2 is recommended.

The arrangement shown in Fig 3 may also be accepted.

Figure 2 : Bilge keel arrangement
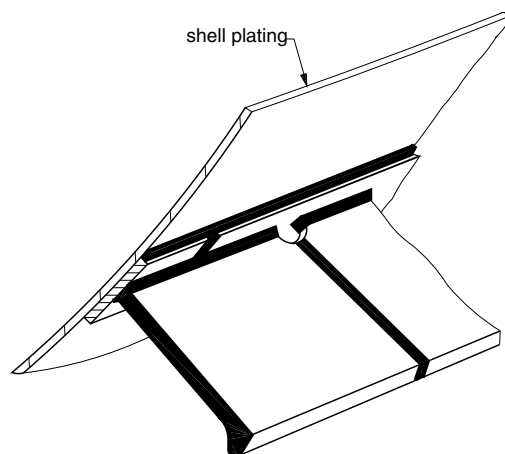
Figure 3 : Bilge keel arrangement
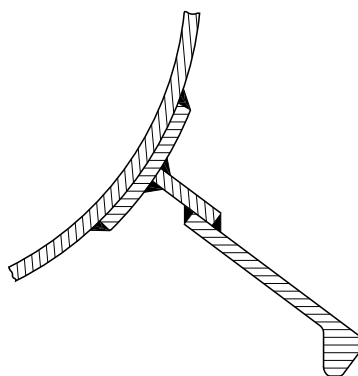
5.5.2 Materials

The bilge keel and the intermediate flat are to be made of aluminium having the same yield stress as that of the bilge strake.

5.5.3 Welding

Welding of bilge keel with intermediate flat is to be in accordance with Sec 3.

6 Side structure arrangement

6.1 General

6.1.1 In a transverse framing system, structure of sides is made of transverse frames, possibly supported by horizontal stringers.

6.1.2 In a longitudinal framing system, structure of sides is made of secondary longitudinal stiffeners supported by vertical primary supporting members.

6.1.3 Where the sheerstrake (connection between side shell and deck plate) is rounded, the radius, in mm, is to be not less than 15 t_S, where t_S is the thickness, in mm, of the sheerstrake.

6.2 Stiffener arrangements

6.2.1 In general, the section modulus of 'tweendeck frames is to be not less than that required for frames located immediately above.

6.2.2 Transverse web frames and secondary side frames are to be attached to floors and to deck beams by brackets or any other equivalent structure (see Sec 6, [5]).

6.2.3 For transverse framing system, the attention of the Designer is drawn on the risk of buckling of side shell plate panels in way of ends of frames. Extra thicknesses or additional vertical intercostal stiffeners may be requested on the side shell.

6.3 Openings in the shell plating

6.3.1 Openings in side shell are to be well rounded at the corners and located, as far as practicable, well clear of superstructure ends.

6.3.2 Large-sized openings are to be adequately compensated by means of insert plates of increased thickness. Such compensations are to be partial or total, depending on the stresses occurring in the area of the openings.

6.3.3 Secondary stiffeners cut in way of openings are to be attached to local structural members supported by the continuous adjacent secondary stiffeners, or any other equivalent arrangement.

6.3.4 The sea chest thickness is generally to be equal to that of the local shell plating

6.3.5 Openings for stabilizer fins are considered by the Society on a case-by-case basis.

7 Deck structure arrangements

7.1 General

7.1.1 Adequate continuity of decks (plates and stiffeners) is to be ensured in way of:
- stepped or knuckled strength decks
- changes in the framing system
- large openings.

7.1.2 Deck supporting structures under cranes and windlass are to be adequately stiffened.

7.1.3 Pillars or other supporting structures are generally to be fitted under heavy concentrated loads on decks.

7.1.4 Stiffeners are to be fitted in way of the ends and the corners of deck houses and partial superstructures.

7.1.5 Beams fitted at side of a deck hatch are to be efficiently supported by at least two deck girders located at each side of the deck opening.

7.2 Opening arrangements

7.2.1 The deck openings are to be as much spaced apart as possible.
As practicable, they are to be located as far as possible from the highly stressed deck areas or from the stepped deck areas.

7.2.2 Extra thicknesses or additional reinforcements may be requested where deck openings are located:
- close to the primary transverse cross structure of platform of multihull
- in areas of deck structural singularity (stepped deck...)
- in way of the fixing of out-fittings.

7.2.3 As a rule, all the deck openings are to be fitted with rounded corners. Generally, the corner radius is not to be less than 5% of the transverse width of the opening.

7.2.4 Corner radiusing, in the case of two or more openings athwart ship in one single transverse section, is considered by the Society on a case-by-case basis.

7.3 Hatch supporting structure

7.3.1 Hatch side girders and hatch end beams of reinforced scantling are to be fitted in way of cargo hold openings.
In general, hatched end beams and deck transverses are to be in line with bottom and side transverse structures, so as to form a reinforced ring.
Adequate continuity of strength of longitudinal hatch coamings is to be ensured.
The details of connection of deck transverses to longitudinal girders and web frames are to be submitted to the Society for approval.

7.4 Pillars arrangement under deck

7.4.1 Pillars are to be connected to the bottom at the intersection of floors and bottom girders and at deck at the intersection of deck beams and deck girders.
Where it is not the case, an appropriate local structure is to be fitted to support the pillars.

7.4.2 Pillars are to be attached at their heads and heels by continuous welding.
Heads and heels of pillars are to be attached to the surrounding structure by means of brackets, insert plates or doubling plates so that the loads are well distributed.
In general, the thickness of insert plate or doubling plates is to be not less than 1,5 times the thickness of the pillar.

7.4.3 If tensile stress is expected in the pillar, an insert plate is to be put in place of doubling plate and head and heel brackets may be required.

7.4.4 In tanks and in spaces intended for products which may procure explosive gases, solid or open section pillars are to be fitted.

7.4.5 Where pillars are made of steel or stainless steel, their connection to the hull structure is to be made of bi-metallic joints or equivalent systems. These systems are to be type-approved.

7.4.6 Manholes may not be cut in the web of primary structure in way of the head and heel of pillars.

7.4.7 Tight or non-tight bulkheads may be considered as pillars, provided their scantling complies with [8.4].

7.4.8 Scantling of the pillars are to comply with the requirements of Sec 8.

7.5 Deck structure in way of launching appliances used for survival craft or rescue boats

7.5.1 The scantling of deck structure supporting launching appliances used for survival craft or rescue boats is to be determined by direct calculations, as defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

7.5.2 Attention is drawn on any possible specific requirement that could be issued by the Flag Administration with respect to structure reinforcement and to structural fire protection.

8 Bulkhead structure arrangements

8.1 General

8.1.1 Plane bulkheads may be horizontally or vertically stiffened.

Stiffening of horizontally framed bulkheads consists of horizontal secondary stiffeners supported by vertical primary supporting members.

Stiffening of vertically framed bulkheads consists of vertical secondary stiffeners which may be supported by horizontal stringers.

The structural continuity of the vertical and horizontal primary supporting members with the surrounding supporting hull structures is to be carefully ensured.

8.1.2 As a general rule, transverse bulkheads are to be stiffened, in way of bottom and deck girders, by vertical stiffeners in line with these girders or by an equivalent system.

Where a deck girder is not continuous, the bulkhead vertical stiffener supporting the end of the deck girder is to be strong enough to sustain the bending moment transmitted by the deck girder.

8.2 Watertight bulkheads

8.2.1 Crossing through watertight transverse bulkheads of bottom, side shell or deck longitudinal stiffeners are to be closed by watertight collar plates.

8.2.2 Ends of stiffeners of watertight bulkheads are to be aligned with the hull structure members, and are to be fitted with end brackets.

Where this arrangement is made impossible due to hull lines, any other solution may be accepted provided embedding of the bulkhead secondary stiffeners is satisfactorily achieved.

8.2.3 The secondary stiffeners of watertight bulkheads in the 'tweendecks may be snipped at ends, provided their scantling is increased accordingly.

8.2.4 Watertight doors

The thickness of watertight doors is to be not less than the adjacent bulkhead plating, taking into account their actual spacing.

Where bulkhead stiffeners are cut in way of watertight door, reinforced stiffeners are to be fitted and suitably overlapped; cross-bars are to be provided to support the interrupted stiffeners.

8.3 Non-tight bulkheads

8.3.1 As a rule, non-tight bulkheads not acting as pillars are to be provided with vertical stiffeners with a maximum spacing equal to:
- 0,9 m apart, for transverse bulkheads
- two frames spacings, with a maximum of 1,5 m, for longitudinal bulkheads.

8.3.2 Swash bulkheads

As a rule, the total area of the openings in a tank swash bulkhead is to be between 10% and 30% of the total area of the swash bulkhead.

8.4 Bulkheads acting as pillars

8.4.1 As a rule, bulkheads acting as pillars (i.e those designed to sustain the loads transmitted by a deck structure) are to be provided with vertical stiffeners being at a maximum two frames apart.

8.4.2 A vertical stiffening member is to be fitted on the bulkhead in line with the deck primary supporting member transferring the loads from the deck to the bulkhead and is to be checked as defined in Sec 8.

8.5 Bracketed stiffeners

8.5.1 The bracket scantlings at ends of bulkhead stiffeners are to be defined by direct calculation, taking into account the bending moments and shear forces acting on the stiffeners in way of the brackets, as defined in Sec 6, [5].

9 Superstructure and deckhouse structure arrangements

9.1 Superstructure materials

9.1.1 Special attention is to be given to any specific requirements from the Flag Administration about the structural materials and the structural fire protection in the superstructures.

9.2 Connections of superstructures and deckhouses with the hull structure

9.2.1 Superstructure and deckhouse frames are to be fitted, as far as practicable, in way of deck structure and are to be efficiently connected.

Ends of superstructures and deckhouses are to be efficiently supported by bulkheads, diaphragms, webs or pillars.

Where hatchways are fitted close to the ends of superstructures, additional strengthening may be required.

9.2.2 Construction details

The vertical stiffeners of the superstructure and deckhouse walls of the first tier (directly located above the freeboard deck) are to be attached to the decks at their ends.

Brackets are to be fitted at the lower end and, preferably, at the upper end of the vertical stiffeners of exposed front bulkheads of engine casings and superstructures.

9.2.3 Connection to the hull deck of the corners of superstructures and deckhouses is considered by the Society on a case-by-case basis. Where necessary, local reinforcements may be required.

9.2.4 As a general rule, the side plating at ends of superstructures is to be tapered into the side shell bulwark or the sheerstrake of the strength deck.

Where a raised deck is fitted, the local reinforcement in way of the step is to extend, as a general rule, over at least 3-frame spacings.

9.3 Structural arrangement of superstructures and deckhouses

9.3.1 Superstructures contributing to the hull girder longitudinal strength are to be examined on top of local scantling, taking into account the global strength analysis as defined in Sec 5.

9.3.2 Web frames, transverse partial bulkheads or other equivalent strengthening of each superstructure tier are to be arranged, where practicable, in line with the transverse reinforced structure below.

Web frames are also to be arranged in way of large openings, tender davits, winches, provision cranes and other areas subjected to local loads.

Web frames, pillars, partial bulkheads and similar strengthening are to be arranged, in conjunction with deck transverse, at ends of superstructures and deckhouses.

9.3.3 Openings

All the openings in superstructures and deckhouses exposed to greenseas are to be fitted with sills or coamings as defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

The attention of the Shipowners, Shipyards and Designer is drawn on the fact that the flag Administration may request application of National Rules.

9.3.4 Sidescuttles, windows and skylights

Sidescuttles, windows and skylights arrangement and scantlings are to be as defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

9.3.5 Access and doors

Access openings cut in side plating of enclosed superstructures are to be fitted with doors having a strength equivalent to the strength of the surrounding structure.

Special consideration is to be given to the connection of the doors to the surrounding structure.

Securing devices which ensure watertightness are to include tight gaskets, clamping dogs or other similar appliances, and are to be permanently attached to the bulkheads and doors. These doors are to be operable from both sides.

10 Special features

10.1 General

10.1.1 Scantling and arrangement of the following features are to be as defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]):

- fore part structure
- aft part structure
- machinery space
- bow doors and inner doors
- side doors and stern doors
- movable decks, inner ramps and external ramps
- bulwarks
- hatch covers
- rudder
- propeller shaft bracket
- water jet propulsion tunnel
- equipment in chain and anchor.

10.2 Foils and trim tab supports

10.2.1 Foils and trim tab supports are not covered within the scope of classification and/or certification.

Forces and moments induced by these elements, as well as the designer calculation, are to be submitted for the examination of the surrounding ship structure reinforcements.

As a general rule, attachment structure of foils to the ship structure is to be located within watertight compartment or equivalent.

10.3 Lifting appliances

10.3.1 As a rule, the welded fixed parts of lifting appliances fitted into the hull, and their local reinforcements, are considered as integral part of the hull and are to be checked as defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

10.4 Helicopter deck and platform

10.4.1 Arrangement and structure of helicopter deck located on weather deck or on platform permanently connected to the hull is to be examined according to the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

10.4.2 Attention is drawn on any possible specific requirement that could be issued by the Flag Administration with respect to structural fire protection.

11 Hull protection

11.1 Protection against corrosion

11.1.1 Corrosion protection of hull and superstructure is not covered by the Classification and/or the Certification.

It is incumbent upon the shipowner and the shipbuilder to take measures for the protection of materials against various types of corrosion of aluminium alloy structure in marine atmosphere.

Basic following principles may be followed to ensure a corrosion protection:
- adequate selection of alloys
- structural design avoiding trap of sea water (drain hole, wells, etc.)
- control of the risks of galvanic corrosion
- drying of stagnant sea-water and humidity retention zones
- regular inspection of sensible zones (batteries, heterogeneous assemblies, etc.)
- regular maintenance of protective anodes.

As a rule, a protective coating is to be requested for aluminium structure built in 6000 series alloy in direct contact with sea water, to prevent risk of uniform corrosion.

12 Additional requirements in relation to the service notation or the service feature assigned to the ship

12.1 General

12.1.1 Service notations and service features
The service notations define the type and/or service of the ship which is considered for its classification.

A service notation may be completed by one or more additional service features giving further precision regarding the type of service of the ship.

The service notation and the additional service features are defined in NR467 Steel Ships, Pt A, Ch 1, Sec 2, [4].

12.1.2 Additional requirements
The hull arrangement and hull structure requirements in relation to the service notation or service feature assigned to the ship and to be applied in addition to the present Rules are defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

12.2 Strengthening for ice navigation

12.2.1 When requested by the Owner, an additional ice class notation may be assigned according to NR467, Rules for Steel Ships, Pt A, Ch 1, Sec 2, [6.10].

Hull strengthening required for the assignment of this additional class notation is defined in NR467, Rules for Steel Ships, Part F, Chapter 8.

The following parameters considered in the scantling formulae of NR467 Rules are to be taken as follow:
- the minimum yield stress of the material R_{eH} is to be taken equal to the minimum yield stress R_y as defined in Sec 2, [2.3]
- the abrasion and corrosion addition, in mm, for platings is to be taken equal to 4 mm. Where a special surface coating is applied, shown by experience to be capable of withstanding the abrasion of ice, a lower value may be accepted by the Society on a case by case basis.

12.3 Strengthened bottom (STRENGTHBOTTOM)

12.3.1 Application
The additional class notation **STRENGTHBOTTOM** is assigned, in accordance with NR467 Steel Ships Pt A, Ch 1, Sec 2, to ships built with specially strengthened bottom structures so as to be able to be loaded and/or unloaded when properly stranded.

The general requirements defined in NR467 Steel Ships, Pt F, Ch 15, Sec 1 [1] are applicable.

12.3.2 Primary supporting members arrangement
a) Ships with a longitudinally framed bottom:

As a rule, solid floors and side girders are to be fitted with a maximum spacing between floors and girders not greater than $0.9 \, L^{0,25}$.

The number and size of holes on floors and girders are to be kept as small as possible, and are to be such as to allow complete inspection of double bottom structures.

b) Ships with a transversally framed bottom:

As a rule, floors are to be fitted at every frame.

Side girders are to be fitted on each side of the ship with a maximum spacing not greater than $0.9 \, L^{0,25}$.

The number and size of holes on floors and girders are to be kept as small as possible, and are to be such as to allow complete inspection of double bottom structures

12.3.3 Bottom scantling
a) Plating:

The thickness of the bottom and bilge platings obtained according to Sec 6, [2.2] are to be increased by 50% and, as a rule, are not to be less than 8 mm.

b) Secondary and primary stiffeners:

The section modulus w, in cm³, and the shear section area A_{Sh}, in cm², of longitudinal or transverse bottom secondary stiffeners are to be not less than the greater of the following values:

- the values obtained according to Sec 6, [3.3]
- the values obtained by the following formula:

$$Z = 1000\frac{ps\ell^2}{m\sigma_{locam}}$$

$$A_{sh} = 5\frac{ps\ell}{\tau_{locam}}$$

where:

p	:	Sea pressures, in kN/m², as defined in Sec 6, [1.2.1] a)
ℓ	:	Span, in m, of stiffeners
s	:	Spacing, in m, of stiffeners
m	:	End stiffener conditions as defined in Sec 6, [3.1.2]
τ_{locam}	:	Permissible shear stress, in N/mm² to be taken $0,3R_y$, with R_y as defined in Sec 2, [2.3].
σ_{locam}	:	Permissible bending stress, in N/mm² to be taken equal to, with R_y as defined in Sec 2, [2.3].

- for secondary stiffeners:
  - $0,45R_y$ for longitudinal stiffener
  - $0,65R_y$ for transversal stiffener
- for primary stiffeners:
  - $0,35R_y$ for longitudinal stiffener
  - $0,65R_y$ for transversal stiffener.

12.3.4 Particular case

Ships defined in Sec 5, [1.2.1] may be considered by the Society on a case-by-case basis, taking into account the specific hull girder loads induced by loading and unloading when stranded.

In this case, the section modulus w, in cm³, and the shear section area A_{Sh}, in cm², of longitudinal or transverse bottom secondary stiffeners are to be not less than the greater of the following values:

- the values obtained according to Sec 6, [3.3]
- the values obtained by the following formula:

$$Z = 1250\frac{ps\ell^2}{m(0,65R_y - \sigma_g)}$$

$$A_{sh} = 5\frac{ps\ell}{\tau_{locam}}$$

where:

σ_g	:	Hull girder normal stresses, in N/mm², in stranded conditions determined by direct calculation.

12.3.5 Welding between secondary and primary stiffeners

As a general rule, the total resistant weld section A_W, in cm², connecting the continuous secondary stiffeners to the web of primary members are to be as defined in Sec 3, [2.7] taking into account a coefficient φ increased by 20%.

Section 8   Pillars

Symbols

A : Cross-sectional area, in cm^2, of the pillar

E : Young's modulus of aluminium, equal to 70000 N/mm^2

f : Fixity condition coefficient, to be obtained from Tab 1

I : Minimum moment of inertias, in cm^4, of the pillar in relation to its principal axis

ℓ : Span, in m, of the pillar

$R_{p\,0,2}$: Proof stress (yield strength), in N/mm^2, of the parent metal in delivery conditions, as specified

$R'_{p\,0,2}$: Proof stress (yield strength), in N/mm^2, of the parent metal in as-welded conditions as defined in Sec 2

σ_E : Euler column buckling stress of the pillar, in N/mm^2, to be obtained from the following formula:

$$\sigma_E = \pi^2 E \frac{I}{A(f\ell)^2} 10^{-4}$$

σ_{CB} : Global pillar buckling stress, in N/mm^2

σ_{CL} : Local pillar buckling stress, in N/mm^2.

1   General

1.1   Application

1.1.1 The requirements of this Section apply to pillars (independent profiles or bulkhead stiffeners) made of aluminium alloys.

1.1.2 The present Section only deals with the buckling check of the pillars (the general requirements relating to pillar arrangement are given in Sec 7, [7.4]).

1.1.3   Calculation approach

For aluminium pillars, the pillar buckling stresses σ_{CB} and σ_{CL}, in N/mm^2, and the maximum allowable axial load P_C, in kN, are to be successively examined according the two following methods:

- global column buckling, and

- local buckling.

1.1.4   Compression axial load

Where pillars are vertically aligned, the compression axial load F_A, in kN, is equal to the sum of the loads supported by the pillar considered and those supported by the pillars located above, multiplied by a load factor r.

The load factor depends on the relative position of each pillar with respect to that considered (i.e. the number of tiers separating the two pillars).

The compression axial load in the pillar is to be obtained, in kN, from the following formula:

$$F_A = A_D p_s + \sum_i r Q_i$$

where:

A_D : Area, in m^2, of the portion of the deck or the platform supported by the pillar considered

p_s : Pressure on deck, in kN/m^2, as defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2], item b)).

r : Load factor depending on the relative position of each pillar above the one considered, to be taken equal to:

- r = 0,9 for the pillar immediately above the pillar considered

- r = 0,9^i > 0,478 for the ith pillar of the line above the pillar considered

Q_i : Vertical local load, in kN, supported by the ith pillar of the line above the pillar considered, if any.

Table 1 : Coefficient f

Conditions of fixity						
f	0,5 **(1)**	0,7	1,0	2,0	1,0	2,0

(1) End clamped condition may only be considered when the structure in way of pillar ends can not rotate under the effect of loadings.

2 Critical buckling stresses

2.1 Buckling of pillars subjected to compression axial load

2.1.1 Global critical column buckling stress

The global critical column buckling stress σ_{CB} of pillars made of aluminium alloy is to be obtained, in N/mm², from the following formula:

$$\sigma_{CB} = 2 R'_{p0,2} \cdot C$$

where:

C : Coefficient to be taken equal to one of the following formulae or deduced from Fig 1:

- for alloys series 5000:

$$\frac{1}{1 + \lambda + \sqrt{(1 + \lambda)^2 - 0,68 \cdot \lambda}}$$

- for alloys series 6000:

$$\frac{1}{1 + \lambda + \sqrt{(1 + \lambda)^2 - 3,2 \cdot \lambda}}$$

where:

$$\lambda = \frac{R_{p0,2}'}{\sigma_E}$$

2.1.2 Local critical buckling stress

The local critical buckling stress σ_{CL} of pillars made of aluminium alloy is to be obtained, in N/mm², from the following formula:

$\sigma_{CL} = 2 R_{p\,0,2}' \, C$

where:

C : Coefficient as defined in [2.1.1], with:

$$\lambda = \frac{R_{p0,2}'}{\sigma_{Ei}}$$

σ_{Ei} : Euler local buckling stress, in N/mm², to be taken equal to:

- for circular tubular pillars:

$$\sigma_{Ei} = 12,5\left(\frac{E}{206000}\right)\left(\frac{t}{D}\right)10^4$$

       t : Pillar thickness, in mm
      D : Pillar outer diameter, in mm

- for rectangular tubular pillars:

$$\sigma_{Ei} = 78\left(\frac{E}{206000}\right)\left(\frac{t}{b}\right)^2 10^4$$

      b : Greatest dimension of the cross-section, in mm
      t : Plating thickness in relation to b, in mm

- for built up pillars, the lesser of:

$$\sigma_{Ei} = 78\left(\frac{E}{206000}\right)\left(\frac{t_W}{h_W}\right)^2 10^4$$

$$\sigma_{Ei} = 32\left(\frac{E}{206000}\right)\left(\frac{t_F}{b_F}\right)^2 10^4$$

h_W, t_W : Web height and web thickness, respectively, of built-up section, in mm

b_F, t_F : Face plate width and face plate thickness, respectively, of built-up section, in mm.

2.1.3 Maximum allowable axial load

The maximum allowable axial load P_C, in kN, is the smaller of the following values:

$$P_C = \frac{\sigma_{CB}A}{10SF_{CB}}$$

$$P_C = \frac{\sigma_{CL}A}{10SF_{CL}}$$

where:

SF_{CB}, SF_{CL}: Safety coefficients for pillar buckling as defined in the Society Rules for the classification of ships (see Sec 1, [1.1.2] b).

Figure 1 : Coefficient C
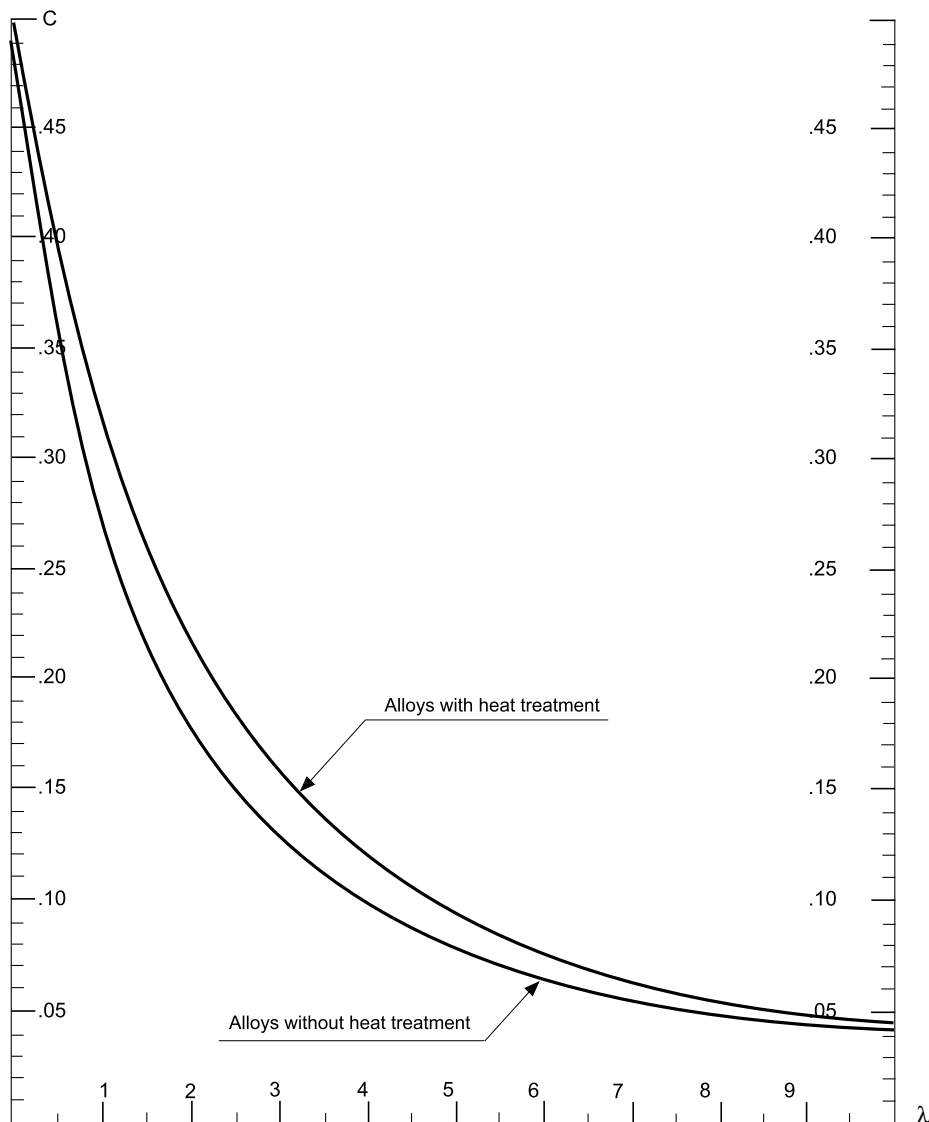
2.2 Buckling of pillars subjected to compression axial load and bending moments

2.2.1 Checking criteria

In addition to the requirements in [2.1], the scantling of the pillar loaded by the compression axial load and bending moments are to comply with the following formula:

$$10F\left(\frac{1}{A} + \frac{\Phi e}{w_P}\right) + \left(10^3 \frac{M_{max}}{w_P}\right) \leq 0,85 R'_{p0,2}$$

where:

F : Actual compression load, in kN, acting on the pillar

A : Cross-sectional area, in cm², of the pillar

e : Eccentricity, in cm, of the compression load with respect to the centre of gravity of the cross-section

$$\Phi = \frac{1}{1 - \frac{10F}{\sigma_E A}}$$

w_P : Minimum section modulus, in cm³, of the cross-section of the pillar

M_{max} : Max (M_1, M_2, M_0)

M_1 : Bending moment, in kN.m, at the upper end of the pillar

M_2 : Bending moment, in kN.m, at the lower end of the pillar

$$M_0 = \frac{0,5(\sqrt{1 + t^2})(M_1 + M_2)}{\cos(u)}$$

$$u = 0,5\pi \sqrt{\frac{10F}{\sigma_E A}}$$

$$t = \frac{1}{\tan(u)}\left(\frac{M_2 - M_1}{M_2 + M_1}\right)$$

provided that:

$$-\tan^2 u \leq \frac{M_2 - M_1}{M_2 + M_1} \leq \tan^2 u$$

2.3 Vertical bulkhead stiffener acting as pillar

2.3.1 When a vertical stiffening member is fitted on the bulkhead in line with the deck primary supporting member transferring the loads from the deck to the bulkhead (as a pillar), this vertical stiffener is to be calculated as defined in [2.1] or [2.2], taking into account an associated plating of a width equal to 30 times the plating thickness.

3 Pillars in tanks

3.1 General

3.1.1 Where pillars are submitted to tensile stress due to internal pressure in tank, the tensile stress in the pillar and the shear stresses in the connection elements between the pillar and the supported structure of the tank are to be lower than the permissible stresses defined in the Society Rules for the classification and/or certification of ships for primary structure element.

As a rule, brackets are to be provided at the connection of the pillar ends with the tank structure.

Doubling plate are not to be used at pillar ends.

3.1.2 Pillars in tanks are not to be of hollow profile type.

Section 9   Hull Construction, Survey and Testing

1   General

1.1   Scope

1.1.1 The purpose of this Section is to define hull construction and Shipyard survey requirements within the scope of the classification of ships and/or certification of ships hulls required to be built in compliance with to the applicable Society's Classification Rules and surveyed during construction by the Society.

The scope of classification is defined in NR467 Rules for Steel Ships, Part A.

2   Hull structure drawings

2.1   General

2.1.1 The structure drawings are to be submitted for examination in accordance with the present Rule Note and the applicable Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

2.1.2 The type of aluminium alloys, including grade, temper and minimum proof stress, is to be specified by the Shipyard on the structure drawings.

2.1.3 The details of the welded and/or riveting connections between the main structural elements, including throat thicknesses and joint types, are to be specified by the Shipyard on the structure drawings or in the weld booklet, as defined in Sec 3, [1.2.1].

3   Hull construction and Shipyard procedures

3.1   Shipyard details and procedures

3.1.1 The following details are to be submitted by the Shipyard to the Society:
- design office and production work staff
- production capacity (number of units per year, number of types, sizes)
- total number of hull units already built.

3.1.2 The following procedures are to be submitted by the Shipyard to the Society:
a) Traceability
  - procedure to ensure traceability of materials, consumables and equipment covered by the Society's Rules (from the purchase order to the installation or placing on ship)
  - data to ensure traceability of the production means (describing the different steps such as inspection or recording during production)
  - handling of non-conformities (from the reception of materials or equipment to the end of construction)
  - handling of client complaints and returns to after-sales department.
b) Construction
  - procedure to ensure that the hull is built in accordance with the approved drawings, as defined in Article [2]
  - procedure to precise the equipment references, the references to any equipment approval, the suppliers' technical requirements, the precautions to be taken when installing the equipment
  - builder's inspection process and handling of imperfections
  - procedure to ensure that the remedial measures concerning the indications noticed by the Surveyor of the Society during the survey are taken into account and reported to the Surveyor.
    Procedures are also to define:
    - the precautions to be taken to comply with the suppliers and Society requirements in order not to cause, during installation, structure damages affecting structural strength and watertightness, and
    - the preparations to be made on the hull in anticipation of installation.

3.2   Materials

3.2.1 The following details about materials used are to be submitted by the Shipyard to the Society:
- list of aluminium alloys used for plates, stiffeners, filler products, with their references and suppliers' identification
- references of existing material approval certificates.

3.2.2 The storage conditions of materials and welding consumables are to be in dry places without condensation and clear of the ground and generally in accordance with the manufacturers' recommendations at Shipyard's diligence.

Materials are to be identifiable in the storage site (quality of aluminium alloy and welding consumables, reference of batches and type of approval certificate).

The builder is to inspect the incoming plates, stiffeners and consumables in accordance with the purchase batches and make the relevant report available to the Surveyor.

3.3 Forming

3.3.1 Forming operations are to be at Shipyard's diligence. Any deviation is to be declared to the Surveyor for assessment.

3.4 Welding

3.4.1 Welding booklet

A welding booklet, including the welding procedures, filler products and the design of joints, as well as the sequence of welding provided to reduce to a minimum restraint during welding operations, is to be submitted to the Society.

Moreover, the welding booklet is:

• to indicate, for each type of joint, the preparations and the various welding parameters

• to define, for each type of assembly:

  - root gap and clearance (as a guidance, typical joint preparations may be found in standard ISO 9692-3)

  - the nature and the extent of the inspections proposed, in particular those of the non-destructive testing

  - criteria for the acceptance of weld imperfections (see [3.5.5]).

3.4.2 Welding consumables, procedures and welder qualifications

The various welding procedures and consumable materials are to be used within the limits of their approval and in accordance with the conditions of use specified in the respective approval documents.

a) Welding filler product

  • The choice by the Shipyard of the welding filler metal is to be made taking into account the welding procedure, the assembly and the grade of aluminium alloy corresponding to the parent metal.

    The welding consumables are to be in accordance with NR216 Materials and Welding.

  • Welding filler products are generally to be approved by the Society and are of type as defined in NR216 Materials and Welding, Ch 11, Sec 15 or of other types accepted as equivalent by the Society.

  • The filler products used are to be mentioned in the   welding specification of the construction concerned.

  • Arc welding of aluminium alloys is to be carried out under an inert atmosphere, using either a refractory electrode (TIG process) or a consumable electrode (MIG process).

  • Automatic or semi-automatic weld may be used for prefabricated panels and on building slip for the connection of blocks.

  • For welding of thicknesses greater about 8 mm, an efficient heating of the plates to be connected is to be carried out in order to prevent risks of condensation as necessary (pre-heating at about 70°C).

b) Qualification of welders: welders for manual welding and for semi-automatic welding processes are to be certified by the Society according to the procedures given in NR476 Approval Testing of Welders unless otherwise agreed.

c) Qualification of weldings procedures: requirements for the approval of welding procedures are to be as defined in NR216 Materials and Welding, Chapter 12, Section 5.

3.4.3 Weather protection

Welding operations in open air are to be avoided as necessary.

Adequate protection from the weather is to be provided to parts being welded; in any event, such parts are to be dry.

3.4.4 Butt connection edge preparation

Preparation of edges and adjusting are to be at Shipyard's diligence. Any deviation is to be declared to the Surveyor for assessment.

3.4.5 Surface condition

The surfaces to be welded are to be free from moisture and other substances, such as mill scale, oil, grease or paint.

Effective means of cleaning are to be adopted. The metal is to be properly degreased prior to the welding by means of a solvent inert for the metal.

Before welding, a mechanical cleaning of the edges to be welded is also to be carried out by means of brushing (stainless steel brush) or scraping. Chemical pickling may also be used.

3.4.6 Assembling and gap

The setting appliances and system to be used for positioning are to provide an adequate tightening adjustment and an appropriate gap of the parts to be welded, while allowing maximum freedom for shrinkage.

Where stiffener ends are butt welded, the weld is to extend over the full section. Chamfers may be needed, in particular for bulb sections. If both sections have a different height, the strength continuity is to be maintained as necessary.

3.4.7 Plate misalignment in butt weld

The misalignment between plates of equal thickness is to be less than 10% of the plate thickness, without being greater than 3 mm.

3.4.8 Plate misalignment in cruciform connections

In the case of cruciform joint, as shown in Fig 1, misalignment "m" is to be such that:

$m \leq t / 2$

where:

$t = \text{Max} (t_1 , t_2)$

The maximum allowable misalignment "m" may be required smaller in case of highly stressed cruciform joints.

Figure 1 : Cruciform connection
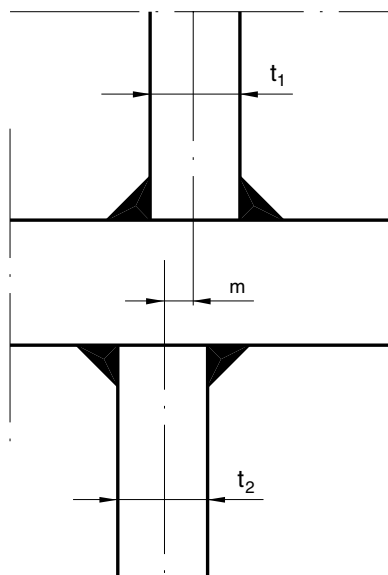
3.4.9 Welding sequences and interpass cleaning

After each run, the surface is to be cleaned by means of a stainless steel brush before it is covered by the next run. The same precaution is to be taken when an interrupted weld is resumed or when two welds are to be connected.

Where a welding is interrupted, the end of the joint is to be carefully grounded and an adequate overlapping of welding lines (typical over 20 mm) is to be provided.

3.5 Examination of welds

3.5.1 General

Yard Inspecting department is to inspect the root gap and clearance before welding, and after welding, the aspect, surface, uniformity and thickness of the welds (the throats of the fillet welds are to be checked by means of gauges) and report to the Surveyor. Where imperfections are found, the weld is to be repaired in agreement with the Surveyor.

The extent, distribution and methods of non-destructive testing (visual, dye-penetrant and radiographic inspection), as well as the criteria for acceptance of weld imperfections adopted by the Shipyard and applied to the construction, are to be defined at the initial stages of construction and presented in the welding booklet or in a document submitted to the Surveyor in charge of the survey.

Note 1: Non-destructive tests are to be carried out by certified qualified personnel or by recognised bodies in compliance with appropriate standards.

3.5.2 Weld categories

As a rule, welds are classified in two categories defining the extent and distribution of non-destructive testing (defined in [3.5.4]) as well as the acceptance criteria (defined in [3.5.5]:

- first category: for butt welds of shell and butt or fillet welds of longitudinal members, primary elements, structure transverse bulkheads, oil and fuel tanks boundaries, engine seating and rudders, fixed parts of lifting appliances
- second category: for other welds.

Choice of the categories for hull and superstructure welds is to be made by the Shipyard before the construction starts (according to the level of stresses, the consequences of a crack and the location of the welds, in particular their accessibility for survey and repair), and submitted to the Society for review.

3.5.3 Shipyard's Inspection methods

The three main methods of inspection to be considered are:

a) Visual inspection: the inspection of welds intends to check the absence of unacceptable visual imperfections and the conformity of welds as defined in the examined structure drawings (type, location, throat thickness)

b) Dye-penetrant testing

c) Radiographic or gamma ray inspection.

For gamma-ray inspection, the following typical conditions are to be observed by the Shipyard:

- fine grain film
- reinforcing screen
- density in the range 2,5 to 4,5
- the image quality given by the image quality indicator (IQI) is to be such that:
  - the minimum diameter of the visible hole is equal to 5% of the assembly thickness, for IQI with hole
  - the minimum diameter of the visible wire is equal to 2% of the assembly thickness, for IQI with wires.

The samples used for the qualification of welders or of the welding procedures can be used to demonstrate the quality of the gamma ray inspection method.

3.5.4 Extent of non-destructive examination - Reporting

The following extents are to be taken into account for the weld inspections carried out by the Shipyard which is to keep records available and to report all findings interesting class or certification of ship hulls to the Surveyor:

a) First category weld:
  - Visual inspection: full length visual inspection of every weld
  - Butt welds: dye-penetrant testing is to be carried out on the weld lengths submitted to radiographic inspection, and on any suspicious length revealed during visual inspection.

    For radiographic inspection, the number N of radiographs is to be not less than the length of the ship, in m, (for multihull, N is to be not less than n times the length of the ship, in m, where n is the number of hulls). The location of these radiographs is determined by the yard with the Surveyor's agreement and is to be mainly localized at the cross-welds and on highly stressed welds.
  - Fillet welds: as a rule, dye-penetrant testing may be carried out at random. The extent of this random check is to be defined in accordance with the Surveyor.

b) Second category weld:
  - Visual inspection: full length visual inspection of every weld.

Where imperfections are detected, the extent/type of the inspection is to be increased/modified as agreed by the yard and the Surveyor.

3.5.5 Acceptance criteria

Criteria for the acceptance of weld imperfections are to be defined and documented in the welding booklet by the Shipyard at the initial stage of construction.

The following main weld imperfections and their acceptance limit, taking into account the weld category as defined in [3.5.2], are to be described:

- exposed or internal local porosity
- open crater pipe
- geometrical imperfection of fillet weld
- local lack of fusion, incomplete penetration.

The criteria are to be based according to the Shipyard technologies and experience or on recognized national or international standards applicable to structures in aluminium alloys. As a guidance, the criteria defined in the standard ISO 10042 may be accepted as far as classification is concerned taking for reference the level C for first category weld and level D for second category weld.

Finished welds are to be as a rule, free from visible cracks and detected planar lack of fusion.

3.6 Tank and weathertight structure testing

3.6.1 General

The pressure testing conditions for tanks, watertight and weathertight structures in order to check the tightness and/or the strength of structural elements are defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

4 Survey for unit production

4.1 General

4.1.1 The survey includes the following steps:
- survey at yard with regards to general requirements of Article [3]
- structure drawing examination (see Article [2])
- survey at yard during unit production with regards to approved drawings, yard's response to comments made by the Society during structure review examination and construction requirements.

These can only focus on the construction stage in progress during the survey. It is to the responsibility of the inspection department of the yard to present to the Surveyor any imperfections noted during the construction of the ship.

5 Alternative survey scheme for production in large series

5.1 General

5.1.1 Where the hull construction is made in large series, an alternative survey scheme based on voluntary basis may be agreed with the Society for hull to be surveyed as far as Classification or Certification is concerned.

5.1.2 The general requirements for the alternative survey scheme, BV Mode I, are given in the Society's Rule Note NR320 as amended.

5.1.3 The alternative survey scheme comprises the following steps:
- type approval
- yard's recognition based on initial audit and periodical audits
- certificate of conformity issued by the yard and submitted to the Society for endorsement.

5.2 Type approval

5.2.1 General

The type approval of a hull made of aluminium alloy and built in large series comprises:
- examination, in accordance with the present Rule Note and the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]), of hull structure drawings and documents defining the main structural components of the hull
- examination of certain items of equipment and their fittings if requested by the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2])
- inspection of the first hull (or a hull representing the large series production).

5.2.2 Examination of hull structure drawings

The structure drawing examination is to be carried out as defined in [2].

5.2.3 Examination of certain items of equipment

The equipment requiring a particular drawing examination is defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]). As a general rule, this equipment consists mainly in portholes, deck hatches and doors.

This examination may be carried out as defined in the Society's Rules or through an homologation process, at the satisfaction of the Society.

5.2.4 Inspection

The purpose of the inspection, carried out by a Surveyor of the Society according to [3] on the initial hull of the series (or a representative hull of the series), is to make surveys at yard during unit production with regards to approved drawings, yard's response to comments made by the Society during structure review examination and construction requirements.

5.2.5 Type Approval Certificate

A Type Approval Certificate (TAC) is issued for the initial hull covered by the type approval procedure.

5.3 Quality system documentation

5.3.1 The quality system documentation submitted to the Society is to include the information required in [3.1] and in NR320 as amended.

5.4   Manufacturing, testing and inspection plan (MTI plan) prepared by the Shipyard

5.4.1 For each type of hull, the manufacturing, testing and inspection plan is to detail specifically:

a) Materials:

Special requirements of the supplier (storage conditions, type of checks to be performed on incoming products and properties to be tested by the yard before use).

- Storage conditions:

  Information about storage sites (ventilation conditions, supplier data sheets specifying the storage conditions, listing documents to record arrival and departure dates for consignment).

- Reception:

  Information about consignment (traceability of consignment specifying date of arrival, type of inspection, check on product packaging, types of specific tests performed).

- Traceability:

  Description of the yard process to ensure traceability of the materials from the time of the reception to the end of the production operations.

b) Hull construction:

Description of the yard process to ensure that the scantlings and construction meet the rule requirements in relation to the approved drawings.

c) Installation of internal structure:

Information about the main operations of the internal structure installation.

d) Equipment:

The main equipment to be covered by the rules of the Society are portholes, windows and deck hatches, watertight doors, independent tanks and rudders, the scheduled tests and traceability on the equipment upon arrival and/or after installation.

e) Testing and damage reference documents:

For all the previously defined MTI plan processes, procedures are to be written, defining the types of tests or inspections performed, the acceptance criteria and the means of handling non-conformities.

5.5   Society's certificate

5.5.1   Certificate of recognition

After completion of the examination, by the Society, of the quality assurance manual, the MTI plan and the yard audit, a Certificate of recognition may be granted as per the provisions of NR320 as amended.

5.5.2   Certificate of conformity

Each hull may be certified individually upon request made to the Society.

A certificate of conformity is to be issued by the Yard and endorsed by the Society for each hull to be surveyed as far as Classification or Certification is concerned.

5.6   Other certification scheme for production in large series

5.6.1 Other certification scheme for production in large series, based on NR320 Classification Scheme of Materials and Equipment may be considered by the Society on a case by case basis.

Appendix 1 Aluminium Properties

1 Mechanical properties

1.1 General

1.1.1 The mechanical properties of the aluminium alloys in delivery condition are reminded in Tab 1 and Tab 2, for information only.

Note 1: The present Tables come from NR216 Materials and Welding. It may be necessary to ensure that these Tables are still the same than those defined in the issue in force of NR216 Materials and Welding.

The mechanical characteristics given in Tab 1 and Tab 2 correspond to general standards values. For more information, refer to the minimum values guaranted by the manufacturer supplier.

1.2 Minimum yield stress for scantling criteria of hull structure

1.2.1 The minimum yield stresses of aluminium alloys to take into account for the check of hull structure are defined in Sec 2.

Table 1 : Mechanical properties for rolled products with 3 mm $\leq$ t $\leq$ 50 mm

Grade	Temper condition	Thickness t (mm)	Yield strength $R_{p\,0,2}$ min (N/mm²)	Tensile strength R_m min or range (N/mm²)	Elongation min (%) **(1)**	
					$A_{50\,mm}$	A_{5d}
5083	O / H111	3 ≤ t ≤ 50	125	275 - 350	16	14
	H112	3 ≤ t ≤ 50	125	275	12	10
	H116	3 ≤ t ≤ 50	215	305	10	10
	H321	3 ≤ t ≤ 50	215 - 295	305 - 385	12	10
5383	O / H111	3 ≤ t ≤ 50	145	290		17
	H116	3 ≤ t ≤ 50	220	305	10	10
	H321	3 ≤ t ≤ 50	220	305	10	10
5059	O	3 ≤ t ≤ 50	160	330		24
	H111	3 ≤ t ≤ 50	160	330	24	24
	H116	3 ≤ t ≤ 20	270	370	10	10
		20 < t ≤ 50	260	360	10	10
	H321	3 ≤ t ≤ 20	270	370	10	10
		20 < t ≤ 50	260	360	10	10
5086	O / H111	3 ≤ t ≤ 50	95	240 - 305	16	14
	H112	3 ≤ t ≤ 12,5	125	250	8	
		12,5 < t ≤ 50	105	240		9
	H116	3 ≤ t ≤ 50	195	275	10 **(2)**	9
5754	O / H111	3 ≤ t ≤ 50	80	190 - 240	18	17
5456	O	3 ≤ t ≤ 6,3	130 - 205	290 - 365	16	
		6,3 < t ≤ 50	125 - 205	285 - 360	16	14
	H116	3 ≤ t ≤ 30	230	315	10	10
		30 < t ≤ 40	215	305		10
		40 < t ≤ 50	200	285		10
	H321	3 ≤ t ≤ 12,5	230 - 315	315 - 405	12	
		12,5 < t ≤ 40	215 - 305	305 - 385		10
		40 < t ≤ 50	200 - 295	285 - 370		10
(1) Elongation in 50 mm applies for thicknesses up to and including 12,5 mm and in 5d for thicknesses over 12,5 mm.						
(2) 8% for thicknesses up to and including 6,3 mm.						

Table 2 : Mechanical properties for extruded products with 3 mm ≤ t ≤ 50 mm

Grade	Temper condition	Thickness t (mm)	Yield strength $R_{p\,0,2}$ min (N/mm²)	Tensile strength R_m min or range (N/mm²)	Elongation min (%) (1) (2)	
					A_{50mm}	A_{5d}
5083	O	3 ≤ t ≤ 50	110	270 - 350	14	12
	H111	3 ≤ t ≤ 50	165	275	12	10
	H112	3 ≤ t ≤ 50	110	270	12	10
5383	O	3 ≤ t ≤ 50	145	290	17	17
	H111	3 ≤ t ≤ 50	145	290	17	17
	H112	3 ≤ t ≤ 50	190	310		13
5059	H112	3 ≤ t ≤ 50	200	330		10
5086	O	3 ≤ t ≤ 50	95	240 - 315	14	12
	H111	3 ≤ t ≤ 50	145	250	12	10
	H112	3 ≤ t ≤ 50	95	240	12	10
6005A	T5	3 ≤ t ≤ 50	215	260	9	8
	T6	3 ≤ t ≤ 10	215	260	8	6
		10 < t ≤ 50	200	250	8	6
6060 (3)	T5	t ≤ 5	120	160	10	10
		5 < t ≤ 25	100	140	10	10
6061	T6	3 ≤ t ≤ 50	240	260	10	8
6106	T5	t ≤ 6	200	250	10	10
6082	T5	3 ≤ t ≤ 50	230	270	8	6
	T6	3 ≤ t ≤ 5	250	290	6	
		5 < t ≤ 50	260	310	10	8

(1) The values are applicable for longitudinal and transverse tensile test specimens as well.

(2) Elongation in 50 mm applies for thicknesses up to and including 12,5 mm and in 5d for thicknesses over 12,5 mm.

(3) 6060 alloy is not to be used for structural members sustaining dynamic loads (slamming and impact loads). The use of 6106 alloy is recommended in that case.

Appendix 2   Buckling Analysis

Symbols

a   :   Length of the longer side of the plate panel, in mm

α :   Aspect ratio of the plate panel, to be taken as:

$$\alpha = \frac{a}{b}$$

b   :   Length of the shorter side of the plate panel, in mm

b_f :   Total breath, in mm, of the flange

E   :   Young's modulus, in N/mm^2, to be taken as a general rules equal to 70000 N/m^2

h_w, t_w, $b_{f\text{-}out}$:Dimensions of the stiffener, in mm, as defined in Fig 1

ν :   Poisson's ratio of the material, to be taken as a general rules equal to 0,3

R_y :   Specified minimum yield stress as defined in Sec 2, [2.3.1]

σ_x :   Stress applied on the shorter side b of the plate panel

σ_y :   Stress applied on the longer side a of the plate panel

σ_E :   Elastic buckling reference stress, in N/mm^2, to be taken as:

$$\sigma_E = \frac{\pi^2 \, E}{12(1-\nu^2)} \left(\frac{t_p}{b}\right)^2$$

s   :   Spacing, in m, between stiffeners

τ :   Applied shear stress, in N/mm^2

t_p :   Thickness, in mm, of the plating considered

t_p, t_w, t_f :   Thickness, in mm, of the attached plating, web and flange.

1   General

1.1   Application

1.1.1 The requirements of this Appendix apply for the buckling check of aluminium structure subjected to:

- for plates:
  - compression and shear stresses induced by overall bending moment and shear forces due to global hull girder loads (see [2.3] and [2.4])
  - compression stress in attached plating of stiffeners induced by local loads (see [3.3.7]).

Note 1: When the plate is submitted to local compression loads, the buckling check may be carried out taking into account the compression stress applied to the plate induced by local loads and requirements defined in [2.3] and [2.4].

- for stiffeners: compression and shear stresses induced by overall bending moment and shear forces due to global hull girder loads (see [3.2]) and/or by local loads (see [3.3]).

2   Buckling analysis for plating

2.1   Calculation hypothesis

2.1.1   General

a) The buckling approach defined in the present Appendix is based on the NI615 Buckling Assessment of Plated Structures, taking into account the following simplifying hypothesis:

- the applied compression stress is considered as uniform along the edges of the plate (the edge ratio Ψ according to NI615 is taken equal to 1)

Note 1: When the applied compression stress along the edges of the plate is not uniform (ratio Ψ different from 1), the applied stress to consider in the present Appendix is to be taken equal to the maximum applied compression stress along the edge

- when the buckling check is carried out with bi-axial compression hypothesis, the stresses σ_x and σ_y are as a general rule determined by finite element calculation or direct calculation.

Note 2: When the compression stress applied on the edge not directly loaded by the global loads is not determined by FEM or direct calculation, this compression stress may be considered as null.

- plate panels are considered as being simply supported on their edges.

b) The buckling approach defined in NI615 Buckling Assessment of Plated Structures may be taken into account instead of the present simplify method when deemed necessary.

2.2 Sign convention for normal stresses

2.2.1 In the present Appendix, compression and shear stresses are to be taken as positive.

Tensile stresses are to be taken as negative.

2.3 Critical stress under buckling

2.3.1 Critical buckling stress by compression of the shorter edge of the panel

The ultimate buckling stress of plate panels, in N/mm², induced by compression of the shorter edge of panel, according to Fig 1, is to be taken as:

$\sigma_{cx}' = C_x R_y$

where:

C_x :   Coefficient equal to:

$C_x = 1,00$ for $\lambda \leq 0,84$

$C_x = 1,13 \left(\dfrac{1}{\lambda} - \dfrac{0,22}{\lambda^2} \right)$ for $\lambda > 0,84$

λ :   Reference degree of slenderness, to be taken as:

$\lambda = \sqrt{\dfrac{R_y}{K_x \sigma_E}}$

K_x :   Buckling factor equal to 4

Figure 1 : Compression on the shorter edge of the panel
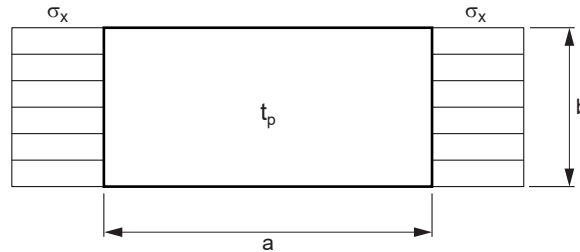
2.3.2 Critical buckling stress by compression of the longer edge of the panel

The ultimate buckling stress of plate panel, in N/mm², induced by compression of the longer edge of panel, according to Fig 2 is to be taken as:

$\sigma_{cy}' = C_y R_y$

where:

$C_y = 1,13 \left[\dfrac{1}{\lambda} - \dfrac{R + F^2 (H - R)}{\lambda^2} \right]$

λ :   Reference degree of slenderness, to be taken as:

$\lambda = \sqrt{\dfrac{R_y}{K_y \sigma_E}}$

$K_y = \left(1 + \dfrac{1}{\alpha^2} \right)^2$

R :   Coefficient equal to:

$R = 0,22$ for $\lambda \geq 0,84$

$R = \lambda \left(1 - \dfrac{\lambda}{1,13} \right)$ for $\lambda < 0,84$

$$F = 1 - \frac{\left(\dfrac{K_y}{0,91} - 1\right)}{\lambda_p^2} \geq 0$$

$$\lambda_p^2 = \lambda^2 - 0,5 \text{ with } 1 \leq \lambda_p^2 \leq 3$$

$$H = \lambda - \frac{2\lambda}{1,13 \ (T + \sqrt{T^2 - 4})} \geq R$$

$$T = \lambda + \frac{14}{15\lambda} + \frac{1}{3}$$

Figure 2 : Compression of the longer edge of the panel
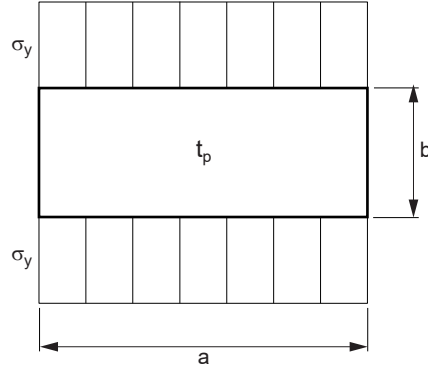
2.3.3 Critical shear buckling stress

The ultimate shear buckling stress of plate panels, in N/mm², according to Fig 3 is to be taken as:

$$\tau_c{'} = C_\tau \ \frac{R_y}{\sqrt{3}}$$

where:

C_t : Coefficient equals to:

$$C_\tau = 1,00 \text{ for } \lambda \leq 0,84$$

$$C_\tau = \frac{0,84}{\lambda} \text{ for } \lambda > 0,84$$

λ : Reference degree of slenderness, to be taken as:

$$\lambda = \sqrt{\frac{R_y}{K_t \sigma_E}}$$

$$K_\tau = \sqrt{3}\left(5,34 + \frac{4}{\alpha^2}\right)$$

Figure 3 : Shear stress
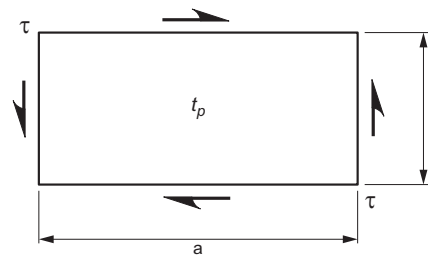
2.4 Buckling check criteria

2.4.1 General

The buckling strength or capacity defined in the present Article takes into account the internal redistribution of loads depending on the load situation, slenderness and type of structure.

2.4.2 Scantling criteria

The plate scantling is to fulfill the following conditions:

- $$\left(\left(\frac{\sigma_x\ SF}{\sigma_{cx}'}\right)^{e_0}+\left(\frac{\sigma_y\ SF}{\sigma_{cy}'}\right)^{e_0}+\left(\frac{|\tau|\ SF}{\tau_c'}\right)^{e_0}-\Omega\right)\le 1$$

  with:

  $$\Omega = B\left(\frac{\sigma_x\ SF}{\sigma_{cx}'}\right)^{e_0/2}\left(\frac{\sigma_y\ SF}{\sigma_{cy}'}\right)^{e_0/2}$$

- when $\sigma_x \ge 0$ (compressive)

  $$\left(\left(\frac{\sigma_x\ SF}{\sigma_{cx}'}\right)^{2/\beta_p^{0,25}}+\left(\frac{|\tau|\ SF}{\tau_c'}\right)^{2/\beta_p^{0,25}}\right)\le 1$$

- when $\sigma_y \ge 0$ (compressive)

  $$\left(\left(\frac{\sigma_y\ SF}{\sigma_{cy}'}\right)^{2/\beta_p^{0,25}}+\left(\frac{|\tau|\ SF}{\tau_c'}\right)^{2/\beta_p^{0,25}}\right)\le 1$$

- $$\left(\frac{|\tau|\ SF}{\tau_c'}\right)\le 1$$

where:

σ_x, σ_y : Actual normal stresses applied on the plate panel, in N/mm^2, respectively in the shorter edge and the longer edge of the panel, taking into account the sign convention for normal stresses defined in [2.2]

τ : Actual shear stress applied on the plate panel, in N/mm^2, taking into account the sign convention for normal stresses defined in [2.2]

σ_{cx}' : Ultimate buckling stress, in N/mm^2, in the shorter edge of the panel, as defined in [2.3.1]

σ_{cy}' : Ultimate buckling stress, in N/mm^2, in the longer edge of the buckling panel, as defined in [2.3.2]

τ_c' : Ultimate buckling shear stresses, in N/mm^2, as defined in [2.3.3]

SF : Safety buckling factor SF_{buck} defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2])

B, e_0 : As defined in Tab 1

Table 1 : Coefficients B and e_0

Applied stresses	B	e_0
$\sigma_x \ge 0$ and $\sigma_y \ge 0$	$0,7 - 0,3\ \beta_p / \alpha^2$	$2/\beta_p^{0,25}$
$\sigma_x < 0$ or $\sigma_y < 0$	1,0	2,0
Note 1: β_p : Plate slenderness parameter taken as: $\quad\beta_p = \dfrac{b}{t_p}\sqrt{\dfrac{R_y}{E}}$		

2.4.3 Plate capacity

For information, the plate limit state is based on the following interaction formula:

- $$\left(\left(\frac{\gamma_{c1}\ \sigma_x\ SF}{\sigma_{cx}'}\right)^{e_0}+\left(\frac{\gamma_{c1}\ \sigma_y\ SF}{\sigma_{cy}'}\right)^{e_0}+\left(\frac{\gamma_{c1}\ |\tau|\ SF}{\tau_c'}\right)^{e_0}-\Omega\right)= 1$$

- when $\sigma_x \ge 0$ (compressive)

  $$\left(\left(\frac{\gamma_{c2}\ \sigma_x\ SF}{\sigma_{cx}'}\right)^{2/\beta_p^{0,25}}+\left(\frac{\gamma_{c2}\ |\tau|\ SF}{\tau_c'}\right)^{2/\beta_p^{0,25}}\right)= 1$$

- when $\sigma_y \ge 0$ (compressive)

  $$\left(\left(\frac{\gamma_{c3}\ \sigma_y\ SF}{\sigma_{cy}'}\right)^{2/\beta_p^{0,25}}+\left(\frac{\gamma_{c3}\ |\tau|\ SF}{\tau_c'}\right)^{2/\beta_p^{0,25}}\right)= 1$$

- $$\left(\frac{\gamma_{c4}\ |\tau|\ SF}{\tau_c'}\right)= 1$$

where:

γ_c : Applied stress multiplier factor involving the plate buckling failure of the above different limit state

The stress multiplier factor as failure,γ_c, is taken as:

$\gamma_c = \text{Min}\,(\gamma_{c1};\ \gamma_{c2};\ \gamma_{c3};\ \gamma_{c4})$

3 Buckling analysis for stiffeners

3.1 Sign convention for stresses

3.1.1 General

In the present Article, compressive and shear stresses are to be taken as positive, tension stresses are to be taken as negative.

3.2 Buckling check induced by global axial loads

3.2.1 General

The critical buckling stress for secondary or primary supporting member is to be obtained, in N/mm², from the following formulae:

$$\sigma_c = \sigma_E \qquad\qquad \text{for } \sigma_E \leq \frac{R_y}{2}$$

$$\sigma_c = R_y\left(1 - \frac{R_y}{4\sigma_E}\right) \quad \text{for } \sigma_E > \frac{R_y}{2}$$

where:

$\sigma_E = \text{min}\,(\sigma_{E1},\ \sigma_{E2},\ \sigma_{E3})$

σ_{E1} :   Euler column buckling stress, in N/mm², given in [3.2.2]

σ_{E2} :   Euler torsional buckling stress, in N/mm², given in [3.2.3]

σ_{E3} :   Euler web buckling stress, in N/mm², given in [3.3.4].

3.2.2 Column buckling stress

The Euler column buckling stress is obtained, in N/mm², from the following formula:

$$\sigma_{E1} = \pi^2 E \frac{I_e}{A_e \ell^2} 10^{-4}$$

I_e :   Moment of inertia, in cm⁴, of the stiffener with attached shell plating of width b_e, about its neutral axis parallel to the plating

A_e :   Sectional area, in cm², of the stiffener with attached plating of width b_e.

ℓ :   Span, in m, of the stiffener

3.2.3 Torsional buckling stress

The Euler torsional buckling stresses is obtained, in N/mm², from the following formula:

$$\sigma_{E2} = \frac{\pi^2 E I_w}{10^4 I_p \ell^2}\left(\frac{K_C}{m^2} + m^2\right) + 0{,}385\,E\frac{I_t}{I_p}$$

where:

ℓ :   Span, in m, of the stiffener

I_w :   Sectoral moment of inertia, in cm⁶, of the stiffener about its connection to the attached plating:

- for flat bars:

$$I_w = \frac{h_w^3 t_w^3}{36} 10^{-6}$$

- for T-sections:

$$I_w = \frac{t_f b_f^3 h_w^2}{12} 10^{-6}$$

- for angles and bulb sections:

$$I_w = \frac{b_f^3 h_w^2}{12(b_f + h_w)^2}[t_f(b_f^2 + 2b_f h_w + 4h_w^2)$$
$$+ 3t_w b_f h_w]\,10^{-6}$$

I_p :   Polar moment of inertia, in cm⁴, of the stiffener about its connection to the attached plating:

- for flat bars:

$$I_p = \frac{h_w^3 t_w}{3} 10^{-4}$$

- for stiffeners with face plate:

$$I_p = \left(\frac{h_w^3 t_w}{3} + h_w^2 b_f t_f\right) 10^{-4}$$

I_t :   St. Venant's moment of inertia, in cm⁴, of the stiffener without attached plating:

- for flat bars:

$$I_t = \frac{h_w t_w^3}{3} 10^{-4}$$

- for stiffeners with face plate:

$$I_t = \frac{1}{3}\left[h_w t_w^3 + b_f t_f^3\left(1 - 0,63\frac{t_f}{b_f}\right)\right] 10^{-4}$$

m   :   Number of half waves, to be taken equal to the integer number such that (see also Tab 2):

$$m^2(m-1)^2 \le K_C < m^2(m+1)^2$$

$$K_C = \frac{C_0 \ell^4}{\pi^4 E I_w} 10^6$$

$$C_0 = \frac{E t_p^3}{2,73\,s} 10^{-3}$$

Table 2 : Number m of half waves

K_C	$0 \le K_C < 4$	$4 \le K_C < 36$	$36 \le K_C < 144$
m	1	2	3

3.2.4 Web buckling stress

The Euler buckling stress σ_{E3} of the stiffener web is obtained, in N/mm², from the following formulae:

- for flat bars:

$$\sigma_{E3} = 5,5\left(\frac{t_w}{h_w}\right)^2 10^4$$

- for built up stiffener with symmetrical flange:

$$\sigma_{E3} = 27\left(\frac{t_w}{h_w}\right)^2 10^4$$

3.2.5 Buckling check criteria

The critical buckling stress of the secondary or primary supporting member is to comply with the following formula:

$$\sigma_c \ge \sigma \cdot SF$$

where:

σ_c :   Critical buckling stress, in N/mm², as calculated in [3.2.1]

σ :   Actual global axial compression stress in the stiffener, in N/mm², induced by the overall hull girder loads

SF   :   Safety buckling factor SF_{buck} defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2]).

3.3 Buckling check induced by local bending and shear loads

3.3.1 General

As a rule, the present Sub Article is to be applied for primary structure elements.

This Sub Article may be also considered for secondary stiffeners when deemed necessary as specify in [3.1.2].

3.3.2 Calculation hypothesis

The buckling approach defined in the present Article is based on the NI615 Buckling Assessment of Plated Structures, taking into account the following simplifying hypothesis:

a) Web:
- the web panels are considered as being simply supported on their edge, except for flat bar where the top of the web is considered free
- the bending stress in the web in way of the attached plating is considered equal to 0.

b) Flange:
    the flange panel is considered as being simply supported on three edges.

The buckling approach defined in NI615 Buckling Assessment of Plated Structures may be taken into account instead of the present simplify method when deemed necessary.

3.3.3 Buckling check area of the stiffeners

The buckling areas and the values of local bending moments and shear forces to consider when a buckling check is carried out are defined in Tab 3 for the different stiffener elements.

3.3.4 Buckling reference stress

The elastic buckling reference stress, in N/mm², is to be taken as:

$$\sigma_E = \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t}{b}\right)^2$$

where:

t : Thickness, in mm, of the considered element of the stiffener (t_w, t_{fl} or t_p)

b : Height of web h_w or breadth of flange $b_{f\text{-}out}$, or shorter edge of the attached plating, in mm.

Table 3 : Buckling check area

Stiffener element	Type of load	End stiffener conditions	Buckling under bending		Buckling under shear for web	
			Area to be checked	Value of bending moment M′, in kNm	Area to be checked	Value of shear force T′, in kN
Attached plating (according to [3.3.7])	Sea pressure or deck loads	Fixed	Mid span	M/2	NA	NA
		simply supported or intermediate conditions	Mid span	M	NA	NA
	Internal pressure	Fixed	End	M	NA	NA
		simply supported or intermediate conditions	NA	NA	NA	NA
Web and flange (according to [3.3.5] or [3.3.6])	Sea pressure or deck loads	Fixed	End	M	End	T
		simply supported or intermediate conditions	NA	NA	End	T
	Internal pressure	Fixed	Mid span	M/2	End	T **(1)**
		simply supported or intermediate conditions	Mid span	M	End	T **(1)**

Note 1: M and T are the bending moments, in kNm, and shear forces, in kN, induced by local loads to be taken equal to:

$M = Z.\sigma_{locam}.10^{-3}$

$T = A_{sh}.\tau_{locam}.10^{-1}$

where:

Z, A_{sh}, σ_{locam}, τ_{locam}: As defined in Sec 6, [4.2.2] a)

Note 2: NA: Not applicable

(1) Bending stress and shear stress buckling are to be examined independently

3.3.5 Flat bar

a) The ultimate buckling stress of the web of flat bar, in N/mm², induced by local bending stress is to be taken as:

$\sigma_{cx}' = C_x R_y$

where:

C_x : Coefficient equal to:

$C_x = 1,00$ for $\lambda \leq 0,7$

$C_x = \dfrac{1}{\lambda^2 + 0,51}$ for $\lambda > 0,7$

$\lambda = \sqrt{\dfrac{R_y}{K_x \sigma_E}}$

$K_x = \left(0,425 + \dfrac{1}{\alpha^2}\right)\dfrac{3}{2}$

$\alpha = \ell_w/h_w$

ℓ_w : Length of the web, in mm, between vertical web stiffener

b) The ultimate buckling stress of the web of flat bar induced by local shear stress, in N/mm^2, is to be taken as:

$$\tau_c' = C_\tau \frac{R_y}{\sqrt{3}}$$

where:

C_t : Coefficient equal to:

$$C_\tau = 1,00 \text{ for } \lambda \leq 0,84$$

$$C_\tau = \frac{0,84}{\lambda} \text{ for } \lambda > 0,84$$

$$\lambda = \sqrt{\frac{R_y}{K_t \sigma_E}}$$

$$K_\tau = \sqrt{3}\left(0,6 + \frac{4}{\alpha^2}\right)$$

$\alpha = \ell_w / h_w$

ℓ_w : Length of the web, in mm, between vertical web stiffener

c) Buckling check criteria:

The web scantling is to fulfill the following condition:

$$\left(\left(\frac{\sigma_x \, SF}{\sigma_{cx}'}\right)^{e_0} + \left(\frac{|\tau| \, SF}{\tau_c'}\right)^{e_0}\right) \leq 1$$

where:

σ_x : Actual bending stress applied to the top of the web, in N/mm^2, equal to:

$$\sigma_x = (M'10^3)/Z_{acttop}$$

τ : Actual web shear stress, in N/mm^2, to be taken equal to:

$$\tau = (T'10)/A_{act}$$

M', T' : As defined in Tab 3

Z_{acttop} : Actual flat bar modulus, in cm^3, calculated at the top of the flat bar

A_{act} : Actual flat bar shear section, in cm^2, of the flat bar

σ_{cx}' : Ultimate buckling stress, in N/mm^2, defined in a)

τ_c' : Ultimate buckling shear stresses, in N/mm^2, defined in b)

SF : Safety buckling factor SF$_{buck}$ defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2])

$$e_0 = 2/\beta_p^{0,25}$$

$$\beta_p = \frac{h_w}{t_w}\sqrt{\frac{R_y}{E}}$$

3.3.6 T-bar and angle bar

a) The ultimate buckling stress of the web of T-bar and angle bar, in N/mm^2, induced by local bending stress is to be taken as:

$\sigma_{cx}' = C_x R_y$

where:

C_x : Coefficient equals to:

$C_x = 1,0 \text{ for } \lambda \leq \lambda_c$

$$C_x = 1,25 \left(\frac{1}{\lambda} - \frac{0,22}{\lambda^2}\right) \text{ for } \lambda > \lambda_c$$

$$\lambda = \sqrt{\frac{R_y}{K_x \sigma_E}}$$

$K_x = 7,63$

$\lambda_c = 0,965$

b) The ultimate buckling stress of the web of T-bar and angle induced by local shear stress, in N/mm^2, is to be taken as:

$$\tau_c' = C_\tau \frac{R_y}{\sqrt{3}}$$

where:

C_t : Coefficient equals to:

$$C_\tau = 1,00 \text{ for } \lambda \leq 0,84$$

$$C_\tau = \frac{0,84}{\lambda} \text{ for } \lambda > 0,84$$

$$\lambda = \sqrt{\frac{R_y}{K_t \sigma_E}}$$

$$K_\tau = \sqrt{3}\left(5,34 + \frac{4}{\alpha^2}\right)$$

$$\alpha = \ell_w/h_w$$

ℓ_w : Length of the web, in mm, between vertical web stiffener

c) The ultimate buckling stress of the flange of T-bar and angle bar, in N/mm², induced by local bending stress is to be taken as:

$$\sigma_{cx}' = C_x R_y$$

where:

C_x : Coefficient equals to:

$$C_x = 1,00 \text{ for } \lambda \leq 0,7$$

$$C_x = \frac{1}{\lambda^2 + 0,51} \text{ for } \lambda > 0,7$$

$$\lambda = \sqrt{\frac{R_y}{K_x \sigma_E}}$$

$$K_x = \left(0,425 + \frac{1}{\alpha^2}\right)$$

$$\alpha = \ell_w/b_{f\text{-}out}$$

ℓ_w : Length of the flange, in mm, between flange tripping bracket

d) Buckling check criteria:

- The web scantling is to fulfill the following condition:

$$\left(\left(\frac{\sigma_x \, SF}{\sigma_{cx}'}\right)^{e_0} + \left(\frac{|\tau| \, SF}{\tau_c'}\right)^{e_0}\right) \leq 1$$

where:

σ_x : Actual bending stress applied to the top of the web, in N/mm², equal to:

$$\sigma_x = (0,9M'10^3)/Z_{actfl}$$

τ : Actual web shear stress, in N/mm², to be taken equal to:

$$\tau = (T'10)/A_{act}$$

M', T' : As defined in Tab 3

Z_{actfl} : Actual stiffener modulus, in cm³, calculated at the top of the flange

A_{act} : Actual web shear section, in cm², of the stiffener

σ_{cx}' : Ultimate buckling stress, in N/mm², defined in item a)

τ_c' : Ultimate buckling shear stress, in N/mm² defined in item b)

SF : Safety buckling factor SF_{buck} defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2])

$$e_0 = 2/\beta_p^{0,25}$$

$$\beta_p = \frac{h_w}{t_w}\sqrt{\frac{R_y}{E}}$$

- The flange scantling is to fulfill the following condition:

$$\left(\frac{\sigma_1 \, SF}{\sigma_{cx}'}\right)^{e_0} \leq 1$$

where:

σ_1 : Actual bending stress applied to the flange, in N/mm², equal to:

$$\sigma_1 = (M'10^3)/Z_{actfl}$$

Z_{actfl} : Actual stiffener modulus, in cm³, calculated at the top of the flange

σ_{cx}' : Ultimate buckling stress, in N/mm² defined in c)

SF   :

$e_0 = 2 / \beta_p^{0,25}$

Safety buckling factor SF_{buck} defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2])

$\beta_p = \dfrac{b_{f-out}}{t_f} \sqrt{\dfrac{R_y}{E}}$

3.3.7   Attached plating

a) General:

The buckling check of the attached plating of stiffener is to be checked in the area where the attached plating is submitted to compressive stresses.

The dimensions of the attached plating to be considered are:

*   loaded edge: spacing between stiffeners parallel to the considered stiffener
*   unloaded edge: spacing between stiffeners perpendicular to the considered stiffener.

b) Case where the loaded edge is the shorter edge of the plate:

The ultimate buckling stress of the attached plating, in N/mm², induced by local bending stress is to be taken as:

$\sigma_{cx}' = C_x R_y$

where:

C_x :   Coefficient equals to:

$C_x = 1,0$ for $\lambda \le 0,84$

$C_x = 1,13 \left(\dfrac{1}{\lambda} - \dfrac{0,22}{\lambda^2} \right)$ for $\lambda > 0,84$

$\lambda = \sqrt{\dfrac{R_y}{K_x \sigma_E}}$

$K_x = 4$

c) Case where the loaded edge is the longer edge of the plate:

The ultimate buckling stress of the attached plating, in N/mm², induced by local bending stress is to be taken as:

$\sigma_{cy}' = C_y R_y$

where:

$C_y = 1,13 \left[\dfrac{1}{\lambda} - \dfrac{R + F^2 (H - R)}{\lambda^2} \right]$

$\lambda = \sqrt{\dfrac{R_y}{K_y \sigma_E}}$

$K_y = \left(1 + \dfrac{1}{\alpha^2} \right)^2$

α   :   Ratio between the longer edge and the shorter edge of the attached plating

R   : $R = 0,22$ for $\lambda \ge 0,84$

$R = \lambda \left(1 - \dfrac{\lambda}{1,13} \right)$ for $\lambda < 0,84$

$F = 1 - \dfrac{\left(\dfrac{K_y}{0,91} - 1 \right)}{\lambda_p^2} \ge 0$

$\lambda_p^2 = \lambda^2 - 0,5$ with $1 \le \lambda_p^2 \le 3$

$H = \lambda - \dfrac{2\lambda}{1,13 \ (T + \sqrt{T^2 - 4})} \ge R$

$T = \lambda + \dfrac{14}{15\lambda} + \dfrac{1}{3}$

d) Buckling check criteria:

The attached plating scantling is to fulfill the following condition:

$\left(\dfrac{\sigma_i \ SF}{\sigma_c'} \right)^{e_0} \le 1$

where:

σ_i :   Actual bending stress applied in the attached plating in the shorter or longer edge, in N/mm², equal to:

$$\sigma_i = (M'10^3)/Z_{actap}$$

Z_{actap} :   Actual stiffener modulus, in cm³, calculated at the associated plating

SF   :   Safety buckling factor SF_{buck} defined in the Society Rules for the classification and/or certification of ships (see Sec 1, [1.1.2])

σ_c' :   Ultimate buckling stress in the shorter edge σ_{cx}' or in the longer edge, σ_{cy}' in N/mm² defined in a) or b)

$$e_0 = 2/\beta_p^{0,25}$$

$$\beta_p = \frac{b}{t_p}\sqrt{\frac{R_{eH\_P}}{E}}$$

b   :   Shorter edge of the attached plating, in mm.

3.4 Web stiffening arrangement for primary supporting members

3.4.1 Webs of primary supporting members are generally to be stiffened where the height, in mm, is greater than 60 t, (t being the web thickness, in mm, of the primary supporting member), by web stiffeners spaced not more than 65 t.

3.4.2 The moment of inertia I, in cm⁴,of stiffeners of web of primary supporting members is to be not less than the value obtained from the following formula:

$$I = 11,4\, st_w(2,5\,\ell^2 - 2s^2)\frac{R_y}{100}$$
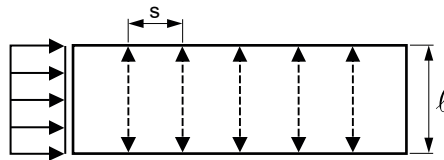
where:

ℓ :   Length, in m, of the web stiffener (see Fig 4)

s   :   Spacing, in m, of web stiffeners (see Fig 4)

t_w :   Web thickness, in mm, of the primary supporting member

R_y :   Minimum yield stress, in N/mm², as defined in Sec 2, [2.3], of the material of the web of primary supporting member.

Figure 4 : Web stiffeners for primary supporting members

3.4.3 As a general rule, tripping brackets welded to the face plate (see Fig 5), to avoid its buckling, are generally to be spaced not more than 2 m and fitted:

- at rounded and knuckle face plates
- at the toe of end brackets
- in way of cross ties
- in way of concentrated loads
- every fourth spacing of secondary stiffeners.

Where the width of the symmetrical face plate is greater than 200 mm, backing brackets are to be fitted in way of the tripping brackets.

3.4.4 The arm length d of the tripping brackets, in m, is to be not less than the greater of the following values:

$$d = 0,38b$$

$$d = 0,85b\sqrt{\frac{s_t}{t}}$$

where:

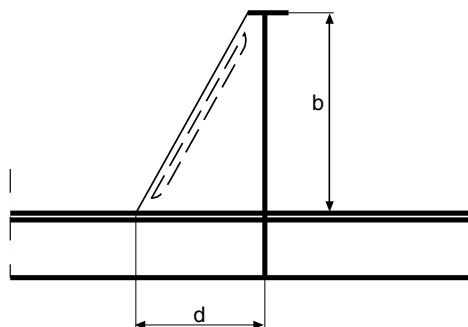b   :   Height, in m, of the tripping brackets, as shown in Fig 5

s_t :   Spacing, in m, of the tripping brackets

t   :   Thickness, in mm, of the tripping brackets.

3.4.5 Tripping brackets with a thickness, in mm, less than 22 times the length in m of the free edge of the bracket are to be flanged or stiffened by a welded face plate.

The sectional area, in cm², of the flanged edge or the face plate is to be not less than 10 times the length in m of the free edge of the bracket.

Figure 5 : Primary tripping bracket

Shaping a World of Trust