SECTION 1 APPLICATION

1 General

1.1 Structural requirements

1.1.1 The wording yacht currently used in the present Rules covers both service notations **yacht** and **charter yacht**, except otherwise indicated in the relevant chapters.

1.1.2 The present Part B of the Rules contains the requirements for determination of the minimum hull scantlings and for the intact and damage stability, applicable to all types of yachts as specified in Pt A, Ch 1, Sec 1, [1.1].

1.1.3 Yachts whose hull materials are different than those given in [1.1.2] and ships with novel features or unusual hull design are to be individually considered by the Society, on the basis of the principles and criteria adopted in the Rules.

1.1.4 The strength of yachts constructed and maintained according to the Rules is sufficient for the draught corresponding to the full load draught. The full load draught considered when applying the Rules is to be not less than that corresponding to the assigned intact ship deepest full load waterline.

1.1.5 Where scantlings are obtained from direct calculation procedures which are different from those specified in Part B, Chapter 8 and Part B, Chapter 9, adequate supporting documentation is to be submitted to the Society as detailed in Ch 1, Sec 3.

1.2 Limits of application to lifting appliances

1.2.1 The fixed parts of lifting appliances, considered as an integral part of the hull, are the structures permanently connected by welding or by laminating, depending on hull material, to the ship's hull (for instance crane pedestals, masts, king posts, derrick heel seatings, etc., excluding cranes, derrick booms, ropes, rigging accessories, and, generally, any dismountable parts).

1.2.2 The fixed parts of lifting appliances and their connections to the ship's structure are covered by the Rules.

2 Rule application

2.1 Materials

2.1.1 General

For the purpose of application of the Rules, the yachts are considered as built in following materials:

- steel (ordinary or high tensile)
- aluminium alloys
- composites
- wood (strip planking only).

Yachts built in traditional wooden construction will be specifically considered, on a case by case basis.

2.1.2 Fire protection

Attention is drawn to the selection of building materials which is not only to be determined from strength consideration, but should also give consideration to structural fire protection and associated class requirements (or Flag Administration requirements, where applicable).

2.2 Rules applicable to various ship parts

2.2.1 The various Chapters and Sections of this present Part B are to be applied for the general arrangement and scantling of ship parts according to Tab 1.

2.3 Rules applicable to other ship items

2.3.1 The various Chapters and Sections of this present Part B are to be applied for the general arrangement and scantling of other ship items according to Tab 2.

Table 1 : Part B Rules requirements applicable for the general arrangement and scantling of ship parts

Parts	Applicable Chapters and Sections
	General
General arrangement	Part B, Chapter 2
Stability	Part B, Chapter 3
Design loads and stresses	Part B, Chapter 4 Part B, Chapter 5 Part B, Chapter 6 Part B, Chapter 7
Scantlings	Part B, Chapter 8 Part B, Chapter 9
Materials	Part B, Chapter 11 Part B, Chapter 12

3 Rounding off of scantlings

3.1

3.1.1 Plate thicknesses on metallic hulls

The rounding off of plate thicknesses on metallic hulls is to be obtained from the following procedure:

a) the thickness is calculated in accordance with the rule requirements

b) the rounded thickness is taken equal to the value rounded off to the nearest half-millimeter.

3.1.2 Stiffener section moduli on metallic hulls

Stiffener section moduli as calculated in accordance with the rule requirements are to be rounded off to the nearest standard value; however, no reduction may exceed 3%.

Table 2 : Part B Rules requirements applicable for the general arrangement and scantling of other items

Items	Applicable Chapters and Sections
Anchors and chain cables	Ch 10, Sec 1
Rudders	Ch 10, Sec 2
Windows and sidescuttles	Ch 10, Sec 3
Shaft brackets	Ch 10, Sec 4
Independent tanks	Ch 10, Sec 5
Chain plates	Ch 10, Sec 6
Solid keel for sailing yachts	Ch 10, Sec 7

SECTION 2 SYMBOLS AND DEFINITIONS

1 Units

1.1 Units definition

1.1.1 Unless otherwise specified, the units used in the Rules are those defined in Tab 1.

2 Symbols

2.1

2.1.1 The main symbols are used in the present Rules are:

L : Rule length, in m, defined in [3.2]

L_{WL} : Waterline length, in m, measured with the ship at rest in calm water, at the full load displacement, as defined in [3.2]

L_{LL} : Length according to International Rules as defined in Pt A, Ch 2, Sec 1, [2.2.1]

L_h : Length according to EC Directive as defined in Pt A, Ch 2, Sec 1, [2.2.1]

L_{HULL} : Hull length, in m, defined in [3.3]

B : Moulded breadth, in m, defined in [3.5]

B_{WL} : Greatest moulded breadth on waterline at draught T, in m, defined in [3.5]

D : Depth, in m, defined in [3.6]

T : Full load draught, in m, defined in [3.7]

Δ : Full load displacement, in tonnes, at draught T, in sea water (density ρ = 1,025 t/m^3).

C_B : Total block coefficient. For catamarans, C_B is to be calculated for a single hull, assuming Δ equal to one half of the ship's displacement

$$C_B = \frac{\Delta}{1,025 L B_{WL} T}$$

C_W : Wave height, in m, defined in [3.10]

V : Maximum speed, in knots, of the yacht

LCG : Ship's longitudinal centre of gravity

a_{CG} : Design vertical acceleration, in g, defined in [3.11]

H_S : Significant wave height, in m, defined in [3.10].

3 Definitions

3.1 Moulded base line

3.1.1 The moulded base line is the horizontal reference line tangent to the upper face of bottom plating at midship.

In the case of yacht with a solid bar keel, the moulded base line is to be taken at the intersection between the upper face of the bottom plating with the solid bar keel at the middle of length L.

Table 1 : Units

Designation	Usual symbol	Units
Ship's dimensions	See [2]	m
Hull girder section modulus	Z	m^3
Density	ρ	t/m^3
Concentrated loads	P	kN
Linearly distributed loads	q	kN/m
Surface distributed loads	p	kN/m^2
Thicknesses	t	mm
Span of ordinary stiffeners and primary supporting members	ℓ	m
Spacing of ordinary stiffeners and primary supporting members	s	m
Bending moment	M	kN.m
Shear force	Q	kN
Stresses	σ, τ	N/mm^2
Section modulus of ordinary stiffeners and primary supporting members	w	cm^3
Section area of ordinary stiffeners and primary supporting members	A	cm^2

3.2 Rule length

3.2.1 The rule length L is equal to L_{WL} where L_{WL} is the waterline length measured with the yacht at rest in calm water, at the full load displacement.

3.3 Hull length

3.3.1 The hull length L_{HULL} is equal to the total hull length, from the extreme foreward part of the hull, excluding any outfitting protusing, and the extreme aft part.

3.4 Ends of rule length L_{WL} and midship

3.4.1 Fore end

The fore end (FE) of the rule length L_{WL} (see Fig 1) is the perpendicular to the full load waterline at the forward side of the stem.

3.4.2 Aft end

The aft end (AE) of the rule length L_{WL} (see Fig 1, is the perpendicular to the full load waterline at a distance L_{WL} aft of the fore end.

3.4.3 Midship

The midship is the perpendicular to the waterline at a distance 0,5L_{WL} aft of the fore end (see Fig 1).

3.5 Breadth

3.5.1 The moulded breadth B, in m, is the greatest moulded breadth measured amidships below the weather deck.

3.5.2 The breadth B_{WL}, in m, is the greatest moulded breadth measured amidships at full load waterline. For catamarans, B_{WL} is the breadth of each hull.

3.6 Depth

3.6.1 The depth D, in m, is the distance measured vertically on the midship transverse section, from the moulded base line to the top of the deck beam at side on the uppermost continuous deck.

3.7 Draught

3.7.1 The full load draught T, in m, is the distance, measured vertically on the midship transverse section, from the moulded base line to the full load waterline.

In the case of ships with a solid bar keel, the moulded base line is to be taken as defined in [3.1].

3.8 Lightweight

3.8.1 The lightweight, in t, is the displacement without cargo, fuel, lubricating oil, ballast water, fresh water and feed water, consumable stores, passengers and crew with their effects, but including liquids in piping.

3.9 Deadweight

3.9.1 The deadweight is the difference, in t, between the displacement, at the summer draught in sea water of density ρ = 1,025 t/m^3, and the lightweight.

3.10 Wave characteristics

3.10.1 The wave height C_W, in m, is the height crest-to-trough of the wave. This wave height is used only for scantling calculation purpose.

3.10.2 The wave height H_S, in m, is the significant wave height ($H_{1/3}$) of the considered sea-state.

3.10.3 The wave lenght L_W, in m, is the distance between two consecutive crests of the wave. This wave length is used only for scantling direct caculation purpose.

3.11 Design vertical acceleration

3.11.1 The design vertical acceleration at LCG, a_{CG} (expressed in g), is to be defined by the designer and corresponds to the average of the 1 per cent highest accelerations in the most severe sea conditions expected, in addition to the gravity acceleration.

3.12 Freeboard deck(m)

3.12.1 The freeboard deck(m) is defined in Ch 2, Sec 2, [2.2.1].

3.13 Bulkhead deck

3.13.1 The bulkhead deck is the uppermost deck up to which the transverse watertight bulkheads are carried.

3.14 Superstructure

3.14.1 The superstructure is defined in Ch 2, Sec 2, [2.2.2].

3.15 Superstructure deck

3.15.1 A superstructure deck is a deck forming the upper boundary of a superstructure.

4 Reference co-ordinate system

4.1

4.1.1 The ship's geometry, motions, accelerations and loads are defined with respect to the following right-hand co-ordinate system (see Fig 2):

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

4.1.2 Positive rotations are oriented in anti-clockwise direction about the X, Y and Z axes.

Figure 1 : Ends and midship

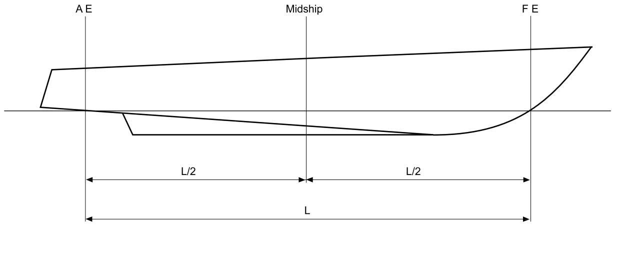
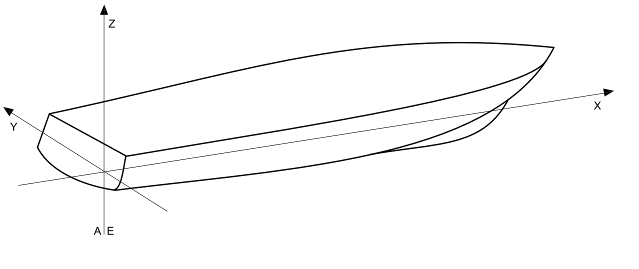


Figure 2 : Reference co-ordinate system



SECTION 3 DOCUMENTATION TO BE SUBMITTED

1 Documentation to be submitted

1.1 Yachts surveyed by the Society during the construction

1.1.1 Plans and documents to be submitted for approval

The plans and documents to be submitted to the Society for approval are listed in Tab 1.

These plans and documents are to be supplemented by further documentation which depends on the service notation and, possibly, the additional class notation (see Pt A, Ch 1, Sec 2) assigned to the ship.

Structural plans are to show details of connections of the various parts of the hull and, in general, are to specify the materials used, including their manufacturing processes, welded procedures and heat treatments (See Part B, Chapter 11 for steel and aluminium hull or Ch 12, Sec 1 for composite hull).

1.1.2 Plans and documents to be submitted for information

In addition to those in [1.1.1], the following plans and documents are to be submitted to the Society for information:

- general arrangement
- lines plan
- hydrostatic curves
- lightweight distribution.

In addition, when direct calculation analyses are carried out by the Designer according to the rule requirements, they are to be submitted to the Society.

1.2 Yachts for which the Society acts on behalf of the relevant Administration

1.2.1 Plans and documents to be submitted for approval

The plans and documents required by the National Regulations requirements are to be submitted to the Society for approval, in addition to those in [1.1].

The list of drawings and documents to be submitted is to be finalized at the beginning of the design review process, depending on Administration requirements.

1.3 Special case of yachts reviewed for E.C. certification

1.3.1 The plans and documents to be submitted to the Society for approval according to Pt A, Ch 1, Sec 4 within the scope of EC certification, are listed in relevant Bureau Veritas documents (e.g. ND 316 R2/DT1/MCE for stability, buoyancy and freeboard and ND 317 R2/DT1/MCE for machinery and installation).

Table 1 : Plans and documents to be submitted for approval for all yachts

Plan or document	Containing also information on
Midship section and/or transverse sections Shell expansion Decks and profiles Double bottom Pillar arrangements Framing plan	Class characteristics Main dimensions Minimum ballast draught Frame spacing Contractual service speed Design loads on decks Steel grades and/or aluminium type or information as given in Ch 12, Sec 1 for composite structures Location and height of air vent outlets of various compartments Corrosion protection Openings in decks and shell and relevant compensations Details of structural reinforcements and/or discontinuities Bilge keel with details of connections to hull structures
Watertight subdivision bulkheads Inner watertight doors	Openings and their closing appliances, if any
Fore part structure Aft part structure	
(1) Where other steering or propulsion systems are adopted (e.g. steering nozzles or azimuth propulsion systems), the plans showing the relevant arrangement and structural scantlings are to be submitted.	

Plan or document	Containing also information on
Transverse thruster, if any, general arrangement, tunnel structure, connections of thruster with tunnel and hull structures	
Foundations of propulsion machinery, generators...	Type, power and r.p.m. of propulsion machinery Mass and centre of gravity of machinery, generators ...
Superstructures and deckhouses	
Transom doors, if any, side doors and other openings in the side shell Plan of outer doors Deck covers, if any	Closing appliances Design loads on deck covers
Windows and side scuttles, arrangements and details	Scantling and mechanical characteristics of glazing
Scuppers and sanitary discharges	
Bulwarks and freeing ports	Arrangement and dimensions of bulwarks and freeing ports on the freeboard deck[(m)] and superstructure deck
Helicopter decks, if any	General arrangement Main structure Characteristics of helicopters: maximum mass , distance between axles of wheels or skids, print area of wheels or skids, rotor diameter
Rudder and rudder horn **(1)**	Maximum ahead service speed (motor propulsion and wind propulsion for sailing yachts)
Sternframe or sternpost, sterntube Propeller shaft boss and brackets **(1)**	
Sea chests, stabiliser recesses, etc.	
Hawse pipes	
Plan of manholes	
Plan of access to and escape from spaces	
Plan of ventilation	Use of spaces
Plan of independent liquid tank and/or capacities	Location and height of air vent outlets of the various compartments
Plan of watertight doors and scheme of relevant manoeuvring devices	Manoeuvring devices Electrical diagrams of power control and position indication circuits
Freeboard calculations, if applicable	
Stability documentation	See Ch 3, Sec 1, [2.1]
Calculations relevant to intact stability and damage stability	See Ch 3, Sec 2 and Ch 3, Sec 3
Equipment number calculation	Geometrical elements for calculation List of equipment Construction and breaking load of steel wires Material, construction, breaking load and relevant elongation of synthetic ropes
Solid keel	Weight and centre of gravity Details of the connection between the hull and the solid keel Mechanical characteristics of the materials used
For sailing yachts: Chainplates Pillar under mast	Forces applied by the rigging and the mast Forces and reinforcements in way of winches Mechanical characteristics of the materials used for chainplates Details of connections with the hull structure

(1) Where other steering or propulsion systems are adopted (e.g. steering nozzles or azimuth propulsion systems), the plans showing the relevant arrangement and structural scantlings are to be submitted.

SECTION 4 CALCULATION PROGRAMMES

1 General

1.1 Application

1.1.1 The present Section deals with the various calculation software developed by Bureau Veritas to help checking the requirements of the present Rules.

1.1.2 The list of software is given hereafter, together with their main purpose and scope of application.

Application for these software is to be transmitted to the following internet address:

- MarinesoftwareMail@bureauveritas.com

Information can also be found on the following web site:

- http://www.veristar.com

2 Software

2.1 STEEL

2.1.1 This software allows any type of 2D or 3D beam analysis, for metallic structure.

It includes user-friendly pre-processing for the modelling and post-processing for the bending moments, shear forces, and resulting stresses analysis.

Curved beams may easily be modelled and calculated, using dedicated pre-processing developed separately.

2.2 COMP 2000

2.2.1 This software allows the detailed strength analysis of any type of composites panel or stiffeners, and calculation of strength characteristics of hull girder transverse section, according to Part B, Chapter 9 and to Part B, Chapter 12.

It includes the failure criteria to be considered.

2.3 MARS

2.3.1 Using the appropriate sub-routine, this software allows the calculation of geometrical characteristics of any transverse section of yachts made of metallic materials.

SECTION 5 CONNECTION WITH PART C

1 General

1.1 Application

1.1.1 The present Section deals with the interconnection and the inter linked requirements of Part B and Part C of the present Rules.

1.2 Inter linked requirements

1.2.1 General

Part B of the present Rules deals with the naval architecture of the yacht design (structure and stability). The requirements therein are generally applicable from the very beginning of the Class design review.

Part C of the present Rules deals with the systems fitted on board the yacht, for propulsion, piping and associated functions, for power generation and control and for fire safety.

Attention of designers is drawn on fact that some naval architecture options, that may be decided early in the design process, are directly influencing the design options for systems covered by Part C, or some statutory matters.

The following requirement [1.2.2] outlines the most important such inter linked options.

1.2.2 Inter linked requirements

The most important inter linked options of the various Parts of the Rules are given in Tab 1.

Table 1 : Inter linked requirements

Naval architecture option	Inter linked systems options
Type of hull (mono - multi) Type of propulsion (motor - sail)	Power generation Emergency source
Hull material	Fire safety Piping materials
Watertight bulkheads (distribution and arrangement)	Damage stability
Openings in hull	Damage stability Loadline **(1)**
(1) If relevant	

SECTION 1 SUBDIVISION ARRANGEMENT

1 Number and arrangement of transverse watertight bulkheads

1.1 Number of watertight bulkheads

1.1.1 General

As a rule, all yachts are to have at least the following watertight transverse bulkheads:

- one collision bulkhead
- one after peak bulkhead
- watertight bulkheading of the machinery space.

1.1.2 Additional bulkheads

Additional bulkheads may be required for yachts having to comply with damage stability criteria, according to requirements of Part B, Chapter 3.

2 Collision bulkhead

2.1 General

2.1.1 A collision bulkhead is to be fitted which is to be watertight up to the bulkhead deck. This bulkhead is to be located at a distance from the forward perpendicular (FE) of not less than 5% of the full load waterline length L_{WL} and not more than 10% of L_{WL} (see Ch 1, Sec 2 for the definitions of L_{WL} and (FE)).

2.1.2 At Owner request and subject to the agreement of the flag Administration, the Society may, on a case by case basis, accept a distance from the collision bulkhead to the forward perpendicular (FE) greater than the maximum specified in [2.1.1], provided that the subdivision and stability calculations show that, when the yacht is in upright condition, flooding of the space forward the collision bulkhead will not result in any part of the bulkhead deck becoming submerged, or in any unacceptable loss of stability.

2.1.3 The bulkhead may have steps or recesses provided they are within the limits prescribed in [2.1.1] and [2.1.2].

As a rule, no door, manhole, ventilation duct or any other opening are to be fitted in the collision bulkhead.

However, when an access through the collision bulkhead is deemed necessary for the proper working of the yacht, a manhole may be accepted provided the following requirements are met:

- agreement of the Owner and Flag Administration on the proposed arrangement, and
- the manhole is fitted, as far as practicable, in the upper part of the collision bulkhead, and
- a permanent watertight close device, having the same resistance than surrounding bulkhead and bolted to the collision bulkhead is provided, and
- a permanent sign, fixed on the collision bulkhead and indicating that the manhole is to be permanently closed, is to be displayed, and
- an audible and/or visual alarm is automatically actuated when the manhole is open.

2.1.4 On a case by case basis, it may be accepted that pipes cross through the collision bulkhead, provided the crossings be fitted in upper part of the collision bulkhead and made watertight.

3 After peak and machinery space bulkheads

3.1 General

3.1.1 An after peak bulkhead bounding the stern tube compartment (see also [4.1.1]) and bulkheads dividing the machinery space(s) from passenger and crew spaces are to be fitted.

These bulkheads are to be made watertight up to the bulkhead deck. They may, however, be stopped to a watertight deck below the bulkhead deck, provided the degree of safety of the ship as regards subdivision and damage stability, when requested, is not thereby diminished.

4 Stern tubes

4.1 General

4.1.1 Where the after peak bulkhead in way of the sterntube stuffing box is not provided, as mentioned in [3.1.1], sterntubes are to be enclosed in a watertight space (or spaces) of moderate volume. Other measures to minimise the danger of water penetrating into the yacht in case of damage to sterntube arrangements may be taken at the discretion of the Society.

5 Compartment with access on hull

5.1 General

5.1.1 Compartment located below the freeboard deck[(m)] (as defined in Ch 2, Sec 2, [2.2.1]) and having a direct access opening on the hull are to be bounded by watertight bulkheads to separate it from the other adjacent compartments also located below the freeboard deck[(m)].

6 Openings in watertight bulkheads and decks

6.1 General

6.1.1 The number of openings in watertight subdivisions is to be kept to a minimum compatible with the design and proper working of the yacht. Where penetration of watertight bulkheads and internal watertight decks are necessary for access, piping, ventilation, electrical cables, etc., arrangement are to be made to maintain the watertight integrity.

6.1.2 Lead or other heat sensitive materials may not be used in systems which penetrate watertight subdivision bulkheads, where deterioration of such systems in the event of fire would impair the watertight integrity of the bulkheads.

6.1.3 Valves not forming part of a piping system are not permitted in watertight subdivision bulkheads.

6.2 Watertight doors

6.2.1 The doors fitted in watertight bulkheads are to be watertight and are to have same strength than surrounding bulkheads.

The watertight bulkhead and door scantlings are to be in compliance with Ch 8, Sec 8.

6.2.2 Class requirements

Indicators are to be provided at the control position showing whether the doors are open or closed.

6.2.3 Other requirements

Some flag Administrations or some International Rules may request that:

- watertight doors which are used while at sea be of sliding watertight doors capable of being remotely closed from the bridge and also be operable locally from each side of the bulkhead
- an audible alarm be provided at the door closure
- the power, control and indicators be operable in the event of main power failure
- particular attention be paid to minimise the effect of control system failure
- each power-operated sliding watertight door be provided with an individual hand-operated mechanism
- the possibility of opening and closing the door by hand at the door itself from both sides be assured.

SECTION 2 INTEGRITY AND OPENINGS IN HULL

1 General

1.1 General

1.1.1 The requirements of the present Section are applicable to yachts and charter-yachts in scope of Classification only.

To that purpose, they only deal with the various protection index to be provided for the openings in decks and superstructures exposed to sea in a view to prevent any flooding of the floating hull under sea effect of such decks and superstructures.

1.1.2 The attention of Shipowners, Shipyards and Designers is drawn on the fact that compliance to the requirements of the present section is not necessarily sufficient at all to allow Flag Administration (to issue a load line certificate for example).

1.1.3 The Flag Administration may request for yacht greater than 24 m length load line application of National Rules and/or International Regulations. In such a case, it is the Owner, the Shipyard or the Designer responsibility to comply with the therein Rules and Regulations, which can be different from the requirements of the present Section.

1.1.4 When agreed by the Flag Administration, the Society may act on behalf of the Flag Administration in scope of National Rules and/or International Regulations.

In such case, the requirements of the present section will be superseded by the National or International Rules recongnized by the Flag Administration.

Note 1: In the scope of the limits of such authorization, the Society only notices the arrangements which are not in accordance with the requirements of the National and/or International Rules. It is to the Flag responsibility to request or not new arrangement within the scope of the National and/or International Rules.

2 Interpretation principle

2.1 General

2.1.1 Main definition

The main definitions of the present section are the one of the International Convention on Load lines, 1966, as amended.

2.1.2 Interpretation

The only purpose of the interpretations given with each definition in the present section (and which may differ from the International Load Line Convention) is to specify the list of requirements applicable for openings protection in scope of Classification only.

2.2 Definitions and interpretations

2.2.1 Freeboard deck

The freeboard deck is normally the uppermost complete deck exposed to weather and sea, which has permanent means of closing all openings in the weather part thereof, and below which all openings in the sides of the ship are fitted with permanent means of watertight closing.

Interpretation:

This deck, noted freeboard deck$^{(m)}$ in the present section, is to be considered as the deck exposed to greenseas, and granting the necessary weathertightness of the hull to prevent any water ingress.

2.2.2 Superstructure

a) A superstructure is a decked structure on the freeboard deck, extending from side to side of the ship or with the side plating not being inboard of the shell plating more than 4 per cent of the breadth (B).

b) An enclosed superstructure is a superstructure with:

   1) enclosing bulkheads of efficient construction

   2) access openings, if any, in these bulkheads fitted with doors complying with the requirements of Regulation 12 of the International Convention on Load Lines 1966 as amended, dealing with the doors arrangement

   3) all other openings in sides or ends of the superstructure fitted with efficient weathertight means of closing.

Interpretation:

A superstructure, noted superstructure$^{(m)}$ in the present section, is to be considered as a decked structure on the freeboard deck$^{(m)}$ and complying with the requirements of Ch 8, Sec 9 and Ch 9, Sec 9 even if it is inboard of the shell plating more than 4% of the breadth. A superstructure$^{(m)}$ may be:

- enclosed$^{(m)}$: if all the openings in the exposed surrounding sides and decks are made weathertight as indicated in [2.2.4] of the present article
- open$^{(m)}$: if the openings in the exposed surrounding sides and decks are not all made weathertight.

Note 1: The part of the freeboard deck$^{(m)}$ sheltered by an enclosed$^{(m)}$ superstructure$^{(m)}$ is not to be considered as a deck exposed to greenseas.

2.2.3 Deckhouse

A deckouse is a decked structure other than a superstructure, located on the freeboard deck$^{(m)}$ or above.

2.2.4 Weathertightness

Weathertight means that in any sea conditions, water will not penetrate into the ships.

The weathertight closing devices (door, hatch cover,....) are to be of strong construction and with strength criteria similar to the adjacent ship's structure.

2.2.5 Green sea exposure location

The locations are defined as follows:

- Fore area: area extending on the forward 1/3 of the ship's rule length
- Aft area: area extending on the aft 2/3 of the ship's rule length
- Fore deck: exposed part of the freeboard deck(m) and side walls or front wall of the first tier of superstructure(m) on the freeboard deck(m), located in the fore area
- 1st tier of fore area: exposed part of the first deck above the freeboard deck(m) and side walls or front wall of superstructure located on this deck, located in the fore area.

3 General arrangement design

3.1 Height of sills and coamings

3.1.1 All the openings giving direct or indirect access below the freeboard deck(m) are to be fitted with closing devices and are to be weathertight.

3.1.2 The above closing means are to be permanently ready for use, fitted with locking devices and with opening outward.

3.1.3 For classification purpose, the openings mentioned in [3.1.1], except the one giving access to machinery space (see [3.1.7]), are to be fitted with sill or coamings having following minimum height:

- fore deck: 600mm
- 1st tier of fore area: 150mm
- aft area:
  - 300mm for doors, hatchways and companion ways directly exposed to green sea effects (see also [3.1.4] and [3.1.5])
  - 200mm for doors in side walls of superstructure (see also [3.1.5]
  - 100mm for protected doors, hatchways and companion ways in aft wall of superstructure (see also [3.1.4] and [3.1.5])
- access to engine room:

  As a rule, the height of sills and coamings giving direct access to machinery spaces is to be 600mm.

  The above height may be reduced to 380mm where the access to machinery space is located in the aft area and this access is not directly exposed to green seas effect.

3.1.4 Deck hatchway not used for access at sea can be provided without coaming except when the hatchway is the only access leading to the steering gear compartment or to the engine room.

In such case, permament warnings are to be fitted close to the concerned deck hatchway, specifying that the deck hatchway under consideration is not to be used when operating in deep sea.

3.1.5 Doors not used during operation in deep sea, can be provided with height of sills reduced by half.

In such case, permament warnings are to be fitted close to the concerned doors, specifying that the door under consideration is not to be used when operating in deep sea.

3.1.6 Removable sills

Except for the fore deck, a part of the required sill of the openings used during operation in deep sea, may be made of removable part, provided:

a) the height of the removable sill is at maximum half of the required height according to [3.1.3], and

b) the removable sill is permanently stored close to the opening, and

c) the weathertightness of the complete sill is satisfactorily demonstrated by a hose test.

3.1.7 For yachts having the navigation notation **sheltered area** or **coastal area** or **unrestricted navigation limited to 60 nautical miles** as defined in Pt A, Ch 1, Sec 2, the height of sills and coamings as required in [3.1.3] may be reduced by half.

In this case, fitting of removable sills according to [3.1.6] cannot be simultaneously accepted.

3.2 Ventilation openings

3.2.1 Spaces located below the freeboard deck(m)

The ventilation openings serviceing spaces located below the freeboard deck(m) are to be protected from direct green-seas effect and are to be fitted, as a rule, with a sill of height equal to 900mm where located in fore area or 760mm where located in aft area.

The ventilation openings must be fitted with water trap system.

Smaller sill heights may be accepted provided:

- ventilation openings is located in a protected area not directly exposed to green seas effect
- ventilation openings are fitted with systems limiting direct water ingress. The efficiency of the system is to be tested by hose.

3.2.2 For yachts having the navigation notation sheltered area or coastal area or unrestricted navigation limited to 60 nautical miles as defined in Pt A, Ch 1, Sec 2, the height of the sills as defined in [3.2.1] may be reduced to 450 mm and 380 mm, respectively.

3.2.3 Engine rooms

As a rule, the sills of ventilation openings serviceing the machinery space are to be in accordance with Pt C, Ch 1, Sec 9, [7.3.8].

Smaller sills as indicated in [3.2.1] may be accepted.

3.3 Scantlings of doors, hatch covers, superstructure windows and side scuttles

3.3.1 The scantlings of the doors, hatch covers, superstructure windows and side scuttles giving access below the freeboard deck are to be determined with sea pressure given in Ch 7, Sec 1, and with due consideration given to the material used for construction.

Weathertighness is to be demonstrated after fitting on board by means of hose tests.

3.3.2 Side scuttles

As a rule, the lower edge of the side scuttle is to be at least 500mm above the waterline.

Side scuttles below the freeboard deck(m) the less exposed to chocks may be fitted with removable deadlights, provided the side scuttle strength is equivalent to the strength of the surrounding hull sides (see Ch 10, Sec 3).

3.3.3 Window arrangement

Opening windows may not be fitted:

- below the freeboard deck(m)
- where they become immersed by any intermediate stage of flooding or the final equilibrium waterplane in any required damage case for ships subject to damage stability regulations
- in the first tier deckhouses considered as being buoyant in the stability calculations.

3.4 Freeing ports

3.4.1 General

Where bulwarks on the weather portions of the freeboard deck(m) or the superstructure(m) decks form wells, ample provision is to be made for rapidly freeing the decks of water and for draining them.

The minimum section area of the freeing ports is determined according to [3.4.2] in scope of classification.

3.4.2 Minimal section

The minimum section area of freeing ports on each side of the yacht and for each well, is based on the volume of the well formed by the deck and the corresponding bulwark.

As a rule, the minimum section area of freeing ports is not to be less than:

- where the exposed deck is not sheltered by any decked construction, the minimum section area A of freeing port on each side, in m^2 is given in Tab 1
- where the exposed deck is sheltered by a superstructure(m) or a decked construction, the minimum section area A of freeing ports on each side, in m^2, is given as a percentage of the lateral surface of the corresponding bulwark, according to Tab 2.

3.4.3 Location

The lower edge of the freeing ports is to be as close to deck as possible.

Freeing ports are to be located in the areas of the well where the sheer is the lowest and in the areas of the well where the sea water may accumulate due to yacht motions at sea.

3.4.4 Protection

All such openings in the bulwarks are to be protected by rails or bars spaced approximately 230mm apart. If shutters are fitted to freeing ports, ample clearance is to be provided to prevent jamming. Hinges are to have pins or bearings of non-corrodible material.

Table 1 : Freeing ports for deck without decked construction

Area A of freeing ports, in m^2	
$\ell_B \le 20$	$\ell_B > 20$
$0{,}7 + 0{,}035\ \ell_B + A_C$	$0{,}07\ \ell_B + A_C$

Note 1:

ℓ_B : Length, in m, of bulwark in the well, to be taken not greater than $0{,}7\ L_{HULL}$

A_C : Area, in m^2, to be taken, with its sign, equal to:

$$A_C = \frac{\ell_B}{25}(h_B - 1{,}2) \quad \text{for } h_B > 1{,}2$$

$$A_C = 0 \quad \text{for } 0{,}9 \le h_B \le 1{,}2$$

$$A_C = \frac{\ell_B}{25}(h_B - 0{,}9) \quad \text{for } h_B < 0{,}9$$

h_B : Mean height, in m, of the bulwark in a well of length ℓ_B

Table 2 : Freeing ports for deck with decked construction

Relative breadth of the superstructure or the decked construction, compared to the breadth of the deck	Minimum area of freeing ports on each side compared to the lateral area of the lateral bulwark
40%	10%
50%	8,6%
60%	7,1%
70%	5%
80% and more	4,3%

SECTION 1 GENERAL REQUIREMENTS

1 General

1.1 Application

1.1.1 General

All yachts may be assigned class only after it has been demonstrated that their stability is adequate. Adequate stability means compliance with standards laid down with the requirements specified in the relevant chapters taking into account the yacht's size and type. See Tab 1.

1.1.2 Approval of the Administration

Evidence of approval by the Administration concerned may be accepted for the purpose of Classification, if demonstrated that their requirements are at least equal to those defined in the relevant chapter of these rules.

2 Examination procedure

2.1 Documents to be submitted

2.1.1 List of documents

For the purpose of the examination of the stability, the following documents are to be submitted:

- lines plan
- general arrangement plan. In addition for sailing yachts, a general arrangement plan showing the sails lowered on the rigging and masts
- capacity plan indicating the volume and position of the centre of gravity (coordinates X, Y, Z), of all compartments and tanks and the free surfaces
- hydrostatic tables or curves
- lightship particulars
- trim and stability booklet
- when applicable, damage stability calculations.

Table 1 : Application

Length	Navigation notation		
	Sheltered area	Coastal area	Unrestricted navigation
$L_{LL} \leq 24m$	Ch 3, Sec 2	Ch 3, Sec 2	Ch 3, Sec 2
$L_{LL} > 24m$	Ch 3, Sec 2	Ch 3, Sec 2	Ch 3, Sec 2 and Ch 3, Sec 3 **(1)**

(1) May be exempted from damage stability for yacht having the navigation notation **unrestricted navigation limited to 60 nautical miles**.

2.1.2 Documents for approval

The report of the inclining experiment, the trim and stability booklet and when applicable the damage stability calculations are to be submitted for approval.

2.1.3 Provisional documentation

Provisional stability documentation based on the estimated lightship particulars should be submitted for examination.

2.1.4 Final documentation

Final stability documentation based on the results of the inclining experiment or the lightweight check is to be submitted for examination.

When the difference between the estimated values of the lightship and those obtained from the inclining experiment or the lightweight check is less than:

- 2% for the displacement and
- 1% of the length between perpendiculars for the longitudinal position of the centre of gravity

and the determined vertical position of the centre of gravity is not greater than the estimated vertical position of the centre of gravity, the provisional stability documentation may be accepted as the final stability documentation.

2.2 Inclining experiment/lightweight check

2.2.1 Definitions

The following definitions are used in the present Chapter:

a) Lightship

   The lightship is a yacht complete in all respects, but without consumable, stores, and crew and effects, and without any liquids on board except for machinery and piping fluids, such as lubricants and hydraulics, which are at operating levels

b) Inclining experiment

   The inclining experiment is a procedure which involves moving a series of known weights, normally in the transverse direction, and then measuring the resulting change in the equilibrium heel angle of the yacht. By using this information and applying basic naval architecture principles, the yacht's vertical centre of gravity (VCG or KG) is determined

c) Lightweight check

   The lightweight check is a procedure which involves auditing all items which are to be added, deducted or relocated on the yacht at the time of the inclining experiment so that the observed condition of the yacht can be adjusted to the lightship condition. The weight and longitudinal, transverse, and vertical location of each item are to be accurately determined and recorded. The lightship displacement and longitudinal centre of gravity (LCG) can be obtained using this information, as well as the static waterline of the yacht at the time of the ligthweight survey as determined by measuring the freeboard or verified draughts marks of the yacht, the yacht's hydrostatic data and the sea water density.

2.2.2 General

The inclining experiment or the lightweight check is to be attended by a Surveyor of the Society. The Society may accept inclining experiment or lightweight check attended by a member of the Flag Administration.

After completion, the yacht is subject to an inclining experiment. In some particular cases as described in [2.2.4], the Society may accept a lightweight check.

2.2.3 Inclining experiment

The inclining experiment is required in the following cases:

- any new yacht, after its completion, except for the cases specified in [2.2.4]
- any yacht, if deemed necessary by the Society, where any alterations are made so as to materially affect the stability.

2.2.4 Lightweight check

The Society may allow a lightweight check to be carried out in lieu of an inclining experiment in the case of:

a) An individual yacht, provided basic stability data are available from the inclining experiment of a sister ship and a lightweight check is performed in order to prove that the sister ship corresponds to the prototype yacht. In such case the Society is satisfied when the result of the lightweight check shows a deviation from the displacement of the prototype yacht not greater than 2%, and not greater than 1% of the length between perpendiculars for the longitudinal position of the centre of gravity. The final stability data to be considered for the sister ship in terms of displacement and position of the centre of gravity are those of the prototype

b) On a case by case basis and subject to the agreement of the flag Administration, provided that:
   - a detailed list of weights, and the positions of their centre of gravity is submitted
   - a lightweight check is carried out, showing accordance between the estimated values and those determined
   - adequate stability is demonstrated in all the loading conditions reported in the trim and stability booklet.

2.2.5 Detailed procedure

A detailed procedure for conducting an inclining experiment is included in Ch 3, App 1. For the lightweight check, the same procedure applies except as provided for in Ch 3, App 1, [1.1.8].

SECTION 2 INTACT STABILITY

1 General

1.1 Information to the Master

1.1.1 Stability booklet

Each yacht is to be provided with a stability booklet, approved by the Society, which contains sufficient information to enable the Master to operate the yacht in compliance with the applicable requirements contained in this Section.

Where any alterations are made to a yacht so as to materially affect the stability information supplied to the Master, amended stability information is to be provided. If necessary the yacht is to be re-inclined.

Stability data and associated plans are to be drawn up in the official language or languages of the issuing country. If the languages used are neither English nor French, the text is to include a translation into one of these languages.

The format of the trim and stability booklet and the information included are specified in Ch 3, App 2.

1.2 Permanent ballast

1.2.1 If used, permanent ballast is to be located in accordance with a plan approved by the Society and in a manner that prevents shifting of position. Permanent ballast is not to be removed from the yacht or relocated within the yacht without the approval of the Society. Permanent ballast particulars are to be noted in the yacht's stability booklet.

1.2.2 Permanent solid ballast is to be installed under the supervision of the Society.

2 Design criteria for all type of yachts

2.1 General intact stability criteria

2.1.1 General

The intact stability criteria specified from [2.1.2] to [2.1.5] are to be complied with for the loading conditions mentioned in Ch 3, App 2, [1.2].

However, the lightship condition not being an operational loading case, the Society may accept that part of the above-mentioned criteria are not fulfilled.

2.1.2 GZ curve area

The area under the righting lever curve (GZ curve) is to be not less than 0,055 m·rad up to $\theta = 30°$ angle of heel and not less than 0,09 m·rad up to $\theta = 40°$ or the angle of down flooding θ_f if this angle is less than 40°. Additionally, the area under the righting lever curve (GZ curve) between the angles of heel of 30° and 40° or between 30°and θ_f, if this angle is less than 40°, is to be not less than 0,03 m rad.

Note 1: θ_f is an angle of heel at which openings in the hull, superstructures or deckhouses which cannot be closed weathertight submerge. In applying this criterion, small openings through which progressive flooding cannot take place need not be considered as open (see Ch 3, App 2, [1.3.3]).

2.1.3 Minimum righting lever

The righting lever GZ is to be at least 0,20 m at an angle of heel equal to or greater than 30°.

2.1.4 Angle of maximum righting lever

The maximum righting arm is to occur at an angle of heel preferably exceeding 30° but not less than 25°.

When the righting lever curve has a shape with two maximums, the first is to be located at a heel angle not less than 25°.

In cases of yachts with a particular design (multihull for example), the Society may accept an angle of heel θ_{max} less than 25° but in no case less than 10°, provided that the area "A" below the righting lever curve is not less than the value obtained, in m.rad, from the following formula:

$$A = 0{,}055 + 0{,}001\ (30° - \theta_{max})$$

where θ_{max} is the angle of heel in degrees at which the righting lever curve reaches its maximum.

2.1.5 Initial metacentric height

The initial metacentric height GM_0 is not to be less than 0,15 m.

3 Severe wind and rolling criterion (weather criterion)

3.1 Scope

3.1.1 This criterion supplements the stability criteria given in [2.1] for yachts of a length L_{LL} greater than 24 m. The more stringent criteria of [2.1] and the weather criterion are to govern the minimum requirements.

3.1.2 Tab 1 can be used for the correspondence between Beaufort scale and wind pressure.

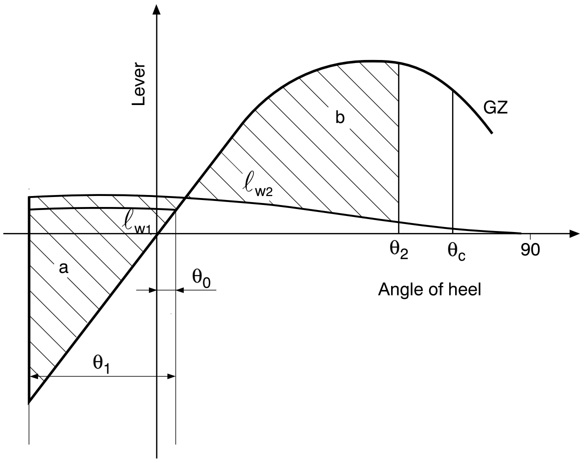
3.2 Weather criterion for motor yachts and sailing yachts with lowered sails

3.2.1 Assumptions

The ability of a yacht to withstand the combined effects of beam wind and rolling is to be demonstrated for each standard condition of loading, with reference to Fig 1 as follows:

- the yacht is subjected to a steady wind pressure acting perpendicular to the yacht's centreline which results in a steady wind heeling lever (ℓ_{w1})

Figure 1 : Severe wind and rolling



- from the resultant angle of equilibrium (θ_0), the yacht is assumed to roll owing to wave action to an angle of roll (θ_1) to windward
- the yacht is then subjected to a gust wind pressure which results in a gust wind heeling lever (ℓ_{w2})
- free surface effects, as described in [4], are to be accounted for in the standard conditions of loading as set out in Ch 3, App 2, [1.2].

3.2.2 Criteria

Under the assumptions of [3.2.1], the following criteria are to be complied with:

- the area "b" is to be equal to or greater than area "a", where:

  a : area above the GZ curve and below ℓ_{w2}, between θ_R and the intersection of ℓ_{w2} with the GZ curve

  b : area above the heeling lever ℓ_{w2} and below the GZ curve, between the intersection of ℓ_{w2} with the GZ curve and θ_2

- the angle of heel under action of steady wind (θ_0) is to be limited to 16° or 80% of the angle of deck edge immersion, whichever is less.

3.2.3 Heeling levers

The wind heeling levers ℓ_{w1} and ℓ_{w2}, in m, referred to in [3.2.2], should vary as the square cosine function of the yacht heel and should be calculated as follows:

$$\ell_{W1} = \frac{PAZ}{1000 g \Delta}$$

and

$\ell_{W2} = 1{,}5 \ell_{W1}$

where:

P : Is according to Tab 2

A : Projected lateral area in m², of the portion of the yacht above the waterline

Z : Vertical distance in m, from the centre of A to the centre of the underwater lateral area or approximately to a point at one half the draught

Δ : Displacement in t.

g = 9,81 m/s²

Table 1 : Beaufort scale

Beaufort	Wind pressure, in N/m²
4	19 - 41
5	42 - 71
6	72 - 118
7	119 - 177
8	178 - 255
9	256 - 363
10	364 - 491
11	492 - 648

Table 2 : Wind pressure

	$L_{LL} \leq 70$ m	$L_{LL} > 70$ m
Unrestricted navigation	reduced pressure according to [3.2.4]	504 N/m²
Restricted navigation	reduced pressure according to [3.2.4]	reduced pressure subject to the agreement of the Administration

3.2.4 Calculation of the wind pressure

For yachts with a length equal or lesser than 70 m, the wind pressure P, in t/m², is to be calculated according to the following formulae:

$$P = 0{,}0514 \left(\frac{Z - T}{10} \right)^{1/3}$$

where :

Z : Vertical distance in m, from the centre of A to the centre of the underwater lateral area or approximately to a point at one half the draught

T : Mean moulded draught in m, of the yacht.

3.2.5 Angles of heel

For the purpose of calculating the criteria of [3.2.2], the angles in Fig 1 are defined as follows:

θ_0 : Angle of heel, in degrees, under action of steady wind

θ_1 : Angle of roll, in degress, to windward due to wave action, calculated as follows:

$$\theta_1 = 109 k X_1 X_2 \sqrt{rs}$$

θ_2 : Angle of downflooding θ_f in degrees, or 50° or θ_c , whichever is less

θ_f : Angle of heel in degrees, at which openings in the hull, superstructures or deckhouses which cannot be closed weathertight immerse. Small openings though which progressive flooding cannot take place need not be considered as open (see Ch 3, App 2, [1.3.3])

θ_c : Angle in degrees, of second intercept between wind heeling lever ℓ_{w2} and GZ curves

$\theta_R = \theta_0 - \theta_1$

X_1 : Coefficient defined in Tab 3

X_2 : Coefficient defined in Tab 4

k : Coefficient equal to:

k = 1,0 for a round-bilged yacht having no bilge or bar keels

k = 0,7 for a yacht having sharp bilge

for a yacht having bilge keels, a bar keel or both, k is defined in Tab 3

OG : Distance in m, between the centre of gravity and the waterline (positive if centre of gravity is above the waterline, negative if it is below)

T_1 : Mean moulded draught in m, of the yacht

$r = 0,73 \pm 0,6\ (OG)/T_1$

s : Factor defined in Tab 4.

Note 1: The angle of roll θ_1 for yachts with anti-rolling devices is to be determined without taking into account the operations of these devices.

Note 2: The angle of roll θ_1 may be obtained, in lieu of the above formula, from model tests or full scale measurements.

The rolling period T_R, in s, is calculated as follows:

$$T_R = \frac{2CB}{\sqrt{GM}}$$

where:

$$C = 0,373 + 0,023\frac{B}{T_1} - 0,043\frac{L_W}{100}$$

The symbols in the tables and formula for the rolling period are defined as follows:

L_W : Length in m, of the yacht at the waterline

T_1 : Mean moulded draught in m, of the yacht

A_K : Total overall area in m² of bilge keels, or area of the lateral projection of the bar keel, or sum of these areas, or area of the lateral projection of any hull appendages generating added mass during yacht roll

GM : Metacentric height in m, corrected for free surface effect.

Intermediate values are to be obtained by linear interpolation from values given in Tab 3 to Tab 4.

3.3 Weather criterion for sailing yachts

3.3.1 For all the operational loading conditions of Ch 3, App 2, [1.2], the wind moment based on the three sailing combinations as described in [3.3.2], has to be calculated according to [3.3.4]. Each condition has to comply with the criteria listed in [3.3.5].

3.3.2 The three sailing combinations which have to be investigated are:

- full sails
- intermediate sails
- reduced sails.

3.3.3 The wind force should be calculated as follows:

$F = 1/2\ C_s\ \rho\ A\ V^2$

Table 3 : Values of coefficient X_1

B/T_1	X_1
≤ 2,4	1,00
2,5	0,98
2,6	0,96
2,7	0,95
2,8	0,93
2,9	0,91
3,0	0,90
3,1	0,88
3,2	0,86
3,4	0,82
≥ 3,5	0,80

Table 4 : Values of coefficient X_2

C_B	X_2
≤ 0,45	0,75
0,50	0,82
0,55	0,89
0,60	0,95
0,65	0,97
≥ 0,70	1,00

Table 5 : Values of coefficient k

$\frac{A_K \times 100}{L \times B}$	k
0,0	1,00
1,0	0,98
1,5	0,95
2,0	0,88
2,5	0,79
3,0	0,74
3,5	0,72
≥ 4,0	0,70

Table 6 : Values of factor s

T_R	s
≤ 6	0,100
7	0,098
8	0,093
12	0,065
14	0,053
16	0,044
18	0,038
≥ 20	0,035

where:

F : Wind force, in N

C_s : Shape coefficient. Without specific available data, this coefficient has to be taken equal to 1,1

ρ : Air mass density, equal to 1,222 kg/m^3

A : Projected area of all the exposed surfaces, in square metres

V : Maximum wind speed, in m/s, for which the yacht is able to operate for each specific combination of sails as described in [3.3.2].

3.3.4 The wind moment is the force F as calculated in [3.3.3], multiplied by the heeling lever Z. The heeling lever Z is the vertical distance in m, from the centre of A to the centre of the underwater lateral area or approximately to a point at one half the draught.

The wind heeling lever is calculated as follows:

$\lambda = \lambda(0)\ (\cos\theta)^2$

where λ(0) is the wind heeling lever at 0°.

3.3.5 Criteria

Under the assumptions of [3.3.4], the following criteria are to be complied with:

- the metacentric height corrected by the free surface effects, has to be greater or equal to 0,30 m
- the angle of the static heel due to the effect of wind has to be limited to 20° or 90% of the immersion of the deck, whichever is less
- the rigthing lever GZ is to be at least 0,50 m at an angle of heel equal to or greater than 50°
- the area above the wind heeling lever λ and below the GZ curve, between the angle of static wind heel and the downflooding angle, has to be at least equal to 0.065 mrd.

4 Effects of free surfaces of liquids in tanks

4.1 General

4.1.1 For all loading conditions, the initial metacentric height and the righting lever curve are to be corrected for the effect of free surfaces of liquids in tanks.

4.2 Consideration of free surface effects

4.2.1 Free surface effects are to be considered whenever the filling level in a tank is equal or less than 98% of full condition. Free surface effects need not be considered where a tank is nominally full, i.e. filling level is above 98%. Nevertheless, in order to take into account the consumption of consumable just after departure, the requirement of [4.2.2] has to be considered.

4.2.2 In calculating the free surfaces effect in tanks containing consumable liquids, it is to be assumed that for each type of liquid at least one transverse pair or a single centreline tank has a free surface and the tank or combination of tanks taken into account are to be those where the effect of free surface is the greatest.

4.3 Water ballast tanks

4.3.1 Where water ballast tanks are to be filled or discharged during the course of a voyage, the free surfaces effect is to be calculated to take account of the most onerous transitory stage relating to such operations.

4.4 GM_0 and GZ curve corrections

4.4.1 The corrections to the initial metacentric height and to the righting lever curve are to be addressed separately as indicated in [4.7.2] and [4.7.3].

4.4.2 In determining the correction to the initial metacentric height, the transverse moments of inertia of the tanks are to be calculated at 0 degrees angle of heel.

4.4.3 The righting lever curve may be corrected by any of the following methods:

- correction based on the actual moment of fluid transfer for each angle of heel calculated
- correction based on the moment of inertia, calculated at 0 degrees angle of heel, modified at each angle of heel calculated.

4.4.4 Whichever method is selected for correcting the righting lever curve, only that method is to be presented in the yacht’s trim and stability booklet. However, where an alternative method is described for use in manually calculated loading conditions, an explanation of the differences which may be found in the results, as well as an example correction for each alternative, are to be included.

4.5 Remainder of liquid

4.5.1 The usual remainder of liquids in the empty tanks need not be taken into account in calculating the corrections, providing the total of such residual liquids does not constitute a significant free surface effect.

5 Icing

5.1 Application

5.1.1 For any yacht operating in areas where ice accretion is likely to occur, adversely affecting a yacht's stability, attention is to be paid to the effect of the ice. The Society reserves its right to request additional calculations on a case by case basis.

SECTION 3 DAMAGE STABILITY

1 General

1.1 Application

1.1.1 The damage stability requirements of this Section are to be applied to yachts having a classification notation **unrestricted navigation** and a length L_{LL} greater than 24 m.

Yachts having the navigation notation **unrestricted navigation limited to 60 nautical miles** as defined in Pt A, Ch 1, Sec 2 may be exempted from damage stability requirements.

2 Assumptions

2.1 Description of the damage

2.1.1 Standard of damage

The damage should occur anywhere along the yacht's length except in way of a watertight bulkhead.

2.1.2 Extent of damage

A circular damage of 1,0 m along the side shell has to be considered from the baseline up to the level of the waterline.

2.2 Method of calculation

2.2.1 Lost buoyancy method

The damage stability calculations have to be performed using the lost buoyancy method (constant displacement).

2.3 Permeabilities

2.3.1 General

For the purpose of the damage stability calculations, the following permeabilities have to be considered:

- 0,95: accomodation or voids
- 0,85: machinery
- 0,60: stores
- 0 or 0,95: for liquids, whichever results in the more se vere requirements.

2.4 Inclining moment

2.4.1 The moment due to the wind pressure should be considered as follows:

- a wind pressure of 120 N/m^2 is to be applied
- the area applicable is to be the projected lateral area of the yacht above the waterline corresponding to the intact condition

  For sailing yachts, the sails should be considered lowered
- the moment arm is to be the vertical distance from a point at one half of the mean draught corresponding to the intact condition to the centre of gravity of the lateral area.

2.5 Damage stability criteria

2.5.1 The following damage stability criteria have to be complied with:

a) in the case of symmetrical flooding due to compartment arrangement, a positive residual metacentric height is to be at least 50 mm as calculated by the constant displacement method

b) in the case of unsymmetrical flooding, the angle of heel is not to exceed 7°. For multihull yacht, an angle of heel up to 10° may be accepted

c) the deck line should not be submerged at the equilibrium

d) the minimum range of the positive residual righting lever curve is to be at least 15° beyond the angle of equilibrium

e) the area under the righting lever curve is to be at least 0,015 m.rd measured from the angle of equilibrium to the lesser of the angle at which progressive flooding occurs, and 22° measured from upright

f) a residual righting lever is to be obtained within the range of positive stability taking into account the heeling moment due the wing pressure, as calculated by the formula:

$$GZ = \frac{Hw}{D} + 0,04$$

where:

H_w : Wind heeling moment as calculated in [2.4.1], in t.m

D : Displacement, in t

GZ : Righting lever, in m.

However, in no case is this righting lever to be less than 0,1 m.

APPENDIX 1 INCLINING EXPERIMENT AND WEIGHING TEST

1 Inclining experiment and lightweight check

1.1 General

1.1.1 The procedure from [1.1.3] to [1.1.8] are to be applied. For multihull or sailing yachts, the procedure from [1.1.2] to [1.1.7] are to be applied. The requirements of [1.1.8] will be examined on a case by case basis. As an alternative to [1.1.8], a detailed list of the weights and their centre of gravity has to be submitted to the Society.

Prior to the experiment, the procedure of the inclining experiment has to be submitted to the Society, for examination.

The report of the inclining experiment has to be signed by the attending Society's Surveyor, in order to confirm all the input data such as density of sea water, draught readings, deflection of the pendulum.

1.1.2 General conditions of the yacht

The Society's Surveyor is to be satisfied of the following:

- the weather conditions are to be favorable
- the yacht is to be moored in a quiet, sheltered area free from extraneous forces, such as to allow unrestricted heeling. The yacht is to be positioned in order to minimize the effects of possible wind, stream and tide
- the yacht is to be transversely upright and the trim is to be taken not more than 1% of the length between perpendiculars. Otherwise, hydrostatic data and sounding tables are to be available for the actual trim
- lifesaving appliances capable of inducing oscillations are to be secured
- the system containing liquids such as pipes, are to be filled
- the bilge and the decks are to be thoroughly dried
- preferably, all tanks are to be empty and clean, or completely full. The number of tanks containing liquids is to be reduced to a minimum taking into account the above-mentioned trim. In particular the filling of slack tanks is to be less than 80% to avoid any influence of structural elements. The shape of the tank is to be such that the free surface effect can be accurately determined and remain almost constant during the experiment. All cross connections are to be closed
- the weights necessary for the inclination are to be already on board, located in the correct place
- all work on board is to be suspended and crew or personnel not directly involved in the inclining experiment is to leave the yacht
- the yacht is to be as complete as possible at the time of the experiment. The number of weights to be removed added or shifted is to be limited to a minimum. Temporary material, tool boxes, staging, sand, debris, etc., on board is to be reduced to an absolute minimum
- lifting keels have to be located on the highest position. Canting keels have to be upright and cannot be used as shifting weights.

1.1.3 Inclining weights

The total weight should be sufficient to provide a minimum inclination of two degrees and a maximum of four degrees of heel to each side. However, a minimum inclination of one degree to each side may be accepted for sailing yachts or multihulls provided that the requirement on pendulum deflection or U-tube difference in height specified in [1.1.4] is complied with. Test weights are to be compact and of such a configuration that the VCG (vertical centre of gravity) of the weights can be accurately determined. Each weight is to be marked with an identification number and its weight. Re-certification of the test weights is to be carried out prior to the incline. A crane of sufficient capacity and reach, or some other means, is to be available during the inclining experiment to shift weights on the deck in an expeditious and safe manner. If the yacht has water ballast tanks, water ballast cannot be used as inclining weight.

1.1.4 Pendulums

The use of two pendulums is requested to allow identification of bad readings at any one pendulum station. However, for yachts of a length equal to or less than 30 m, only one pendulum can be accepted. They are each to be located in an area protected from the wind. The pendulums are to be long enough to give a measured deflection, to each side of upright, of at least 10 cm. To ensure recordings from individual instruments are kept separate, it is suggested that the pendulums be physically located as far apart as practical.

The use of an inclinometer or U-tube is to be considered in each separate case. It is recommended that inclinometers or other measuring devices only be used in conjunction with at least one pendulum.

1.1.5 Means of communications

Efficient two-way communications may be provided between central control and the weight handlers, and between central control and each pendulum station. One person at a central control station is to have complete control over all personnel involved in the experiment. The internal means of communication inside the yacht may be used for this purpose.

1.1.6 Documentation

The person in charge of the inclining experiment is to have available a copy of the following plans at the time of the experiment:

- hydrostatic curves or hydrostatic data
- general arrangement plan of decks, holds, inner bottoms, etc.
- capacity plan showing capacities and vertical and longitudinal centres of gravity of cargo spaces, tanks, etc.
- tank sounding tables
- draught mark locations
- docking drawing with keel profile and draught mark corrections (if available).

1.1.7 Determination of the displacement

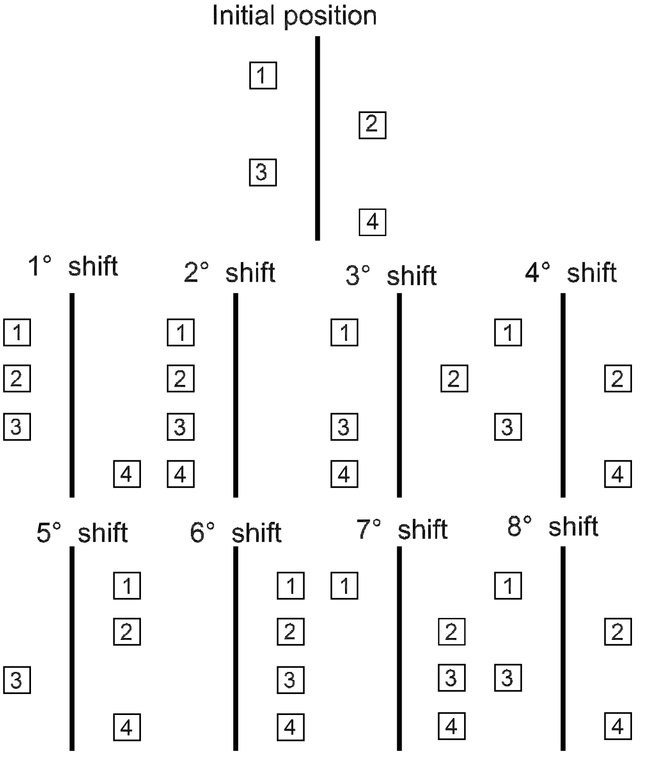
The Society's Surveyor is to carry out all the operations necessary for the accurate evaluation of the displacement of the yacht at the time of the inclining experiment, as listed below:

- draught mark readings are to be taken at aft and forward, at starboard and port sides.These draughts are also to be taken at midship, as far as practicable
- the mean draught (average of port and starboard readings) is to be calculated for each of the locations where draught readings are taken and plotted on the yacht's lines drawing or outboard profile to ensure that all readings are consistent and together define the correct waterline. The resulting plot is to yield either a straight line or a waterline which is either hogged or sagged. If inconsistent readings are obtained, the freeboards/draughts are to be retaken
- the specific gravity of the sea water is to be determined. Samples are to be taken from a sufficient depth of the water to ensure a true representation of the sea water and not merely surface water, which could contain fresh water from run off of rain. A hydrometer is to be placed in a water sample and the specific gravity read and recorded. Where the value of the average calculated specific gravity is different from that reported in the hydrostatic curves, adequate corrections are to be made to the displacement curve
- all double bottoms, as well as all tanks and compartments which can contain liquids, are to be checked, paying particular attention to air pockets which may accumulate due to the yacht's trim and the position of air pipes, and also taking into account the provisions of [1.1.2]
- the possible solid permanent ballast is to be clearly identified and listed in the report
- the yacht should be as upright as possible and have sufficient draught so that any abrupt changes in the waterplane will be avoided as the yacht is inclined from side to side. A deviation from design trim of up to 1% of L_{LL} is normally acceptable when using hydrostatic data calculated at design trim. Otherwise, the hydrostatic data should be calculated for the actual trim. With inclining weights in the initial position, up to one-half degree of list is acceptable.

1.1.8 The incline

The standard experiment generally employs eight distinct weight movements as shown in Fig 1.

Figure 1 : Weight shift procedure



The weights are to be transversally shifted, so as not to modify the yacht's trim and the vertical position of the centre of gravity.

After each weight shifting, the new position of the transverse centre of gravity of the weights is to be accurately determined.

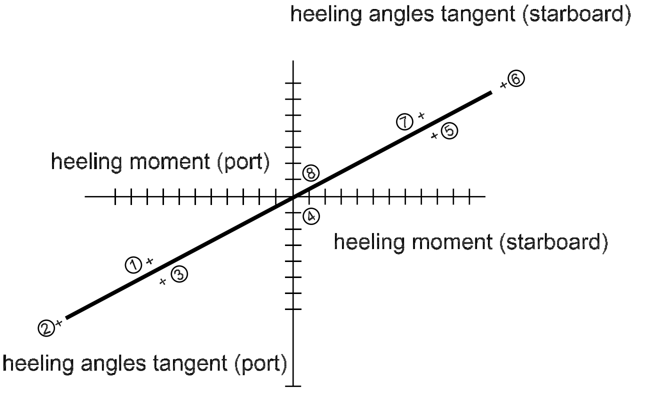
After each weight movement, the distance the weight was moved (centre to centre) is to be measured and the heeling moment calculated, multiplying the distance by the amount of weight moved. The tangent is calculated for each pendulum, dividing the deflection by the length of the pendulum. The resultant tangents are plotted on the graph as shown in Fig 2.

The pendulum deflection is to be read when the yacht has reached a final position after each weight shifting.

During the reading, no movement of personnel is allowed.

For yachts with a length equal to or less than 30 m, six distinct weight movements may be accepted.

Figure 2 : Graph of resultant tangents



APPENDIX 2 TRIM AND STABILITY BOOKLET

1 Trim and stability booklet

1.1 Information to be included in the trim and stability booklet

1.1.1 General

A trim and stability booklet is a stability manual, to be approved by the Society, which is to contain sufficient information to enable the Captain to operate the yacht in compliance with the applicable requirements contained in the Rules.

The format of the stability booklet and the information included vary depending on the yacht type and operation.

1.1.2 List of information

The following information is to be included in the trim and stability booklet:

- a general description of the yacht, including:
  - the yacht's name and the Society classification number
  - the yacht type and service notation
  - the class notations
  - the yard, the hull number and the year of delivery
  - the moulded dimensions
  - the draught corresponding to the summer load line (defined in Ch 1, Sec 2, [3.7]
  - the displacement corresponding to the above-mentioned draught
- clear instructions on the use of the booklet
- general arrangement and capacity plans indicating the assigned use of compartments and spaces (stores, accommodation, etc.)
- a sketch indicating the position of the draught marks referred to the yacht's perpendiculars
- hydrostatic curves or tables corresponding to the design trim, and, if significant trim angles are foreseen during the normal operation of the yacht, curves or tables corresponding to such range of trim are to be introduced. A clear reference relevant to the sea density, in t/m^3, is to be included as well as the draught measure (from keel or underkeel)
- cross curves (or tables) of stability calculated on a free trimming basis, for the ranges of displacement and trim anticipated in normal operating conditions, with indication of the volumes which have been considered in the computation of these curves
- tank sounding tables or curves showing capacities, centres of gravity, and free surface data for each tank
- lightship data from the inclining experiment, as indicated in Ch 3, Sec 1, [2], including lightship displacement, centre of gravity co-ordinates, place and date of the inclining experiment, as well as the Society approval details specified in the inclining experiment report. It is suggested that a copy of the approved experiment report be included

  Where the above-mentioned information is derived from a sister ship, the reference to this sister ship is to be clearly indicated, and a copy of the approved inclining experiment report relevant to this sister ship is to be included
- standard loading conditions as indicated in [1.2] and examples for developing other acceptable loading conditions using the information contained in the booklet
- intact stability results (total displacement and its centre of gravity co-ordinates, draughts at perpendiculars, GM, GM corrected for free surfaces effect, GZ values and curve, criteria as indicated in Ch 3, Sec 2, reporting a comparison between the actual and the required values) are to be available for each of the above-mentioned operating conditions. The method and assumptions to be followed in the stability curve calculation are specified in [1.3]
- damage stability results (total displacement and its maximum permissible centre of gravity height, draughts at perpendiculars, GM, GM corrected for free surfaces effect, GZ values and curve, criteria as indicated in Ch 3, Sec 3, reporting a comparison between the actual and the required values) are to be available for each of the above-mentioned operating conditions. The method and assumptions to be followed in the stability curve calculation are specified in [1.3]
- maximum KG or minimum GM curve or table which can be used to determine compliance with the applicable intact and damage stability criteria when applicable
- information about openings (location, tightness, means of closure), pipes or other progressive flooding sources. the opening used for the calculation of the down flooding angle has to be clearly identified
- information concerning the use of any special cross-flooding fittings with descriptions of damage conditions which may require cross-flooding, when applicable
- any other necessary guidance for the safe operation of the yacht, in particular, limitations regarding maximum allowable wind pressure as calculated in Ch 3, Sec 2, [3]
- a table of contents and index for each booklet.

1.2 Loading conditions

1.2.1 The standard following loading conditions are to be included in the trim and stability booklet:

- yacht in the fully loaded departure condition with full stores and fuel and with full number of passengers with their luggage
- yacht in the fully loaded arrival condition, with full number of passengers and their luggage but with only 10% stores and fuel remaining.

1.3 Stability curve calculation

1.3.1 General

Hydrostatic and stability curves are normally prepared on a designed trim basis. However, where the operating trim or the form and arrangement of the yacht are such that change in trim has an appreciable effect on righting arms, such change in trim is to be taken into account.

1.3.2 Superstructures, deckhouses, etc. which may be taken into account

Enclosed superstructures complying with Ch 1, Sec 2 may be taken into account.

1.3.3 Angle of flooding

In cases where the yacht would sink due to flooding through any openings, the stability curve is to be cut short at the corresponding angle of flooding and the yacht is to be considered to have entirely lost its stability.

Small openings such as those for passing wires or chains, tackle and anchors, and also holes of scuppers, discharge and sanitary pipes are not to be considered as open if they submerge at an angle of inclination more than 30°. If they submerge at an angle of 30° or less, these openings are to be assumed open if the Society considers this to be a source of significant progressive flooding; therefore such openings are to be considered on a case by case basis.

SECTION 1 DESIGN REVIEW FLOW CHART

1 General

1.1 Design review process

1.1.1 Typical chronological steps of the design review aiming at assessing the scantlings of yachts structure against the Rules are given in Tab 1.

Table 1 : Structure design review steps

Steps		Sub-steps	Calculation	BV software	Rules references
1	MATERIALS	Steel	Admissible stresses (local stress and overall stresses)		Ch 4, Sec 3
		Aluminium	Mechanical characteristics in welded conditions		Rule Note NR216 Materials and Welding Ch 4, Sec 3
			Admissible stresses (local stress and overall stresses)		Ch 4, Sec 3
		Composites	Elastic characteristics of single layers	see Ch 1, Sec 4	Ch 12, Sec 3
			Elastic characteristics of laminates	see Ch 1, Sec 4	Ch 12, Sec 4
			Safety factors		Ch 4, Sec 3
2	OVERALL GLOBAL LOADS	Wave global loads	In hogging and sagging conditions		Ch 6, Sec 2
		Still water bending moment			Ch 6, Sec 2
		Rig global loads (if relevant)			Ch 6, Sec 3
		Combination of global loads			Ch 6, Sec 4
3	GLOBAL STRENGTH	Transverse sections geometrical characteristics	Global stresses	see Ch 1, Sec 4	Ch 8, Sec 2 **(1)** Ch 8, Sec 3 **(1)** Ch 8, Sec 4 **(1)** Ch 9, Sec 2 **(2)** Ch 9, Sec 3 **(2)** Ch 9, Sec 4 **(2)**
			Buckling check of members contributing to global strength		
4	LOCAL LOADS	Hydrodynamic loads	Loading on bottom, side, decks		Ch 7, Sec 1
		Slamming loads	Loading on bottom of fast motor yacht and monohull sailing yachts		Ch 7, Sec 2
		Impact pressure	Loading on side shells Loading on underside of catamaran cross deck		Ch 7, Sec 1

(1) for steel and aluminium structure
(2) for composites structures
(3) for steering gear, refer to Pt C, Ch 1, Sec 3

Steps		Sub-steps	Calculation	BV software	Rules references
5	STRUCTURE SCANTLINGS	Platings			Ch 8, Sec 3 **(1)** Ch 9, Sec 3 **(2)**
		Secondary stiffeners			Ch 8, Sec 4 **(1)** Ch 9, Sec 4 **(2)**
		Primary supporting members			Ch 8, Sec 4 **(1)** Ch 9, Sec 4 **(2)**
		Pillars			Ch 8, Sec 10 **(1)** Ch 9, Sec 10 **(2)**
6	WATERTIGHT TRANSVERSE BULKHEADS	Number and locations			Ch 2, Sec 1
		Sea design pressure and admissible stresses.			Ch 7, Sec 1 Ch 4, Sec 3
		Platings and stiffeners			Ch 8, Sec 8 **(1)** Ch 9, Sec 8 **(2)**
7	SUPERSTRUCTURES	Local sea pressure and minimum pressure			Ch 7, Sec 1
		Platings and stiffeners			Ch 8, Sec 9 **(1)** Ch 9, Sec 9 **(2)**
		Doors, windows, height of sills			Ch 2, Sec 2
8	ADDITIONAL CALCULATIONS	Anchors and chains	Equipment number		Ch 10, Sec 1
		Rudder, rudder stock, steering gear **(3)**			Ch 10, Sec 2 Ch 10, Sec 3
		Shaft brackets			Ch 10, Sec 4
		Independent tanks			Ch 10, Sec 5
		Chain plates for sailing yachts standing rigging			Ch 10, Sec 6
		Solid keel for sailing yacht			Ch 10, Sec 7

(1) for steel and aluminium structure
(2) for composites structures
(3) for steering gear, refer to Pt C, Ch 1, Sec 3

SECTION 2 DESIGN LOADS

1 Definitions

1.1 Local loads

1.1.1 Local loads are pressures or forces which are directly applied to the individual structural members such as plating panels, ordinary stiffeners and primary supporting members.

1.1.2 Local loads considered in the present Rules are:

- still water local loads, constituted by the hydrostatic external sea pressures and hull weight distribution
- wave local loads, constituted by the external sea pressures due to waves and the inertial pressures and forces induced by the ship accelerations
- dynamic local loads, constituted by the slamming pressures on the bottom hull (induced by the vertical ship motions) and by impact pressure on the side shell (induced by sea impact on the hull)
- punctual loads, constituted by localized efforts exerted on ship's structure, such as, e.g., loads induced by standing rigging and main sail sheet.

1.1.3 Test loads are local loads constituted by pressures exerted during hydrostatic tests of spaces intended to carry liquids.

1.2 Hull girder loads

1.2.1 Hull girder loads (still water, wave and dynamic) are forces and moments which result as effects of local loads acting on the ship as a whole and considered as a beam.

1.2.2 Hull girder loads considered in the present Rules are:

- still water hull girder loads, resulting from the effect difference in downwards ship weights and upwards buoyancy forces throughout the length of the ship
- wave hull girder loads, induced by the added or substracted buoyancy forces along the float induced by incident waves on the float
- rigging induced global, constitued by all the loads exerted by the standing rigging on the float.

2 Application criteria

2.1 Fields of application

2.1.1 The wave induced and dynamic loads defined in this Chapter corresponds to an operating life of the ship equal to 20 years.

2.1.2 The still water, wave induced and dynamic loads defined in this Chapter are to be used for the determination of the hull girder strength and structural scantlings. These loads are not to be amplified by any safety factor, such safety factor being included in admissible stress levels given in Ch 4, Sec 3.

3 Navigation coefficients

3.1 General

3.1.1 Navigation coefficients depending on navigation notation defined in Pt A, Ch 1, Sec 2 are given in Tab 1.

3.1.2 In scope of application of the present Rules for specific purposes (e.g. evaluation of conformity in scope of EC directive for recreational craft), navigation coefficients depending on navigation may be taken into account.

Such coefficients are given in Tab 1.

Table 1 : Navigation coefficients

Navigation notation	Navigation coefficient n
Unrestricted navigation Design category A and B (EC Directive)	1,00
Coastal area Design category C (EC Directive)	0,90
Sheltered area Design category D (EC Directive)	0,80

SECTION 3 ADMISSIBLE STRESSES

Symbols

SF : Safety factor

$R_{p0,2}$: Minimum guaranteed yield stress, in N/mm^2

R_m : Minimum breaking tensile strength, in N/mm^2.

σ_{VM} : Combined stress calculated according to Von Mises criteria for steel or aluminium structures, and according to Tsaï-Wu criteria in case of composites structures.

1 General

1.1 Characteristics of materials

1.1.1 Steel and aluminium

The characteristics of the materials to be used in the construction of ships are to comply with the applicable requirements of Rule Note NR216 Materials and Welding.

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

1.1.2 Composites

The mechanical characteristics of a given laminate are deduced from the theoretical breaking strength of the elementary layer (reinforcements and resins), as given in [5].

1.2 Admissible stresses

1.2.1 The admissible stress levels are depending on type of loads.

1.2.2 The admissible stress values are given with reference made to:

- yield stress for steel and aluminium materials
- breaking strength for composites materials.

1.2.3 The structure scantlings safety coefficients are taking into account the admissible stress values.

2 Types of stress

2.1 General

2.1.1 As a rule, the notations used for the stresses are:

σ : Bending stress, compression or tensile stress

τ : Shear stress.

2.1.2 Following index are used depending of types of stress considered in the present Rules:

σ_{am}, τ_{am} : Design admissible values of stresses, as defined in the present Chapter

σ_{gl} , τ_{gl} : Stresses resulting from global loads as defined in Part B, Chapter 6

σ_{loc}, τ_{loc} : Stresses resulting from local loads as defined in Part B, Chapter 7

3 Steel structures

3.1 Material factor k

3.1.1 General

Unless otherwise specified, the material factor k has the values defined in Tab 1, as a function of the minimum guaranteed yield stress $R_{p0,2}$.

For intermediate values of $R_{p0,2}$, factor k may be obtained by linear interpolation.

Steels with a yield stress lower than 235 N/mm^2 or greater than 390 N/mm^2 are considered by the Society on a case by case basis.

Table 1 : Material factor k

$R_{p0,2}$, in N/mm^2	k
235	1,00
315	0,78
355	0,72
390	0,68

3.2 Admissible stresses

3.2.1 The admissible stresses are calculated on basis of the yield stress value corresponding to ordinary steel and of material factor k, as indicated in Tab 2.

3.2.2 The admissible stress values to be considered for specific component of the structure may be taken different from the values given in Tab 2. In such a case, the admissible stress values to be considered are indicated in the dedicated parts of the present Rules, dealing with the specific component under consideration.

4 Aluminium alloys for hull structure

4.1 Influence of welding on mechanical characteristics

4.1.1 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 0 or H111) or by heat treatment (series 6000), where:

Table 2 : Admissible stresses for steel structures

Type of stress considered	Structural component considered	Design admissible stress (N/mm^2)
Global stress induced by longitudinal hull girder loads **(1) (2)**	Plating	$\sigma_{glam} = 0,50 \cdot 235 / k$
		$\tau_{glam} = 0,40 \cdot 235 / k$
	Stiffeners	$\sigma_{glam} = 0,50 \cdot 235 / k$
		$\tau_{glam} = 0,40 \cdot 235 / k$
	Safety factor for buckling - plating and stiffeners	SF = 1,8
Local stress induced by local hydrodynamic loads **(1) (2)**	Plating	$\sigma_{locam} = 0,70 \cdot 235 / k$
	Stiffeners	$\sigma_{locam} = 0,65 \cdot 235 / k$
		$\tau_{locam} = 0,40 \cdot 235 / k$
	Safety factor for buckling - plating and stiffeners	SF = 1,8
	Von Mises stress	$\sigma_{VMam} = 0,80 \cdot 235 / k$
Local stress induced by slamming loads on bottom or by impact pressure on side shells **(2)**	Plating	$\sigma_{locam} = 0,75 \cdot 235 / k$
	Stiffeners	$\sigma_{locam} = 0,70 \cdot 235 / k$
		$\tau_{locam} = 0,45 \cdot 235 / k$
Local stress induced by tank testing loads or by exceptional damage loads **(2)**	Plating	$\sigma_{locam} = 0,80 \cdot 235 / k$
	Stiffeners	$\sigma_{locam} = 0,80 \cdot 235 / k$
		$\tau_{locam} = 0,45 \cdot 235 / k$

(1) Admissible stress values indicated in this Table may be increased by 10% when a Finite Element Calculation is submitted to the Society.
(2) Admissible stress values indicated in this Table may be increased by 10% where stainless steels are used.

$R_{p0,2}$: Guaranteed yield stress of the parent metal in delivery condition, in N/mm^2, as indicated by the supplier

R_m : Guaranteed tensile strength of the parent metal in delivery condition, in N/mm^2, as indicated by the supplier.

4.1.2 Consequently, where necessary, a drop in the mechanical characteristics of welded structures with respect to those of the parent material is to be considered in the heat-affected zone.

The heat-affected zone may be taken to extend 25 mm on each side of the weld axis.

4.1.3 Aluminium alloys of series 5000 in 0 condition (annealed) or in H111 condition (annealed flattened) are not subject to a drop in mechanical strength in the welded areas.

4.1.4 Aluminium alloys of series 5000 other than condition 0 or H111 are subject to a drop in mechanical strength in the welded areas.

The mechanical characteristics to consider are normally those of condition 0 or H111.

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

4.1.5 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 are normally indicated by the supplier.

When no information is provided by the supplier, the values of Tab 3 may be used.

**Table 3 : Aluminium alloys
As welded mechanical characteristics**

Aluminium alloy	Temper condition	$R'_{p0,2}$ **(1)**	R'_m **(1)**
5000 serie	0 or H111	$R_{p0,2}$	R_m
5000 serie	Other	Values of 0 or H111 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
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	0,45 $R_{p0,2}$	0,6 R_m
6060 (Sections) **(2)**	T5	0,60 $R_{p0,2}$	0,6 R_m

(1) $R_{p0,2}$ and R_m are defined in [4.1.1].
(2) 6060 alloy is mentioned therein, as it may be proposed by suppliers. However, this aluminium alloy is not accepted for yachts structure according to the present Rules, as it is not to suited to support slamming and impact loads and generally delivered without minimum mechanical characteristics guaranteed by the supplier.

4.2 Extruded plating

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

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

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

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

4.3 Material factor k

4.3.1 The material factor k for aluminium alloys is to be obtained from the following formula:

$$k = \frac{100}{R'_{lim}}$$

where:

- R'_{lim} : Minimum of $R'_{p0,2}$ and $0,7 \cdot R'_m$, in N/mm²
- $R'_{p0,2}$: Minimum guaranteed yield stress of the parent metal in welded condition, in N/mm², determined according to [4.1.4] and [4.1.5]
- R'_m : Minimum guaranteed tensile strength of the parent metal in welded condition, in N/mm², determined according to [4.1.4] and [4.1.5].

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

4.4 Admissible stresses

4.4.1 The admissible stress values are calculated according to Tab 4.

4.4.2 The admissible stress values to be considered for specific component of the structure may be taken different from the values given in Tab 4. In such a case, the admissible stress values to be considered are indicated in the dedicated parts of the present Rules, dealing with the specific component under consideration.

5 Composites structures

5.1 General

5.1.1 In the present Rules, the design review of composites structures is based on safety coefficients applied on the theoretical breaking stresses of the elementary layers (resin systems, fibres and reinforcements) used for the full lay-up laminates.

5.1.2 The theoretical breaking stresses of elementary layers constituting the full lay-up laminate are to be determined as indicated in Ch 12, Sec 3, [5].

Theoretical breaking stresses of core materials used for sandwich laminates are given for general guidance in Ch 12, Sec 2, [4].

5.1.3 The safety factors SF in each elementary layer are defined as being the ratio between the considered theoretical breaking stresses as mentioned in [5.1.2] and the applied stresses.

Table 4 : Admissible stresses for aluminium structures

Type of stress considered	Structural component considered	Design admissible stress (N/mm²)
Global stress induced by longitudinal hull girder loads **(1)**	Plating	$\sigma_{glam} = 0,5 \ \ 100 / k$
		$\tau_{glam} = 0,45 \ \ 100 / k$
	Stiffeners	$\sigma_{glam} = 0,5 \ \ 100 / k$
		$\tau_{glam} = 0,45 \ \ 100 / k$
	Safety factor for buckling - plating and stiffeners	SF = 1,6
Local stress induced by local hydrodynamic loads **(1)**	Plating	$\sigma_{locam} = 0,75 \cdot 100 / k$
	Stiffeners	$\sigma_{locam} = 0,7 \ \ 100 / k$
		$\tau_{locam} = 0,45 \ \ 100 / k$
	Safety factor for buckling - plating and stiffeners	SF = 1,6
	Von Mises stress	$\sigma_{VMam} = 0,9 \ \ 100 / k$
Local stress induced by slamming loads on bottom or by impact pressure on side shells	Plating	$\sigma_{locam} = 0,8 \ \ 100 / k$
	Stiffeners	$\sigma_{locam} = 0,75 \ \ 100 / k$
		$\tau_{locam} = 0,5 \ \ 100 / k$
Local stress induced by tank testing loads or by exceptional damage loads	Plating	$\sigma_{locam} = 0,9 \ \ 100 / k$
	Stiffeners	$\sigma_{locam} = 0,9 \ \ 100 / k$
		$\tau_{locam} = 0,5 \ \ 100 / k$
(1) Admissible stress values indicated in above Table may be increased by 10% when a Finite Element Calculation is submitted to the Society.		

5.2 Types of stress in the elementary layer

5.2.1 Three stresses are considered corresponding to the loading mode of the fibres:

- Stress parallel to the fibre (longitudinal direction). These stresses may be tensile stresses or compressive stresses, and are mostly located as follows:
  - in 0° direction of unidirectional tape or fabric reinforcement systems
  - in 0° and 90° directions of woven roving

  In the present Rules, the corresponding notations are:
  - σ_{LFT} in case of tensile stress
  - σ_{LFC} in case of compressive stress
- Stress perpendicular to the fibre (transverse direction). These stresses may be tensile stresses or compressive stresses, and are mostly located as follows:
  - in 90° direction of unidirectional tape or combined fabrics when the set of fibres are stiched together without criss-crossing

  In the present Rules, the corresponding notations are:
  - σ_{TFT} in case of tensile stress
  - σ_{TFC} in case of compressive stress
- Shear stress parallel to the fibre. These shear stresses may be found in all type of reinforcement systems

  In the present Rules, the corresponding notation is $\tau_{F.}$

5.3 Breaking criteria

5.3.1 Three breaking criteria are used in the present Rules:

a) maximum stress criteria leading to the breaking of the component resin/fibre of one elementary layer of the full lay-up laminate

b) Tsaï Wu (or Hoffman) combined stress criteria with the hypothesis of in-plane stresses

c) critical buckling stress criteria.

The breaking criteria defined in a) and b) are to be checked for each individual layer.

The breaking criteria defined in c) is to be checked for the global laminate.

5.3.2 The Tsaï Wu (or Hoffman) combined stress criteria considered in the present Rules is defined as follows:

$$\left| \frac{\sigma_1{}^2}{\sigma_{br1,T} \cdot \sigma_{br1,C}} + \frac{\sigma_2{}^2}{\sigma_{br2,T} \cdot \sigma_{br2,C}} - \frac{\sigma_1 \sigma_2}{\sigma_{br1,T} \cdot \sigma_{br1,C}} + \frac{\sigma_{br1,C} - \sigma_{br1,T}}{\sigma_{br1,T} \cdot \sigma_{br1,C}} \sigma_1 + \frac{\sigma_{br2,C} - \sigma_{br2,T}}{\sigma_{br2,T} \cdot \sigma_{br2,C}} \sigma_2 + \frac{\tau_{12}{}^2}{\tau_{br12}{}^2} \right|^{-1/2} \geq SF_{CS}$$

where:

σ_1, σ_2, τ_{12}: Local stresses in the individual layer, in N/mm², expressed in local axis, as defined in Ch 12, Sec 4, [4.2.2]

$\sigma_{br1\ T}$, $\sigma_{br1\ C}$: Theoretical breaking stresses, in N/mm², respectively in traction and compressive, of the individual layer in the direction 1 of its local coordinate system, as defined in Ch 12, Sec 3, [5.2.1]

$\sigma_{br2\ T}$, $\sigma_{br2\ C}$: Theoretical breaking stresses, in N/mm², respectively in traction and compressive of the individual layer in the direction 2 of its local coordinate system as defined in Ch 12, Sec 3, [5.2.1]

τ_{br12} : Theoretical in-plane breaking shear stress, in N/mm², of the individual layer as defined in Ch 12, Sec 3, [5.2.1]

SF_{CS} : Minimum admissible safety factor for combined stresses, as defined in [5.4.2].

Note 1:

For σ_1, σ_2, the values are positive in traction and negative in compressive.

For $\sigma_{br1\ T}$, $\sigma_{br1\ C}$, $\sigma_{br2\ T}$, $\sigma_{br2\ C}$, the values are to be taken positive in traction and also in compressive.

5.3.3 It is considered that the full lay-up laminate breaking strength is reached as soon as the lowest breaking strength of any elementary layer is reached. This is referred to as "first ply failure".

5.4 Safety Coefficients

5.4.1 Application to maximum stress criteria

As a general rule, the minimum admissible safety factor SF applicable to maximum stress, considered in the present Rules is to be calculated as follows:

$SF = C_V\ C_F\ C_R\ C_I$

where:

C_V : Coefficient taking into account the ageing effect of the composites. This coefficient is generally taken as 1,2 for monolithic laminates (or face-skins laminates of sandwich) and 1,1 for sandwich core materials

C_F : Coefficient taking into account the fabrication process and the reproducibility of the fabrication. This coefficient is directly linked to the mechanical characteristics to be considered during a composites hull construction and is generally taken as 1,2 in case of a prepreg, or 1,3 in case of infusion and vacuum process, and 1,4 in case of a hand lay up process

C_F is taken as 1,0 for the core materials of sandwich composites

C_R : Coefficient taking into account the type of load carried out by the fibres of the reinforcement fabric. As a rule, this coefficient is taken as:

- 2,6 for a tensile or compressive stress parallel to the continuous fibre of the reinforcement fabric (unidirectional tape, bi-bias, three unidirectional fabric, woven roving)
- 1,2 for tensile or compressive stress perpendicular to the continuous fibre of the reinforcement fabric (unidirectional tapen bi-bias, three unidirectional fabric)

- 2,0 for a shear stress parallel to the fibre in the elementary layer and for interlaminar shear stress in the laminate
- 2,5 for a shear stress in the core material of sandwich laminate
- 2,0 whatever the type of stress in an elementary layer of mat type

C_I : Coefficient taking into account the type of loads. C_I is be taken equal to 1,0 for hydrodynamic sea pressure and 0,8 for slamming loads on bottom or impact pressure on side shell or for test pressure.

Note 1: For structural adhesive joint, see Ch 12, Sec 2, [5.2].

5.4.2 Application to Tsaï Wu (or Hoffman) combined stress criteria

As a general rule, the minimum admissible safety factor SF_{CS} considered for the combined stress in the present Rules (determined in [5.3.2]) is to be calculated as follows:

$SF_{CS} = 2,2\ C_V\ C_F$

where:

C_F : Coefficient as defined in [5.4.1]

C_V : Coefficient as defined in [5.4.1]

5.4.3 Application to critical buckling stress criteria

As a general rule, the minimum admissible safety factor SF_B considered in the present Rules is to be calculated as follows:

$SF_B = 3,8\ C_F$

where:

C_F : Coefficient as defined in [5.4.1].

5.4.4 Additional consideration on safety factors

In some cases, safety factors other than those defined in [5.4.1], [5.4.2] and [5.4.3] may be accepted for one elementary layer when the full lay-up laminate exhibits a sufficient safety margin between the theoretical breaking of this elementary layer and the theoretical breaking of the other elementary layers.

SECTION 4 STRUCTURE CALCULATION PRINCIPLES

1 Hull girder - Structural continuity

1.1 General principles

1.1.1 Attention is to be paid to the structural continuity:

- in way of changes in the framing system
- at the connections of primary or ordinary stiffeners.

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

Ordinary 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.

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

1.1.4 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.

1.1.5 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 Strength characteristics of hull girder transverse sections

2.1 Hull girder transverse sections

2.1.1 General

Hull girder transverse sections are to be considered as being constituted by the members contributing to the hull girder longitudinal strength, i.e. all continuous longitudinal members below the strength deck defined in [2.2].

For the catamaran, the members of each float as well as superstructure contributing to the hull girder longitudinal strength are to be taken into account.

2.1.2 Members of various metallic materials

Where the members contributing to the longitudinal strength are made in materials not having one single value of Young's modulus E, the equivalent sectional area that may be included in the hull girder transverse sections is obtained, in m², from the following formula:

$$A_{SE} = \frac{E_{REF}}{E_M} A_M$$

where:

E_{REF} : Reference Young's modulus, in N/mm², considered for the whole transverse section

E_M : Actual Young's modulus, in N/mm², of the considered member

A_M : Sectional area, in m², of the member under consideration.

2.1.3 Members in composite materials

Where the members contributing to the longitudinal strength are made in various composite materials, the neutral axis and the inertia of the hull girder transverse sections are calculated on the same basis as explained in Ch 12, Sec 4, [6.2] for stiffeners.

In this case, the value of Z_{Xi} to take into account is the distance between the baseline of the transverse section and the neutral axis of each sub-element of the hull.

2.1.4 The transverse sectional areas of openings such as hatch covers, sideshell ports, sideshell doors, in the members contributing to the longitudinal hull girder strength, are to be deduced from the considered transverse section.

2.1.5 Lightening holes, draining holes and single scallops

Lightening holes, draining holes and single scallops in longitudinals need not be deducted if their height is less than 0,25 h_W, without being greater than 75 mm, where h_W is the web height, in mm, of the considered longitudinal.

2.2 Strength deck

2.2.1 The strength deck is, in general, the uppermost continuous deck.

In the case of a superstructure or deckhouses contributing to the longitudinal strength, the strength deck is the deck of the superstructure or the deck of the uppermost deckhouse.

2.2.2 A superstructure extending at least 0,4 L may generally be considered as contributing to the longitudinal strength.

The presence of openings in the side shell and longitudinal bulkheads is to be taken into account in the analysis of the transverse sections of the hull girder.

2.2.3 When the analysis of the hull girder strength is performed with a Finite Elements Analysis, the presence of large openings in side shell, decks and longitudinal bulkheads is to be taken into account in the analysis. This may be done in two ways:

- by including these openings in the finite element model

- by assigning to the plate panel between the side frames beside each opening an equivalent thickness, in mm, obtained from the following formula:

$$t_{EQ} = 10^3 \left[\ell_P \left(\frac{Gh^2}{12EI_J} + \frac{1}{A_J} \right) \right]^{-1}$$

where according to Fig 1:

ℓ_P : Longitudinal distance, in m, between the frames beside the opening

h : Height, in m, of openings

I_J : Moment of inertia, in m^4, of the opening jamb about the transverse axis y-y

A_J : Shear area, in m^2, of the opening jamb in the direction of the longitudinal axis x-x

G : Coulomb's modulus, in N/mm^2, of the material used for the opening jamb, to be taken equal to:

- for steels:

  $G = 8{,}0 \cdot 10^4\ N/mm^2$

- for aluminium alloys:

  $G = 2{,}7 \cdot 10^4\ N/mm^2$.

2.3 Section modulus

2.3.1 The section modulus in any point of a transverse section is given, in m^3, by the following formula:

$$Z_A = \frac{I_Y}{|z - N|}$$

where:

I_Y : Moment of inertia, in m^4 of the transverse section

z : Z co-ordinate, in m, of the point above base line

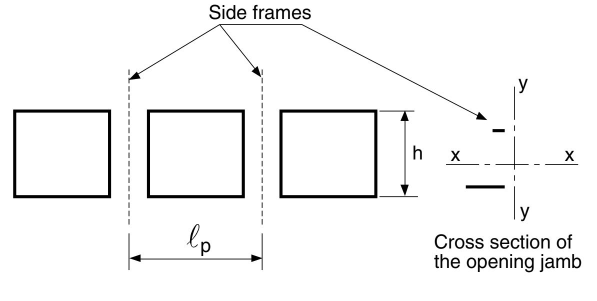
N : Z co-ordinate, in m, of the centre of gravity of the transverse section, above base line.

2.3.2 The section moduli at bottom and at deck are given, in m^3, by the following formulae:

- at bottom:

$$Z_{AB} = \frac{I_Y}{N}$$

Figure 1 : Side openings



- at deck

$$Z_{AB} = \frac{I_Y}{V_D}$$

where:

I_Y, N : Defined in [2.3.1]

V_D : Vertical distance, in m, equal to $V_D = z_D - N$, where:

z_D : z co-ordinate, in m, of the strength deck, above the base line.

2.4 Moments of inertia

2.4.1 The moment of inertia I_Y, in m^4, is calculated with respect to the horizontal neutral axis.

2.5 First moments

2.5.1 The first moment S, in m^3, at a level z above the baseline is that, calculated with respect to the horizontal neutral axis, of the portion of the hull transverse sections defined in [2.1] located above the z level.

2.6 Overall longitudinal strength

The overall longitudinal strength in any point of a transverse section, in N/mm^2, is obtained as:

$$\sigma_A = \frac{M_V}{Z_A}$$

where:

M_V : Overall bending moment of combination global loads calculated as indicated in Ch 6, Sec 4

Z_A : Section modulus calculated according to [2.3.1].

3 Stiffener calculation

3.1 Span of stiffeners

3.1.1 General

The span ℓ of stiffeners is to be measured as shown in Fig 2 to Fig 5.

Figure 2 : Stiffener without brackets

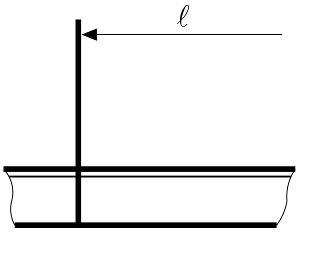


Figure 3 : Stiffener with a stiffener at one end

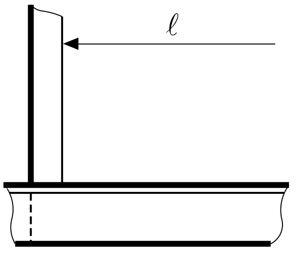


Figure 4 : Stiffener with end bracket

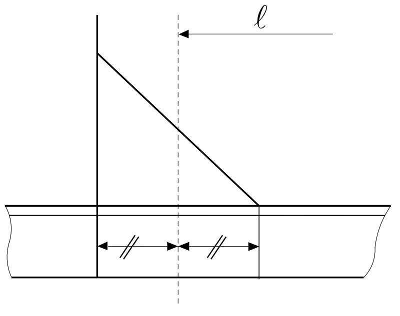


Figure 5 : Stiffener with a bracket and a stiffener at one end

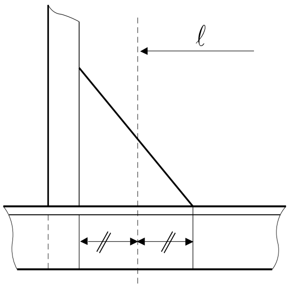
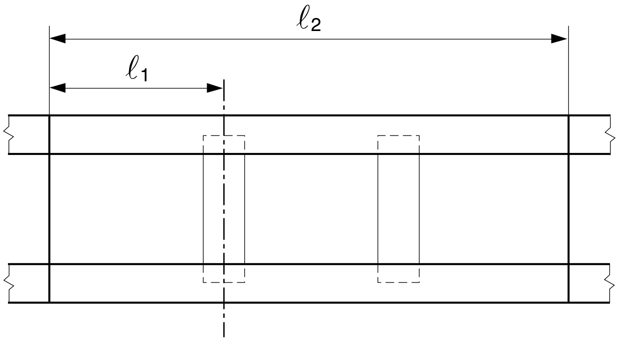


Figure 6 : Span of stiffeners in the case of open floors



3.1.2 Open floors

The span ℓ of transverse ordinary stiffeners connected by one or two struts is to be taken as the greater of 1,4 ℓ_1 and 0,7 ℓ_2, where ℓ_1 and ℓ_2 are the spans defined in Fig 6.

3.2 Scantling of a stiffener made of steel or aluminium

3.2.1 For each structural member, the scantling of stiffeners is obtained by considering successively the loads sustained by the structure under consideration, and the relevant associated admissible stress levels.

When the structural member under consideration is sustaining compressive load, actual stress level is to be checked against buckling stress as given in Ch 4, Sec 3.

3.2.2 For steel and aluminium structural members, the Rules scantlings are directly given by the Rules formulae.

3.2.3 The Society may also consider direct calculations based on actual geometry, Rules loads and admissible stress.

3.2.4 Special attention is to be paid to connection of ordinary stiffeners and surrounding supporting structure.

3.2.5 As a rule, the design section modulus Z, in cm^3, and the shear area A_{sh}, in cm^2, calculated according in Ch 8, Sec 4, for a stiffener sustaining lateral pressure are obtained from typical formulae, as follows:

$$Z = 1000 \cdot coeff \cdot \frac{p \cdot s \cdot l^2}{m \cdot \sigma_{ad}}$$

$$A_{sh} = 10 \cdot coeff \cdot \frac{p \cdot s \cdot l}{\tau_{ad}}$$

where:

10, 1000: Unit coefficient

coeff : This reduction coefficient may be of two different types:

- $(1 - s / 2\ell)$ in case of a load uniformly distributed over the full span of the stiffener. In such a case, this reduction coefficient express the load directly transferred to the primary supporting members at end of the stiffener
- $(3\ell^2 - 0{,}36) \cdot 0{,}3/\ell^3$ in case of impact pressure applied on side shell as defined in Ch 7, Sec 1, [2.3]. In that formula, ℓ is to be taken not less than 0,6 m

p : Local pressure, in kN/m², which may be a uniform load applied over the the full span of the stiffener or a uniform load applied on a part of the span only

s : Loaded width supported by the siffener, in m

ℓ : Span of the stiffener, in m

σ_{ad}, τ_{ad} : Rule admissible stresses, in N/mm², as defined in Ch 4, Sec 3, Tab 2 or Ch 4, Sec 3, Tab 4 and depending on the type of materials and on the type of load (hydrodynamic load, slamming, impact load, test load or exceptional load in damage situation) m : Coefficient depending on end conditions of the stiffener. This coefficient m may be taken as:

- 12, when the cross section at the end of the stiffener cannot rotate under the effect of the lateral load (fixed end)
- 8, when the cross section at the end of the stiffener can rotate freely under the effect of the lateral load (simply supported end)
- 10, when the cross section at the end of the stiffener is in an intermediate condition between fixed end-condition and simply supported end-condition.

As a rule, m is taken equal to 12 when:

- the stiffener is supported at end with a constant load either side of the support, making the rotation of the cross section impossible (case of an outside shell longitudinals)
- the stiffener is attached to a supporting structure with a significantly higher stiffness than the one of the stiffener.

As a rule, m is taken equal to 8 when:

- the stiffener is snipped at end.

3.3 Scantling of a stiffener made of composite

3.3.1 For each structural member, the scantling of stiffeners is obtained by considering successively the loads sustained by the structure under consideration, and the relevant associated safety factors.

3.3.2 For composite structural members, the calculation of stresses is directly given by the Rules formulae Ch 12, Sec 4, [6] and compared to the theoritical breaking stresses, estimated in Ch 12, Sec 3, [5], taking into account the safety factors as defined in Ch 4, Sec 3, [5.4].

The calculation of the stiffeners flexural moment and shear force are given in Ch 9, Sec 4.

3.3.3 Special attention is to be paid to connection of ordinary stiffeners and surrounding supporting structure. As a general rule, the scantling coefficient "m" taking into account the end conditions of the stiffener is to be taken as given in [3.2.5].

4 Plating calculation

4.1 General

4.1.1 Plating thicknesses are calculated with consideration given to elementary plate panel between secondary stiffeners and primary supporting members.

4.1.2 Steel and aluminium alloys

As a rule, for steel and aluminium plates sustaining lateral pressure, rule thickness, in mm, given by typical scantling formulae indicated in Ch 8, Sec 3 are as follows:

$$t = 22,4 \cdot \mathrm{coeff} \cdot \mu \cdot s \cdot \sqrt{\frac{p}{\sigma_{ad}}}$$

where:

22,4 : Unit coefficient, allowing to express directly the thickness from the ratio of the bending moment of the elementary plate panel with fixed boundaries and the corresponding section modulus

μ : Coefficient for the aspect ratio of the elementary plate panel, taking account of the stress distribution along the larger side and the smaller side of the panel

p : Local pressure, in kN/m^2, which may be a uniform load applied over the full span of the plate or a uniform load applied on a part of the span only (impact pressure on side shell)

s : Smaller side, in m, of the elementary plate panel

σ_{ad} : Rule permissible stress, in N/mm^2, depending on the type of material and on the type of load, as defined in Ch 4, Sec 3, Tab 2 or Ch 4, Sec 3, Tab 4

coeff : Coefficient equal to:

- In case of uniformly distributed hydrodynamic loads, as given in:

  coeff = 1

- In case of impact pressure on side shells (loads distributed on a part only of the elementary plate panel), as given in Ch 7, Sec 1, [2.3]:

  - coeff = 1, if

    $$\frac{\ell}{0,6} \le 1 + s$$

  - coeff = $(1+s)^{-1/2}$, if

    $$\frac{\ell}{0,6} > 1 + s$$

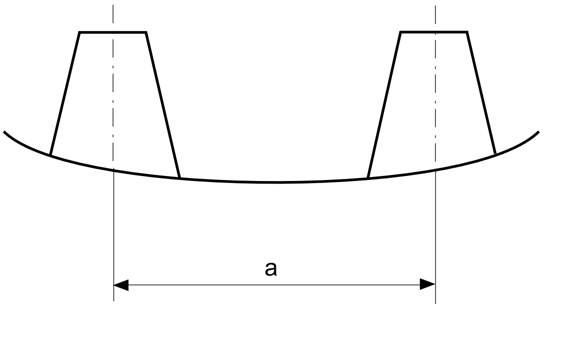
4.1.3 Composites

As a rule, for composite materials, scantling formulae are expressed as a function of the bending moment and the shear force on the edges of the elementary plate panel, as defined in Ch 9, Sec 3, [7].

The dimensions of elementary plate panel is to be considered as shown on Fig 7.

The calculation of stresses in each elementary layers is given in Ch 12, Sec 4 and compared to the theoretical breaking stresses estimated in Ch 12, Sec 3, [5], taking into account the safety factors as defined in Ch 4, Sec 3, [5.4].

Figure 7 : Composite elementary plate panel



SECTION 1 MOTIONS AND ACCELERATIONS

1 General

1.1 Application

1.1.1 The accelerations considered in this section are the dynamic vertical accelerations induced by ship motions and resulting in slamming phenomenon on bottom area.

1.1.2 The vertical acceleration (expressed in g) corresponds to the average of the 1 per cent highest accelerations in the most severe sea conditions expected, in addition to the gravity acceleration. This acceleration is referred to as design vertical acceleration.

1.1.3 Slamming phenomenon on bottom area generally occur on high speed motor yachts (heave acceleration) and on monohull sailing yachts (heave and pitch accelerations).

1.1.4 Specific slamming phenomenon occurring on fore part of underside of catamaran cross deck are directly dealt with in Ch 7, Sec 2 and are not depending of the vertical acceleration of the present Section.

1.1.5 The Society keeps the possibility to perform similar calculation for other types of yachts, if deemed necessary.

1.1.6 As an alternative to the formulas of this section, the Society may accept values of ship motions and accelerations derived from direct calculations or obtained from model test, when justified on the basis of yacht's characteristics and intended service. In general, the values of ship motions and accelerations to be determined are those which can be reached with a probability level of 10^{-5}. In any case, the model tests or the calculations, including the assumed sea scatter diagrams and spectra, are to be submitted to the Society for approval.

2 Design vertical acceleration

2.1 High speed motor yachts

2.1.1 The requirements of this Article apply to motor yachts:

- for which $V \geq 7{,}16\ \Delta^{1/6}$

  where V is the maximum speed in knots and Δ the moulded displacement at full load draught in sea water, in tonnes, and when hull lines have been so designed, and
- featuring planning hull to reach the contractual speed.

It is the designer responsibility to specify whether the hull is of planning type, and to specify the type of design as defined in [2.1.7] and [2.1.8].

Motor yachts for which $V \geq 10\ L_{WL}^{0,5}$ shall be individually considered by the Society.

2.1.2 The design vertical acceleration at LCG (ship's longitudinal centre of gravity), a_{CG} (expressed in g) is to be defined by the designer and indicated on drawings where the main characteristics of yacht are specified.

2.1.3 It is the designer's responsibility to provide for a relation between the speed and the significant wave height that provides a maximum vertical acceleration less than the design value. This relation may be determined on the basis of results of model test or full-scale measurements.

The table of the speed relative to the sea states, characterised by their significant wave height, is to be annexed to the Certificate of Classification according to Ship Rules, Part A, Ch 1, Sec 2, [4.10].

2.1.4 Where model test results or full-scale measurements are not available, the formula in [2.1.5] may be used to define maximum speeds compatible with design acceleration, depending on sea states having a significant height H_S.

2.1.5 The maximum allowable speed V in significant wave height H_S is related to the yacht's geometry and motion characteristics and to the design vertical acceleration a_{CG} by the following formula:

$$H_S = \left(\frac{3555 \cdot C_B \cdot a_{CG}}{\left(\frac{V}{\sqrt{L_{WL}}}\right)^2 \cdot (50 - \alpha_{dCG}) \cdot \left(\frac{\tau}{16} + 0,75\right)} - \left(0,084 \cdot \frac{B_W}{T}\right) \right) \cdot T$$

where:

- H_S : Significant wave height, in m, corresponding to speed V
- α_{dCG} : Deadrise angle, in degrees, at LCG, to be taken between 10° and 30°
- τ : Trim angle during navigation, in degrees, to be taken not less than 4°
- V : Ship speed in knots
- C_B : Bloc coefficient
- T : Full load draught, in m
- B_W : Maximum breadth at full load waterline. For catamarans, B_W is to be taken as the sum of the breath of each hulls.

2.1.6 The formula in [2.1.5] is valid only if all following relationships are simultaneously complied with:

- $3500 < \Delta / (0{,}01\ L_{WL})^3 < 8700$
- $3 < L_{WL} / B_W < 5$
- $10° < \alpha_{dCG} < 30°$
- $0{,}2 < H_S / B_W < 0{,}7$
- $3{,}6 < V / (L_{WL})^{0.5} < 10{,}9$

Table 1 : foc for motor yacht

Type of design **(1)**	Cruise motor yacht	Sport motor yacht	Offshore raceing motor yacht	Motor yacht with specific equipments (e.g. safety belts)
foc	0,666	1,000	1,333	1,666
(1) See [2.1.8].				

Table 2 : Soc for motor yacht

Sea conditions	Open sea **(1)**	Restricted open sea **(2)**	Moderate environment **(3)**	Smooth sea **(4)**
Soc	C_F **(5)**	0,3	0,23	0,14

(1) Category A in case of EC Directive, **unrestricted navigation** for Classification.
(2) Category B in case of EC Directive.
(3) Category C in case of EC Directive, **coastal area** for Classification.
(4) Category D in case of EC Directive, **sheltered area** for Classification.
(5) $C_F = 0,2 + \frac{0,6}{V/\sqrt{L_W}} \geq 0,32$

2.1.7 When the design vertical acceleration a_{CG} is not provided by the designer, the following value may be used, taking into account the type of design associated to the sea conditions. In such case the design vertical acceleration is to be mentioned on drawings.

$$a_{CG} = foc \cdot Soc \cdot \frac{V}{\sqrt{L_{WL}}}$$

where foc and Soc values are indicated in Tab 1 and Tab 2.

The sea areas referred to in Tab 2 are defined with reference to significant wave heights H_s which are exceeded for an average of not more than 10 percent of the year:

- Open-sea service: $H_s \geq 4,0$ m
- Restricted open-sea service: $2,5 \text{ m} \leq H_s < 4,0$ m
- Moderate environment service: $0,5 \text{ m} < H_s < 2,5$ m
- Smooth sea service: $H_s \leq 0,5$ m.

2.1.8 The type of design is to be defined by the yacht designer in order to estimate the foc parameter specified in Tab 1 and if necessary the maximum value of a_{CG}.

The type of design can be ranged as follows:

- Cruise Motor yacht:

  At maximum speed in service, the hull is mainly intended to be sustained by a combination of buoyancy and planning effect

- Sport Motor yacht:

  At maximum speed in service, the hull may be submitted during short moments to only planning effect

- Offshore racing Motor yacht:

  At maximum speed in service, the hull is consistently submitted to planning effect

- Motor yacht with specific equipments:

  The yacht is submitted to the same effect as Offshore racing Motor yacht and is fitted with safety arrangement (for example safety belts).

2.1.9 The design vertical acceleration a_{CG} may be taken not more than the values in Tab 3.

2.2 Sailing yacht - Monohull

2.2.1 The vertical accelerations considered in this article are induced by the ship behaviour at sea, and particularly heave and pitch.

The combination of heave and pitch acceleration is defined in [2.2.4]

2.2.2 The heave design vertical acceleration, in g, may be calculated as follows:

$a_H = 2,7 \text{ foc} \cdot \text{Soc}$

where foc and Soc are defined in Tab 4 and Tab 5.

The sea areas referred to in Tab 5 are defined with reference to significant wave heights H_s which are exceeded for an average of not more than 10 percent of the year:

- Open-sea service: $H_s \geq 4,0$ m
- Restricted open-sea service: $2,5 \text{ m} \leq H_s < 4,0$ m
- Moderate environment service: $0,5 \text{ m} < H_s < 2,5$ m
- Smooth sea service: $H_s \leq 0,5$ m.

Table 3 : Maximum values of a_{CG}

Type of yachts	Limit value of a_{CG}, in g
Cruise motor yacht	1,0
Sport motor yacht	1,5
Offshore racing motor yacht	2,0
Motor yacht with specific equipments (e.g. safety belts)	2,5

Table 4 : foc for sailing yacht

Type of design	Cruise sailing yacht	Sport sailing yacht	Race sailing yacht **(1)**
foc	0,666	1,000	1,333
(1) This value is given for information only, racing yachts not being covered by these Rules (see Pt A, Ch 1, Sec 1, [1.1.3]).			

Table 5 : Soc for sailing yacht

Sea conditions	Open sea **(1)**	Restricted open sea **(2)**	Moderate environment **(3)**	Smooth sea **(4)**
Soc	0,30	0,27	0,23	0,20

(1) Category A in case of EC Directive, unrestricted navigation for Classification.
(2) Category B in case of EC Directive.
(3) Category C in case of EC Directive, **coastal area** for Classification.
(4) Category D in case of EC Directive, **sheltered area** for Classification.

2.2.3 The pitch design vertical acceleration a_P, in g, in any longitudinal location x, may be determined as follows, as shown on Fig 1.

$$a_P = a_{PFP} \cdot \frac{x - x_K}{L_{WL} - x_K}$$

without being taken less than 0

where:

x_K : Co-ordinate x of the centre of gravity of the keel measured from aft perpendicular

x : Co-ordinate x of the calculation point measured from aft perpendicular

a_{PFP} : Pitch vertical acceleration at fore perpendicular, equal to:

- $3\ a_H$ for race sailing yacht (see Note 1)
- $2,1\ a_H$ for bulb keel sailing yacht
- $1,5\ a_H$ for sailing yacht with bar keel
- a_H for lifting keel yachts

where a_H is calculated according to [2.2.2].

Note 1: This value is given for information only, racing yachts being not covered by these Rules (see Pt A, Ch 1, Sec 1, [1]).

2.2.4 Total design acceleration for slamming pressure

The total design vertical acceleration a_v to be considered for the calculation of the slamming pressure is to be taken equal to:

$$a_V = a_H + a_p$$

where:

a_H : Heave acceleration as defined in [2.2.2]

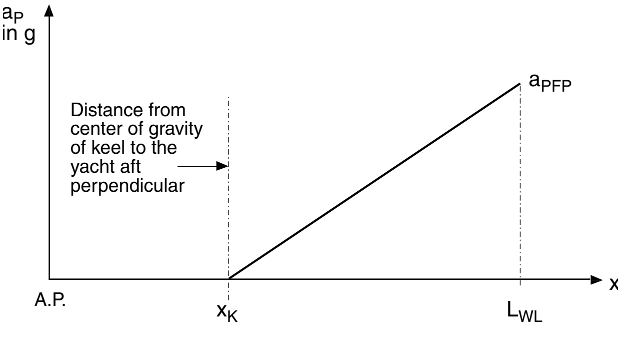
a_p : Pitch acceleration as defined in [2.2.3].

2.3 Slow speed motor yacht and Sailing yacht - multihulls

2.3.1 For slow speed motor yachts and for multihulls sailing yachts, no specific acceleration are to be calculated.

The effect of yacht motions are directly taken into consideration in the Rules formulae for the hydrodynamic loads (refer to Ch 7, Sec 1.

Figure 1 : Pitch acceleration longitudinal distribution



SECTION 1 GENERAL

1 Definitions

1.1 Global loads

1.1.1 Global loads are made of forces and bending moment on the hull girder, resulting from application of local loads throughout the ship.

1.1.2 The different global loads (also named hull girder loads) are defined in Ch 4, Sec 2, [1.2].

1.2 Sign conventions of vertical bending moments and shear forces

1.2.1 The sign conventions of bending moments and shear forces at any ship transverse section are as shown in Fig 1, namely:

- the vertical bending moment M is positive when it induces tensile stresses in the strength deck (hogging bending moment); it is negative in the opposite case (sagging bending moment)
- the vertical shear force Q is positive in the case of downward resulting forces preceding and upward resulting forces following the ship transverse section under consideration ; it is negative in the opposite case.

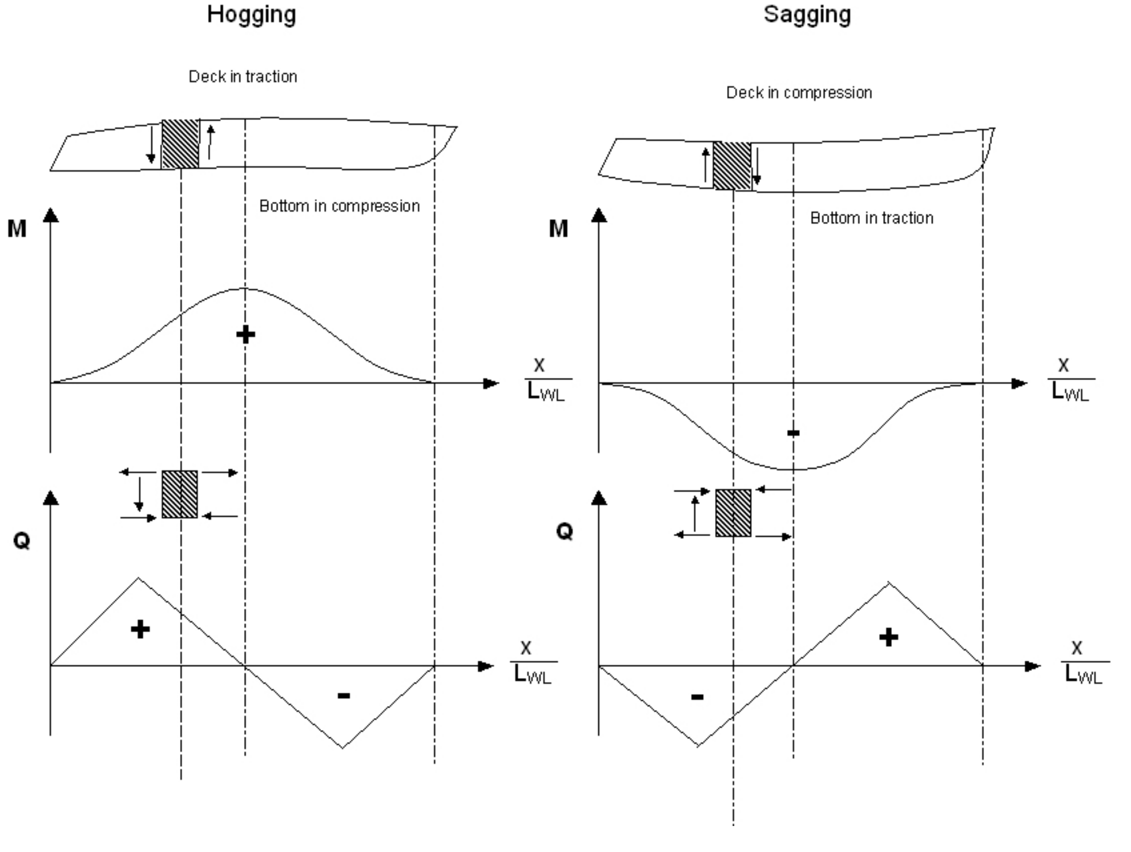
1.2.2 The resulting forces correspond to the difference between the vertical sea pressure and the vertical forces applied to the hull.

1.3 Application

1.3.1 As a rule, the global loads are to be taken into consideration in the following situations:

- yacht with important length (superior to 40 m), or
- sailing yacht, of monohull or multihull type, having important compression force induced by the mast and important forces induced by standing rigging, or
- ship having large openings in decks or significant geometrical structure discontinuity at bottom or decks, or
- ship with transverse framing system, or
- ship with deck structure made of small plate thicknesses and large spacing of secondary stiffeners.

Figure 1 : Sign conventions for shear forces Q and bending moments M



SECTION 2 HYDROSTATIC AND HYDRODYNAMIC LOADS

Symbols

L_{WL} : Length at waterline at full load, in m

L_{HULL} : Hull length, as defined in Ch 1, Sec 2, [3.3.1], in m

$M_{WV,H}$: Wave vertical bending moment in hogging condition, in kN.m

$M_{WV,S}$: Wave vertical bending moment in sagging condition, in kN.m

$M_{SW,H}$: Still water vertical bending moment in hogging condition, in kN.m

$M_{SW,S}$: Still water vertical bending moment in sagging condition, in kN.m

Q_{SW} : Still water vertical shear force, in kN

Q_{WV} : Wave vertical shear force, in kN.

1 Still water loads

1.1 General

1.1.1 As a rule, the actual hull lines and lightweight distribution are to be submitted, for determination of longitudinal distribution of still water bending moment and shear force.

A capacity plan, showing localization and volumes of fresh water tanks, diesel oil tanks and water ballast, is also to be submitted.

1.2 Loading conditions

1.2.1 As a rule, the longitudinal distribution of still water bending moments and shear force are to be calculated with the following loading conditions:

- ship with 100% full capacities
- ship with 10% capacities.

Note 1: distribution of M_{sw} is to be the same as M_{wv}

1.3 Still water bending moment and shear force

1.3.1 If the information required in [1.1.1] and [1.2.1] are not defined, at a preliminary design stage, the still water bending moment and shear force (values and conditions) may be taken as per Tab 1.

2 Wave loads

2.1 General

2.1.1 Wave loads are induced by encountered waves in head sea or quartering sea.

The design encountered waves, considered with a probability level of 10^{-5}, may be represented by equivalent static wave as described in [2.1.2] and [2.1.3].

Table 1 : Still water bending moments (SWBM) and still water shear forces (QSW)

Type of yachts	SWBM	QSW
Conventional motor yachts	$M_{SW,H} = 0,8\ M_{WV,H}$	$Q_{SW} = 0,8\ Q_{WV}$
Motor yachts with large transom	$M_{SW,H} = 0,4\ M_{WV,H}$	$Q_{SW} = 0,4\ Q_{WV}$
Multihull motor yacht	$M_{SW,H} = 0,6\ M_{WV,H}$	$Q_{SW} = 0,6\ Q_{WV}$
Monohull sailing yacht	$M_{SW,S} = 0,2\ M_{WV,H}$	$Q_{SW} = 0,2\ Q_{WV}$
Multihull sailing yacht	$M_{SW,H} = 0,6\ M_{WV,H}$	$Q_{SW} = 0,6\ Q_{WV}$

2.1.2 Head sea

For monohull and catamaran type yachts, the characteristics of encountered wave to consider in head sea (equivalent static wave) are as follows:

- sinusoïdal type
- wave length L_W ,in m, with:

  $L_W = 0,5\ (L_{WL} + L_{HULL})$
- wave height C_W crest-to-trough, in m, with:

  $C_W = (118 - 0,36\ L_W)\ L_W\ 10^{-3}$

2.1.3 Quartering sea

Moreover, for catamaran type yacht, the characteristics of encountered waves to consider in quartering sea (equivalent static wave) are as follows:

- sinusoïdal type
- such an incidence that the crest of wave is aligned with forward perpendicular of starboard float hull and aft perpendicular of port float hull, the two next troughs of waves being respectively at aft perpendicular of starboard float hull and fore perpendicular of port float hull (see Fig 3)
- wave length L_{WQ} , in m, resulting from the quartering wave position defined on (see Fig 3)
- wave height C_{WQ} crest-to-trough, in m, with:

  $C_{WQ} = (118 - 0,36\ L_{WQ})\ L_{WQ}\ 10^{-3}$

2.2 Vertical wave bending moment and shear forces - head sea condition

2.2.1 General

The maximum vertical wave bending moment in hogging (resulting in tensile stress at deck) is corresponding to ship sailing in waves with characteristics according to [2.1.2], with crest of wave at midship perpendicular.

The maximum vertical wave bending moment in sagging (resulting in compression stress at deck) is corresponding to ship sailing in waves with characteristics according to [2.1.2], with trough of wave at midship perpendicular.

The following requirements give the Rules vertical wave bending moment and shear force values and corresponding longitudinal distributions, to be considered for monohulls and catamarans (in head sea).

2.2.2 Bending moment and shear force

The maximum value of vertical wave bending moment, in kN.m, and shear force, in kN, are obtained from the following formulas:

$M_{WV,H} = M_{WV,S} = 0,25\ n\ C_W\ L_W^2\ B_W\ C_B\ 0,625$

$Q_{WV} = 0,78\ n\ C_W\ L_W\ B_W\ C_B\ 0,625$

with:

C_W : Wave height, in m, as defined in [2.1.2]

L_W : Wave length, in m, as defined in [2.1.2]

B_W : Maximum breadth at waterline, in m. For catamarans, B_W is to be taken as the sum of maximum breadth at waterline for both floats

C_B : Block coefficient

n : Navigation coefficient defined in Ch 4, Sec 2, [3].

2.2.3 Distribution

The longitudinal distribution shown in Fig 1 and Fig 2 may be used for longitudinal distribution of vertical wave bending moment and wave shear force.

Figure 1 : Vertical wave bending moment distribution

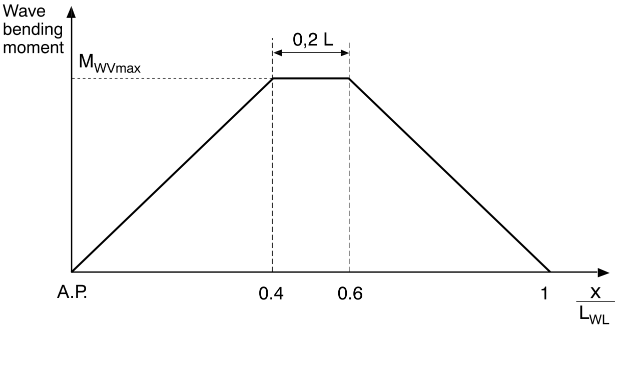
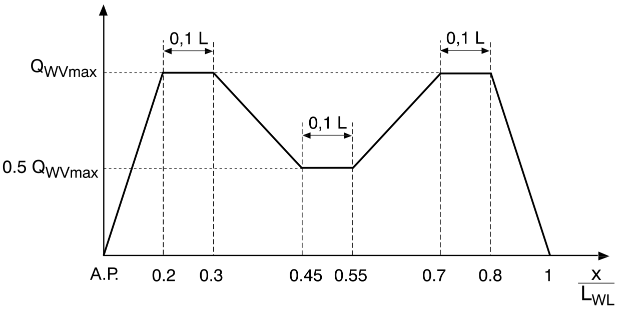


Figure 2 : Vertical wave shear force distribution



2.3 Wave torque - quartering sea for multihull only

2.3.1 General

The maximum wave torque is resulting from ship sailing in waves with characteristics according to [2.1.3], with forward perpendicular of starboard float hull and aft perpendicular of port float hull on crest of wave (see Fig 3).

The maximum wave torque is the torque alongside the transverse horizontal axis, resulting from the action of one float on the other one.

The following requirements give the Rule wave torque value to be considered for catamarans (in quartering seas).

2.3.2 Torque

The maximum value of wave torque moment, in kN.m, is obtained from the following formula:

$M_{WT} = n\ C_{WQ}\ L_W^2\ B_W\ C_B\ 0,625$

with:

C_{WQ} : Wave height, in m, as defined in [2.1.3]

L_W : $L_W = 0,5\ (L_{WL} + L_{HULL})$

B_W : Maximum breadth at waterline of one float, in m

C_B : Block coefficient

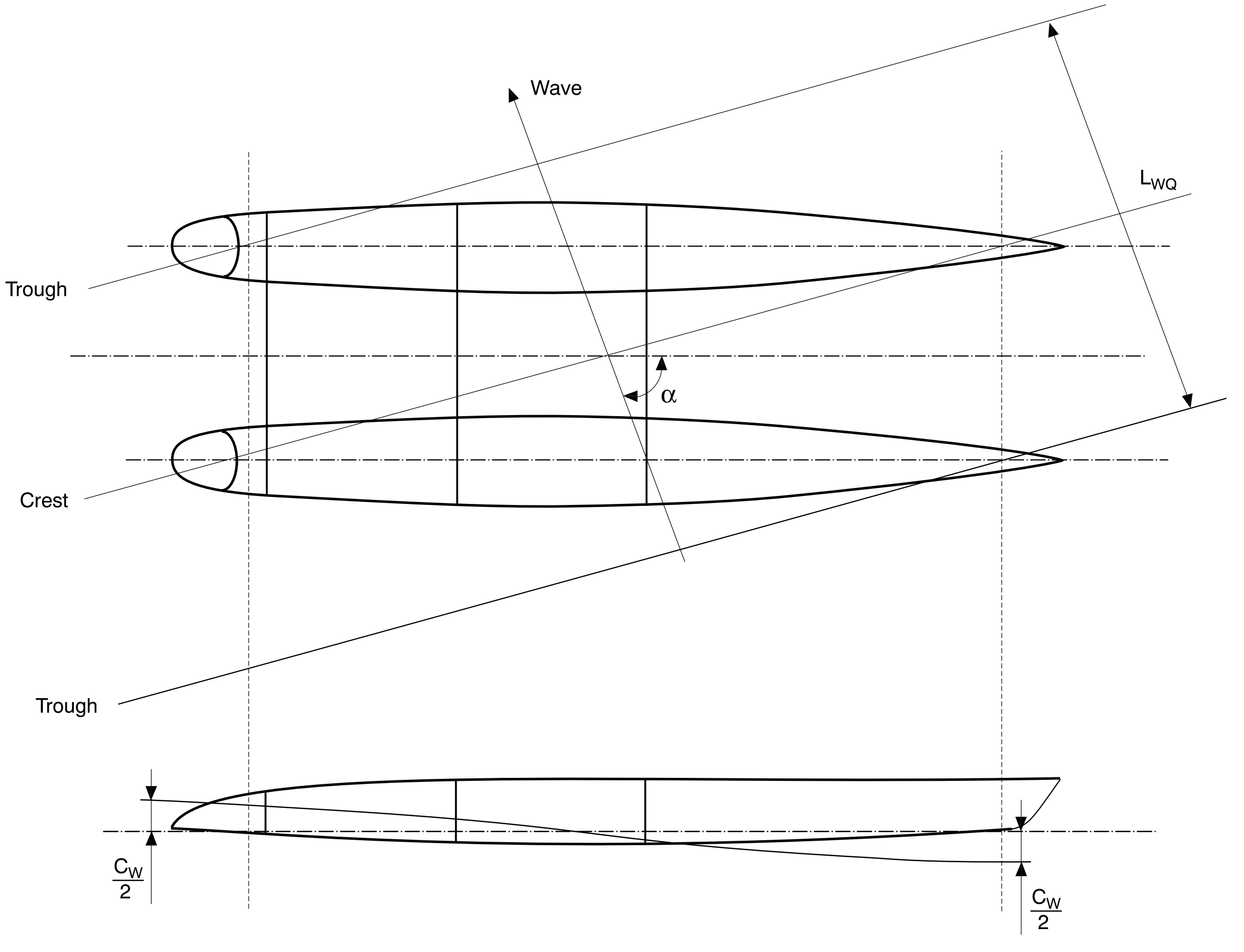
n : Navigation coefficient defined in Ch 4, Sec 2, [3].

2.4 Alternatives

2.4.1 As an alternative, the Society may consider direct calculation of wave vertical bending moments and shear forces, performed to better take into account the actual hull lines.

In such a case, wave characteristics are to comply with the requirements of [2.1.3] and the calculations are to be submitted to the Society for approval.

Figure 3 : Wave torque on catamarans



SECTION 3 SPECIFIC GLOBAL LOADS

1 General

1.1 Application

1.1.1 The specific global loads of this Section are applicable to sailing yacht (monohull or catamaran) and to catamarans (sailing yachts or motor yachts).

1.1.2 The multihulls with more than two floats are not covered by the present Section and are to be submitted to a special examination.

1.1.3 Other requirements may be considered for such specific global loads, in case of yachts having unusual particulars.

2 Rig loads

2.1 General

2.1.1 The rig global loadings described in that Section are generally to be considered for yachts featuring:

- a sailing configuration where mast, stays, shrouds and backstay induce significant loads in the hull girder
- a deck with large openings or significant structural discontinuity
- a deck with transverse framing system.

2.1.2 The rig global loads inducing a hull girder bending effect are to be combined with still water and wave global loads as indicated in Ch 6, Sec 4.

2.1.3 The rig loads to be considered in the present Section are the forces induced by the standing rigging:

- stays
- vertical shrouds and lower shrouds
- backstay.

The loads induced by the standing rigging during normal navigation conditions are to be indicated by the Yard and/or by the Designer, for the various navigation conditions taking account of:

- sails reduction versus apparent wind speed
- sails configuration for all wind heading from head wind to down wind.

2.1.4 The combination calculations are carried out without any trim and list.

2.1.5 The Society reserves the right to determine the rig loads from the sizing of the shrouds. In such case, the forces are corresponding to the breaking strength of the shroud under consideration, divided by a coefficient of 2,5 (this coefficient is generally the safety factor on breaking strength used for the design of shrouds in the scantling riggings).

The Society may consider a different value for this coefficient, on a case by case basis, upon satisfactory justification given by the Yard and/or the Designer.

2.2 Sailing monohull with one mast

2.2.1 The maximum hull girder bending moment M_{RIG}, in kN.m, induced by the standing rigging, is the mean value of fore rig induced hull girder bending moment M_{RIGF} and aft rig induced hull girder bending moment M_{RIGA}, defined as follows:

- where only the forestay is loaded:

  $M_{RIGF} = F_E \sin\alpha_E \; L_E$
- where only the baby stay is loaded:

  $M_{RIGF} = F_{BE} \sin\alpha_{BE} \; L_{BE}$
- where both the main stay and the baby stay are loaded simultaneously:

  $M_{RIGF} = F_E \sin\alpha_E \; L_E + F_{BE} \sin\alpha_{BE} \; L_{BE}$
- $M_{RIGA} = M_P + M_{V1} + M_{D1}$

  where:

  $M_P = F_P \sin\alpha_P \; L_P$

  $M_{V1} = F_{V1} \; L_{V1}$

  $M_{D1} = F_{D1} \sin\alpha_{D1} \; L_{D1}$

The symbols are shown on Fig 1, where:

F_P : Load on backstay, in kN

F_{V1} : Load on vertical shroud, in kN

F_{D1} : Load on lower shroud, in kN

F_E : Load on forestay, in kN

F_{BE} : Load on baby stay, in kN

α_I : Angle from the horizontal, in °, as shown on Fig 1

L_I : Horizontal distance from mast foot, in m, as shown on Fig 1.

2.2.2 The maximum hull girder vertical shear force Q_{RIG}, in kN, induced by the standing rigging, is the mean value of fore rig induced hull girder vertical shear force Q_{RIGF} and aft rig induced hull girder vertical shear force Q_{RIGA}, defined as follows:

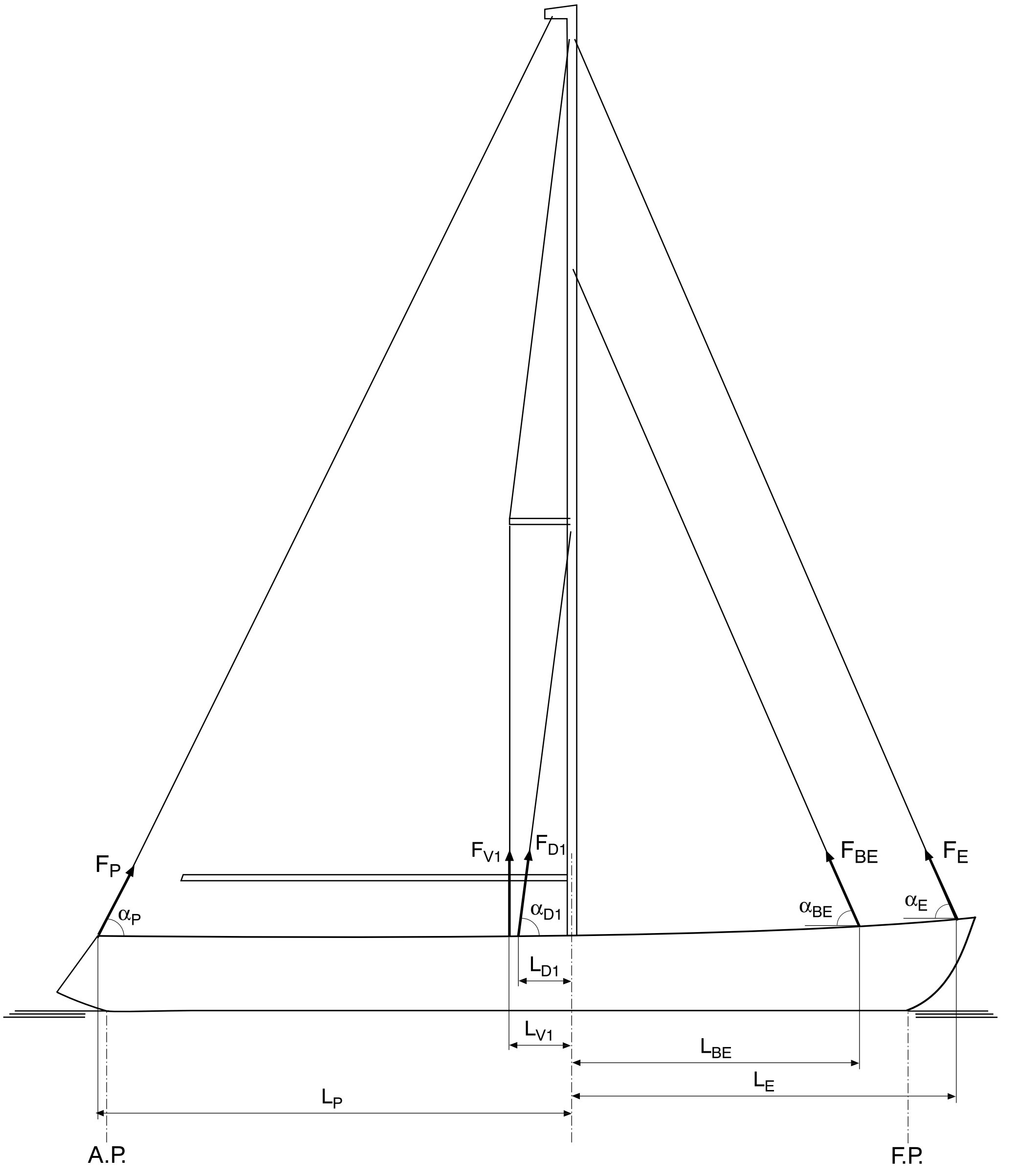
- where only the main stay is loaded:

  $Q_{RIGF} = F_E \sin\alpha_E$
- where only the baby stay is loaded:

  $Q_{RIGF} = F_{BE} \sin\alpha_{BE}$
- where both the main stay and the baby stay are loaded simultaneously:

  $Q_{RIGF} = F_E \sin\alpha_E + F_{BE} \sin\alpha_{BE}$

Figure 1 : Rig loads designation



- $Q_{RIGA} = Q_P + Q_{V1} + Q_{D1}$

  where:

  $Q_P = F_P \sin \alpha_P$

  $Q_{V1} = F_{V1}$

  $Q_{D1} = F_{D1} \sin \alpha_{D1}$

The symbols are defined in [2.2.1].

2.3 Sailing monohull with several masts

2.3.1 In case of sailing monohull with more than one mast, the hull girder bending moments and shear forces induced by the standing rigging are determined from a direct calculation.

This calculation is to be carried out with following assumptions:

- the hull is considered as a series of beams of constant inertia, fixed in way of each mast (see Fig 3)
- this beam is vertically loaded by the various forces exerted by the standing rigging (see Fig 2).

The hull girder is then analysed by steps, bending moments and shear forces being calculated individually for each span between masts.

The hull girder rig bending moments and shear forces are generally calculated in way of each mast.

The design value of the hull girder rig bending moment in way of each mast is the mean value of the bending moments calculated either side of the mast under consideration.

The design value of the hull girder rig shear force in way of each mast is the mean value of the shear forces calculated either side of the mast under consideration.

2.3.2 The actual distribution of hull girder bending moments and shear forces may be calculated by means of beam analysis.

2.3.3 Where the top of masts are attached to each other by an horizontal shroud, the rig loads will be subject to special examination.

Figure 2 : Rig loads designation for sailing yachts with several masts

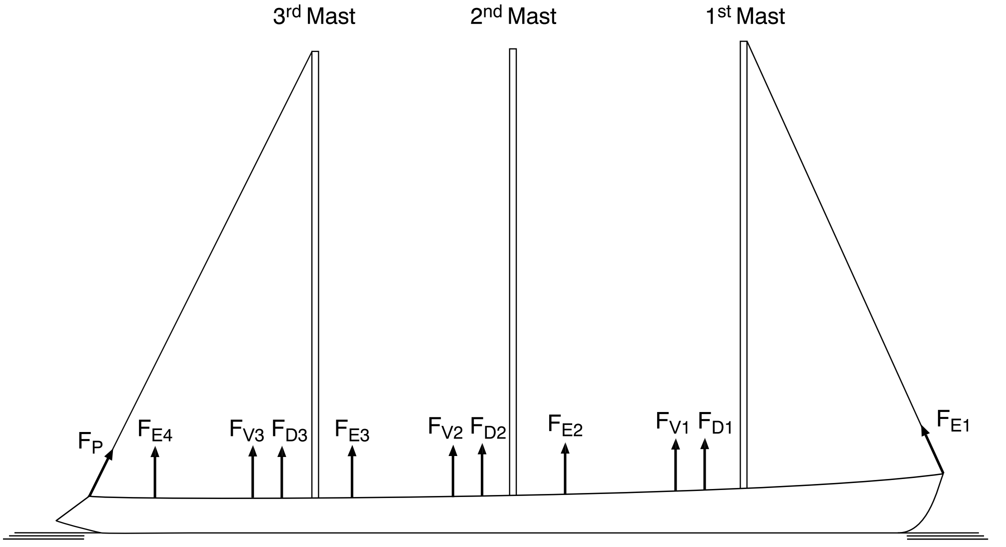
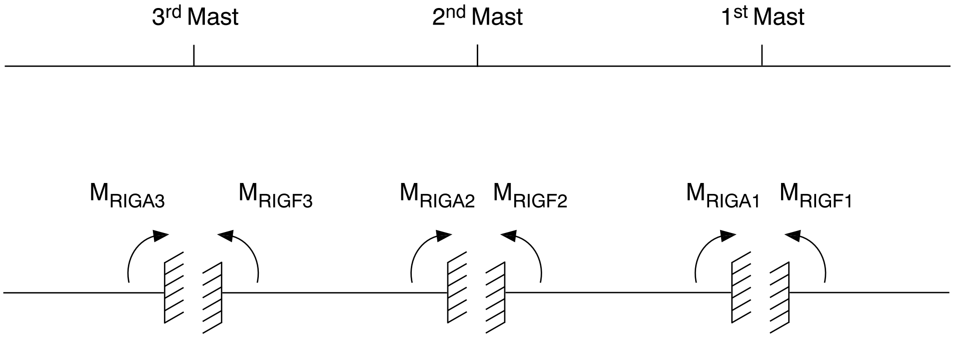


Figure 3 : Hull girder analysis



2.4 Sailing catamarans with one mast or more than one mast

2.4.1 General

The rig loads considered in the present sub-article may induce:

- a global vertical bending moment
- a global torsional connecting moment (rig torque).

The loads induced by the standing rigging during normal navigation conditions are to be indicated by the Yard and/ or by the Designer, for the various navigation conditions taking account of:

- sails reduction versus apparent wind speed
- sails configuration for all wind heading from head wind to down wind.

The Society reserves the right to determine the rig loads from the sizing of the shrouds. In such case, the forces are corresponding to the breaking strength of the shroud under consideration, divided by a coefficient of 2,5 (this coefficient is generally the safety factor on breaking strength used for the design of shrouds in the scantling riggings).

The Society may consider a different value for this coefficient, on a case by case basis, upon satisfactory justification given by the Yard and/or the Designer.

2.4.2 Vertical bending moment induced by rig

The hull girder bending moment induced by the standing rigging, M_{RIG} , is to be calculated according to sub-article [2.2].

2.4.3 Torque induced by rig

The rig loads considered in the present requirement are the rig forces that induce a torsional connecting moment in the cross deck between the floats. These forces are non-symetrical with respect to longitudinal axis, and are:

- the forces exerted by the vertical shrouds and lower shrouds
- the forces exerted by the backstay.

The hull girder torsque bending moment induced by the standing rigging, M_{RIGT} , is equal to:

$$M_{RIGT} = F_{V1}\ L_{V1}' + F_{D1}\ L_{D1}'\ \sin\alpha_{D1} + F_P\ L_P'\ \sin\alpha_P$$

where L_{V1}', L_{D1}' and L_P' are the horizontal distances from respectively vertical shroud chain plate, lower shroud chain plate and side backstay chain plate to cross deck center of rotation, determined as indicated in Ch 8, Sec 2 for steel and aluminium yachts, or Ch 9, Sec 2 for composites yachts.

3 Loading induced by deck diving into waves (broaching)

3.1 General

3.1.1 This type of loading corresponds the situation where the catamaran sails in quartering head seas and has the fore end of the floats burying themselves into the encountered waves.

3.1.2 The assumptions considered to determine the corresponding global loads are the following one:

- 10° longitudinal trim
- 10° tranverse list
- 1g broaching horizontal deceleration
- the float getting the bigger broaching effect is submerged from the extreme fore end to the forward part of the forward cross deck structure.

3.2 Loads and stresses

3.2.1 Vertical and horizontal forces to be applied on the fore part of the floats, in kN, are defined as follows.

The vertical force F′, in kN, induced by Archimedian overpressure resulting from the deck diving, is to be calculated according to the following formula:

$$F' = \frac{1,8 \cdot 9,807 \cdot \Delta \cdot d \cdot \sin 10^o}{\delta_1 + \delta_2}$$

The horizontal force F″, in kN, induced by Archimedian overpressure resulting from the deck diving, is to be calculated according to the following formula:

$F'' = F' \cos 80°$

where:

Δ : Full load diplacement, in T, of the catamaran

d : Horizontal distance between the extreme fore end of each float and the forward part of the forward cross beam

δ_1, δ_2 : Sinkages, in m, of a point located at mid-distance between the extreme fore end of each float and the fore stem of the forward cross deck structure (at d/2)

$$\delta_1 = \frac{3}{8} \cdot L_{WL} \cdot \tan 10^o$$

$$\delta_2 = \frac{1}{8} \cdot L_{WL} \cdot \tan 16^o$$

L_{WL} : Length of each float, in m, at full load waterline.

3.2.2 Load distribution

The distribution of the loads on the fore part of the floats may be considered as linear load applied according to Fig 4.

3.2.3 For non conventional loaction of the fore part of the cross deck between hulls, the Society may decide to consider another load distribution, on a case by case basis.

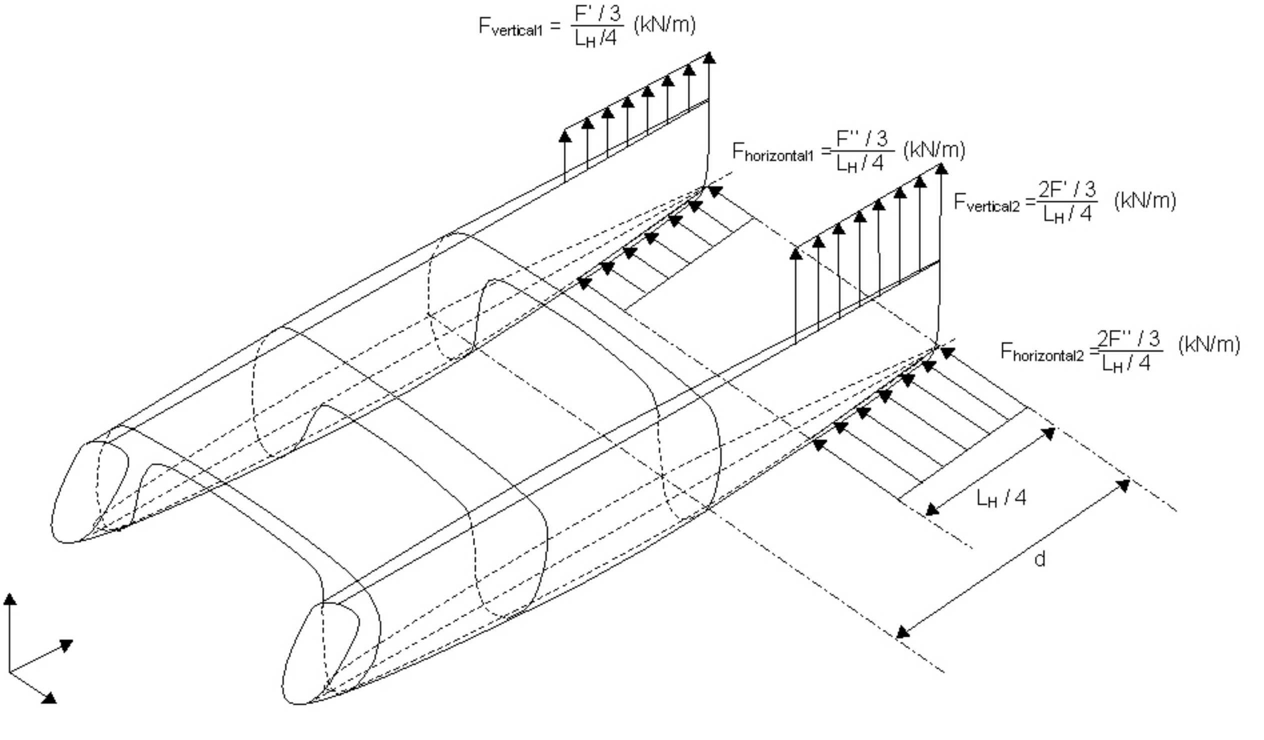
3.2.4 Bending moment M_E and shear force Q_E

The bending moments and shear forces induced in the cross deck by this type of loads are to be determined according to Ch 8, Sec 2 for steel or aluminium yacht and Ch 9, Sec 2 for composite yacht.

3.2.5 Admissibles stresses

The admissible stresses to be considered for the cross deck scantlings under this type of loading are defined in Ch 4, Sec 3.

Figure 4 : Loading of catamarans due to digging in



SECTION 4 COMBINATION OF GLOBAL LOADS

1 General

1.1 Application

1.1.1 The global strength of the hull girder and the global strength of the platform of catamarans are checked according to:

- Ch 8, Sec 2 for steel or aluminium yachts
- Ch 9, Sec 2 for composites yachts.

1.1.2 The global loads to consider are defined in Ch 6, Sec 2 to Ch 6, Sec 3, taking account of combination as defined in [1.2].

1.1.3 The combination of global loads are mainly used to check:

- the strength of the decks and the upper part of side shell(s) against buckling
- the strength of the bottom of hull(s) against buckling
- the strength of the primary structure of the platform of catamarans, and particularly the transverse bulkheads connecting the floats
- the shearing strength of side shell(s) and longitudinal bulkheads.

1.2 Combination

1.2.1 The combinations of global loads (bending moments and shear forces) are to be made according respectively to Tab 1 and Tab 2.

Table 1 : Bending moments

Bending moments (kN.m)	Monohull		Catamarans	
Situation	Motor	Sailing	Motor	Sailing
Hogging	$M_{SW} + M_{WV0°}$	$M_{SW} + M_{WV0°}$	$M_{SW} + M_{WV0°}$	$M_{SW} + M_{WV0°}$
Sagging	$M_{SW} – M_{WV0°}$	$M_{SW} – M_{WV0°} – 0,7\ M_{RIG}$	$M_{SW} – M_{WV0°}$	$M_{SW} – M_{WV0°} – 0,7\ M_{RIG}$
Quartering seas	–	–	$M_{WV45°}$	$M_{WV45°} + 0,7\ M_{RIGT}$
Solid water over the bow	–	–	M_E	$M_E + 0,7\ M_{RIGT}$

Note 1:
M_{SW} : Still water bending moment (see Ch 6, Sec 2, [1])
$M_{WV0°}$: Wave bending moment in head sea (MWV,H or MWV,S) (see Ch 6, Sec 2, [2.2.2])
$M_{WV45°}$: Wave bending moment in quartering seas as calculated in Ch 8, Sec 2, [2.2] or Ch 9, Sec 2, [2.2]
M_E : Bending moment due to loading induced by bow diving into waves as defined in Ch 6, Sec 3, [3]
M_{RIG} : Hull girder vertical bending moment induced by the rig (see Ch 6, Sec 3, [2])
M_{RIGT} : Rig torque induced by the unsymmetrical rig loads (see Ch 8, Sec 2, [2.1.7] or Ch 9, Sec 2, [2.1.8]).

Table 2 : Vertical shear force

Vertical shear force (kN)	Monohull		Catamarans	
Situation	Motor	Sailing	Motor	Sailing
Hogging	$Q_{SW} + Q_{WV0°}$	$Q_{SW} + Q_{WV0°}$	$Q_{SW} + Q_{WV0°}$	$Q_{SW} + Q_{WV0°}$
Sagging	$Q_{SW} – Q_{WV0°}$	$M_{SW} – Q_{WV0°} – 0,7\ Q_{RIG}$	$Q_{SW} – Q_{WV0°}$	$Q_{SW} – Q_{WV0°} – 0,7\ Q_{RIG}$
Quartering seas	–	–	$Q_{WV45°}$	$Q_{WV45°} + 0,7\ Q_{RIG}$
Solid water over the bow	–	–	Q_E	$Q_E + 0,7\ Q_{RIG}$

Note 1:
Q_{SW} : Still water vertical shear force (see Ch 6, Sec 2, [1])
$Q_{WV0°}$: Wave vertical shear force in head sea (QWV) (see Ch 6, Sec 2, [2.2.2])
$Q_{WV45°}$: Wave vertical shear force in quartering seas as calculated in Ch 8, Sec 2, [2.2] or Ch 9, Sec 2, [2.2]
Q_E : Vertical shear force due to loading induced by bow diving into waves as defined in Ch 6, Sec 3, [3]
Q_{RIG} : Vertical shear force induced by the rig (see Ch 6, Sec 3, [2])

SECTION 1 HYDRODYNAMIC LOADS

Symbols

C_W : Wave height defined in [1.1.3]

L_W : Wave length, defined in [1.1.3]

X_I : Wave load coefficient, defined in [2.2.1] and in Tab 1

B_W : Breadth at waterline. For catamarans, see Fig 3

ℓ : Distance between internal sideshells of catamaran at waterline, defined in Fig 3

p_s : Sea pressure defined from [2] to [4]

p_{smin} : Minimum pressure on side shell as defined in [2.3]

p_{sumin} : Minimum pressure on superstructure as defined in Tab 3

p_{dmin} : Minimum pressure on deck as defined in [3.1.2].

1 Sea pressure

1.1 General

1.1.1 The local loads induced by the sea pressure on any point of the outside shell are the combined action of the hydrostatic pressure and the pressure induced by waves.

1.1.2 The hydrostatic pressures are calculated with full load condition.

1.1.3 The pressure induced by waves is given as a function of:

- the wave height C_W, in m, equal to:

  $C_W = 10 \log (L_W) - 10$

  without being taken less than 3m, where:

  L_W : Wave length equal to $0,5 (L_{WL} + L_{HULL})$
- a wave load coefficient X_i, defined inTab 1, and depending on the longitudinal location and on the type of yacht.

1.1.4 Bottom area

The bottom area is the part of the hull located below the full load waterline (see Fig 1).

1.1.5 Side shell area

The side shell area is the part of the hull located above the full load waterline.

1.2 Bottom and side shell

1.2.1 Bottom sea pressure for monohull

For monohull, sea pressure on bottom is considered uniform on the bottom area in any transverse section.

1.2.2 Side shell sea pressure for monohull

For monohull, side shell sea pressure are derived from the bottom sea pressure, taking into account the vertical distance z between the calculation point and the full load waterline in the considered transverse area (see Fig 2).

1.2.3 Bottom and side shell sea pressure for catamaran

In case of catamarans, the sea pressure for bottom and side shell are calculated taking account of a vertical distance between load point and base line, as shown on Fig 3.

2 Pressure on bottom and side shell

2.1 General

2.1.1 In any point, the design sea pressure to be taken into account for platings, secondary stiffeners and primary stiffeners is given in [2.2]

Figure 1 : Definition of bottom area for monohulls

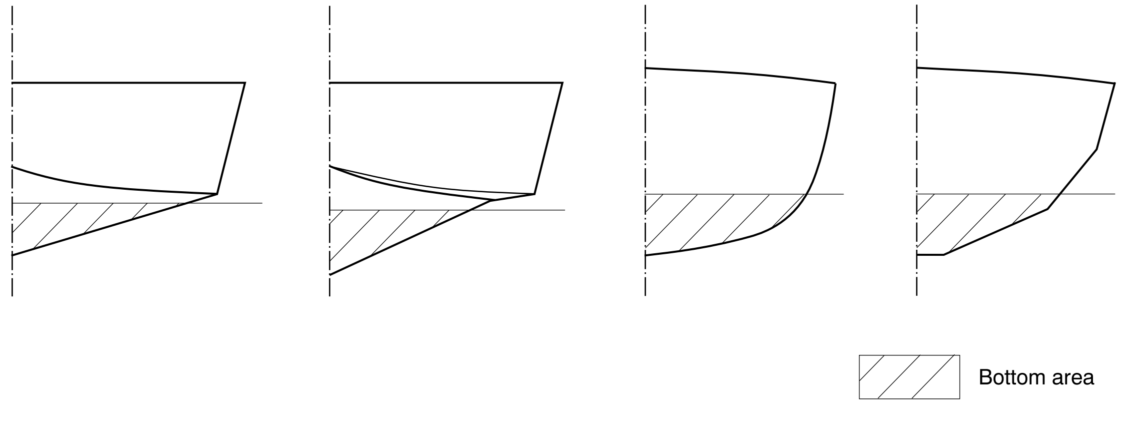


Figure 2 : Vertical distance z for monohull

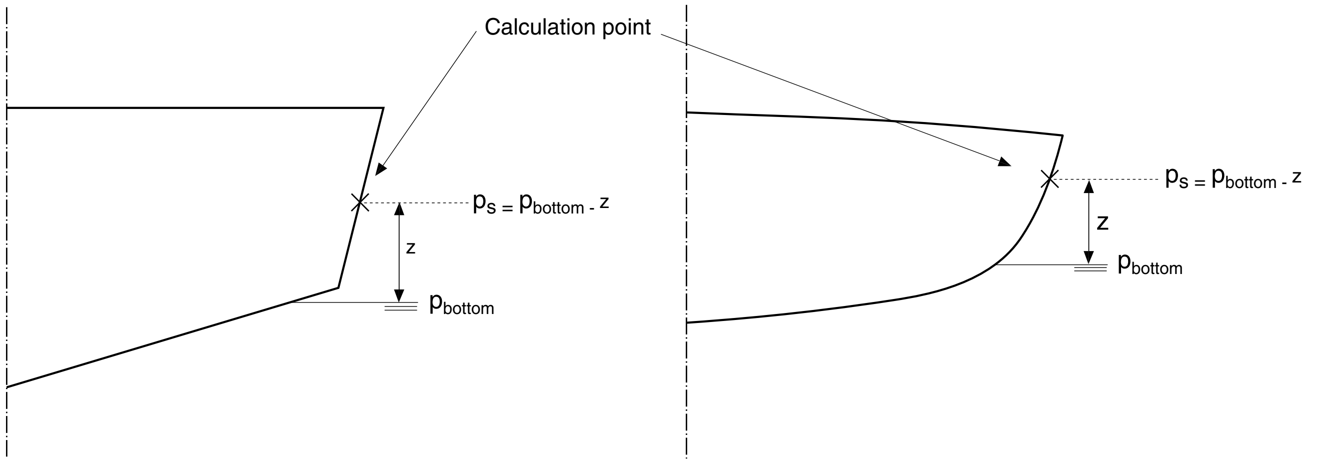
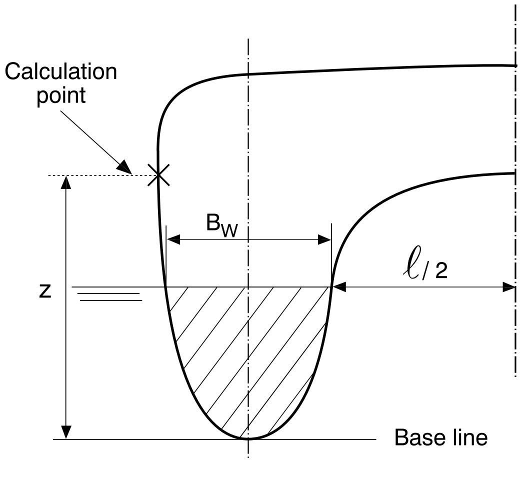


Figure 3 : Vertical distance z for catamarans



2.2 Sea pressure

2.2.1 For all types of yachts, the sea pressure in any point of the bottom and side shell, in kN/m², is defined by the following formula:

$$P_S = 9,807 n \left[T + \left(\frac{C_W}{X_I} + h_2 \right) - z \right]$$

where:

n : Coefficient depending on the navigation notation, as given in Pt B, Ch 4, Sec 2

T : Full load draught, in m

C_W : Wave height, defined in [1.1.3], in m

X_I : Wave load coefficient shown on Fig 4, and defined in Tab 1

z : Vertical distance from calculation point to the full load waterline (monohull) or to the base line (catamarans). For monohull, bottom pressure is calculated with z = 0

h_2 : Distance in m, equal to:

- for monohull: $h_2 = 0$
- for bottom or external side shell of catamarans: $h_2 = 0$
- for internal side shell of catamaran and inner side of cross deck of catamaran:

$$h_2 = \frac{B_W \left(T + \frac{C_W}{X_I} \right) C_B}{\ell}$$

where:

B_W : Breadth at full load waterline at considered transverse section (see Fig 3)

ℓ : Distance between internal side shells at waterline at considered transverse section, in m, as defined in Fig 3

C_B : Block coefficient defined in Ch 1, Sec 2, [2.1.1].

Table 1 : Wave load coefficients

Type of yachts	Area 4 **(1)** X_4	Area 3 **(1)** X_3	Area 2 **(1)** X_2	Area 1 **(1)** X_1
Monohull motor yacht	2,8	2,2	1,9	1,7
Monohull sailing yacht	2,2	1,9	1,7	1,4
Multihull motor yacht	2,8	2,2	1,9	1,4
Multihull sailing yacht	2,5	2,2	1,7	1,1
(1) See Fig 4 for definition of areas.				

Figure 4 : Load areas and coefficient X_i for the external side shell and bottom sea pressure

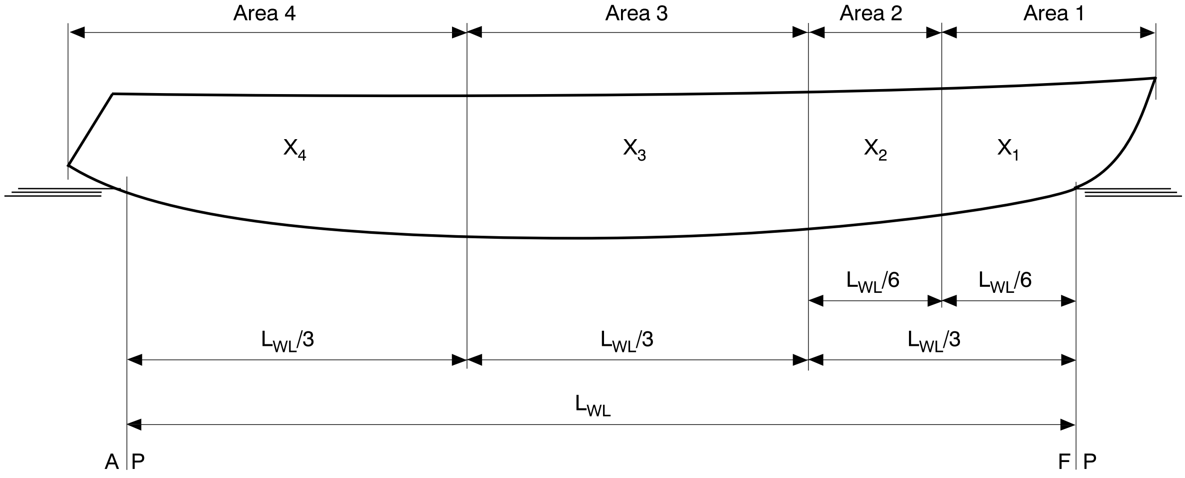
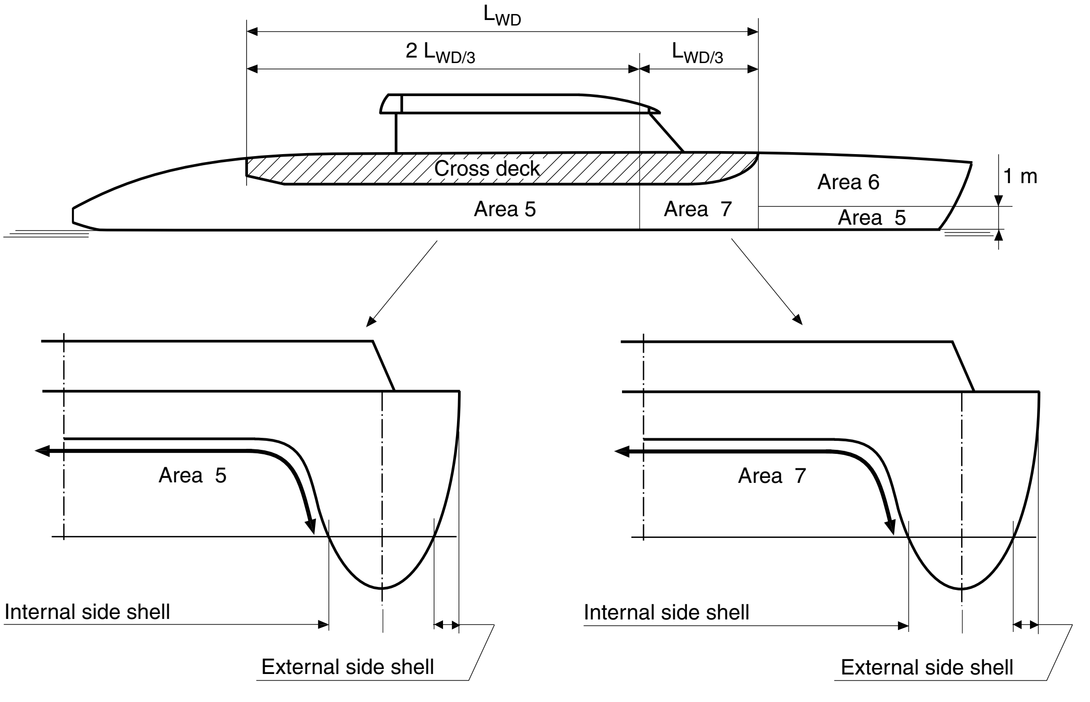


Figure 5 : Load areas for the impact pressure on internal side shell on catamaran



2.3 Impact pressure on side shell

2.3.1 General

The impact pressure given hereafter is to be considered as a minimum pressure on side shell and is to be taken into account only for plating and secondary stiffeners located on side shell area as defined in [1.1.5].

Impact pressure on side shell represents the local wave impact load and is locally distributed like a water column of 0,6 m diameter. The admissible stresses or the safety coefficients to be considered are given in Ch 4, Sec 3.

2.3.2 Monohull

In any point of the side shell of monohull, the impact pressure p_{smin}, in kN/m², is to not be less than:

- in areas 1 and 2 as defined in Fig 4 (from fore perpendicular to $L_{WL}/3$ aft of fore perpendicular), between the full load waterline and 1 m above:

  $p_{smin} = 80\ n\ K_2$

- elsewhere:

  $p_{smin} = 50\ n\ K_2$

where:

n : Coefficient depending on the navigation notation, as given in Ch 4, Sec 2

k_2 : $K_2 = 0,455 - \left(0,35 \cdot \dfrac{u^{0,75} - 1,7}{u^{0,75} + 1,7}\right)$

with:

$K_2 \geq 0,50$ for plate panel

$K_2 \geq 0,45$ for stiffener,

and:

$u = 100\ s / S_r$

S_r : reference area, m², equal to:

$$S_r = 0,7\frac{\Delta}{T}$$

For catamaran, Δ in the above formula is to be taken as half the craft displacement

s : Surface of the elementary plate panel or surface of the plate panel supported by the stiffener, in m²

T : Full load draught, in m.

2.3.3 Catamaran

In any point of the external side shell of catamaran, the impact pressure p_{smin}, in kN/m², is to not be less than:

- in areas 1 and 2, as defined in Fig 4 (from fore perpendicular to $L_{WL}/3$ aft of fore perpendicular), between the full load waterline and 1 m above: $p_{smin} = 80\ n\ K_2$
- elsewhere, $p_{smin} = 50\ n\ K_2$

where:

n, K_2 : As defined in [2.3.2]

In any point of the internal side shell and the underside of cross deck of catamarans, the impact pressure p_{smin}, in kN/m², is to be not less than:

- in area 5 as defined in Fig 5: $p_{smin} = 80\ n\ K_2$
- in area 6 as defined in Fig 5: $p_{smin} = 50\ n\ K_2$
- in area 7 as defined in Fig 5: $p_{smin} = 120\ n\ K_2$

where:

n, K_2 : As defined in [2.3.2].

3 Pressure on decks

3.1 Exposed decks

3.1.1 The sea pressure on any point of exposed deck, in kN/m², is to be not less than the greater of the sea pressure given hereafter and the minimum pressure given in [3.1.2]:

$$P_s = (p_0 - z_D 9,807)\varphi_1 n$$

where:

φ_1 : Reduction coefficient depending of the location of the considered deck with respect to the full load waterline:

- $\varphi_1 = 1,00$ for freeboard deck(m), as defined in Ch 2, Sec 2, [2.2.1]
- $\varphi_1 = 0,75$ for the first deck just above the freeboard deck(m), as defined in Ch 2, Sec 2, [2.2.1]
- $\varphi_1 = 0,50$ for the decks above

n : Navigation coefficient as as defined Ch 4, Sec 2

p_0 : Sea pressure on bottom in the considered area, in kN/m², calculated according to [2.2.1] with z = 0

z_D : Vertical distance, in m, between the deck at side at the considered transverse section and the full load waterline (for monohull) or the baseline (for catamaran).

3.1.2 The pressure given in [3.1.1] is to be not less than the following minimal sea pressure p_{dmin}, in kN/m²:

- in areas 1 and 2, as defined in Fig 4 (from fore perpendicular to $L_{WL}/3$ aft of fore perpendicular):

  $p_{dmin} = 15\ n\ \varphi_1$
- in areas 3 and 4 (elsewhere):

  $p_{dmin} = 10\ n\ \varphi_1$

where:

φ_1, n : As defined in [3.1.1].

3.2 Accommodation decks

3.2.1 The pressure on accommodation decks is to be not less than:

- $p_s = 5$ kN/m², in large spaces (lounges, cinema, restaurant, kitchens, etc)
- $p_s = 3$ kN/m², in cabins
- $p_s = 10$ kN/m², in technical spaces and machinery spaces.

3.3 Superstructure deck

3.3.1 The pressure on exposed and accommodation superstructure decks are to be not less than the values given in [3.1] and [3.2].

However, when an exposed superstructure deck is not directly exposed to green seas effect, the pressure on this deck is to be taken not less than:

- $p_S = 5$ kN/m² for decks accessible to passengers or crew members.
- $p_S = 3$ kN/m² for decks not accessible to passengers or crew members.

4 Pressure on superstructures

4.1 General

4.1.1 In any point, the design pressure is to be taken as the sea pressure given in [4.2], without being taken less than the minimum pressure given in [4.3].

4.2 Sea pressure

4.2.1 The design pressure to be considered for scantlings of fore walls, side walls and aft walls of superstructures and deckhouses, in kN/m², is to be not less than:

$$p_S = 7 \cdot a \cdot c \cdot n \cdot (b \cdot f - z_S)$$

where:

a : Coefficient as given in Tab 2

c : Coefficient equal to:

- for monohull - motor yacht:

  $c = 0{,}3 + 0{,}7\ b_i / B_i$

- for monohull - sailing yacht: $c = 1{,}0$
- for catamarans (sailing or motor): $c = 0{,}5$

where:

B_i : Breadth of hull at the considered longitudinal location

b_i : Breadth of superstructure or deckhouse at the considered longitudinal location

Table 2 : Coefficient a

Location		a
Front wall	First tier	$2{,}0 + L_{WL}/ 120$
	2nd tier and above	$1{,}0 + L_{WL}/ 120$
Aft wall		$0{,}5 + L_{WL} / 1000$
Side walls		$0{,}5 + L_{WL} / 150$

n : Navigation coefficient as defined Ch 4, Sec 2, [3]

b : Coefficient equal to:

- in areas 1 and 2 as defined in Fig 4 (from fore end to $L_{WL}/3$ aft of fore perpendicular): $b = 1{,}5$
- in areas 3 and 4 (elsewhere): $b = 1{,}0$

f : Coefficient equal to:

$f = -\ 2\ L_W^2 / 8000 + 0{,}1\ L_W - 1$

L_W : Wave length, in m, as defined in [1.1.3]

z_S : Vertical distance, in m, between the full load waterline and the calculation point, located as follows:

- for plating: mid-height of the elementary plate panel
- for stiffeners: mid-span.

4.3 Minimum pressures

4.3.1 As a rule, the design pressures to be considered for scantling of plating and supporting members of superstructures are to be not less than the minimum pressures p_{smin} given in Tab 3.

4.3.2 When the front wall is sloped aft, the front wall pressures values (sea pressures and minimum pressure) can be multiplied by cos a, where a is the angulation between z axis and straight line tangent to superstructure as shown on Fig 6.

5 Pressure in tanks

5.1 General

5.1.1 Scantlings of watertight bulkeadings of tanks are to be determined with design pressures given in Tab 4.

Tank testing conditions are also to be checked with testing pressures given in Tab 4.

Figure 6 : angulation of superstructures

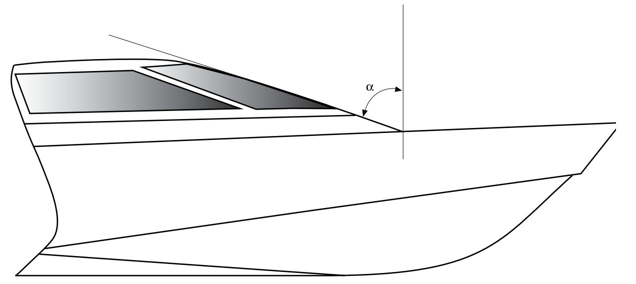


Table 3 : Minimum pressures

Type of wall	Location	p_{sumin} (in kN/m²)
Unprotected front wall	Lower tier, areas 1 and 2	21
	Lower tier, areas 3 and 4	15
	Upper tiers	10
Protected front wall or side walls	Lower tier	10
	Upper tiers	7
Unprotected aft wall	Lower tier, area 4	10
	Lower tier, areas 1, 2 and 3	7
	Upper tiers	7
Protected aft wall	Anywhere	5
Note 1: Areas are defined in Fig 4.		

Table 4 : Tank design and testing pressures

Type of tanks	Design pressure, in kN/m²	Testing pressure, in kN/m²
Water ballast Fresh water tank	$p_S = 11\ [(z_{AP} - z_{TOP}) + z_1]$	$p_T = 11\ (d_{AP} + z_1)$ without being less than p_V
Gas-oil or Fuel-oil tank	$p_S = 11\ [(z_{AP} - z_{TOP}) + z_1]$	$p_T = 11\ (d_{AP} + z_1)$ or $p = 10\ (2{,}4 + z_1)$ whichever is the greater, without being less than p_V

Note 1:

z_{TOP} : Z co-ordinate, in m, of the top of the tank

z_{AP} : Z co-ordinate, in m, of the moulded deck line of the deck to which the air pipes extend

d_{AP} : Vertical distance, in m, between the top of the tank and the top of the air pipe

z_1 : Vertical distance, in m, between the calculation point and the top of the tank

p_V : Safety pressure of valves, if applicable, in bar.

6 Pressure on bulkheads

6.1 General

6.1.1 Two types of watertight bulkheads are covered by the present Article :

- ordinary watertight bulkheads, fitted to partition the yacht into watertight compartments for damage stability purposes. The design pressure on such bulkheads is given in [6.1.3],
- watertight bulkheads forming boundary of a liquid capacity (Gas-oil, water ballast, fresh water, etc). The design pressure on such bulkheads is given in [5].

6.1.2 Non-watertight bulkheads are not subject to any design lateral pressure.

6.1.3 Scantlings of ordinary watertight bulkeads are to be determined with design pressures given in Tab 5.

However, in case of special arrangement of watertight bulkheads, the Society may request specific analysis and determination of design pressures to be used.

Table 5 : Watertight bulkheads design pressure

Type of bulkheads	Design pressure, in kN/m^2
Watertight bulkhead other than collision bulkhead	$p_S = 10\ (1.3T - z) > 0$
Collision bulkhead	$p_S = 10\ (D - z) > 0$

Note 1:
T : Full draught, in m,
z : Z co-ordinate, in m, of the calculation point
D : Depth as defined in Ch 1, Sec 2, [3.6]

SECTION 2 BOTTOM SLAMMING LOADS

1 General

1.1 Slamming loads

1.1.1 As a rule, bottom slamming loads given in the present Section, in kN/m^2, are applied to the following types of ships:

- high speed motor yacht of monohull and multihull type
- sailing yachts of monohull type.

1.1.2 Slamming loads sustained by plating and ordinary stiffeners may be considered as uniform pressures.

1.2 Slamming areas

1.2.1 As a rule, bottom slamming loads are to be calculated at following areas:

- high speed motor yacht of monohull type: bottom area, from centreline to upper limit of bilge or hard chine, and from transom to fore end
- sailing yacht of monohull type: bottom area, from centreline to waterline at side, and from centre of gravity of the keel or the bulb keel to fore end
- motor yacht of multihull type: bottom area, from centreline of each hull to upper limit of bilge or hard chine, and from transom to fore end.

2 High speed motor yacht of monohull or multihull type

2.1 Plating and stiffeners

2.1.1 If slamming is expected to occur, the slamming pressure, in kN/m^2, considered as acting on the bottom of hull is to be not less than:

$$p_{sl} = 70 \cdot \frac{\Delta}{S_r} \cdot K_1 \cdot K_2 \cdot K_3 \cdot a_{CG}$$

where:

Δ : Displacement, in tonnes. For catamaran, Δ in the above formula is to be taken as half of the craft displacement

S_r : Reference area, in m^2, equal to:

$$S_r = 0,7 \cdot \frac{\Delta}{T}$$

For catamaran, Δ in the above formula is to be taken as half the craft displacement

K_1 : Longitudinal bottom slamming pressure distribution factor (see Fig 1):

- for $x/L < 0,5$: $K_1 = 0,5 + x/L$
- for $0,5 \le x/L \le 0,8$: $K_1 = 1,0$
- for $x/L > 0,8$: $K_1 = 3,0 - 2,5\ x/L$

where x is the distance, in m, from the aft perpendicular to the load point

K_2 : Factor accounting for slamming area, equal to:

$$K_2 = 0,455 - 0,35 \cdot \frac{u^{0,75} - 1,7}{u^{0,75} + 1,7}$$

with:

- $K_2 \ge 0,50$ for plating
- $K_2 \ge 0,45$ for ordinary stiffeners
- $K_2 \ge 0,35$ for primary stiffeners

$$u = 100 \cdot \frac{s}{S_r}$$

where s is the area, in m^2, supported by the element (plating or stiffener). For plating, the supported area is the spacing between the stiffeners multiplied by their span, without taking for the latter more than three times the spacing between the stiffeners

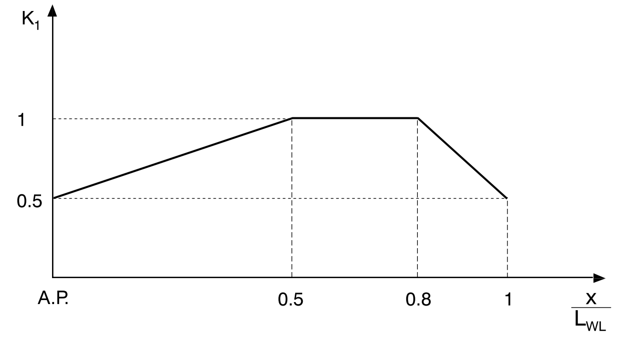
K_3 : Factor accounting for shape and deadrise of the hull, equal to:

$$K_3 = (50 - \alpha_d)/(50 - \alpha_{dCG}) \le 1$$

where α_{dCG} is the deadrise angle, in degrees, measured at LCG and α_d is the deadrise angle, in degrees, between horizontal line and straight line joining the edges of respective area measured at the longitudinal position of the load point; values taken for α_d and α_{dCG} are to be between 10° and 30°

a_{CG} : Design vertical acceleration at LCG, defined in Ch 5, Sec 1, [2.1.7].

Figure 1 : K_1 distribution factor



3 Sailing yachts of monohull type

3.1 Plating and stiffeners

3.1.1 The slamming pressure, in kN/m², considered as acting on the bottom of hull is to be not less than:

$$p_{sl} = 70 \cdot \frac{\Delta}{S_r} \cdot K_2 \cdot K_3 \cdot a_v$$

where:

Δ : Displacement, in tonnes

S_r : Reference area, m², equal to:

$$S_r = 0,7 \cdot \frac{\Delta}{T}$$

K_2 : Factor accounting for slamming area, equal to:

$$K_2 = 0,455 - 0,35 \cdot \frac{u^{0,75} - 1,7}{u^{0,75} + 1,7}$$

with:

- $K_2 \geq 0,50$ for plating
- $K_2 \geq 0,45$ for ordinary stiffeners
- $K_2 \geq 0,35$ for primary stiffeners

$$u = 100 \cdot \frac{s}{S_r}$$

where s is the area, in m², supported by the element (plating, stiffener, floor or girder). For plating, the supported area is the spacing between the stiffeners multiplied by their span, without taking for the latter more than three times the spacing between the stiffeners

K_3 : Factor accounting for shape and deadrise of the hull, equal to:

$$K_3 = (50 - \alpha_d)/(50 - \alpha_{dCG}) \leq 1$$

where α_{dCG} is the deadrise angle, in degrees, measured at LCG and α_d is the deadrise angle, in degrees, between horizontal line and a reference line defined in Fig 2 at the transversal section considered; α_d is not to be taken greater than 50 degrees

a_v : Total vertical acceleration resulting from the sum of heave and pitch acceleration (refer to Ch 5, Sec 1, [2.2.4]).

3.1.2 As a rule, the slamming pressure is to be calculated along the ship, from center of gravity of the keel or the bulb keel to fore part of ship.

Longitudinal location of calculation points can be taken as indicated in Fig 3. The value of the total vertical acceleration a_v is to be calculated at each calculation point P_i.

Figure 2 : Deadrise angle

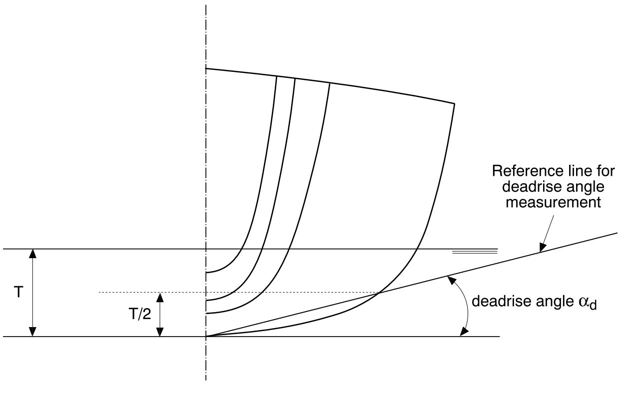
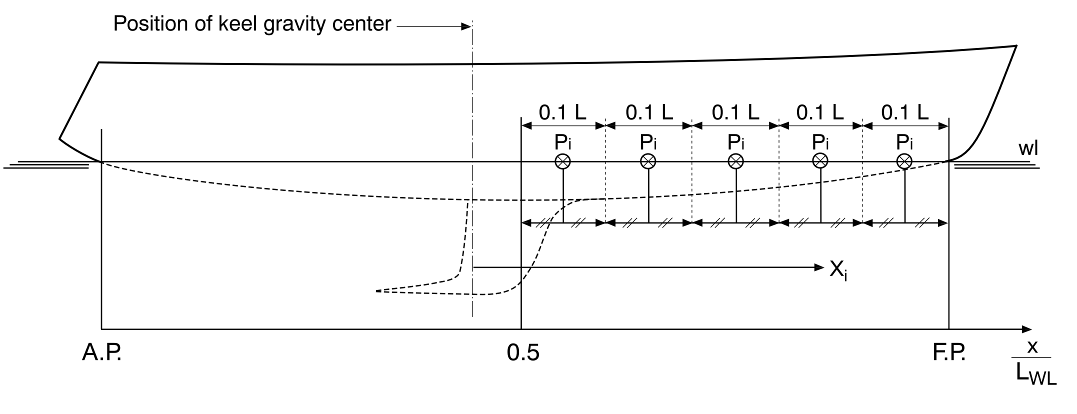


Figure 3 : Calculation points for slamming pressure



SECTION 1 GENERAL

1 Application

1.1 General

1.1.1 The requirements of the present chapter are applicable to structural members of hull and superstructures of yachts and charter yachts built in steel and/or in aluminium (totally or partly).

SECTION 2 HULL GIRDER AND CROSS DECK

1 Hull girder of monohull and catamaran

1.1 General

1.1.1 The global loads are to be taken into account for the review of hull girder of monohull and catamaran and for the cross deck of catamaran in the cases listed in Ch 6, Sec 1, [1.3].

1.1.2 The design review of hull girder structure consists in:

- checking that global stresses are less than the admissible values given in Ch 4, Sec 3, Tab 2 and Ch 4, Sec 3, Tab 4 as appropriate (σ_{glam}, τ_{glam})
- checking that the actual safety factors for buckling of plating and stiffeners contributing to longitudinal hull girder strength are more than the admissible values given in Ch 4, Sec 3, Tab 2 and Ch 4, Sec 3, Tab 4, as appropriate (SF).

1.1.3 The calculation of global stresses is carried out on basis of:

- the combination of global loads (bending moments) as indicated in Ch 6, Sec 4,
- the actual strength characteristics of the hull girder as indicated in Ch 4, Sec 4

1.1.4 The buckling strength of structural members contributing to the longitudinal hull girder strength is checked on basis of:

- relevant requirements of Ch 8, Sec 3 for plating
- relevant requirements of Ch 8, Sec 4 for stiffening members.

1.1.5 As a rule, the checking of the hull girder strength is to be carried out for monohull yachts and for catamarans yachts.

2 Cross deck of catamaran

2.1 Estimation of stiffness of cross deck

2.1.1 The design review of the main structure of the cross deck of catamarans under global wave torque may be checked by means of a beam model analysis, as shown on Fig 1. Any other justified checking method may be considered.

This design review consists in:

- checking that global stresses in floats are less than the admissible values given in Ch 4, Sec 3, Tab 2 and Ch 4, Sec 3, Tab 4 as appropriate (σ_{glam}, τ_{glam})
- checking that local stresses in cross connecting structure (cross beams or transverse bulkheads) are less than the admissible values given in Ch 4, Sec 3, Tab 2 and Ch 4, Sec 3, Tab 4 as appropriate (σ_{locam}, τ_{locam}).

2.1.2 The purpose of the present calculation is to determine the loads distribution in the cross deck between floats, versus flexural and shear stiffnesses of the primary structure of the cross deck.

2.1.3 Each resisting transverse member between floats is modelized as a beam, taking account of:

- flexural inertia about an horizontal axis, depending mainly on the web height of the transverse cross beam or bulkhead, the roof deck thickness or the float deck thickness and the thickness of the underside of the cross deck (wet deck)
- vertical shear inertia, depending on the web height of the transverse cross beams or bulkheads and their thickness
- their span between inner side shell of floats.

Figure 1 : Cross deck of catamarans - Model principle

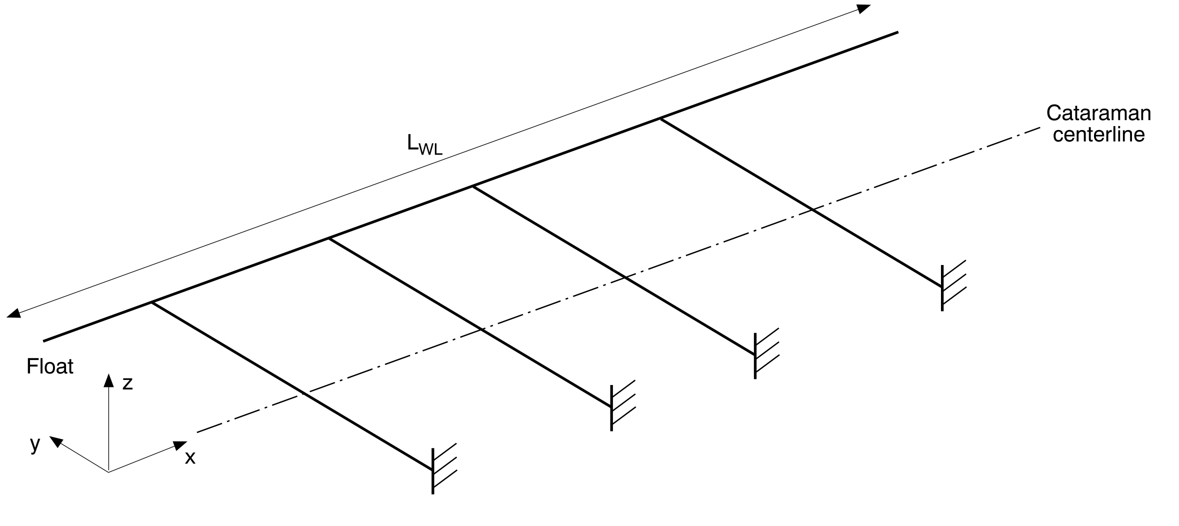
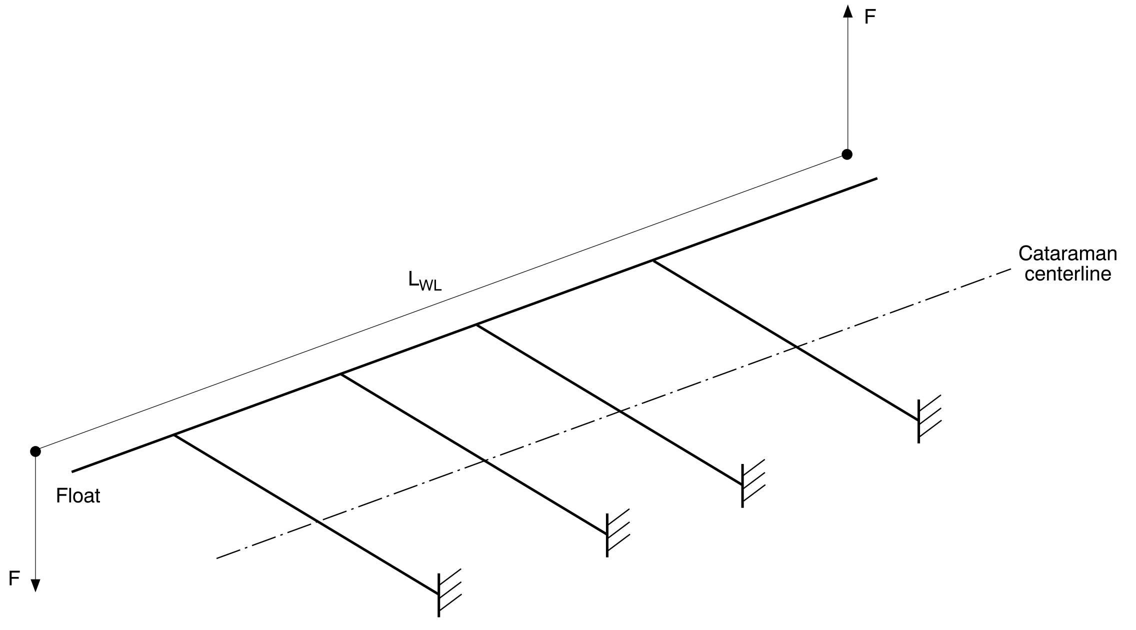


Figure 2 : Application of wave torque in beam model



2.1.4 As far as possible, the beam model of the float is to have:

- vertical and horizontal inertias close to the actual one of the float
- a shear inertia close to the actual one of the float
- a torsional inertia about longitudinal float axis close to the actual one of the float.

The second float is not described as a beam in the beam model. Instead, the transverse cross beams in the beam model are fully fixed at their intersection with this float.

2.1.5 Wave torque model

The wave torque moment exerted on the cross deck may be represented by 2 vertical forces F, equal in magnitude and opposite in direction, as shown on Fig 2. The magnitude of the force F, in kN, is to be taken equal to:

$F = M_{WT} / L_{WL}$

where:

M_{WT} : Wave torque moment, in kN.m, calculated according to Ch 6, Sec 2, [2.3.2]

L_{WL} : Length of the float at full load waterline, in m, as described in the beam model (see Fig 1).

2.1.6 Digging in loading model

The loading due to digging in, as described in Ch 6, Sec 3, [3], may be satisfactorily taken into account in the beam model by applying a differential vertical loading F_V (difference between the vertical loads exerted on both floats) and a differential horizontal load F_H (difference between the horizontal loads exerted on both floats), as shown on Fig 3.

The linear loads to input in the beam model, F_V and F_H , in kN/m, are to be calculated as follows, with F′ and F″ calculated according to Ch 6, Sec 3, [3.2]:

$$F_V = \frac{F'/3}{L_{WL}/4}$$

$$F_H = \frac{F''/3}{L_{WL}/4}$$

2.1.7 Rig torque

For catamaran sailing yacht, the torque exerted by standing rigging may be represented by 2 vertical forces F_{RIG}, equal in magnitude and opposite in direction, as indicated in [2.1.5]. The magnitude of the force F, in kN, is to be taken equal to:

$F_{RIG} = M_{RIGT} / L_{WL}$

where:

M_{RIGT} : Rig torque, in kN.m, calculated according to the method given in Ch 6, Sec 3, [2.4]

L_{V1}', L_{D1}', L_P': Distances, in m, between various chain plates of the standing rigging and the center of rotation of the cross deck, measured according to Fig 4.

The longitudinal position of the center of rotation of the cross deck is estimated from the results of the beam model analysis specified in [2.1.5].

2.1.8 Combination of loadings

The two loading cases to be considered are defined in Ch 6, Sec 4 and are reminded below for information:

- wave torque loading combined with 70 percent of the rig torque
- digging in torque combined with 70 percent of the rig torque.

2.2 Floats structure

2.2.1 The structure of each float is to be checked as indicated in [1], considering the vertical bending moments and the vertical shear forces coming from the beam model analysis performed to check the cross deck structure, as shown on Fig 5.

Figure 3 : Application of digging in loads in beam model

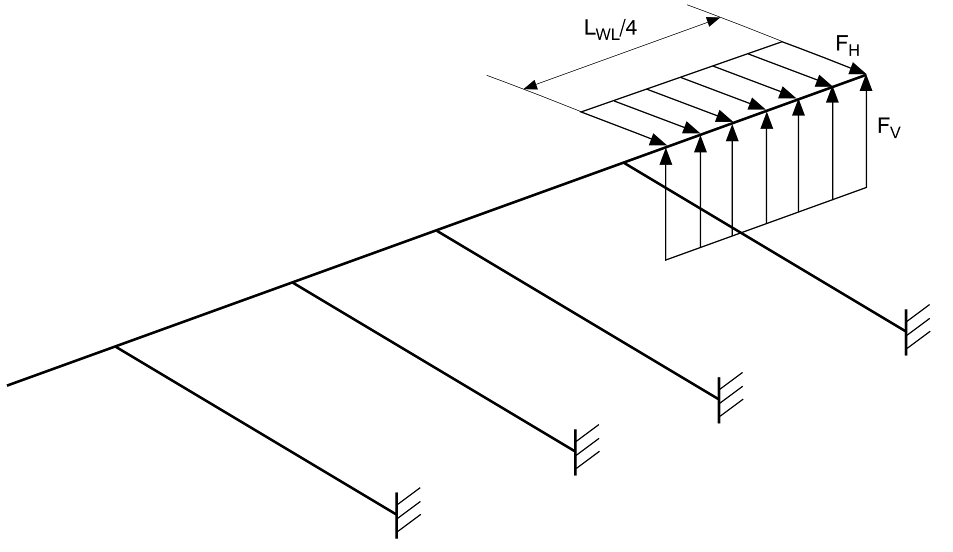
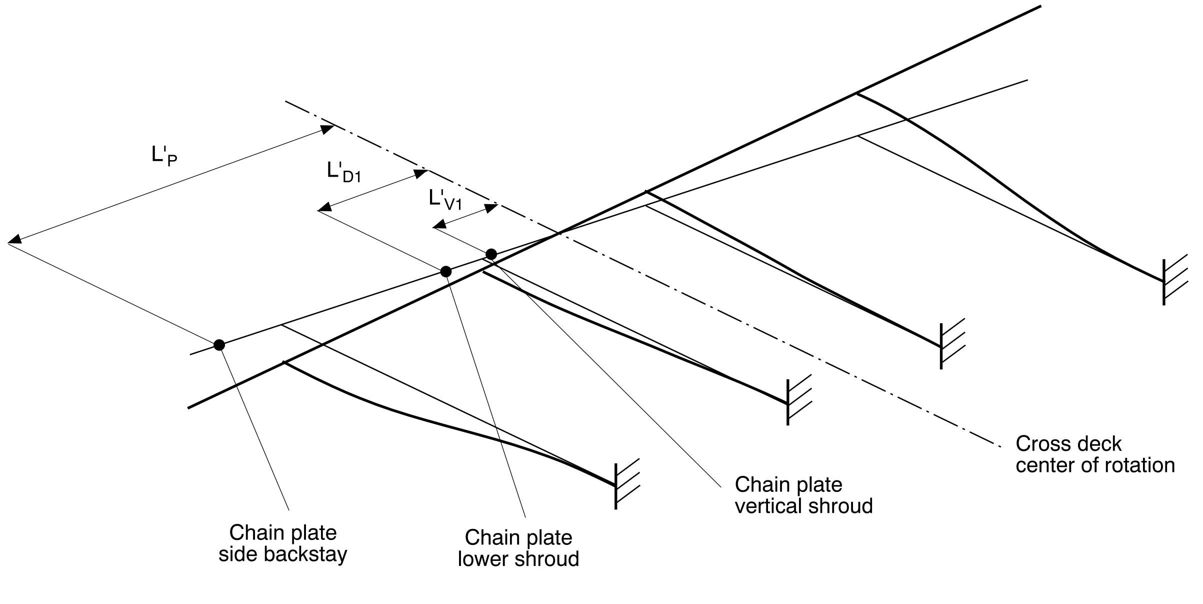


Figure 4 : Rig lever arm inducing rig torque



2.2.2 The geometrical characteristics of the float may be determined using Bureau Veritas Rule software "MARS", as indicated in Ch 1, Sec 4, [2.3], or any other equivalent mean.

The transverse sections to be considered are to take into account all the longitudinal continuous members (plates and longitudinal stiffeners) in the areas shown on Fig 6:

b_R : Breadth equal to 10% of the roof length

b_{WD} : Breadth equal to 10% of the cross deck length.

2.3 Primary transverse structure between floats

2.3.1 Each resisting transverse cross member between floats (cross beams, bulkheads) is checked against flexural and shear strength, taking account of the bending moments and shear forces resulting from the beam model analysis described in [2].

The values of bending moments and shear forces to consider are the one calculated in the transverse beams of the beam model, in way of the modelized float.

The transverse distribution of vertical bending moments and vertical shear force is indicated in Fig 7.

2.3.2 Particular attention is to be paid to:

- shear buckling check of transverse bulkheads
- compression/bending buckling check of wet deck and cross deck plating in areas where the bending moment is maximum.

2.3.3 For catamarans sailing yachts, the cross beam supporting the mast is to be checked as indicated in [2.3.1] and [2.3.2], with added effect of loads induced by mast on this particular cross beam.

This cross beam may be considered as fixed in way of inside side plating of floats and loaded by the mast (considererd as a concentrated force).

The mast compressive load, as given by the Shipyard or the Designer, is to be considered with a contribution factor 0,7.

Figure 5 : Overall loads in the float

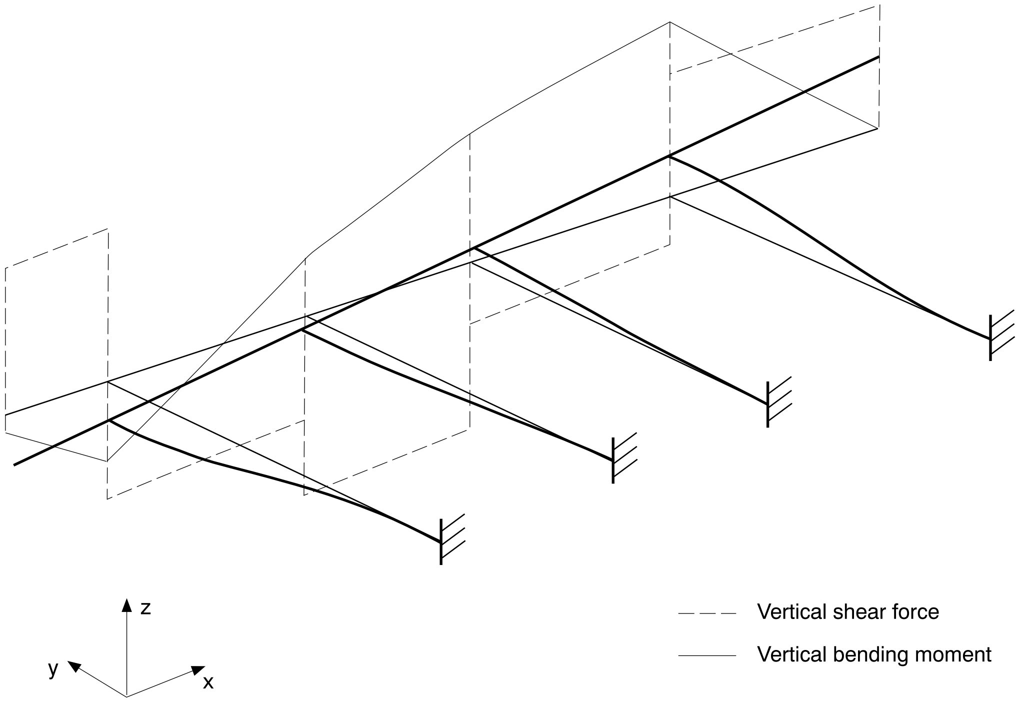


Figure 6 : Area to take into account for continuous members (plates and stiffeners) for hull girder strength

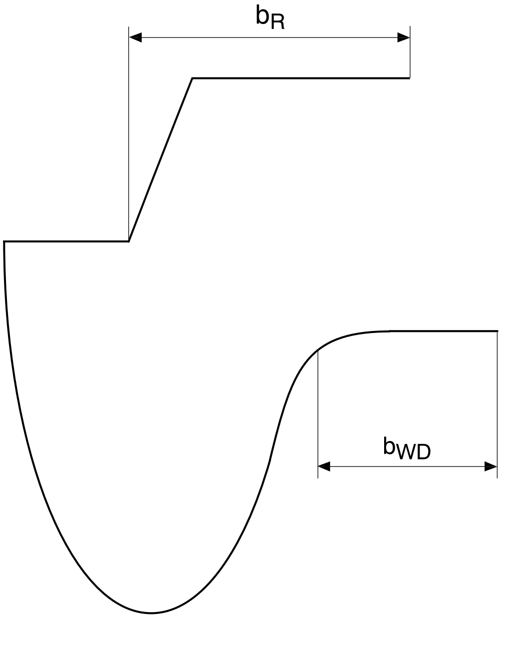
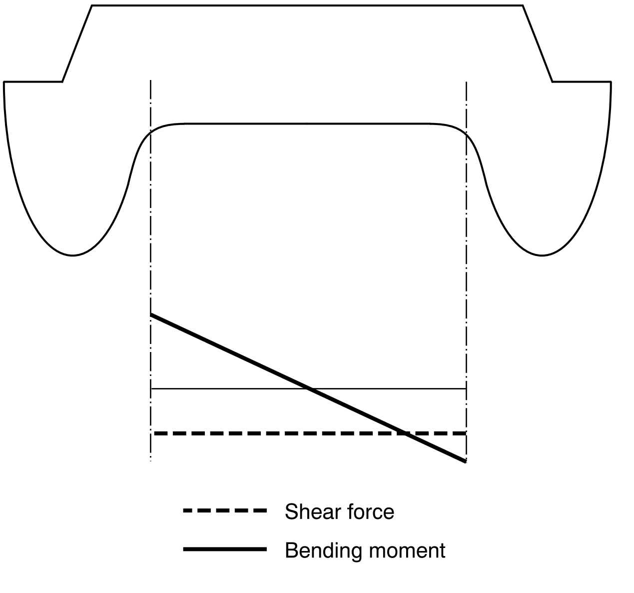


Figure 7 : Transverse distribution of bending moment and shear force



SECTION 3 PLATING

Symbols

E : Young's modulus, in N/mm², to be taken equal to:
- for steels in general: $E = 2{,}06.10^5$ N/mm²
- for stainless steels: $E = 1{,}95.10^5$ N/mm²
- for aluminium alloys: $E = 7{,}0.10^4$ N/mm²

1 General

1.1 Insert plates and doublers

1.1.1 A local increase in plating thickness is generally to be achieved through insert plates. Local doublers are normally only allowed for temporary repair.

2 Buckling check of plating

2.1 General

2.1.1 The requirements of this Article apply for the buckling check of plating subjected to in-plane compression stresses, acting on one or two sides, or to shear stress.

Rectangular plate panels are considered as being simply supported. For specific designs, other boundary conditions may be considered, at the Society's discretion, provided that the necessary information is submitted for review.

2.2 Loading principles

2.2.1 Panel loaded by compression/bending stress

See Fig 1.

2.2.2 Panel loaded by shear stress

See Fig 2.

2.2.3 Panel loaded by compression stress on 4 edges

See Fig 3.

2.3 Load model and calculation

2.3.1 Sign convention for normal stresses

The sign convention for normal stresses is as follows:
- tension: positive
- compression: negative.

2.3.2 As a rule, the normal and shear stress considered for buckling check of plating are the stresses determined by a direct calculation taking into account the global loads as defined in Part B, Chapter 6 and the strength characteristics of hull girder transverse sections as defined in Ch 4, Sec 4, [2].

2.3.3 The hull areas to be checked according to the requirements of the present section are:
- bottom and decks plating
- side shell plating, in the upper area below strength deck
- deck area around mast of monohull sailing yachts (buckling under compression stress on four edges)
- bottom and deck plating of cross deck of catamarans, in way of transverse primary bulkheads
- primary transverse bulkheads of catamarans (buckling under shear stress).

Figure 1 : Buckling of a simply supported rectangular plate panel subjected to compression and bending, with and without shear

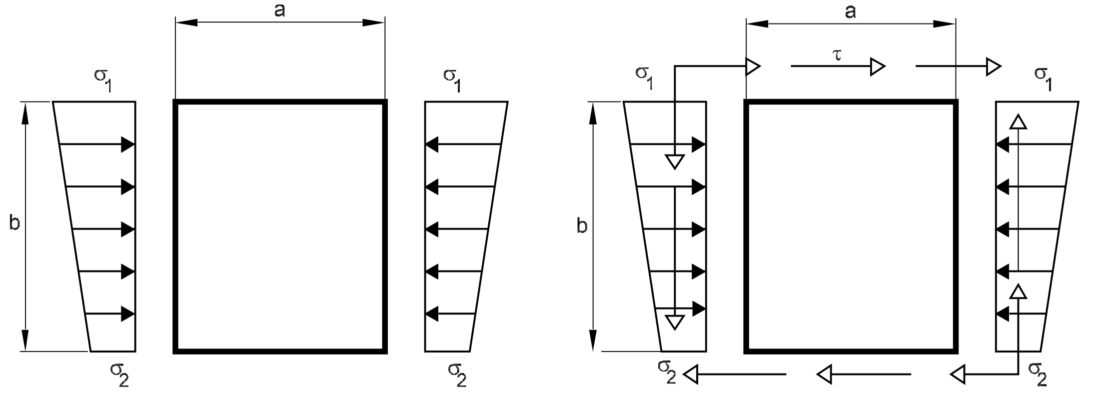


Figure 2 : Buckling of a simply supported rectangular plate panel subjected to shear

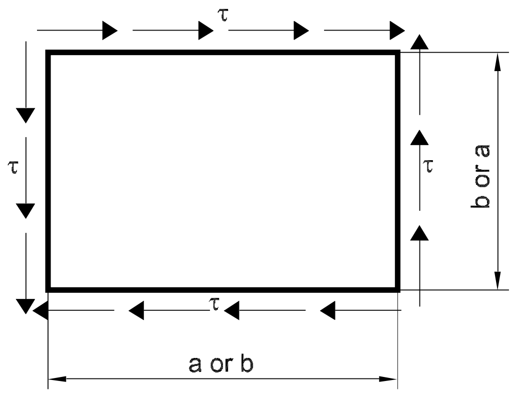
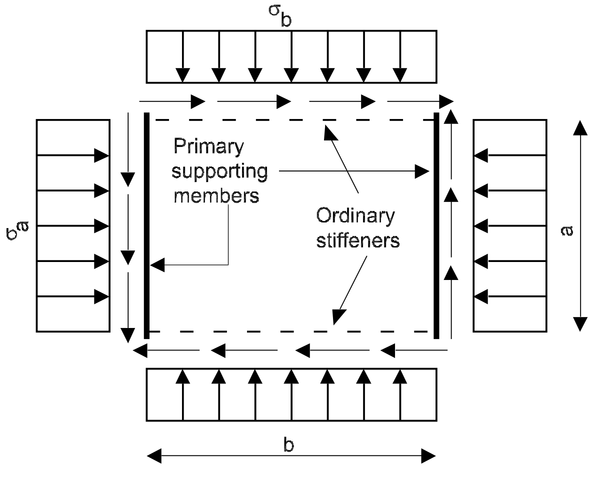


Figure 3 : Buckling of a simply supported rectangular plate panel subjected to bi-axial compression and shear



2.4 Critical stresses

2.4.1 Compression and bending for plane panel

The critical buckling stress is to be obtained, in N/mm², from the following formulae:

$$\sigma_c = \sigma_E \quad \text{for } \sigma_E \le \frac{R_{p0,2}}{2}$$

$$\sigma_c = R_{p0,2}\left(1 - \frac{R_{p0,2}}{4\sigma_E}\right) \quad \text{for } \sigma_E > \frac{R_{p0,2}}{2}$$

where:

σ_E : Euler buckling stress, to be obtained, in N/mm², from the following formula:

$$\sigma_E = \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t}{b}\right)^2 K_1 \varepsilon 10^{-6}$$

$R_{p0,2}$: Minimum guaranteed yield stress, in N/mm², of the plating material, defined in Ch 4, Sec 3

t : Minimum thickness of the plate panel, in mm

a, b : Lengths, in m, of the sides of the panel, as shown in Fig 1and Fig 3

K_1 : Buckling factor defined in Tab 1

ε : Coefficient to be taken equal to:

- $\varepsilon = 1$ for $\alpha \ge 1$,
- $\varepsilon = 1,05$ for $\alpha < 1$ and side "b" stiffened by flat bar
- $\varepsilon = 1,10$ for $\alpha < 1$ and side "b" stiffened by bulb section
- $\varepsilon = 1,21$ for $\alpha < 1$ and side "b" stiffened by angle or T-section
- $\varepsilon = 1,30$ for $\alpha < 1$ and side "b" stiffened by primary supporting members.

$\alpha = a/b$

2.4.2 Shear for plane panel

The critical shear buckling stress is to be obtained, in N/mm², from the following formulae:

$$\tau_c = \tau_E \quad \text{for } \tau_E \le \frac{R_{p0,2}}{2\sqrt{3}}$$

$$\tau_c = \frac{R_{p0,2}}{\sqrt{3}}\left(1 - \frac{R_{p0,2}}{4\sqrt{3}\tau_E}\right) \quad \text{for } \tau_E > \frac{R_{p0,2}}{2\sqrt{3}}$$

where:

τ_E : Euler shear buckling stress, to be obtained, in N/mm², from the following formula:

$$\tau_E = \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t}{b}\right)^2 K_2 10^{-6}$$

K_2 : Buckling factor to be taken equal to:

$$K_2 = 5,34 + \frac{4}{\alpha^2} \quad \text{for } \alpha > 1$$

$$K_2 = \frac{5,34}{\alpha^2} + 4 \quad \text{for } \alpha \le 1$$

$R_{p0,2}$: Minimum guaranteed yield stress, in N/mm², of the plating material, defined in Ch 4, Sec 3

t : Minimum thickness of the plate panel, in mm.

a,b : Lengths, in m, of the sides of the panel, as shown in Fig 1 and Fig 3

$\alpha = a/b$

2.4.3 Bi-axial compression and shear for plane panel

The critical buckling stress $\sigma_{c,a}$ for compression on side "a" of the panel is to be obtained, in N/mm², from the following formula:

$$\sigma_{c,a} = \left(\frac{2,25}{\beta} - \frac{1,25}{\beta^2}\right)R_{p0,2}$$

where:

β : Slenderness of the panel, to be taken equal to:

$$\beta = 10^3 \frac{a}{t}\sqrt{\frac{R_{p0,2}}{E}}$$

without being taken less than 1,25.

t : Minimum thickness of the plate panel, in mm.

The critical buckling stress $\sigma_{c,b}$ for compression on side "b" of the panel is to be obtained, in N/mm², from the formulae in [2.4.1].

The critical shear buckling stress is to be obtained, in N/mm², from the formulae in [2.4.2].

Table 1 : Buckling factor K_1 for plate panels

Load pattern	Aspect ratio	Buckling factor K_1
$0 \le \psi \le 1$	$\alpha \ge 1$ $\alpha < 1$	$\dfrac{8,4}{\psi + 1,1}$ $\left(\alpha + \dfrac{1}{\alpha}\right)^2 \dfrac{2,1}{\psi + 1,1}$
$-1 < \psi < 0$		$(1 + \psi)K_1' - \psi K_1'' + 10\psi(1 + \psi)$
$\psi \le -1$	$\alpha \dfrac{1 - \psi}{2} \ge \dfrac{2}{3}$ $\alpha \dfrac{1 - \psi}{2} < \dfrac{2}{3}$	$23,9\left(\dfrac{1 - \psi}{2}\right)^2$ $\left(15,87 + \dfrac{1,87}{\left(\alpha\dfrac{1 - \psi}{2}\right)^2} + 8,6\left(\alpha\dfrac{1 - \psi}{2}\right)^2\right)\left(\dfrac{1 - \psi}{2}\right)^2$

Note 1:

$\psi = \dfrac{\sigma_2}{\sigma_1}$

K_1' : Value of K_1 calculated for $\psi = 0$

K_1'' : Value of K_1 calculated for $\psi = -1$

2.5 Checking criteria

2.5.1 The safety factor between the critical stress as calculated in [2.4] and the actual compression and shear stress as calculated in [2.3.2] is to be not less than the minimum safety factor defined inCh 4, Sec 3, Tab 2 and Ch 4, Sec 3, Tab 4.

3 Plating sustaining lateral pressure

3.1 General

3.1.1 Load point

Unless otherwise specified, lateral pressure is to be calculated at the lower edge of the plate panel.

3.2 Plating scantling

3.2.1 As a rule, rule thickness of plates sustaining lateral pressure is given, in mm, by the formulae:

$$t = 22,4 \cdot coeff \cdot \mu \cdot s \cdot \sqrt{\frac{p}{\sigma_{ad}}}$$

where:

coeff : Coefficient equal to:

- In general case, coeff = 1
- In case of impact pressure on side shells (loads distributed on a part only of the elementary plate panel), as given in Ch 7, Sec 1, [2.3]:
  - coeff = 1, if $\dfrac{\ell}{0,6} \le 1 + s$
  - coeff = $(1+s)^{-1/2}$, if $\dfrac{\ell}{0,6} > 1 + s$

s : Smaller side, in m, of the elementary plate panel

μ : Aspect ratio coefficient of the elementary plate panel, equal to:

$$\sqrt{1,1 - \left(0,5 \cdot \frac{s^2}{\ell^2}\right)}$$

without being taken more than 1, where:

ℓ : Longer side, in m, of the elementary plate panel

p : Local pressure, in kN/m², given in Ch 7, Sec 1 for bottom, sides, decks and superstructures, and in Ch 7, Sec 2 for bottom slamming loads.

σ_{ad} : Rule admissible stress, in N/mm², defined in Ch 4, Sec 3, Tab 2 or Ch 4, Sec 3, Tab 4 whatever the case.

SECTION 4 STIFFENERS

Symbols

E : Young's modulus, in N/mm², to be taken equal to:

- for steels in general:
  $E = 2,06.10^5$ N/mm²
- for stainless steels:
  $E = 1,95.10^5$ N/mm²
- for aluminium alloys:
  $E = 7,0.10^4$ N/mm²

1 General

1.1 Geometric properties

1.1.1 Built section

The geometric properties of built sections as shown in Fig 1 may be calculated as indicated in the following formulae. These formulae are applicable provided that:

$A_a \geq t_f b_f$

$\frac{h_w}{t_p} \geq 10$

$\frac{h_w}{t_f} \geq 10$

where:

A_a : Sectional area, in mm², of the attached plating.

The section modulus of a built section with attached plating is to be obtained, in cm³, from the following formula:

$$w = \frac{h_w t_f b_f}{1000} + \frac{t_W h_W^2}{6000}\left(1 + \frac{A_a - t_f b_f}{A_a + \frac{t_W h_W}{2}}\right)$$

The distance from face plate to neutral axis is to be obtained, in cm, from the following formula:

$$v = \frac{h_W(A_a + 0,5 t_W h_W)}{10(A_a + t_f b_f + t_W h_W)}$$

The moment of inertia of a built section with attached plating is to be obtained, in cm⁴, from the following formula:

$I = w\,v$

The shear sectional area of a built section with attached plating is to be obtained, in cm², from the following formula:

$$A_{Sh} = \frac{h_w t_w}{100}$$

1.1.2 Bulb section: equivalent angle profile

A bulb section may be taken as equivalent to an angle profile.

The dimensions of the equivalent angle profile are to be obtained, in mm, from the following formulae:

$$h_w = h'_w - \frac{h'_w}{9,2} + 2$$

$$t_w = t'_w$$

$$b_f = \alpha\left[t'_w + \frac{h'_w}{6,7} - 2\right]$$

$$t_f = \frac{h'_w}{9,2} - 2$$

where:

h'_w, t'_w : Height and thickness of the bulb section, in mm, as shown in Fig 2

α : Coefficient equal to:

$1,1 + \frac{(120 - h'_w)^2}{3000}$ for $h'_w \leq 120$

1 for $h'_w > 120$

Figure 1 : Dimensions of a built section

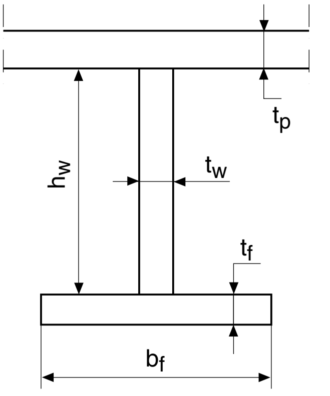
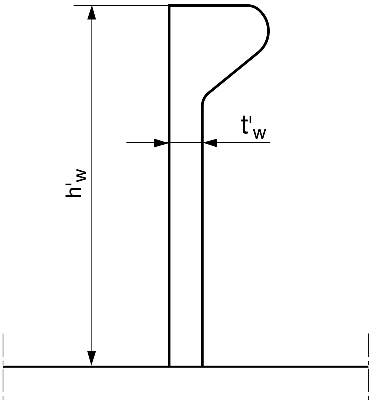


Figure 2 : Dimensions of a bulb section



1.1.3 Stiffener not perpendicular to the attached plating

Where the stiffener is not perpendicular to the attached plating, the actual net section modulus may be obtained, in cm^3, from the following formula:

$$w = w_0 \sin\alpha$$

where:

w_0 : Actual net section modulus, in cm^3, of the stiffener assumed to be perpendicular to the plating

α : Angle between the stiffener web and the attached plating.

1.2 Ordinary stiffeners

1.2.1 Span

The span ℓ, in m, of ordinary stiffeners is to be taken as indicated in Ch 4, Sec 4, [3].

1.2.2 Attached plating for lateral loading

The width of the attached plating to be considered for the yielding check of ordinary stiffeners is to be obtained, in m, from the following formulae, where s is the spacing between ordinary stiffeners, in m:

- where the plating extends on both sides of the ordinary stiffener:

  $b_P = s$
- where the plating extends on one side of the ordinary stiffener (i.e. ordinary stiffeners bounding openings):

  $b_P = 0{,}5s$

1.2.3 Attached plating for buckling check

Where ordinary stiffeners are sustaining compression stress, the width of attached plate and the buckling check method are given in [2].

1.2.4 Where ordinary stiffeners are continuous through primary supporting members, their connection to the web of the primary supporting member is to be in accordance with [1.6].

1.2.5 As a rule, where ordinary stiffeners are cut at primary supporting members, brackets are to be fitted to ensure the structural continuity. Their net section modulus and their net sectional area are to be not less than those of the ordinary stiffeners.

1.3 Primary supporting members

1.3.1 Span

The span ℓ, in m, of primary supporting members is to be taken as indicated in Ch 4, Sec 4, [3].

1.3.2 Attached plating

The width of the attached plating to be considered for the yielding check of primary supporting members analysed through beam structural models is to be obtained, in m, from the following formulae, where s is the spacing of the primary supporting members:

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

  $b_P = \min(s;\ 0{,}2\ell)$
- where the plating extends on one side of the primary supporting member (i.e. primary supporting members bounding openings):

  $b_P = 0{,}5\min(s;\ 0{,}2\ell)$

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

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

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

1.3.5 Where openings such as lightening holes or duct routing for pipes, electrical cable... are cut in primary supporting members, they are to be equidistant from the face plate and the attached plate. As a rule, their height is not to be more than 20% of the primary supporting member web height.

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

1.3.7 Over half of the span in the middle of the primary supporting members, the length of openings is to be not greater than the distance between adjacent openings.

At the ends of the span, the length of openings is to be not greater than 25% of the distance between adjacent openings.

1.4 Large openings in primary supporting members

1.4.1 In the case of large openings as shown in Fig 3, the secondary stresses in primary supporting members are to be considered for the reinforcement of the openings.

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:

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

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

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

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

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

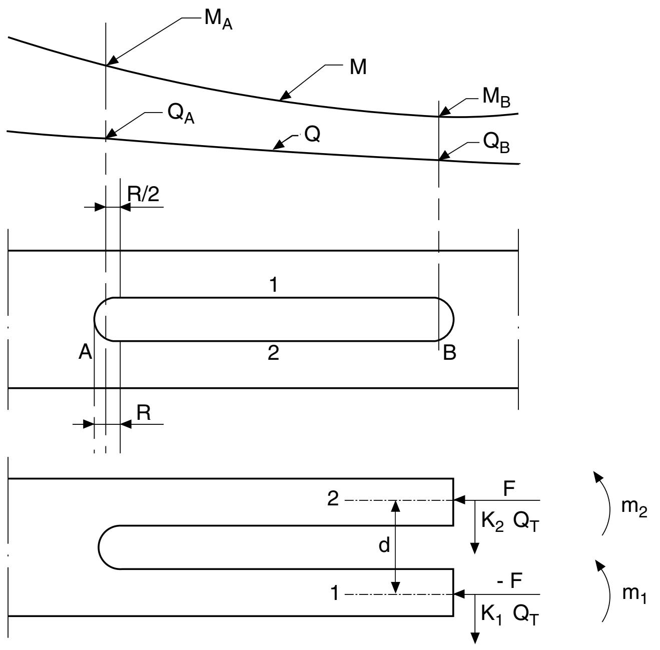
$$\sigma_{m1} = \frac{m_1}{w_1}10^3$$

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

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

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

Figure 3 : Large openings in primary supporting members - Secondary stresses



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

$$K_1 = \frac{I_1}{I_1 + I_2}$$

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

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 in Ch 4, Sec 3, Tab 2 or Ch 4, Sec 3, Tab 4 applicable. Where these checking criteria are not complied with, the cut-out is to be reinforced according to one of the solutions shown in Fig 4 to Fig 6:

- continuous face plate (solution 1): see Fig 4
- straight face plate (solution 2): see Fig 5
- compensation of the opening (solution 3): see Fig 6
- combination of the above solutions.

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

1.5 Web stiffening arrangement for primary supporting members

1.5.1 Webs of primary supporting members are generally to be stiffened where the height, in mm, is greater than 100 t, where t is the web thickness, in mm, of the primary supporting member.

In general, the web stiffeners of primary supporting members are to be spaced not more than 110 t.

1.5.2 The section modulus of web stiffeners of non-watertight primary supporting members is to be not less than the value obtained, in cm³, from the following formula:

$$w = 2{,}5 s^2 t S_s^2$$

where:

s : Length, in m, of web stiffeners

t : Web thickness, in mm, of the primary supporting member

S_s : Spacing, in m, of web stiffeners.

Moreover, web stiffeners located in areas subject to compression stresses are to be checked for buckling in accordance with [2].

Figure 4 : Stiffening of large openings in primary supporting members - Solution 1

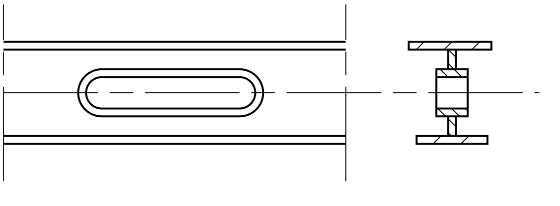


Figure 5 : Stiffening of large openings in primary supporting members - Solution 2

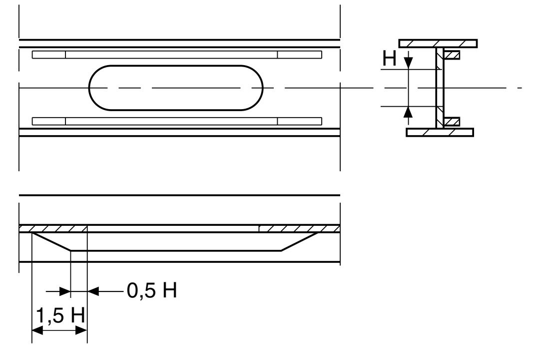
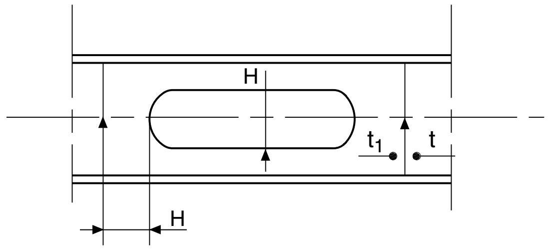


Figure 6 : Stiffening of large openings in primary supporting members - Solution 3

Inserted plate



1.5.3 Tripping brackets (see Fig 7) welded to the face plate are generally to be fitted:

- every fourth spacing of ordinary stiffeners
- at the toe of end brackets
- at rounded face plates
- in way of cross ties
- in way of concentrated loads.

Where the width of the symmetrical face plate is greater than 400 mm, backing brackets are to be fitted in way of the tripping brackets.

1.5.4 In general, the width of the primary supporting member face plate is to be not less than one tenth of the depth of the web, where tripping brackets are spaced as specified in [1.5.3].

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

$$d = 0,38b$$

$$d = 0,85b\sqrt{\frac{s_t}{t}}$$

where:

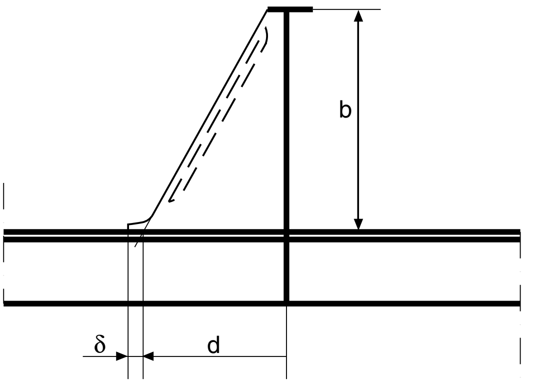
b : Height, in m, of tripping brackets, shown in Fig 7

s_t : Spacing, in m, of tripping brackets

t : Thickness, in mm, of tripping brackets.

It is recommended that the bracket toe should be designed as shown in Fig 7.

Figure 7 : Primary supporting member: web stiffener in way of ordinary stiffener



1.5.6 Steel tripping brackets with a thickness, in mm, less than $16,5L_b$ are to be flanged or stiffened by a welded face plate.

Aluminium tripping brackets with a thickness, in mm, less than $22L_b$ are to be flanged or stiffened by a welded face plate.

The sectional area, in cm^2, of the flanged edge or the face plate is to be not less than $10L_b$, where L_b is the length, in m, of the free edge of the bracket.

Where the depth of tripping brackets is greater than 3 m, an additional stiffener is to be fitted parallel to the bracket free edge.

1.6 Connections of ordinary stiffeners and primary supporting members

1.6.1 Where ordinary stiffeners are continuous through primary supporting members, they are to be connected to the web plating so as to ensure proper transmission of loads, e.g. by means of one of the connection details shown in Fig 8 to Fig 11.

Connection details other than those shown in Fig 8 to Fig 11 may be considered by the Society on a case by case basis. In some cases, the Society may require the details to be supported by direct calculations submitted for review.

Figure 8 : End connection of ordinary stiffener Without collar plate

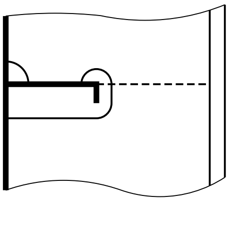


Figure 9 : End connection of ordinary stiffener Collar plate

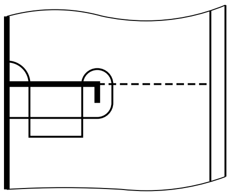


Figure 10 : End connection of ordinary stiffener One large collar plate

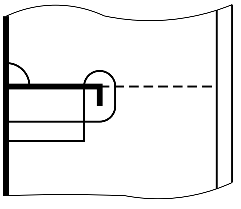


Figure 11 : End connection of ordinary stiffener Two large collar plates

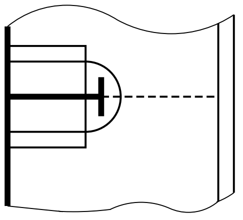
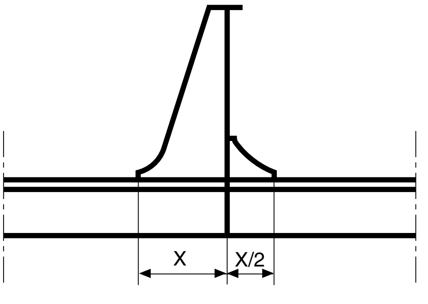


Figure 12 : End connection of ordinary stiffener Backing bracket



1.6.2 Where ordinary stiffeners are cut at primary supporting members, brackets are to be fitted to ensure the structural continuity. Their section modulus and their sectional area are to be not less than those of the ordinary stiffeners.

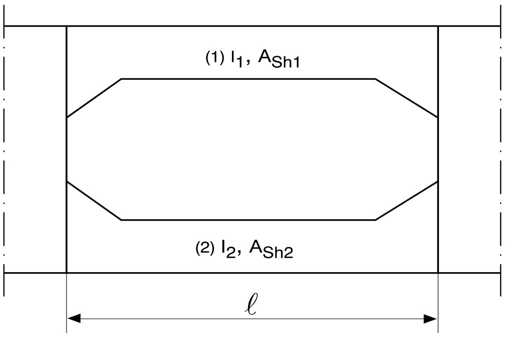
The thickness of brackets is to be not less than that of ordinary stiffeners.

Steel brackets with thickness, in mm, less than $16,5L_b$, where L_b is the length, in m, of the free edge of the end bracket, are to be flanged or stiffened by a welded face plate. The sectional area, in cm², of the flanged edge or face plate is to be at least equal to $10L_b$.

Aluminium brackets with thickness, in mm, less than $22L_b$, where L_b is the length, in m, of the free edge of the end bracket, are to be flanged or stiffened by a welded face plate. The sectional area, in cm², of the flanged edge or face plate is to be at least equal to $10L_b$.

1.6.3 Where necessary (high stress level), the Society may require backing brackets to be fitted, as shown in Fig 12, in order to improve the fatigue strength of the connection.

Figure 13 : Large openings in the web of primary supporting members



1.6.4 Where large openings are fitted in the web of primary supporting members (see Fig 13), their influence is to be taken into account by assigning an equivalent shear sectional area to the primary supporting member.

This equivalent shear sectional area is to be obtained, in cm², from the following formula:

$$A_{Sh} = \frac{A_{Sh1}}{1 + \frac{0,0032\,\ell^2 A_{Sh1}}{I_1}} + \frac{A_{Sh2}}{1 + \frac{0,0032\,\ell^2 A_{Sh2}}{I_2}}$$

where (see Fig 13):

I_1, I_2 : Moments of inertia, in cm⁴, of deep webs (1) and (2), respectively, with attached plating around their neutral axes parallel to the plating

A_{Sh1}, A_{Sh2} : Shear sectional areas, in cm², of deep webs (1) and (2), respectively, to be calculated according to [1.1.1].

ℓ : Span, in cm, of deep webs (1) and (2).

1.7 Bracketed end connections

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

With the exception of primary supporting members of transversely framed single sides, the height of end brackets is to be not less than that of the primary supporting member.

1.7.2 The thickness of the end bracket web is generally to be not less than that of the primary supporting member web.

1.7.3 The scantlings of end brackets are generally to be such that the section modulus of the primary supporting member with end brackets is not less than that of the primary supporting member at mid-span.

1.7.4 The width, in mm, of the face plate of end brackets is to be not less than $50(L_b+1)$, where L_b is the length, in m, of the free edge of the end bracket.

Moreover, the thickness of the face plate is to be not less than that of the bracket web.

1.7.5 Where necessary, face plate of end brackets are to be symetrical.

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

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

1.8 Recommended dimensions of steel ordinary stiffeners

1.8.1 Flat bar

The dimensions of a flat bar ordinary stiffener (see Fig 14) are to comply with the following requirement:

$$\frac{h_w}{t_w} \le 20\sqrt{k}$$

1.8.2 T-section

The dimensions of a T-section ordinary stiffener (see Fig 15) are to comply with the following two requirements:

$$\frac{h_w}{t_w} \le 55\sqrt{k}$$

$$\frac{b_f}{t_f} \le 33\sqrt{k}$$

$$b_f t_f \ge \frac{h_w t_w}{6}$$

1.8.3 Angle

The dimensions of a steel angle ordinary stiffener (see Fig 16) are to comply with the following two requirements:

$$\frac{h_w}{t_w} \le 55\sqrt{k}$$

$$\frac{b_f}{t_f} \le 16,5\sqrt{k}$$

$$b_f t_f \ge \frac{h_w t_w}{6}$$

1.9 Recommended dimensions of aluminium ordinary stiffeners

1.9.1 Flat bar

The dimensions of a flat bar ordinary stiffener (see Fig 14) are to comply with the following requirement:

$$\frac{h_w}{t_w} \le 15\sqrt{k}$$

1.9.2 T-section

The dimensions of a T-section ordinary stiffener (see Fig 15) are to comply with the following two requirements:

$$\frac{h_w}{t_w} \le 33\sqrt{k}$$

$$\frac{b_f}{t_f} \le 21\sqrt{k}$$

$$b_f t_f \ge \frac{h_w t_w}{6}$$

2 Buckling check

2.1 Width of attached plating

2.1.1 The width of the attached plating to be considered for the buckling check of ordinary stiffeners is to be obtained, in m, from the following formulae:

- where no local buckling occurs on the attached plating:

  $b_e = s$
- where local buckling occurs on the attached plating:

  $$b_e = \left(\frac{2,25}{\beta_e} - \frac{1,25}{\beta_e^2}\right)s$$

  to be taken not greater than s

where:

$$\beta_e = \frac{s}{t_p}\sqrt{\frac{\sigma_b}{E}}10^3$$

σ_b : Global hull girder compression stress σ_X or σ_Y, in N/mm², acting on the plate panel, defined in Ch 4, Sec 4, according to the direction x or y considered.

Figure 14 : Dimensions of a flat bar

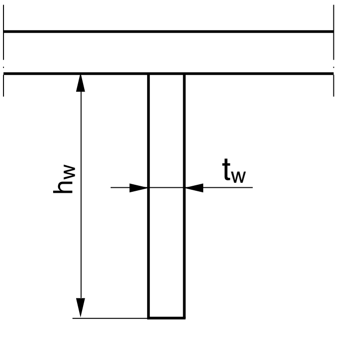


Figure 15 : Dimensions of a T-section

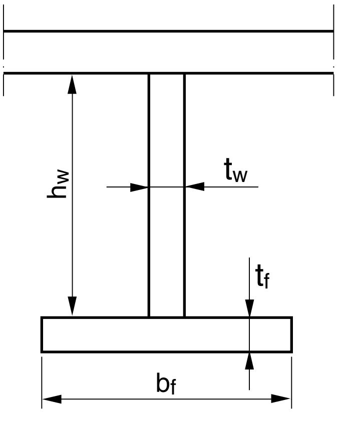
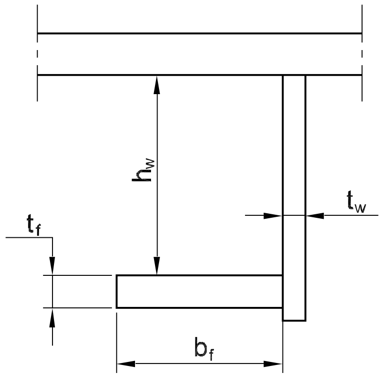


Figure 16 : Dimensions of an angle



2.2 Critical stress for steel members

2.2.1 General

The critical buckling stress is to be obtained, in N/mm², from the following formulae:

$$\sigma_c = \sigma_E \quad \text{for } \sigma_E \le \frac{R_{p0,2}}{2}$$

$$\sigma_c = R_{p0,2}\left(1 - \frac{R_{p0,2}}{4\sigma_E}\right) \quad \text{for } \sigma_E > \frac{R_{p0,2}}{2}$$

where:

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

σ_{E1} : Euler column buckling stress, in N/mm², given in [2.2.2]

σ_{E2} : Euler torsional buckling stress, in N/mm², given in [2.2.3]

σ_{E3} : Euler web buckling stress, in N/mm², given in [2.2.4]

$R_{p0,2}$: Minimum guaranteed yield stress, in N/mm², of the stiffener material, defined in Ch 4, Sec 3.

2.2.2 Column buckling of axially loaded stiffeners

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

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

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.

2.2.3 Torsional buckling of axially loaded stiffeners

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

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

where:

I_w : Sectorial 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:

$$I_w = \frac{b_f^3 h_w^2}{12(b_f + h_w)^2}[t_f b_f^2 + 2 b_f h_w + 4 h_w^2 + 3 t_w b_f h_w]\ 10^{-6}$$

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 1):

$$m^2(m-1)^2 \le K_C < m^2(m+1)^2$$

K_C : $K_C = \frac{C_0 \ell^4}{\pi^4 E I_w} 10^6$

C_0 : Spring stiffness of the attached plating:

$$C_0 = \frac{E t_p^3}{2{,}73 s} 10^{-3}$$

2.2.4 Web buckling of axially loaded stiffeners

The Euler buckling stress of the stiffener web is obtained, in N/mm², from the following formulae:

- for flat bars:

$$\sigma_E = 16\left(\frac{t_W}{h_W}\right)^2 10^4$$

- for stiffeners with face plate:

$$\sigma_E = 78\left(\frac{t_W}{h_W}\right)^2 10^4$$

Table 1 : Torsional buckling of axially loaded stiffeners 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

2.3 Critical stress for aluminium members

2.3.1 General

The critical buckling stress is to be obtained, in N/mm², from the following formulae:

$$\sigma_c = \sigma_E \qquad \text{for } \sigma_E \le \frac{R'_{p0,2}}{2}$$

$$\sigma_c = R'_{p0,2}\left(1 - \frac{R'_{p0,2}}{4\sigma_E}\right) \qquad \text{for } \sigma_E > \frac{R'_{p0,2}}{2}$$

where:

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

σ_{E1} : Euler column buckling stress, in N/mm², given in [2.2.2]

σ_{E2} : Euler torsional buckling stress, in N/mm², given in [2.2.3]

σ_{E3} : Euler web buckling stress, in N/mm², given in [2.2.4]

$R'_{p0,2}$: Minimum guaranteed yield stress of the parent metal in welded condition, in N/mm², defined in Ch 4, Sec 3.

2.3.2 Column buckling of axially loaded stiffeners

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

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

2.3.3 Torsional buckling of axially loaded stiffeners

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

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

where:

I_w : Sectorial 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:

$$I_w = \frac{b_f^3 h_w^2}{12(b_f + h_w)^2}[t_f b_f^2 + 2 b_f h_w + 4 h_w^2 + 3 t_w b_f h_w] 10^{-6}$$

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 1):

$$m^2(m-1)^2 \le K_C < m^2(m+1)^2$$

K_C : $K_C = \frac{C_0 \ell^4}{\pi^4 E I_w} 10^6$

C_0 : Spring stiffness of the attached plating:

$$C_0 = \frac{E t_p^3}{2,73 s} 10^{-3}$$

2.3.4 Web buckling of axially loaded stiffeners

The Euler buckling stress of the stiffener web is obtained, in N/mm², from the following formulae:

- for flat bars:

$$\sigma_E = 5,5\left(\frac{t_W}{h_W}\right)^2 10^4$$

- for stiffeners with face plate:

$$\sigma_E = 27\left(\frac{t_W}{h_W}\right)^2 10^4$$

2.4 Checking criteria

2.4.1 As a rule, the normal stress considered for buckling check of stiffener is the stress determined by a direct calculation taking into account the global loads as defined in Part B, Chapter 6 and the strength characteristics of hull girder transverse sections as defined in Ch 4, Sec 4, [2].

2.4.2 Stiffeners parallel to the direction of compression

The critical buckling stress of the ordinary stiffener is to comply with the following formula:

$$\sigma_c \ge \sigma \cdot SF$$

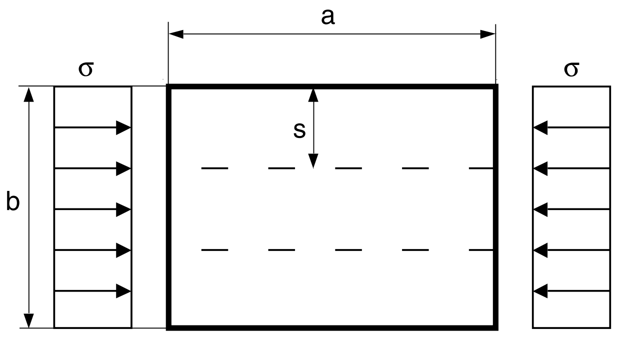
where:

σ_c : Critical buckling stress, in N/mm², as calculated in [2.2.1] or [2.3.1]

σ : Compression stress in the stiffener, in N/mm², as defined in [2.4.1]

SF : Safety factor as defined in Ch 4, Sec 3, Tab 2 or Ch 4, Sec 3, Tab 4.

Figure 17 : Buckling of stiffeners parallel to the direction of compression



3 Ordinary stiffeners sustaining lateral pressure

3.1 General: load point

3.1.1 Lateral pressure for longitudinal stiffener

Unless otherwise specified, lateral pressure is to be calculated at mid-span of the ordinary stiffener considered.

3.1.2 Lateral pressure for transversal stiffener

Unless otherwise specified, lateral pressure is to be calculated at the lower point and at the upper point of the ordinary stiffener considered.

3.2 Bending check

3.2.1 As a rule, the design section modulus Z, in cm^3, of ordinary stiffeners sustaining lateral pressure is given by the formulae:

- for longitudinal stiffeners:

$$Z = 1000 \cdot coeff \cdot \frac{p \cdot s \cdot \ell^2}{m \cdot \sigma_{ad}}$$

where:

ℓ : Span of the siffener, in m, measured as indicated in Ch 4, Sec 4, [3]

s : Spacing between siffeners, in m,

p : Lateral pressure, in kN/m^2, as given

1) For hydrodynamic loads

a) For longitudinal stiffeners

$p = p_S$

as defined in Ch 7, Sec 1 taken into account [3.1.1]

b) For transversal stiffeners

$p = 3\ p_{S\ lower} + 2\ p_{S\ upper}$

where $p_{S\ lower}$ and $p_{S\ upper}$ are defined in Ch 7, Sec 1, taken into account [3.1.2]

2) For bottom slamming loads

$p = p_{sl}$, as defined in Ch 7, Sec 2

3) For impact pressure on side shell

$p = p_{Smin}$, as defined in Ch 7, Sec 1, [2.3]

σ_{ad}, τ_{ad} : Rule admissible stresses, in N/mm^2, depending on the type of materials and on the type of load (hydrodynamic load, slamming and impact load, test load or exceptional load in damage situation), defined in Ch 4, Sec 3, Tab 2 or Ch 4, Sec 3, Tab 44.

m : Coefficient depending on load type and/or end conditions :

- m = 60 for load type p as defined in 1) b)
- m = 12, 10 or 8 for types p as defined in 1) a), 2), 3), and depending on end conditions, as defined in Ch 4, Sec 4, [3.2].

coeff : Reduction coefficient equal to:

- $(1 - s / 2\ell) \geq 0$ in general case
- $(3\ell^2\text{-}0{,}36)\ 0{,}3/\ell^3$ for ordinary side shell stiffeners in the case where p is taken equal to the impact pressure on side shell p_{Smin} as defined in Ch 7, Sec 1, [2.3.2] or Ch 7, Sec 1, [2.3.3], with ℓ being taken not less than 0,6m
- 1 for decks ordinary stiffeners.

3.3 Shearing check

3.3.1 As a rule, the design shear area A_{sh}, in cm^2, of ordinary stiffeners sustaining lateral pressure is given by the formulae:

$$A_{sh} = 5 \cdot coeff \cdot \frac{p \cdot s \cdot \ell}{\tau_{ad}}$$

where:

s, ℓ : As indicated [3.2.1]

p : Lateral pressure, in kN/m^2, as given

1) For hydrodynamic loads

a) For longitudinal stiffeners

$p = p_S$

as defined in Ch 7, Sec 1 taken into account [3.1.1]

b) For transversal stiffeners

$p = (0{,}7\ p_{S\ lower} + 0{,}3\ p_{S\ upper})$

where $p_{S\ lower}$ and $p_{S\ upper}$ are defined in Ch 7, Sec 1, taken into account [3.1.2]

2) For bottom slamming loads

$p = p_{sl}$, as defined in Ch 7, Sec 2

3) For impact pressure on side shell

$p = p_{Smin}$, as defined in Ch 7, Sec 1, [2.3]

coeft : Reduction coefficient equal to:

- $(1 - s / 2\ell) \geq 0$ in general case
- $0{,}6/\ell$, without being taken superior to 1, for ordinary side shell stiffeners in the case where p is taken equal to the impact pressure on side shell $p_{s\ min}$ as defined in Ch 7, Sec 1, [2.3.2] or Ch 7, Sec 1, [2.3.3].
- 1 for decks ordinary stiffeners

τ_{ad} : Rule admissible shear stresse, in N/mm^2, as defined in Ch 4, Sec 3, Tab 2 or Ch 4, Sec 3, Tab 4 as appropriate.

4 Primary supporting members sustaining lateral pressure

4.1 General

4.1.1 The primary supporting members are designed as indicated in [3] for ordinary stiffeners without taking into account the coefficients coeff and coeft, with lateral loads depending on primary member under consideration:

- bottom primary members: hydrodynamic loads as given in Ch 7, Sec 1, [2.2] and Ch 7, Sec 2, [2] or Ch 7, Sec 2, [3]
- side primary members: hydrodynamic loads as given in Ch 7, Sec 1, [2.2]
- decks primary members: minimum sea loads as given in Ch 7, Sec 1, [3.1] or Ch 7, Sec 1, [3.2].

For deck primary structure exposed to sea pressure, the section modulus Z and shear area A_{sh} , calculated as indicated in [3], can be reduced by the following coefficients:

- 0,8 for primary structure of exposed supertructure decks
- $(1-0,05\ell) > 0,8$ for primary structure of exposed decks.

5 Curved primary supporting members

5.1 General

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

The curvate primary stiffener analysis can be carried out with Bureau Veritas program defined in Ch 1, Sec 4.

5.1.2 Model principles

In case of 2-D or 3-D beam structural model, the curved primary supporting members are to 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 knuckles equivalent springs is considered as unaffecting the local bending moment and shear forces distribution where the angle between two successive beams is not more than 3°.

SECTION 5 BOTTOM STRUCTURE

1 General

1.1 Application

1.1.1 The requirements of this Section apply to longitudinally or transversely framed single and double bottom structures.

1.1.2 The requirements of the present section are given for guidance. Any other arrangement may be considered.

1.2 General arrangement

1.2.1 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.

1.2.2 In case of a charter yacht of more than 12 passengers being considered by the Flag Administration as a passenger ship, it might be necessary to provide a continuous double bottom. In such a case, the relevant requirements of the Ship Rules, are applicable.

1.2.3 Adequate tapering is to be provided between double bottom and adjacent single bottom structures. Similarly, adequate continuity is to be provided in the case of height variation in the double bottom. Where such a height variation occurs within 0,6 L amidships, the inner bottom is generally to be maintained continuous by means of inclined plating.

1.2.4 Provision is to be made for the free passage of water from all parts of the bottom to the sections, by means of scallops in floors and bottom girders.

2 Single bottom

2.1 Longitudinal framing

2.1.1 As a general rule, longitudinally framed single bottom yachts are to be fitted with a centre girder formed by a vertical continuous or intercostal web plate and a horizontal face plate continuous over the floors.

Intercostal web plates are to be aligned and welded to floors.

2.1.2 Where side girders are fitted in lieu of centre girder, the scarfing is to be adequately extended and additional stiffening of the centre bottom may be required. Arrangements similar to [2.1.1] are to be provided.

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

2.1.4 Centre and side girders are to be extended as far aft and forward as practicable.

2.1.5 As a rule, longitudinal girders are to be fitted in way of each line of pillars.

If not, pillars are to be located in way of a local longitudinal member.

2.1.6 Longitudinal ordinary stiffeners are generally to be continuous when crossing primary members.

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

2.2 Transverse framing

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

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

In some particular cases, it may be accepted that floors end at side on a longitudinal member of the side shell or the bottom.

2.2.3 Openings and cut-outs in web of floors are to be taken into account for shear analysis of floors.

3 Double bottom

3.1 Double bottom height

3.1.1 The double bottom height is to be sufficient to ensure access to all parts and, in way of the centre girder, is to be not less than 0,7 m.

3.1.2 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 plate floors.

Where this is impossible, suitable longitudinal structures such as partial girders, longitudinal brackets etc., fitted across the knuckle are to be arranged.

3.2 Floors

3.2.1 Plate floors are to be fitted:

- in way of transverse watertight bulkheads
- in way of double bottom steps.

3.2.2 Where the double bottom height exceeds 0,9 m, plate floors are to be fitted with vertical stiffeners spaced not more than 1 m apart.

These stiffeners may consist of:

- either longitudinal girders welded to floors
- or flat bars with a width equal to one tenth of the floor depth and a thickness equal to the floors thickness.

3.2.3 Plate floors are generally to be provided with stiffeners in way of longitudinal ordinary stiffeners.

3.2.4 Where the double bottom height exceeds 0,9 m, watertight floors are to be fitted with stiffeners having a net section modulus not less than that required for tank bulkhead vertical stiffeners.

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

3.3 Bottom and inner bottom longitudinal ordinary stiffeners

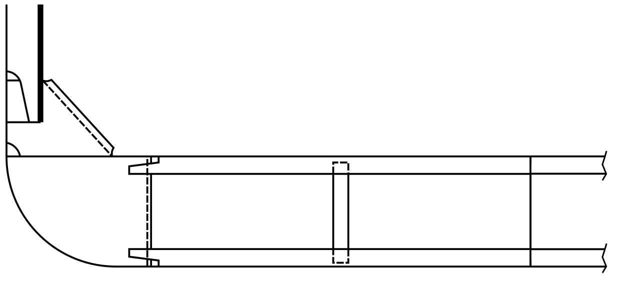
3.3.1 Bottom and inner bottom longitudinal ordinary stiffeners are generally to be continuous through the floors.

4 Bottom structure in way of bulb keel of sailing yachts

4.1 General

4.1.1 The loads induced by the bulb keel on the bottom structure are given in Ch 10, Sec 7.

Figure 1 : Open floor



4.1.2 As a rule, all the reinforced structural members of the bottom in way of the bulb keel are to be double continuous welded.

4.1.3 As a rule, the reinforced structural members of the bottom in way of the bulb keel are checked by direct calculations.

4.2 Keel welded to the bottom structure

4.2.1 Bottom structure is to be locally fitted with longitudinal structure members aligned with side platings of keel fin.

This local reinforcement of bottom structure is to be designed to transfer the tensile/compression forces induced by the sids platings of the keel fin to the floors.

4.2.2 Floors located at fore end and aft end of the keel fin are to be designed to sustain the loads defined in Ch 10, Sec 7 and corresponding to the load case of keel grounding.

4.2.3 As a rule, bottom plate rule thickness calculated according to Ch 8, Sec 3 is to be increased by 50% in way of keel fin.

5 Bilge keel

5.1 Arrangement, scantlings and connections

5.1.1 Arrangement

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

The ends of the bilge keel are to be sniped at an angle of 15° or rounded with 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.

5.1.2 Materials

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

5.1.3 Scantlings

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

5.1.4 Welding

Welding of bilge keel and intermediate plate connections is to be in accordance with Ch 11, Sec 2 for steel structure and Ch 11, Sec 3 for aluminium structure.

Figure 2 : Bilge keel arrangement

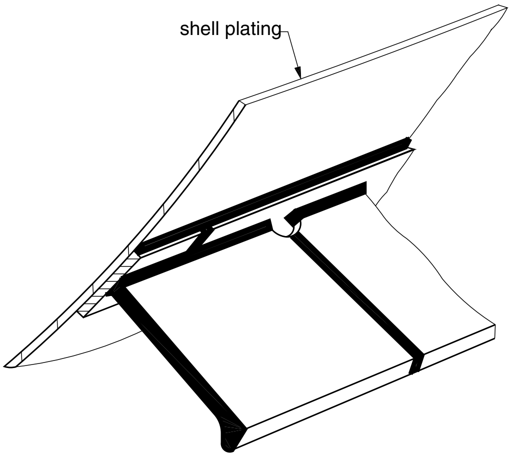
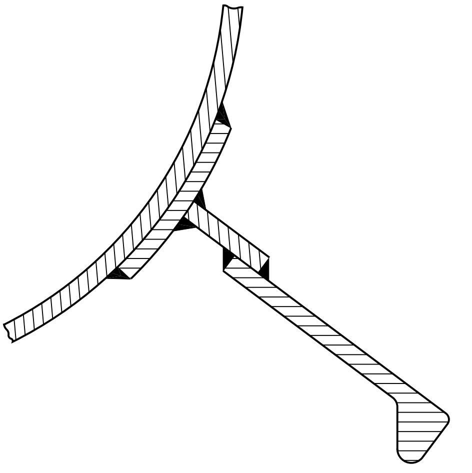


Figure 3 : Bilge keel arrangement



SECTION 6 SIDE STRUCTURE

1 General

1.1 Application

1.1.1 The requirements of this Section apply to longitudinally or transversally framed side structures.

1.2 General

1.2.1 Structures of sides with transverse framing system are made of transverse frames, possibly supported by horizontal stringers.

1.2.2 Structures of sides with longitudinal framing system are made of ordinary longitudinal stiffeners supported by vertical primary supporting members.

1.2.3 The sheerstrake may be rounded. If it 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.

2 Structure arrangement

2.1 Stiffeners

2.1.1 The ordinary stiffeners are normally to be continuous through the primary supporting members.

Otherwise, the detail of the connection is examined by the Society on a case by case basis.

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

2.1.3 Web frames and ordinary side frames are to be attached to floors by brackets, or any other equivalent structure.

2.1.4 For transverse framing system, attention of Designer is drawn on the risk of vertical buckling of plate panels at ends of frames. Extra-thickness or additional vertical intercostals may be requested.

2.2 Openings in the shell plating

2.2.1 Openings in the yacht sides are to be well rounded at the corners and located well clear of superstructure ends.

2.2.2 Openings for stabiliser fins are considered by the Society on a case by case basis. The thickness of sea chests is generally to be that of the local shell plating.

2.2.3 Openings of considerable size are to be adequately compensated by means of insert plates of increased thickness. Such compensation is to be partial or total depending on the stresses occurring in the area of the openings.

2.2.4 Ordinary stiffeners cut in way of openings are to be attached to local structural member supported by continuous adjacent ordinary stiffeners.

2.3 Side shell plating in way of chain plates of sailing yachts

2.3.1 Where chainplates are welded directly on the side shell plating, the following requirements apply:

- as a rule, chain plates are to be inserted in the side shell plating, where they are parallel to it
- where there thickness is significantly larger that the side shell plate thickness, chain plates are to be welded to an inserted plate having extra thickness. The thickness of this inserted plate is to be intermediate between the thickness of chain plate and thickness of side shell.

2.3.2 Local reinforcements may be requested on the side shell, to distribute adequately the secondary loads induced by the chain plate. These local reinforcements are to be connected to the stiffening system of the side shell.

2.3.3 Chain plates scantling are to be according to Ch 10, Sec 6.

2.4 Upper brackets of frames

2.4.1 The arm length of upper brackets connecting frames to deck beams is to be not less than the value obtained, in mm, from the following formula:

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

where:

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

w : Required section modulus of the stiffener, in cm^3, given in [2.4.2] and [2.4.3] and depending on the type of connection

t : Bracket thickness, in mm.

2.4.2 For connections of perpendicular stiffeners located in the same plane (see Fig 1) or connections of stiffeners located in perpendicular planes (see Fig 2), the required section modulus is to be taken equal to:

$w = w_2$ if $w_2 \leq w_1$

$w = w_1$ if $w_2 > w_1$

where w_1 and w_2 are the required section moduli of stiffeners, as shown in Fig 1 and Fig 2.

Figure 1 : Connections of perpendicular stiffeners in the same plane

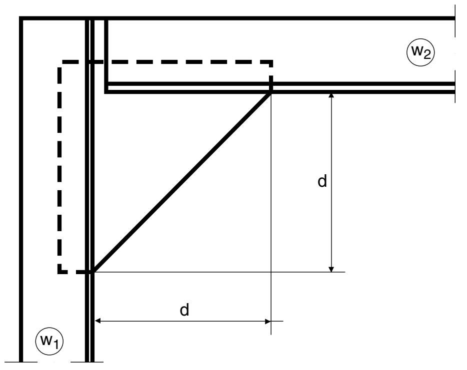
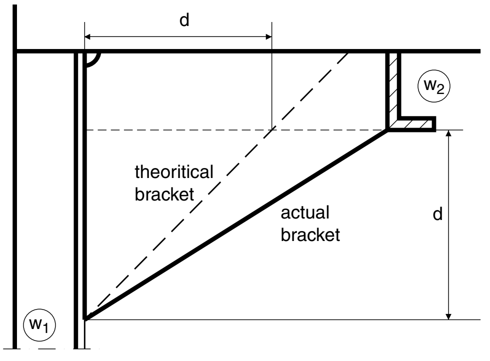


Figure 2 : Connections of stiffeners located in perpendicular planes



2.4.3 For connections of frames to deck beams (see Fig 3), the required section modulus is to be taken equal to:

- for bracket "A":

  $w_A = w_1$ if $w_2 \le w_1$

  $w_A = w_2$ if $w_2 > w_1$

- for bracket "B":

  $w_B = w'_1$ need not be greater than w_1

where w_1, w'_1 and w_2 are the required section moduli of stiffeners, as shown in Fig 3.

2.5 Lower brackets of frames

2.5.1 In general, frames are to be bracketed to the inner bottom or to the face plate of floors as shown in Fig 4.

2.5.2 The arm lengths d_1 and d_2 of lower brackets of frames are to be not less than the value obtained, in mm, from the following formula:

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

where:

φ : Coefficient equal to:
- for unflanged brackets:

  $\varphi = 50$
- for flanged brackets:

  $\varphi = 45$

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

t : Bracket thickness, in mm.

2.5.3 Where the bracket thickness, in mm, is less than $16,5L_b$, where L_b is the length, in m, of the bracket free edge, the free edge of the bracket is to be flanged or stiffened by a welded face plate.

The sectional area, in cm^2, of the flange or the face plate is to be not less than $10L_b$.

Figure 3 : Connections of frames to deck beams

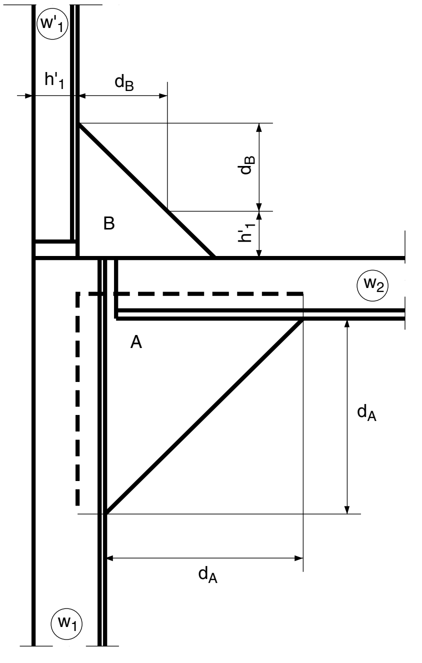
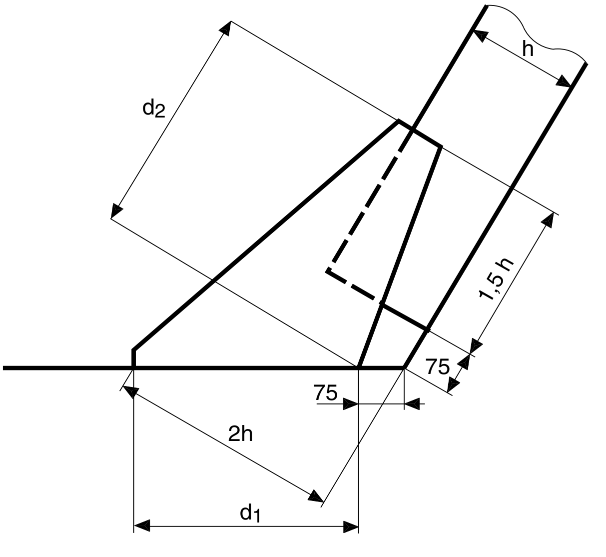


Figure 4 : Lower brackets of main frames



SECTION 7 DECK STRUCTURE AND PILLARS

1 General

1.1 Application

1.1.1 The requirements of this Section apply to longitudinally or transversely framed deck structures.

1.2 General

1.2.1 The deck supporting structure consists of ordinary stiffeners (beams or longitudinals), longitudinally or transversely arranged, supported by primary supporting members which may be sustained by pillars or bulkheads.

1.2.2 Adequate continuity of strength is to be ensured in way of:

- stepped strength decks
- changes in the framing system.

Details of structural arrangements are to be submitted for review to the Society.

1.2.3 Deck supporting structures under cranes and king posts are to be adequately stiffened.

1.2.4 Pillars or other supporting structures are generally to be fitted under heavy concentrated loads.

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

1.2.6 Where beams are fitted in a hatched deck, these are to be effectively supported by at least two longitudinal girders located in either side of the deck opening.

1.2.7 As a rule, the buckling strength of decks is to be checked under global hull girder loads.

1.2.8 The buckling strength of decks may also be requested to be checked under transverse loads:

- in way of mast of sailing yacht. The loads to consider are the horizontal transversal compression force induced by the traction in the shrouds
- in way of transverse bulkheads of cross deck of catamarans. The loads to consider are induced by the global torque exerted on the cross deck.

2 Structure arrangement

2.1 Stiffeners

2.1.1 Deck longitudinals are to be continuous in way of deck transverses and transverse bulkheads.

Other arrangements may be considered, provided adequate continuity of longitudinal strength is ensured.

2.2 Openings

2.2.1 The deck openings are to be as much spaced apart as possible.

As practicable, they are to be fitted as far as possible from highly stressed deck areas or from stepped deck areas.

2.2.2 Extra thickness or additional reinforcements may be requested where deck openings are located:

- in the area of mast foot on sailing yachts
- in the areas of standing rigging chain plates on sailing yachts
- close to the primary transverse cross bulkheads on catamarans
- in areas of deck structural singularity (cockpit, stepped deck...)
- in way of the fixing of out-fittings.

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

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

3 Pillars

3.1 General

3.1.1 Pillars are to be connected to the inner bottom at the intersection of girders and floors and at deck at the intersection of deck beams and deck girders.

3.1.2 Where pillars are not connected to the intersection of primary supporting members, partial floors, partial girders, partial deck beams or partial deck girders, an other appropriate structure is to be fitted to support the pillars.

3.1.3 As a general rule, heads and heels of pillars are to be attached to the surrounding structure by means of brackets.

3.1.4 Pillars are to be attached at their heads and heels by continuous welding.

3.1.5 Manholes may not be cut in the girders and floors below the heels of pillars.

3.1.6 Tight or non-tight bulkheads may be considered as pillars, provided that their scantling comply with [3.2].

3.2 Scantling

3.2.1 The scantlings of pillars are to comply with the requirements of Ch 8, Sec 10.

SECTION 8 BULKHEADS STRUCTURE

1 General

1.1 Application

1.1.1 The requirements of this Section apply to longitudinal or transverse bulkhead structures.

1.2 General

1.2.1 Bulkheads may be horizontally or vertically stiffened.

Horizontally framed bulkheads consist of horizontal ordinary stiffeners supported by vertical primary supporting members.

Vertically framed bulkheads consist of vertical ordinary stiffeners which may be supported by horizontal girders.

1.2.2 The number and location of watertight bulkheads are to be in accordance with the relevant requirements of damage stability criteria, when applicable, as defined in Part B, Chapter 3.

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

1.2.4 As a rule, openings may not be cut in the collision bulkhead below the freeboard deck(m). (Refer also to Ch 2, Sec 1, [2]).

The number of openings in the collision bulkhead above the freeboard deck(m) is to be kept to the minimum compatible with the design and proper working of the yacht.

All such openings are to be fitted with means of closing to weathertight standards.

1.2.5 Certain openings below the freeboard deck(m) are permitted in the other bulkheads, but these are to be kept to a minimum compatible with the design and proper working of the yacht and to be provided with watertight doors having strength such as to withstand the head of water to which they may be subjected.

1.2.6 The transverse bulkheads are to be stiffened in way of deck girders by vertical stiffeners in line with the deck girder or by an equivalent system. Where the deck girder is not continuous, the vertical stiffener supporting the end of the deck girder is to be strong enough to sustain the bending moment at end of the deck girder.

2 Structural arrangement

2.1 Watertight bulkheads

2.1.1 The crossing of transverse watertight bulkheads and bottom, side shell or deck longitudinal stiffeners are to fitted with watertight collar plates.

2.1.2 Ordinary stiffeners of watertight bulkheads are to end in way of hull structure members, and are to be fitted with end brackets.

2.1.3 Where requirement of [2.1.2] is made not possible by hull lines, any other solution may be accepted provided the embedding of bulkhead ordinary stiffeners is satisfactorily achieved.

2.1.4 The ordinary stiffeners of watertight bulkheads may be snipped at ends in the tweendecks, provided their scantlings is increased accordingly.

2.1.5 Watertight bulkheads are to be fitted with watertight doors in way of passage.

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

2.1.7 Where vertical stiffeners are cut in way of watertight doors, reinforced stiffeners are to be fitted on each side of the door and suitably overlapped; cross-bars are to be provided to support the interrupted stiffeners.

2.2 Non-tight bulkheads

2.2.1 Non-tight bulkheads not acting as pillars are to be provided with vertical stiffeners with a maximum spacing equal to:

- 0,9 m, for transverse bulkheads
- two frame spacings, with a maximum of 1,5 m, for longitudinal bulkheads.

2.2.2 As a rule, the total area of openings in wash bulkheads fitted in tanks is to be between 10% and 30% of the total area of the wash bulkhead.

2.3 Bulkheads acting as pillars

2.3.1 Non-tight bulkheads acting as pillars (i.e. those that are designed to sustain the loads transmitted by a deck structure) are to be provided with vertical stiffeners with a maximum spacing equal to:

- two frame spacings, when the frame spacing does not exceed 0,75 m
- one frame spacing, when the frame spacing is greater than 0,75 m.

2.3.2 A vertical stiffening member is to be fitted on the bulkhead, in line with the deck primary supporting member transfering the load from the deck to the bulkhead.

This vertical stiffener, in association with a width of plating equal to 35 times the plating thickness, is to comply with the applicable requirements for pillars, the load supported being determined in accordance with the same requirements.

2.4 Bracketed ordinary steel stiffeners

2.4.1 Where bracketed ordinary stiffeners are fitted, the arm lengths of end brackets of ordinary stiffeners, as shown in Fig 1 and Fig 2, are to be not less than the following values, in mm:

- for arm length a:
  - brackets of horizontal stiffeners and bottom bracket of vertical stiffeners:

    $a = 100\ell$
  - upper bracket of vertical stiffeners:

    $a = 80\ell$
- for arm length b, the greater of:

$$b = 80\sqrt{\frac{w + 20}{t}}$$

$$b = \alpha\frac{ps\ell}{t}$$

where:

ℓ : Span, in m, of the stiffener measured between supports

w : Section modulus, in cm^3, of the stiffener

t : Thickness, in mm, of the bracket

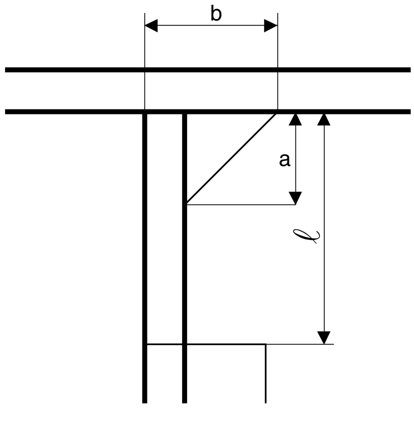
p : Design pressure, in kN/m^2, calculated at mid-span

α : Coefficient equal to:

$\alpha = 4,9$ for tank bulkheads

$\alpha = 3,6$ for watertight bulkheads.

Figure 1 : Bracket at upper end of ordinary stiffener on plane bulkhead



2.4.2 The connection between the stiffener and the bracket is to be such that the section modulus of the connection is not less than that of the stiffener.

2.5 Bracketed ordinary aluminium stiffeners

2.5.1 Where bracketed ordinary stiffeners are fitted, the arm lengths of end brackets of ordinary stiffeners, as shown in Fig 1 and Fig 2, are to be not less than the following values, in mm:

- for arm length a:
  - brackets of horizontal stiffeners and bottom bracket of vertical stiffeners:

    $a = 100\ell$
  - upper bracket of vertical stiffeners:

    $a = 80\ell$
- for arm length b, the greater of:

$$b = 90\sqrt{\frac{w}{t}}$$

$$b = 100$$

where:

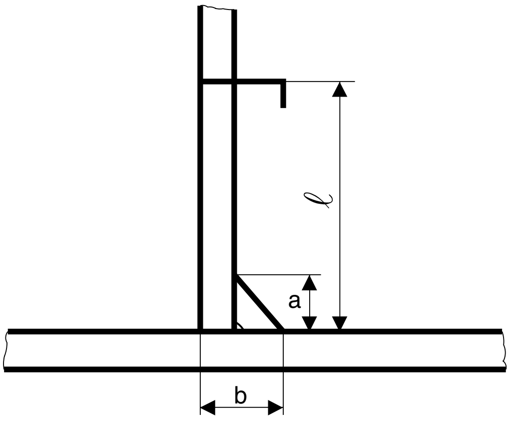
ℓ : Span, in m, of the stiffener measured between supports

w : Section modulus, in cm^3, of the stiffener

t : Thickness, in mm, of the bracket

2.5.2 The connection between the stiffener and the bracket is to be such that the section modulus of the connection is not less than that of the stiffener.

Figure 2 : Bracket at lower end of ordinary stiffener on plane bulkhead



SECTION 9 SUPERSTRUCTURES

1 General

1.1 Application

1.1.1 The requirements of this Section apply to front, side and aft bulkheads and decks of superstructures and deckhouses as defined in Ch 2, Sec 2, [2.2.2], which may or may not contribute to the longitudinal strength.

1.2 General

1.2.1 The pressures acting on superstructures are given in Ch 7, Sec 1, [3] for decks and Ch 7, Sec 1, [4] for side and front walls.

In addition, for superstructures contributing to the hull girder longitudinal strength, global loads according to Part B, Chapter 6, as relevant, are also to be considered.

1.2.2 The strength of plating and stiffeners of superstructures is to be checked according to Ch 8, Sec 3 and Ch 8, Sec 4 respectively.

In addition, for superstructures contributing to the hull girder longitudinal strength, overall strength is also to be checked according to Ch 8, Sec 2, [1].

2 Structural arrangement

2.1 Connections of superstructures and deckhouses with the hull structure

2.1.1 Superstructure and deckhouse frames are to be fitted as far as practicable as extensions of those underlying and are to be effectively connected to both the latter and the deck beams above.

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.

2.1.2 Connection to the deck of corners of superstructures and deckhouses is considered by the Society on a case by case basis. Where necessary, local reinforcements, doublers or reinforced welding may be required.

2.1.3 The side plating at ends of superstructures is to be tapered into the bulwark or sheerstrake of the strength deck.

Where a raised deck is fitted, this arrangement is to extend over at least 3 frame spacings.

2.2 Structural arrangement of superstructures and deckhouses

2.2.1 Strengthening in way of superstructures and deckhouses

As a general rule, web frames, transverse partial bulkheads or other equivalent strengthening are to be fitted inside deckhouses of at least 0,5B in breadth extending more than 0,15L in length within 0,4L amidships. These transverse strengthening reinforcements are to be arranged, where practicable, in line with the transverse bulkheads below.

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

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

2.2.2 Openings

Continuous coamings are to be fitted above and below doors or similar openings, as defined in Ch 2, Sec 2, [3].

2.2.3 Access and doors

Access openings cut in sides 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 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.

2.2.4 Superstructure materials

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

2.2.5 Strengthening of deckhouses in way of tenders and liferafts

Stiffening of sides of deckhouses in way of tenders and liferafts, if any, is to be compatible with the launching operation. Deckhouses in way of launching appliances are to be adequately strenghtened.

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

2.2.7 Constructional details

Lower tier stiffeners are to be attached to the decks at their ends.

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

SECTION 10 PILLARS

1 General

1.1 Application

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

1.1.2 The present Section deals with the buckling check of the pillars.

The general requirements relating to pillars arrangement are given in Ch 8, Sec 7, [3].

2 Pillars made of steel

2.1 Buckling of pillars subjected to compression axial load

2.1.1 Compression axial load

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

The weighting factor depends on the relative position of each pillar with respect to that considered.

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 m², of the portion of the deck or the platform supported by the pillar considered

p_s : Pressure on deck, in kN/m², as defined in Ch 7, Sec 1, [3]

r : Coefficient which depends on the relative position of each pillar above the one considered, to be taken equal to:

- for the pillar immediately above that considered:

  $r = 0,9$

- for the i^{th} pillar of the line above the pillar considered, to be taken not less than 0,478

  $r = 0,9^i$

Q_i : Vertical load, in kN, from the i^{th} pillar of the line above the pillar considered, if any.

2.1.2 Critical column buckling stress of pillars

The critical column buckling stress of pillars is to be obtained, in N/mm², from the following formulae:

$$\sigma_{cB} = \sigma_{E1} \quad \text{for} \quad \sigma_{E1} \le \frac{R_{p0,2}}{2}$$

$$\sigma_{cB} = R_{p0,2}\left(1 - \frac{R_{p0,2}}{4\sigma_{E1}}\right) \quad \text{for} \quad \sigma_{E1} > \frac{R_{p0,2}}{2}$$

where:

σ_{E1} : Euler column buckling stress, to be obtained, in N/mm², from the following formula:

$$\sigma_{E1} = \pi^2 E \frac{I}{A(f\ell)^2} 10^{-4}$$

I : Minimum moment of inertia, in cm⁴, of the pillar

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

ℓ : Span, in m, of the pillar

f : Coefficient, to be obtained from Tab 1

E : Young's modulus, in N/mm², to be taken equal to:

- for steels in general:

  $E = 2,06.10^5$ N/mm²

- for stainless steels:

  $E = 1,95.10^5$ N/mm²

$R_{p0,2}$: Minimum guaranteed yield stress, in N/mm², as defined in Ch 4, Sec 3.

2.1.3 Critical local buckling stress of built-up pillars

The critical local buckling stress of built-up pillars is to be obtained, in N/mm², from the following formulae:

$$\sigma_{cL} = \sigma_{E2} \quad \text{for} \quad \sigma_{E2} \le \frac{R_{p0,2}}{2}$$

$$\sigma_{cL} = R_{p0,2}\left(1 - \frac{R_{p0,2}}{4\sigma_{E2}}\right) \quad \text{for} \quad \sigma_{E2} > \frac{R_{p0,2}}{2}$$

where:

σ_{E2} : Euler local buckling stress, to be taken equal to the lesser of the values obtained, in N/mm², from the following formulae:

- $\sigma_{E2} = 78\left(\frac{E}{206000}\right)\left(\frac{t_W}{h_W}\right)^2 10^4$

- $\sigma_{E2} = 32\left(\frac{E}{206000}\right)\left(\frac{t_F}{b_F}\right)^2 10^4$

h_W : Web height of built-up section, in mm

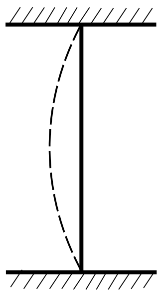
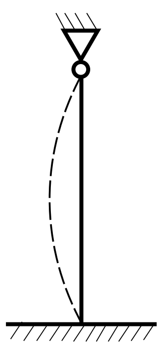
t_W : Web thickness of built-up section, in mm

b_F : Face plate width of built-up section, in mm

t_F : Face plate thickness of built-up section, in mm

$R_{p0,2}$: Minimum guaranteed yield stress, in N/mm², as defined in Ch 4, Sec 3.

Table 1 : Coefficient f

Boundary conditions of the pillar	f
Both ends fixed 	0,5
One end fixed, one end pinned 	$\frac{\sqrt{2}}{2}$
Both ends pinned 	1,0

2.1.4 Critical local buckling stress of pillars having hollow rectangular section

The critical local buckling stress of pillars having hollow rectangular section is to be obtained, in N/mm², from the following formulae:

$$\sigma_{cL} = \sigma_{E3} \quad \text{for} \quad \sigma_{E3} \le \frac{R_{p0,2}}{2}$$

$$\sigma_{cL} = R_{p0,2}\left(1 - \frac{R_{p0,2}}{4\sigma_{E3}}\right) \quad \text{for} \quad \sigma_{E3} > \frac{R_{p0,2}}{2}$$

where:

σ_{E3} : Euler local buckling stress, to be taken equal to the lesser of the values obtained, in N/mm², from the following formulae:

- $\sigma_{E3} = 78\left(\frac{E}{206000}\right)\left(\frac{t_2}{b}\right)^2 10^4$
- $\sigma_{E3} = 78\left(\frac{E}{206000}\right)\left(\frac{t_1}{h}\right)^2 10^4$

b : Length, in mm, of the shorter side of the section

t_2 : Web thickness, in mm, of the shorter side of the section

h : Length, in mm, of the longer side of the section

t_1 : Web thickness, in mm, of the longer side of the section

$R_{p0,2}$: Minimum guaranteed yield stress, in N/mm², as defined in Ch 4, Sec 3.

2.1.5 Checking criteria

The scantlings of steel pillars loaded by the compression axial load F_A defined in [2.1.1] are to comply with the formulae in Tab 2.

3 Pillars made of aluminium alloys

3.1 Buckling of pillars subjected to compression axial load

3.1.1 Compression axial load

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

The weighting factor depends on the relative position of each pillar with respect to that considered.

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 m², of the portion of the deck or the platform supported by the pillar considered

p_s : Pressure on deck, in kN/m², as defined in Ch 7, Sec 1, [3]

r : Coefficient which depends on the relative position of each pillar above the one considered, to be taken equal to:

- for the pillar immediately above that considered:

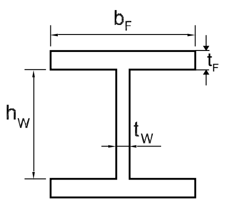
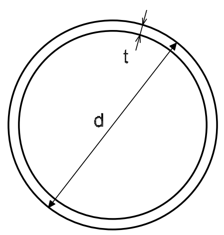
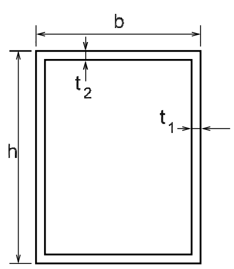
  r = 0,9

- for the i^{th} pillar of the line above the pillar considered, to be taken not less than 0,478:

  $r = 0{,}9^i$

Q_i : Vertical load, in kN, from the i^{th} pillar of the line above the pillar considered, if any.

Table 2 : Buckling check of steel pillars subject to compression axial load

Pillar cross-section	Column buckling check	Local buckling check	Geometric condition
Built-up 	$\frac{\sigma_{cB}}{SF} \geq 10\frac{F_A}{A}$	$\frac{\sigma_{cL}}{SF} \geq 10\frac{F_A}{A}$	$\frac{b_F}{t_F} \leq 40$
Hollow tubular 	$\frac{\sigma_{cB}}{SF} \geq 10\frac{F_A}{A}$	Not required	$\frac{d}{t} \leq 55$ $t \geq 5{,}5$ mm
Hollow rectangular 	$\frac{\sigma_{cB}}{SF} \geq 10\frac{F_A}{A}$	$\frac{\sigma_{cL}}{SF} \geq 10\frac{F_A}{A}$	$\frac{b}{t_2} \leq 55$ $\frac{h}{t_1} \leq 55$ $t_1 \geq 5{,}5$ mm $t_2 \geq 5{,}5$ mm

Note 1:

σ_{cB} : Critical column buckling stress, in N/mm², defined in [2.1.2]

σ_{cL} : Critical local buckling stress, in N/mm², defined in [2.1.3] for built-up section or in [2.1.4] for hollow rectangular section

SF : Safety factor, to be taken equal to:
- SF = 2,00 for column buckling
- SF = 1,05 for local buckling

F_A : Compression axial load in the pillar, in kN, defined in [2.1.1]

A : Sectional area, in cm², of the pillar.

3.1.2 Critical column buckling stress of pillars

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

$$\sigma_{cB} = 2 \cdot R_{p0,2}' \cdot C$$

where:

$R_{p\,0,2}'$: Minimum as-welded guaranteed yield stress of aluminium alloy used, in N/mm²

C : Coefficient as given in Fig 1, and equal to:
- for alloys without heat treatment:

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

- for alloys with heat treatment:

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

Where:

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

$$\sigma_E = \frac{69,1}{\left(\frac{f \cdot \ell}{r}\right)^2}$$

ℓ : Length of pillar, in m

r : Minimum radius of gyration, in cm, of the pillar cross section, equal to:

$$r = \sqrt{\frac{I}{A}}$$

I : Minimum moment of inertia, in cm^4, of the pillar cross section

A : Area, in cm^2, of the pillar cross section

f : Coefficient given in Tab 3 depending on the conditions of fixing of the pillar.

3.1.3 Critical local buckling stress

The critical local buckling stress of pillars made of aluminium alloy is to be obtained, in N/mm^2, from the following formulae:

$$\sigma_{cL} = 2 \cdot R_{p0,2}' \cdot C$$

where:

C : Coefficient as defined in [3.1.4]

$$\lambda = \frac{R_{p0,2}'}{\sigma_{E1}}$$

$R_{p\,0,2}'$: Minimum as-welded guaranteed yield stress of aluminium alloy used, in N/mm^2

σ_{E1} : Stress defined below.

- For tubular pillars with a rectangular cross-section, the stress σ_{E1}, in N/mm^2, is given by:

$$\sigma_{E1} = 252000 \cdot \left(\frac{t}{b}\right)^2$$

where:

b : Greatest dimension of the cross-section, in mm

t : Plating thickness, in mm

- For tubular pillars with a circular cross-section, the stress σ_{E1}, in N/mm^2, is given by:

$$\sigma_{E1} = 43000 \cdot \frac{t}{D}$$

D : Outer diameter, in mm

t : Plating thickness, in mm.

- For pillars with I cross-sections, the stress σ_{E1}, in N/mm^2, is the lesser of the following values:

$$\sigma_{E1} = 252000 \cdot \left(\frac{t_w}{h_w}\right)^2$$

$$\sigma_{E1} = 105000 \cdot \left(\frac{t_f}{b_f}\right)^2$$

where:

t_w : Web thickness, in mm

h_w : Web height, in mm

t_f : Thickness of face plate, in mm

h_f : Width of face plate, in mm.

3.1.4 Checking criteria

The scantlings of aluminium pillars loaded by the compression axial load F_A defined in [3.1.1] are to comply with the formulae in Tab 4.

Table 3 : Coefficient f

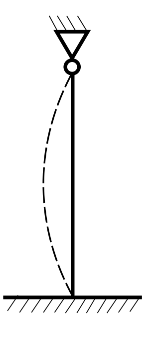
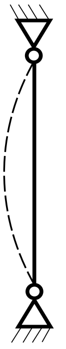
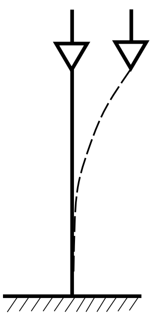
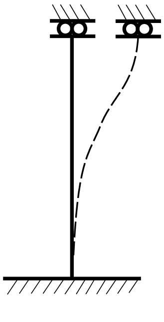
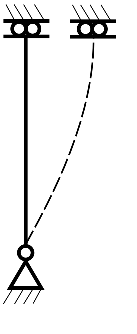
Conditions of fixity					
f	0,7	1,0	2,0	1,0	2,0

Figure 1 : Coefficient C

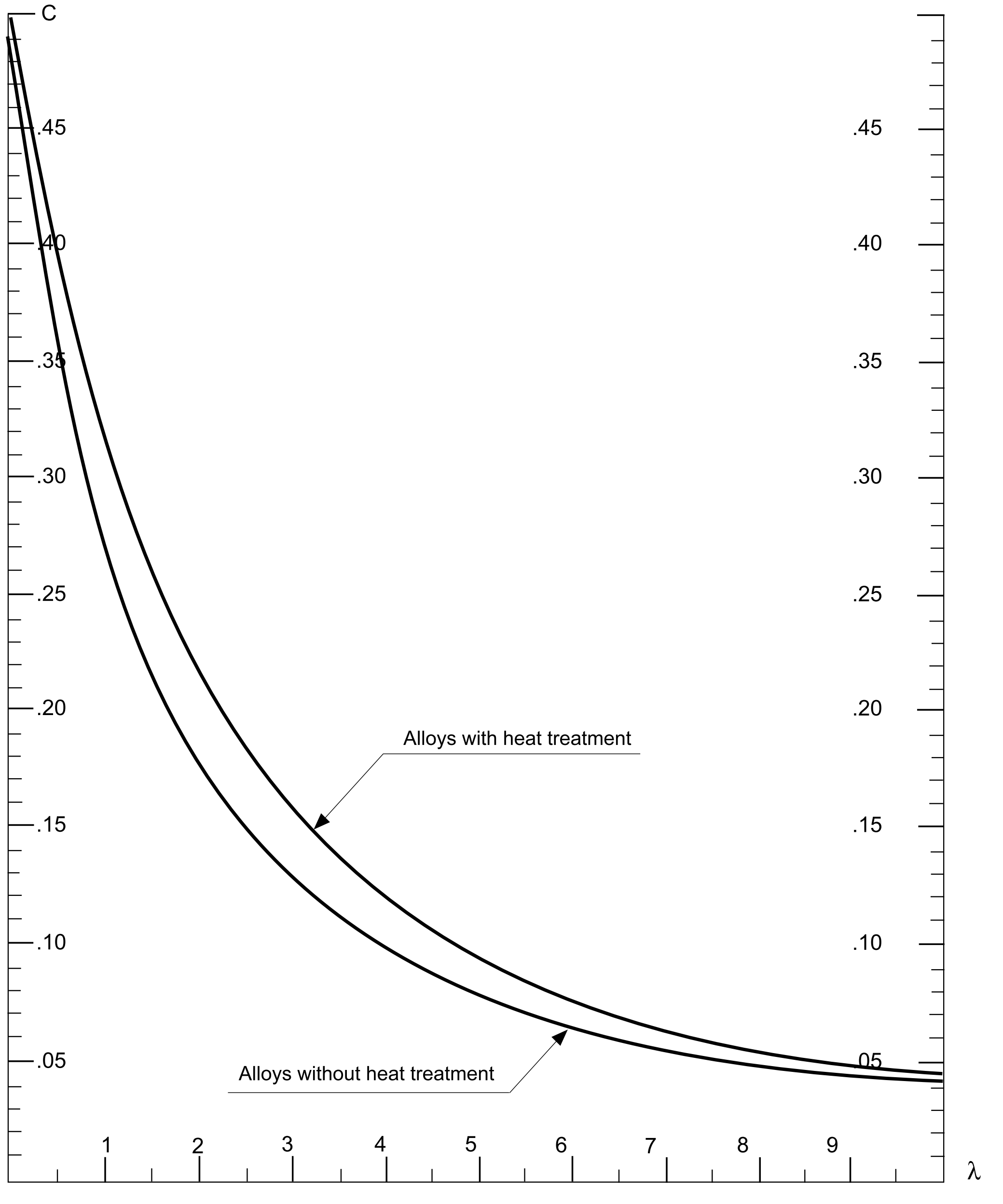
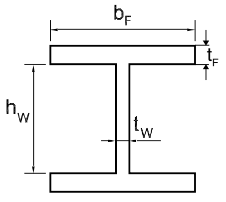
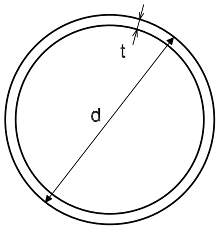
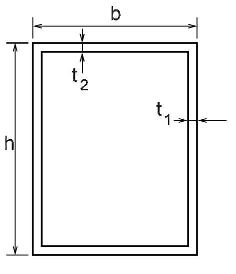


Table 4 : Buckling check of aluminium pillars subject to compression axial load

Pillar cross-section	Column buckling check	Local buckling check
Built-up 	$\frac{\sigma_{cB}}{SF} \geq 10\frac{F_A}{A}$	$\frac{\sigma_{cL}}{SF} \geq 10\frac{F_A}{A}$
Hollow tubular 	$\frac{\sigma_{cB}}{SF} \geq 10\frac{F_A}{A}$	$\frac{\sigma_{cL}}{SF} \geq 10\frac{F_A}{A}$
Hollow rectangular 	$\frac{\sigma_{cB}}{SF} \geq 10\frac{F_A}{A}$	$\frac{\sigma_{cL}}{SF} \geq 10\frac{F_A}{A}$

Note 1:

σ_{cB} : Critical column buckling stress, in N/mm², defined in [2.1.2]

σ_{cL} : Critical local buckling stress, in N/mm², defined in [2.1.3] for built-up section and circular or rectangular hollow section

SF : Safety factor, to be taken equal to:

- SF = 1,6+ 0,5 (fℓ/r) for column buckling
- SF = 1 for local buckling

F_A : Compression axial load in the pillar, in kN, defined in [2.1.1]

A : Sectional area, in cm², of the pillar.

SECTION 1 GENERAL

1 Application

1.1 General

1.1.1 The requirements of the present chapter are applicable to structural members of hull and superstructures of yachts and charter yachts built in composite (totally or partly).

SECTION 2 HULL GIRDER AND PLATFORM OF CATAMARANS

1 Hull girder

1.1 General

1.1.1 The global loads are to be taken into account for the review of hull girder of monohull and catamaran and for the cross deck of catamaran in the cases listed in Ch 6, Sec 1, [1.3].

1.1.2 The design review of hull girder structure consists in:

- checking that global stresses safety factors SF are more than the admissible values given in Ch 4, Sec 3, [5.4]
- checking that the actual safety factors for buckling of plating contributing to longitudinal hull girder strength are more than the admissible values given in Ch 4, Sec 3, [5.4].

1.1.3 The calculation of global stresses is carried out on basis of:

- the combination of global loads (bending moments) as indicated in Ch 6, Sec 4
- the actual strength characteristics of the hull girder as indicated in Ch 4, Sec 4.

1.1.4 The buckling strength of structural members contributing to the longitudinal hull girder strength is checked on basis of the relevant requirements of Ch 9, Sec 3 for plating.

1.1.5 As a rule, the checking of the hull girder strength is to be carried out for monohull yachts and for catamaran yachts.

2 Cross deck of catamaran

2.1 Estimation of stiffness of cross deck

2.1.1 The design review of the main structure of the cross deck of catamarans under global wave torque may be checked by means of a beam model analysis, as shown on Fig 1. Any other justified checking method may be considered.

This design review consists in:

- checking that global stresses safety factors SF in floats are more than the admissible values given in Ch 4, Sec 3, [5.4]
- checking that local stresses safety factors SF in cross connecting structure (cross beams or transverse bulkheads) are more than the admissible values given in Ch 4, Sec 3, [5.4].

2.1.2 The purpose of the present calculation is to determine the loads distribution in the cross deck between floats, versus flexural and shear stiffnesses of the primary structure of the cross deck.

2.1.3 Each resisting transverse member between floats is modelized as a beam, taking account of:

- flexural inertia about an horizontal axis, depending mainly on the web height of the transverse cross beam or bulkhead, the roof deck thickness or the float deck thickness, the thickness of the underside of the cross deck (wet deck) and the young modulus of each of these elements
- vertical shear inertia, depending on the web height of the transverse cross beams or bulkheads, their thicknesses and their own shear modulus
- their span between inner side shell of floats.

2.1.4 As far as possible, the beam model of the float is to have:

- vertical and horizontal inertias and young modulus close to the actual one of the float
- a shear inertia and shear modulus close to the actual one of the float
- a torsional inertia about longitudinal float axis and shear modulus close to the actual one of the float.

The second float is not described as a beam in the beam model. Instead, the transverse cross beams in the beam model are fully fixed at their intersection with this float.

2.1.5 The flexural inertia, young modulus, shear inertia and shear modulus of each structural element of the model can be estimated as defined in Ch 12, Sec 4.

2.1.6 Wave torque model

The wave torque moment exerted on the cross deck may be represented by 2 vertical forces F, equal in magnitude and opposite in direction, as shown on Fig 2. The magnitude of the force F, in kN, is to be taken equal to:

$F = M_{WT} / L_{WL}$

where:

M_{WT} : Wave torque moment, in kN.m, calculated according to Ch 6, Sec 2, [2.3]

L_{WL} : Length of the float at full load waterline, in m, as described in the beam model (see Fig 1).

2.1.7 Digging in loading model

The loading due to digging in, as described in Ch 6, Sec 3, [3], may be satisfactorily taken into account in the beam model by applying a differential vertical loading F_V (difference between the vertical loads exerted on both floats) and a differential horizontal load F_H (difference between the horizontal loads exerted on both floats), as shown on Fig 3.

The linear loads to input in the beam model, F_V and F_H , in kN/m, are to be calculated as follows, with F′ and F″ calculated according to Ch 6, Sec 3, [3.2]:

$$F_V = \frac{F'/3}{L_{WL}/4}$$

$$F_H = \frac{F''/3}{L_{WL}/4}$$

Figure 1 : Cross deck of catamarans - Model principle

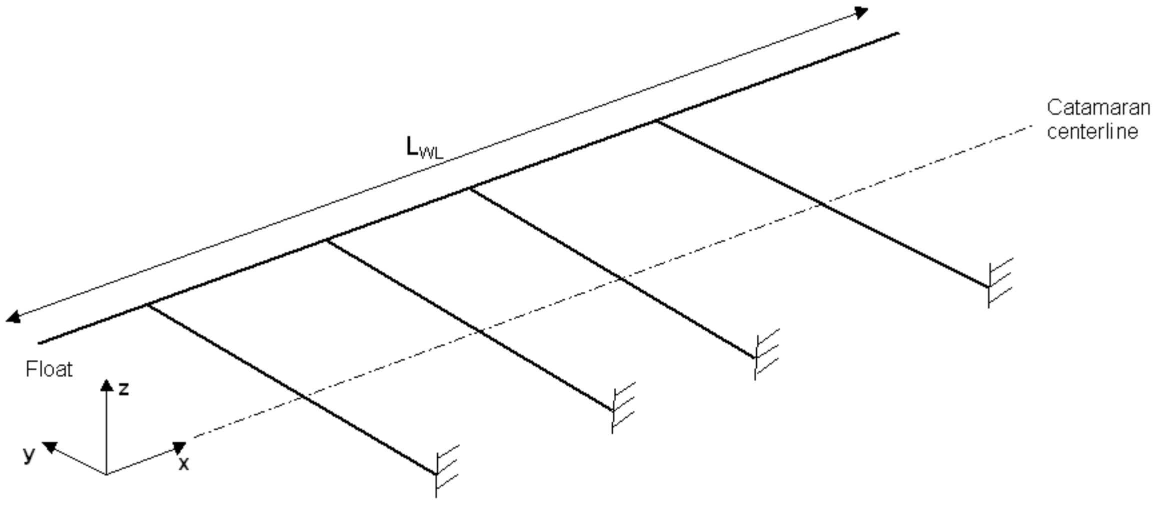
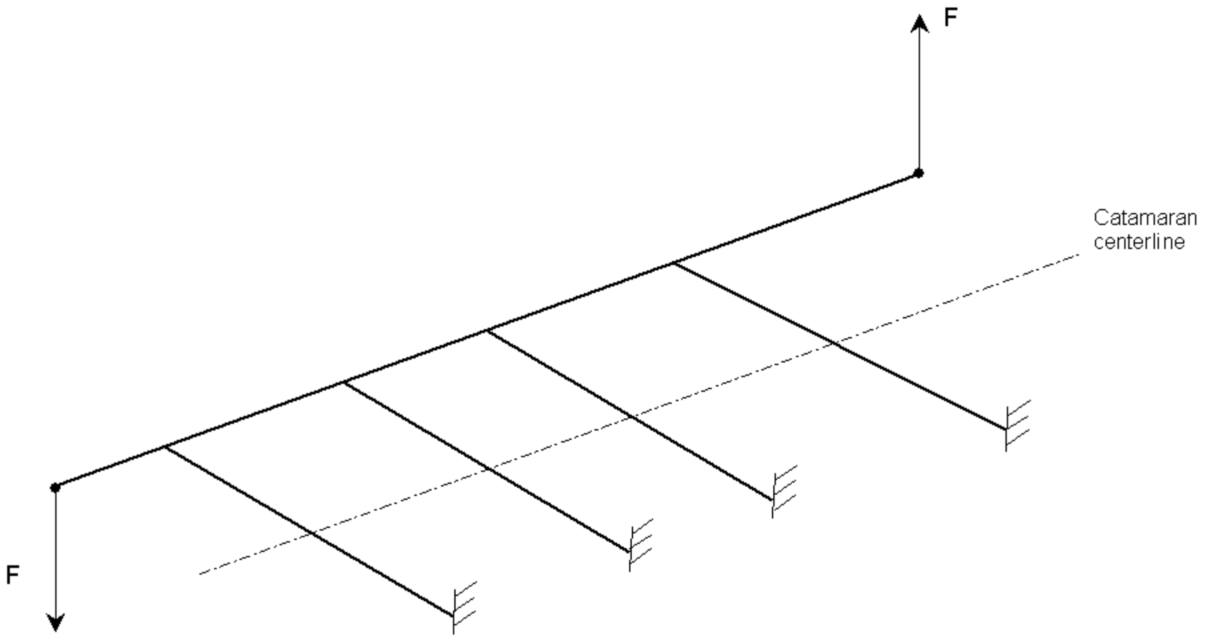


Figure 2 : Application of wave torque in beam model



2.1.8 Rig torque

For catamaran sailing yacht, the torque exerted by standing rigging may be represented by 2 vertical forces F_{RIG}, equal in magnitude and opposite in direction, as indicated in [2.1.6]. The magnitude of the force F, in kN, is to be taken equal to:

$F_{RIG} = M_{RIGT} / L_{WL}$

where:

M_{RIGT} : Rig torque, in kN.m, calculated according to the method given in Ch 6, Sec 3, [2.4]

L_{V1}', L_{D1}', L_P': Distances, in m, between various chain plates of the standing rigging and the center of rotation of the cross deck, measured according to Fig 4.

The longitudinal position of the center of rotation of the cross deck is estimated from the results of the beam model analysis specified in [2.1.6].

2.1.9 Combination of loadings

The two loading cases are defined in Ch 6, Sec 4 and are reminded below for information:

- wave torque loading combined with 70 percent of the rig torque
- digging in torque combined with 70 percent of the rig torque.

Figure 3 : Application of digging in loads in beam model

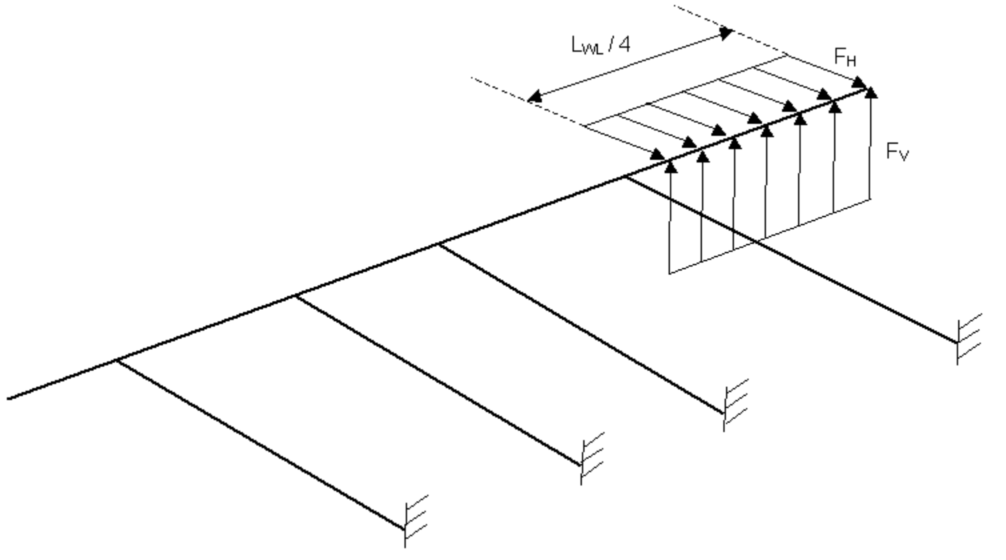
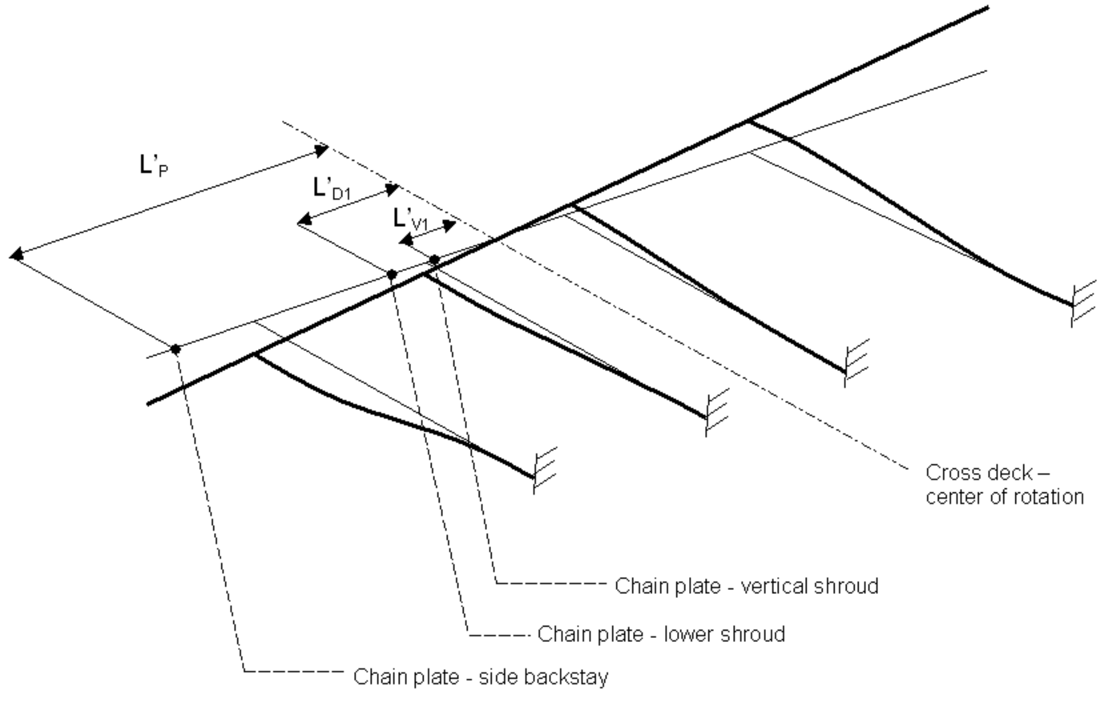


Figure 4 : Rig lever arm inducing rig torque



2.2 Floats structure

2.2.1 The structure of each float is to be checked as indicated in [1], considering the vertical bending moments and the vertical shear forces coming from the beam model analysis performed to check the cross deck structure, as shown on Fig 5.

2.2.2 The geometrical characteristics of the float may be determined using Bureau Veritas Rule software or any other equivalent mean (see Ch 1, Sec 4).

The transverse sections to be considered are to take into account all the longitudinal continuous members (laminates and longitudinal stiffeners) in the area shown on Fig 6, where:

b_R : Breadth equal to 10% of the roof length

b_{WD} : Breadth equal to 10% of the cross deck length.

Figure 5 : Overall loads in the float

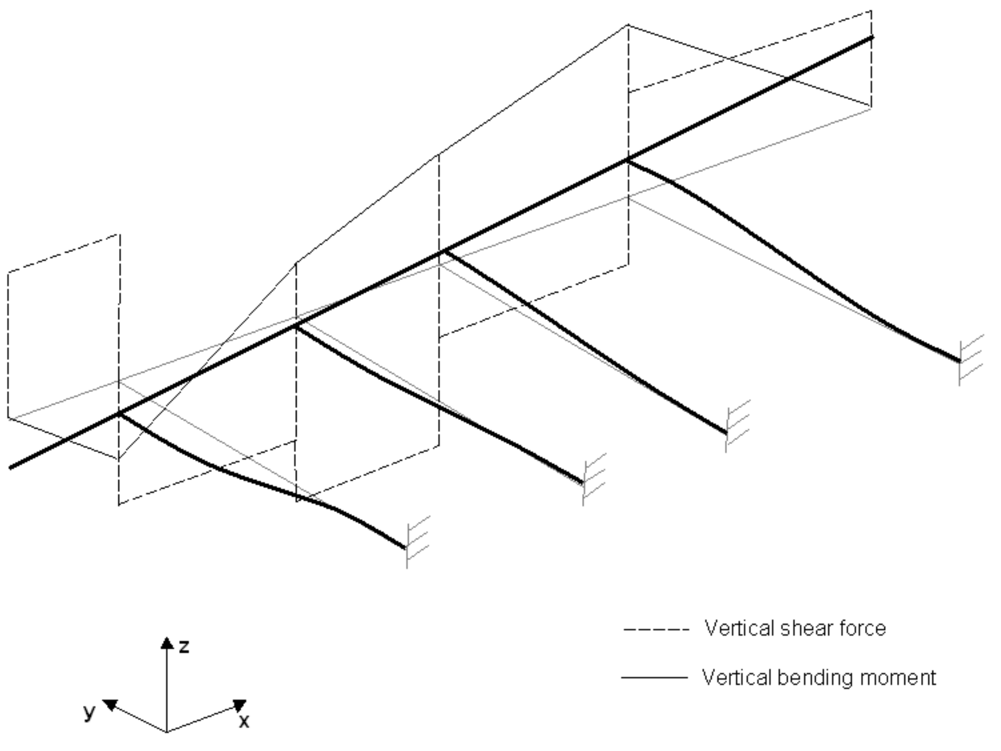


Figure 6 : Area to take into account for continuous members (laminates and stiffeners) for hull girder strength

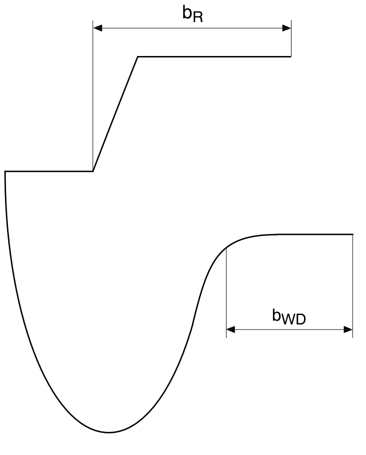
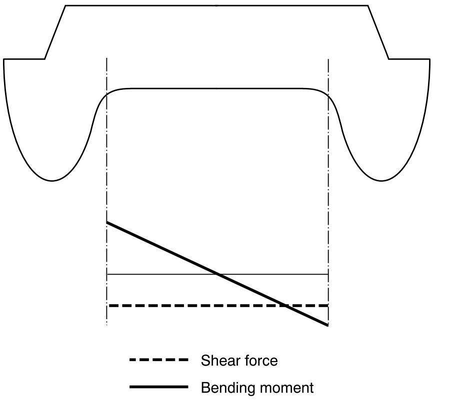


Figure 7 : Transverse distribution of bending moment and shear force



2.3 Primary transverse structure between floats

2.3.1 Each resisting transverse cross member between floats (cross beams, bulkheads) is checked against flexural and shear strength, taking account of the bending moments and shear forces resulting from the beam model analysis described in [2.1].

The values of bending moments and shear forces to consider are the one calculated in the transverse beams of the beam model, in way of the modelized float.

The transverse distribution of vertical bending moments and vertical shear force is indicated in Fig 7.

2.3.2 Particular attention is to be paid to:

- shear buckling check of transverse bulkheads
- compression/bending buckling check of wet deck and cross deck plating in areas where the bending moment is maximum.

2.3.3 For catamarans sailing yachts, the cross beam supporting the mast is to be checked as indicated in [2.3.1] and [2.3.2], with added effect of loads induced by mast on this particular cross beam.

This cross beam may be considered as fixed in way of inside side plating of floats and loaded by the mast (considered as a concentrated force).

The mast compressive load, as given by the Shipyard or the Designer, is to be considered with a contribution factor 0,7.

SECTION 3 LAMINATE PANEL

1 General

1.1 Load conditions

1.1.1 As a general rule, the laminate panels are to be examined for the two following conditions:

- compression and shear buckling check, as defined in [2], where the laminate panels are submitted to global loads (as for example deck or bottom area under global hull bending, side shell or web of cross deck beam under global shear forces)
- local flexural and shear check, as defined in [7], where the laminate panels are submitted to lateral pressure.

1.2 Checking process

1.2.1 The laminate panel check consists in:

- estimating the loading condition of the laminate panel, as defined in this present section
- estimating the mechanical characteristics of the laminate, as defined in Ch 12, Sec 4
- comparing the safety factors and the appropriate minimum rules safety factors as defined in Ch 4, Sec 3, [5.4].

1.3 Calculation program process

1.3.1 All the following calculations may be automatically carried out by Bureau Veritas program (see Ch 1, Sec 4):

- critical buckling checks
- flexural moments distribution under hydrodynamic loads
- shear forces distribution under hydrodynamic loads
- laminate panel stress analysis
- dynamical amplification coefficient.

2 Buckling check of laminate panels

2.1 General

2.1.1 The requirements of this article apply for the global buckling of laminate panel subjected to in-plane compression stresses acting on one side or to in-plane shear stresses.

2.1.2 Only global buckling is examined for sandwich laminates. As a general rules, the buckling modes such as shear crimping, local face dimpling and face wrinkling are not sampling cases with usual sandwich used in yacht hull construction.

2.1.3 When particular sandwich designs are used such as foam core with low density, honeycomb core or thin faceskins, the buckling modes mentioned in [2.1.2] are to be specially examined.

2.1.4 The buckling check of the laminate panels as defined hereafter are based on the following hypothesis on boundary conditions:

- for monolithic laminate, all laminate edges are supposed simply supported in way of the laminate supports
- for sandwich laminate, all laminate edges are supposed clamped in way of the laminate supports.

2.1.5 Global laminate parameters

Global flexural rigidity, global shear rigidity and global tensile rigidity of laminates are defined in Ch 12, Sec 4, [5] and may be evaluated with Bureau Veritas program defined in Ch 1, Sec 4.

2.1.6 The hull areas to be checked according to the requirements of the present section are:

For compression buckling:

- bottom and decks panel
- side shell panel, in the upper area below strength deck
- deck area around mast of monohull sailing yachts
- bottom and deck panel of cross deck of catamarans, in way of transverse primary bulkheads.

For shear buckling:

- primary transverse bulkheads of catamarans
- hull side shells.

2.1.7 Loading principles

The loadings considered for buckling check are those inducing compression and shear stresses as shown in Fig 1 and Fig 2.

Figure 1 : Buckling of a rectangular laminate panel subjected to compression

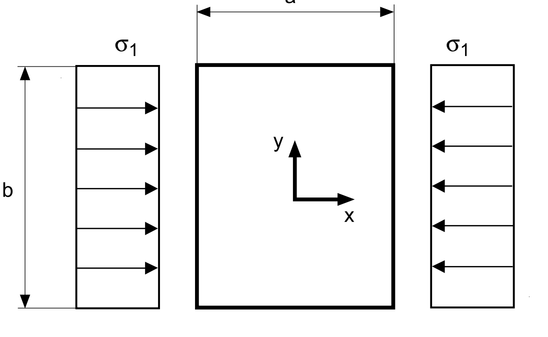
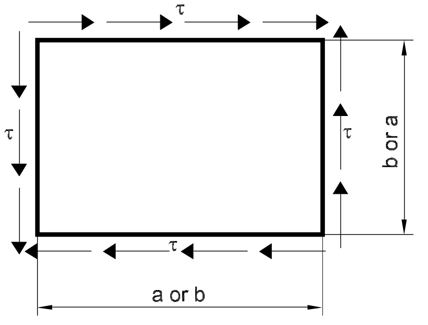


Figure 2 : Buckling of a rectangular laminate panel subjected to shear



3 Compression buckling check of monolithic laminates

3.1 General

3.1.1 For specific designs, other boundary conditions than those defined in [2.1.4] may be considered.

3.2 Hypothesis

3.2.1 Monolithic laminates are considered as orthotropic materials.

3.3 Critical compression buckling stress

3.3.1 Load in X-direction

The critical compression buckling stress, in N/mm², is estimated from the following formula:

$$\sigma_C = \frac{\pi^2 10^{-6}}{m^2 a^2 t}[D_{11} m^4 + 2(D_{12} + 2D_{33}) m^2 \alpha^2 + D_{22} \alpha^4]$$

where

a : Unloaded side of the laminate, parallel to the X-direction of the laminate, in m

b : Loaded side of the laminate, parallel to the Y-direction of the laminate, in m

α : Aspect ratio, $\alpha = a/b$

t : Laminate thickness, in mm

D_{11}, D_{12}, D_{22}, D_{33}: Global flexural rigidity matrix coefficients, as defined in Pt B, Ch 12, Sec 4, [4.1.1], in N.mm²/mm

Note 1: These coefficients are to be calculated for the laminate with the same global axis X and Y.

m : Number of half-waves in loading X-direction. This number depends on α, as follows:

if $\alpha \le \sqrt{2}\left(\frac{D_{11}}{D_{22}}\right)^{\frac{1}{4}}$ $m = 1$

if $\sqrt{2}\left(\frac{D_{11}}{D_{22}}\right)^{\frac{1}{4}} < \alpha \le \sqrt{6}\left(\frac{D_{11}}{D_{22}}\right)^{\frac{1}{4}}$ $m = 2$

if $\alpha > \sqrt{6}\left(\frac{D_{11}}{D_{22}}\right)^{\frac{1}{4}}$ $m = 3$

3.3.2 Load in Y-direction

The critical compression buckling stress, in N/mm², is estimated from the following formula:

$$\sigma_C = \frac{\pi^2 10^{-6}}{n^2 b^2 t}\left[\frac{D_{11}}{\alpha^4} + \frac{2(D_{12} + 2D_{33})}{\alpha^2} n^2 + D_{22} n^4\right]$$

where

a : Loaded side of the laminate, parallel to the X-direction of the laminate, in m

b : Unloaded side of the laminate, parallel to the Y-direction of the laminate, in m

α : Aspect ratio, $\alpha = a/b$

t : Laminate thickness, in mm

D_{11}, D_{12}, D_{22}, D_{33}: Global flexural rigidity matrix coefficients, as defined in Ch 12, Sec 4, [4.1.1], in N.mm²/mm

Note 1: These coefficients are to be calculated for the laminate with the same global axis X and Y.

n : Number of half-waves in loading Y-direction. This number depends on α, as follows:

if $1/\alpha \le \sqrt{2}\left(\frac{D_{22}}{D_{11}}\right)^{\frac{1}{4}}$ $n = 1$

if $\sqrt{2}\left(\frac{D_{22}}{D_{11}}\right)^{\frac{1}{4}} < 1/\alpha \le \sqrt{6}\left(\frac{D_{22}}{D_{11}}\right)^{\frac{1}{4}}$ $n = 2$

if $1/\alpha > \sqrt{6}\left(\frac{D_{22}}{D_{11}}\right)^{\frac{1}{4}}$ $n = 3$

3.4 Compression buckling criteria

3.4.1 The safety factor between the critical stress as calculated in [3.3] and the actual compression stress as calculated according to Ch 9, Sec 2, is to be not less than the minimum safety factor defined in Ch 4, Sec 3, [5.4].

4 Shear buckling check of monolithic laminates

4.1 General

4.1.1 For specific designs, other boundary conditions than those defined in [2.1.4] may be considered.

4.2 Hypothesis

4.2.1 Monolithic laminates are considered as orthotropic materials.

4.3 Critical shear buckling stress

4.3.1 The critical shear buckling stress, in N/mm², is estimated with the following formula:

$$\tau_C = C_\beta \frac{(D_{11} D_{22}^3)^{\frac{1}{4}}}{t\left(\frac{b}{2}\right)^2} 10^{-6}$$

where:

a : Side parallel to the X-direction of the laminate, in m

b : Side parallel to the Y-direction of the laminate, in m

t : Laminate thickness, in mm

D_{11}, D_{12}, D_{22}, D_{33}: Defined in [3.3.1], in N.mm²/mm

C_β : Coefficient depending on θ and β:

$$C_\beta = (7{,}1\theta + 3{,}9)\beta^2 + (7{,}3\theta^3 - 11{,}7\theta^2 + 3{,}2\theta - 0{,}8)\beta + 5{,}2\theta + 8{,}1$$

where:

$$\theta = \frac{D_{12} + 2D_{33}}{\sqrt{D_{11}D_{22}}}$$

$$\beta = \frac{b}{a}\left(\frac{D_{11}}{D_{22}}\right)^{\frac{1}{4}}$$

4.4 Shear buckling criteria

4.4.1 The safety factor between the critical stress as calculated in [4.3] and the actual compression stress as calculated according to Ch 9, Sec 2, is to be not less than the minimum safety factor defined in Ch 4, Sec 3, [5.4].

5 Compression buckling check of sandwich laminates

5.1 General

5.1.1 For specific designs, other boundary conditions than those defined in [2.1.4] may be considered.

5.2 Hypothesis

5.2.1 Sandwich faceskins are considered as orthotropic and core as isotropic materials.

5.3 Critical compression buckling stress

5.3.1 The critical compression buckling stress, in N/mm², is estimated from the following formula:

$$\sigma_c = E_t\frac{\pi^2[EI]}{b^2H}K_1 10^{-6}$$

where:

E_t : Minimum global tensile rigidity of the sandwich in the loading direction, in N/mm²:

$E_t = \min(E_{t,1}, E_{t,2})$

where

$E_{t,1}$: Global tensile rigidity of the upper faceskin of sandwich panel in the loading direction, as defined in Ch 12, Sec 4, [4.1.1]

$E_{t,2}$: Global tensile rigidity of the lower faceskin of sandwich panel in the loading direction, as defined in Pt B, Ch 12, Sec 4, [5.1]

[EI] : Global flexural rigidity of the sandwich panel to be obtained, in Nmm²/mm, from the following formula:

$$[EI] = \sqrt{D_{11}D_{22}}$$

D_{11} and D_{22} are the global flexural rigidity matrix coefficients of the sandwich panel, as defined in Pt B, Ch 12, Sec 4, [4.1.1]

H : Global compression rigidity, to be calculated, in N/mm, as follows:

$$H = E_{t,1}t_{F1} + E_{t,2}t_{F2} + E_Ct_C$$

with

t_{F1} : Upper faceskin thickness, in mm

t_{F2} : Lower faceskin thickness, in mm

t_C : Core thickness, in mm

E_C : Core tensile rigidity, in N/mm²

Note 1: In case of anisotropic core, E_C is to be the core tensile rigidity in the loading direction.

b : Loaded side of the sandwich panel, in m

α : Aspect ratio, α=a/b

K_1 : Buckling coefficient, obtained from the following formulae:

- simply supported conditions (for information only):

  $K = 2V^2 - 4{,}1V + 3{,}1$

  if $\alpha \geq 0{,}9V^{-0{,}15} - 0{,}45$

  or $\alpha \geq 0{,}9$

  $K_1 = A\alpha^2 + B\alpha + C$

  if $\alpha < 0{,}9V^{-0{,}15} - 0{,}45$

  if $V \leq 0{,}2$

  $A = 120V^2 - 116V + 20{,}4$

  $B = -350V^2 + 227V - 36{,}8$

  $C = 205V^2 - 113{,}5V + 19{,}7$

  if $V > 0{,}2$

  $A = -2V + 2$

  $B = -10{,}8V^2 + 19{,}3V - 8{,}5$

  $C = 5V^2 - 10V + 6$

- clamped conditions:

  $K_1 = A\alpha^2 + B\alpha + C$

  $$A = 0,1\left(\frac{1}{V^{1,2}} - 1\right)$$

  $$B = -0,2\left(\frac{1}{V^{1,45}} - 1\right)$$

  $$C = \frac{1}{V}$$

  A is not more than 5,5

  B is not less than -19,5

  C is not more than 23,5

where:

$$V = \frac{\pi^2[EI]}{b^2G_Ct_C}\cdot 10^{-6}$$

[EI] : Global flexural rigidity of the sandwich panel, in Nmm²/mm

G_C : Core shear rigidity (in laminate plane xy), in N/mm^2.

5.4 Compression buckling criteria

5.4.1 The safety factor between the critical stress as calculated in [5.3] and the actual compression stress as calculated according to Ch 9, Sec 2, is to not be less than the minimum safety factor defined in Ch 4, Sec 3, [5.4].

6 Shear buckling check of sandwich laminate

6.1 General

6.1.1 For specific designs, other boundary conditions than those defined in [2.1.4] may be considered.

6.2 Hypothesis

6.2.1 Sandwich faceskins are considered as orthotropic and core as isotropic materials.

6.3 Critical shear buckling stress

6.3.1 The critical shear buckling stress, in N/mm^2, is estimated with the following formula:

$$\tau_C = \frac{\pi^2 G_{XY}[EI]}{b^2 N} K_2 10^{-6}$$

where

[EI] : Global flexural rigidity of the sandwich panel, in N.mm^2/mm, as defined in [5.3.1]

G_{XY} : Minimum global shear rigidity, in N/mm^2

$G_{XY} = \min(G_{XY,1}, G_{XY,2})$

with

$G_{XY,1}$: Global shear rigidity of the upper faceskin of sandwich panel in laminate plane xy, as defined in Ch 12, Sec 4, [5.1]

$G_{XY,2}$: Global shear rigidity of the lower faceskin of sandwich panel in laminate plane xy, as defined in Ch 12, Sec 4, [5.1]

N : Global shear rigidity, in N/mm, to be calculated, as follows:

$N = G_{XY,1} t_{F1} + G_{XY,2} t_{F2} + G_C t_C$

With:

t_{F1}, t_{F2}, t_C, G_C: Defined in [5.3.1]

b : Smaller side of the laminate panel, in m

a : Longer side of the laminate panel, in m

K_2 : Buckling coefficient, obtained from the following formulae:

- simply supported conditions (for information only):

$$K_2 = \frac{4}{3}\,\frac{4 + 3\dfrac{b^2}{a^2}}{1 + \dfrac{1}{3}\left[13 + 9\dfrac{b^2}{a^2}\right]V}$$

if $0 \le V \le \dfrac{1}{1 + \dfrac{b^2}{a^2}}$

$$K_2 = \frac{1}{V}$$

if $V > \dfrac{1}{1 + \dfrac{b^2}{a^2}}$

- clamped conditions:

$$K_2 = \frac{1}{3}\,\frac{27 + 17\dfrac{b^2}{a^2}}{1 + \dfrac{1}{3}\left[23 + 13\dfrac{b^2}{a^2}\right]V}$$

if $0 \le V \le \dfrac{3}{4\left(1 + \dfrac{b^2}{a^2}\right)}$

$$K_2 = \frac{1}{V}$$

if $V > \dfrac{3}{4\left(1 + \dfrac{b^2}{a^2}\right)}$

where:

$$V = \left(\frac{\pi^2 [EI]}{b^2 G_C t_C}\right) \times 10^{-6}$$

6.4 Shear buckling criteria

6.4.1 The safety factor between the critical stress as calculated in [6.3] and the actual compression stress as calculated according to Ch 9, Sec 2, is to be not less than the minimum safety factor defined in Ch 4, Sec 3, [5.4].

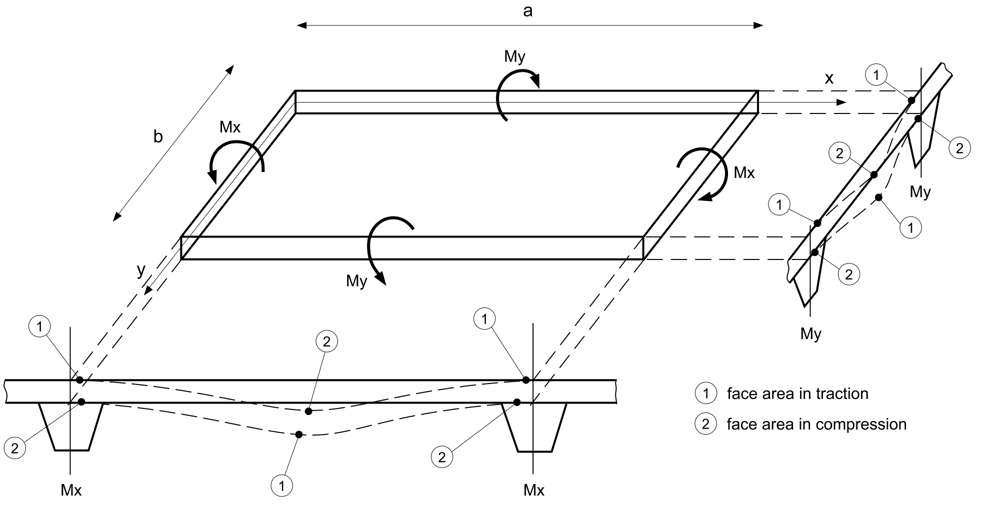
7 Laminate panel sustaining lateral pressure

7.1 General

7.1.1 The laminate panels are to be examined according to the following processes taking into account the type of lateral pressure:

- in case of hydrodynamic loads as defined in Ch 7, Sec 1 (for bottom, side, decks, superstructure, tanks...): as defined in [7.2]
- in case of bottom slamming loads as defined in Ch 7, Sec 2 (for bottom laminate panel): as defined in previous case plus as defined in [7.3]
- in case of impact pressure on side shell, as defined in Ch 7, Sec 1, [2.3] (for side shell of monohull and specific area for catamaran): as defined in the first previous cases plus as defined in [7.4]

Figure 3 : Flexural moments



7.1.2 Load point

Unless otherwise specified, lateral pressure is to be calculated at the middle of the plate panel.

7.2 Laminate panel under hydrodynamic loads

7.2.1 Flexural moment distribution at panel boundaries

Each side of the laminate panel is considered as clamped.

The absolute value of the moments M_X and M_Y, as shown on Fig 3, induced by the lateral pressure, are respectively the moment at the middle of side "b" and the moment at the middle of side "a". They are to be estimated, in kN.m per meter width, from the following formulae:

$$|M_X| = D_{11} \cdot A \cdot p_S \cdot \frac{10^{-6}}{8a^2} \cdot k_{S,X}$$

$$|M_Y| = D_{22} \cdot A \cdot p_S \cdot \frac{10^{-6}}{8b^2} \cdot k_{S,Y}$$

Note 1: The sign of the moments are to be chosen in order to respect the traction and compression areas of the laminate under lateral pressure, as shown on Fig 3.

where:

A : Parameter obtained from the following formula:

$$A = \frac{\beta \cdot a^4 \cdot 10^6}{7D_{11} + 4(D_{12} + 2D_{33})\alpha^2 + 7D_{22}\alpha^4}$$

a : Side of the laminate panel in x direction, in m

b : Side of the laminate panel in y direction, in m

α : Aspect ratio, $\alpha = a/b$

D_{11}, D_{12}, D_{22}, D_{33}: Global flexural rigidity matrix coefficients, as defined in Ch 12, Sec 4, [4.1.1], in $N.mm^2/mm$

Note 2: These coefficients are to be calculated for the laminate with the same global axis X and Y.

p_S : Local pressure, in kN/m^2, defined in Ch 7, Sec 1, for bottom, sides, decks, superstructure, tanks and bulkheads

β : Coefficient, equal to:

if $a \le b$ $\quad \beta = 6,15\left(\frac{a}{b}\right)^{0,07}$

if $a > b$ $\quad \beta = 6,15\left(\frac{b}{a}\right)^{0,07}$

β is not less than 5,5

$k_{S,X}$, $k_{S,Y}$: Reductor factor in case of shell plating with stiffeners with wide base, equal to:

$$k_{S,X} = 1 - 3\left(\frac{w_{S,X}}{a}\right)\left(1 - \frac{w_{S,X}}{a}\right)$$

$$k_{S,Y} = 1 - 3\left(\frac{w_{S,Y}}{b}\right)\left(1 - \frac{w_{S,Y}}{b}\right)$$

where $k_{S,X}$ and $k_{S,Y}$ are taken not less than 0,4 and where a, b, $w_{S,X}$ and $w_{S,Y}$, in m, are defined in Fig 4:

Figure 4 : defintion of $w_{S,X}$ and $w_{S,Y}$

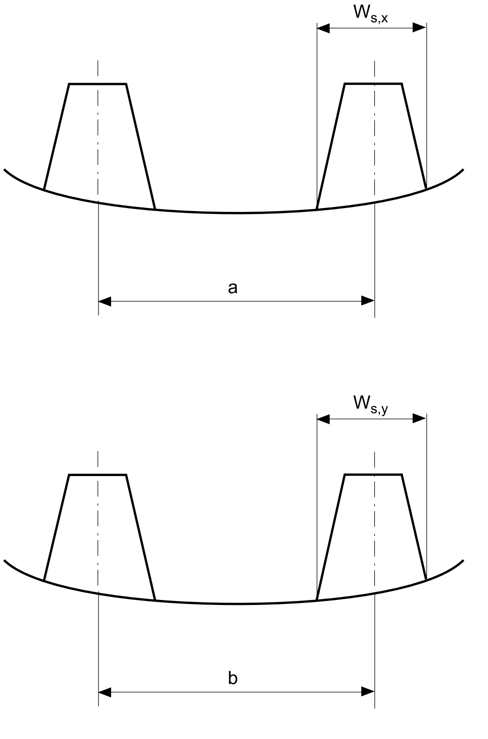
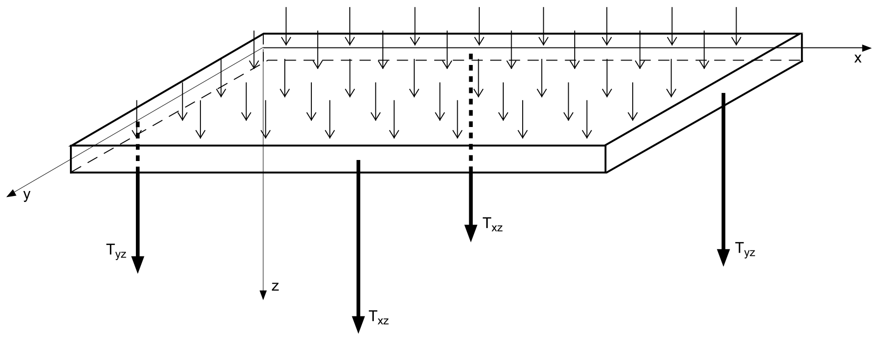


Figure 5 : Shear forces



7.2.2 Transversal shear forces distribution at panel boundaries

Each side of the laminate panel is considered as clamped.

Shear forces T_{XZ} and T_{YZ}, as shown on Fig 5, induced by the lateral pressure, are respectively the shear force on side "a" and the shear force on side "b". They are to be estimated, in kN per meter width, from the following formulae:

$$T_{YZ} = \frac{a p_S}{2\left(1 + \alpha^4 \frac{D_{22}}{D_{11}}\right)}$$

$$T_{XZ} = \alpha^3 \frac{D_{22}}{D_{11}} T_{YZ}$$

where

$\alpha = a/b$: Aspect ratio

a,b : Sides panel as defined in [7.2.1], in m

D_{11}, D_{12}, D_{22}, D_{33}: As defined in [7.2.1], in N.mm²/mm

p_S : As defined in [7.2.1], in kN/m².

7.2.3 Laminate panel stress analysis

Laminate panel stresses are to be checked according to Ch 12, Sec 4, [4], taking into account the values of flexural moments M_X and M_Y and the shear forces T_{XZ} and T_{YZ} as defined herebefore.

The safety coefficients between applied stresses and theoretical breaking stresses estimated in Ch 12, Sec 3, [5], are to be in accordance with the minimum appropriate safety coefficients defined in Ch 4, Sec 3, [5.4].

7.2.4 Calculation program process

The calculation of flexural moments, shear forces, elementary layer stresses can be automatically carried out by Bureau Veritas program defined in Ch 1, Sec 4.

7.3 Laminate bottom panel under slamming loads

7.3.1 Dynamical amplification phenomena

The dynamical slamming load amplification phenomena concerns only sandwich laminate sustaining lateral slamming loads.

As a general rules, this phenomena is not observed for monolithic laminate and is not to be taken into account.

7.3.2 Estimation of the dynamical amplification coefficient

The dynamical amplification coefficient is a coefficient increasing the slamming loads as defined in Ch 7, Sec 2 and to be taken into account for the sandwich laminate.

This coefficient K_{DA} is defined as follows:

- for monolithic laminate: $K_{DA} = 1$
- for sandwich laminate:

for $t_0/T < 0,9$: $K_{DA} = 0,98\left(1 + \frac{\sin(\pi t_0/T)}{\pi t_0/T}\right)$

for $0,9 \le t_0/T \le 2$: $K_{DA} = 1,1$

for $t_0/T > 2$: $K_{DA} = 1$

where

t_0 : Pulse rise time, in s, obtained from the following formula:

$$t_0 = 0,03\sqrt{\frac{L}{43}}$$

L : Rule length, in m, as defined in Ch 1, Sec 2, [3.2]

T : Sandwich panel proper period, in s, calculated as follows:

$$T = \frac{1}{f\sqrt{\frac{K}{K + \frac{\rho_W}{\pi W}}}}$$

K : Coefficient, in m⁻¹, equal to:

$$K = \sqrt{\frac{1}{a_S^2} + \frac{1}{b_L^2}}$$

a_S : Smaller side of the sandwich panel, in m

b_L : Longer side of the sandwich panel, in m

f : Proper frequency of the sandwich panel, in Hz, obtained from the following formula:

$$f = 150 a_S^{-1,8}$$

ρ_W : Water mass density, in general equal to 1025 kg/m³

W : Total laminate weight per square meter, in kg/m², as defined in Ch 12, Sec 4, [5.2].

7.3.3 Flexural moments and shear forces under slamming loads

The moments and shear forces induced by the lateral slamming pressure are to be estimated as defined in [7.2.1] and [7.2.2] herebefore with a local load p_{Sl} equal to the slamming load defined in Ch 7, Sec 2, multiplied by K_{DA} defined in [7.3.2].

The stress analysis is to be carried out with the same manner than [7.2.3].

7.3.4 Calculation program process

The dynamical amplification calculation of the laminate panel can be automatically carried out by Bureau Veritas program defined in Ch 1, Sec 4.

7.4 Laminate panel under impact pressure on side shell

7.4.1 Dynamical amplification phenomena

The same dynamical amplification phenomena as defined in [7.3.1] is applied in case of impact pressure on side shell as defined in Ch 7, Sec 1, [2.3].

The amplification coefficient is to be estimated as defined in [7.3.2].

7.4.2 Sandwich analysis

In case of sandwich laminate under impact pressure on side shell, only the core shear stress is to be taken into account.

As a general rule, the core shear stress, in N/mm², is to be obtained from the following formula:

$$\tau = \frac{0,6 \cdot p_{smin}}{4t} K_{DA}$$

where

p_{smin} : Impact pressure on side shell, in kN/m², as defined in Ch 7, Sec 1, [2.3]
with $K_2 = 1$

t : Thickness of the sandwich (core + faceskins), in mm

K_{DA} : Dynamical amplification coefficient, as defined in [7.3.2]].

The shear safety factor between the applied core shear stress as calculated in [7.4.2] and the theoretical shear breaking stress of the core estimated in Ch 12, Sec 2, [4], is to be in accordance with the appropriate safety factor defined in Ch 4, Sec 3, [5.4].

7.4.3 Monolithic analysis

The absolute value of the moments M_X and M_Y, induced by the impact pressure on side shell, are respectively the moment at the middle of side "b" and the moment at the middle of side "a". They are to be estimated, in kN.m per meter width, from the following formulae:

$$|M_X| = D_{11} \cdot A \cdot p_{Smin} \cdot \frac{10^{-6}}{8a^2} \cdot coef_X \cdot k_{S,X}$$

$$|M_Y| = D_{22} \cdot A \cdot p_{Smin} \cdot \frac{10^{-6}}{8b^2} \cdot coef_Y \cdot k_{S,Y}$$

Note 1: The sign of the moments are to be chosen in order to respect the traction and compression areas of the laminate under lateral pressure, as shown on Fig 3.

where:

A : Parameter obtained from the following formula:

$$A = \frac{\beta \cdot a^4 \cdot 10^6}{7D_{11} + 4(D_{12} + 2D_{33})\alpha^2 + 7D_{22}\alpha^4} K_{DA}$$

a : Side of the laminate panel in x direction, in m

b : Side of the laminate panel in y direction, in m

α : Aspect ratio, $\alpha = a/b$

D_{11}, D_{12}, D_{22}, D_{33}: Global flexural rigidity matrix coefficients, as defined in Ch 12, Sec 4, [4.1.1], in N.mm²/mm

Note 2: These coefficients are to be calculated for the laminate with the same global axis X and Y.

p_{Smin} : Impact pressure on side shell, in kN/m², as defined in Ch 7, Sec 1, [2.3]

K_{DA} : Dynamical amplication coefficient, $K_{DA} = 1$

β : Coefficient, equal to:

if $a \le b$ $\quad \beta = 6,15\left(\frac{a}{b}\right)^{0,07}$

if $a > b$ $\quad \beta = 6,15\left(\frac{b}{a}\right)^{0,07}$

β is not less than 5,5

$coef_X$, $coef_Y$: Reduction coefficients (without dimension), due to a non-uniform lateral pressure on the panel, equal to:

- $coef_X = \frac{1}{(1+a)^2}$ if $0,6(1+a) \le b$

  $coef_X = 1$ if $0,6(1+a) > b$

- $coef_Y = \frac{1}{(1+b)^2}$ if $0,6(1+b) \le a$

  $coef_Y = 1$ if $0,6(1+b) > a$

$k_{S,X}$, $k_{S,Y}$: Reduction factor as defined in [7.2.1].

Shear forces T_{XZ} and T_{YZ}, induced by the lateral pressure, are respectively the shear force on side "a" and the shear force on side "b". They are to be estimated, in kN per meter width, from the following formulae:

$$T_{YZ} = 0,3 \frac{p_{Smin}}{\left(1 + \alpha^3 \frac{D_{22}}{D_{11}}\right)} K_{DA}$$

$$T_{XZ} = \alpha^3 \frac{D_{22}}{D_{11}} T_{YZ}$$

where

$\alpha = a/b$: Aspect ratio

a,b : Sides panel as defined in [7.4.3], in m

D_{11}, D_{12}, D_{22}, D_{33}: As defined in [7.4.3], in N.mm²/mm

p_{Smin} : As defined in [7.4.3], in kN/m²

K_{DA} : As defined in [7.4.3].

Laminate panel stresses are to be checked according to Ch 12, Sec 4, [4], taking into account the values of flexural moments M_X and M_Y and the shear forces T_{XZ} and T_{YZ} as defined herebefore.

The safety coefficients between applied stresses and theoretical breaking stresses estimated in Ch 12, Sec 3, [5], are to be in accordance with the minimum appropriate safety coefficients defined in Ch 4, Sec 3, [5.4].

SECTION 4 STIFFENERS

1 General

1.1 Geometric and rigidity calculation of a stiffener

1.1.1 The mechanical characteristics of a stiffener made up of composite is to be estimated as defined in Ch 12, Sec 4, [6].

1.2 Ordinary stiffeners

1.2.1 Span

The span ℓ, in m, of ordinary stiffeners is to be taken as indicated in Ch 4, Sec 4, [3].

1.2.2 Laminate attached plating for lateral loading

The width of the laminate attached plating to be considered for the yielding check of ordinary stiffeners is to be obtained, in m, from the following formulae, where s is the spacing between ordinary stiffeners, in m:

- where the laminate attached plating extends on both sides of the ordinary stiffener:

  $b_P = s$

- where the laminate attached plating extends on one side of the ordinary stiffener (i.e. ordinary stiffeners bounding openings):

  $b_P = 0{,}5s$.

1.2.3 Where ordinary stiffeners are continuous through primary supporting members, their connection to the web of the primary supporting member is to be in accordance with [1.5.1].

1.2.4 As a rule, where ordinary stiffeners are cut at primary supporting members, brackets are to be fitted to ensure the structural continuity of the ordinary stiffeners by ensuring the continuity of the longitudinal fibres located in the ordinary stiffener flange.

1.3 Primary supporting members

1.3.1 Span

The span ℓ , in m, of primary supporting members is to be taken as indicated in Ch 4, Sec 4, [3].

1.3.2 Laminate attached plating

The width of the laminate attached plating to be considered for the yielding check of primary supporting members analysed through beam structural models is to be obtained, in m, from the following formulae, where s is the spacing of the primary supporting members:

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

  $b_P = \min (s; 0{,}2\ell)$

- where the laminate plating extends on one side of the primary supporting member (i.e. primary supporting members bounding openings):

  $b_P = 0{,}5 \min (s; 0{,}2\ell)$

1.3.3 The web shear area of primary supporting members is to take into account the section reduction due to cut-outs provide for the ordinary stiffeners passage through the primary supporting members, if relevant.

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

1.3.5 Where openings such as duct routing for pipes, electrical cable..., are cut in primary supporting members, they are to be equidistant from the face plate and the attached plate. As a rule, their height is not to be more than 20% of the primary supporting member web height.

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

1.3.7 Over half of the span in the middle of the primary supporting members, the length of openings is to be not greater than the distance between adjacent openings.

At the ends of the span, the length of openings is to be not greater than 25% of the distance between adjacent openings.

1.4 Large openings in primary supporting members

1.4.1 In the 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.

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

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

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

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

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

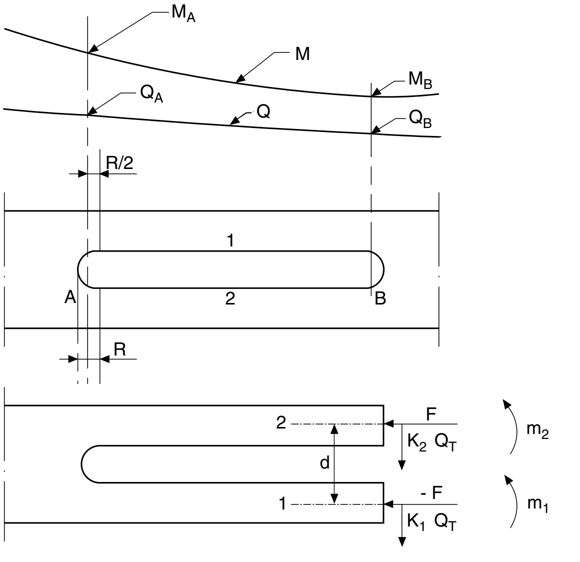
where:

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)

Figure 1 : Large openings in primary supporting members - Secondary stresses



I_1, I_2 : Moments of inertia, in cm^4, of members (1) and (2) with attached plating, as defined in Ch 12, Sec 4, [6.2]

$$K_1 = \frac{I_1}{I_1 + I_2}$$

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

- Members (1) and (2) are subjected to a uniforme compressive or tensile strain, in percent, equal to:

$$\varepsilon_{F1} = 10\frac{F}{\sum_i (S_i E_{Xi})_1}100$$

$$\varepsilon_{F2} = 10\frac{F}{\sum_i (S_i E_{Xi})_2}100$$

with $\Sigma(S_iE_i)_1$ and $\Sigma(S_iE_i)_2$, respectively the sum of the product of the section, in cm^2, and the Young modulus, in N/mm^2, of each element (laminate attached plating, web stiffener and flange stiffener) of the stiffener 1 and the stiffener 2.

- Members (1) and (2) are subjected to a flexural strain induced by secondary flexural moments m_1 and m_2.

The longitudinal strain, in percent, of each element of members (1) and (2) induced by m_1 and m_2 are:

$$\varepsilon_{Xi(1)} = \frac{m_1 d_{i(1)}}{10 E_{Xi(1)} I_1}100$$

$$\varepsilon_{Xi(2)} = \frac{m_2 d_{i(2)}}{10 E_{Xi(2)} I_2}100$$

as defined in Ch 12, Sec 4, [6.2.3].

Note: The suffix (1) and (2) are only used to differentiate the members (1) and (2).

- The web of members (1) and (2) are subjected to a shear strain, in percent, induced by the shear force Q_T equal to:

$$\gamma_{XY(1)} = 10\frac{Q_T}{\sum_i (S_i G_i)_{(1)}}100$$

$$\gamma_{XY(2)} = 10\frac{Q_T}{\sum_i (S_i G_i)_{(2)}}100$$

where Q_T is the shear force, in kN, applied to members (1) and (2), equal to Q_A or Q_B, whichever is greater.

$\Sigma(S_iG_i)$ as defined in Ch 12, Sec 4, [6.2.5], is the sum of the product of the section, in cm^2, and the Coulomb modulus, in N/mm^2, of each element (laminate attached plating, web stiffener and flange stiffener) of the stiffener 1 and the stiffener 2.

The suffix (1) and (2) being only used to differentiate the members (1) and (2).

- The local stresses in way of large openings are to be examined in each composite element making up the members (1) and (2) as defined in Ch 12, Sec 4, [6] in the two following cases:
  - stresses induced by force F and secondary flexural moment m_1 and m_2. In this case, the global strain is to be equal to the sum of the strains induced by F and m_1 and m_2;
  - shear stress induced by Q_T.
- The stresses estimated are to comply with the safety factors defined in Ch 4, Sec 3, [5.4].

1.4.2 When stresses do not comply with safety factors defined in Ch 4, Sec 3, [5.4], the number of elementary layers in web members (1) and (2) and/or the number of elementary layers provided to edge the large opening are to be increased.

1.5 Connections of primary stiffeners and primary supporting member

1.5.1 Where ordinary stiffeners are continuous through primary supporting members, they are to be connected to the web plating so as to ensure proper transmission of loads, e.g. by means of the principal connection details shown in Fig 2.

Other principal connection may be considered by the Society on a case by case basis.

1: a local reinforcement of primary stiffener web can be necessary if (h_P - h_S) is not sufficient.

2: a local laminate connection between the ordinary stiffener and the primary structure is to be provided as follows:

- laminate connection (number of elementary layer) is to be defined according to shear stress defined in Ch 12, Sec 4, [6.2.5] (where T is the shear force in the ordinary stiffener at its ends) and safety factor defined in Ch 4, Sec 3, [5.4].
- laminate connection surface on ordinary stiffener and primary structure is to be defined taking into account the previous shear force T, the structural adhesive characteristics defined in Ch 12, Sec 2, [5.2] and safety factor defined in Ch 4, Sec 3, [5.4].

Figure 2 : Connection detail

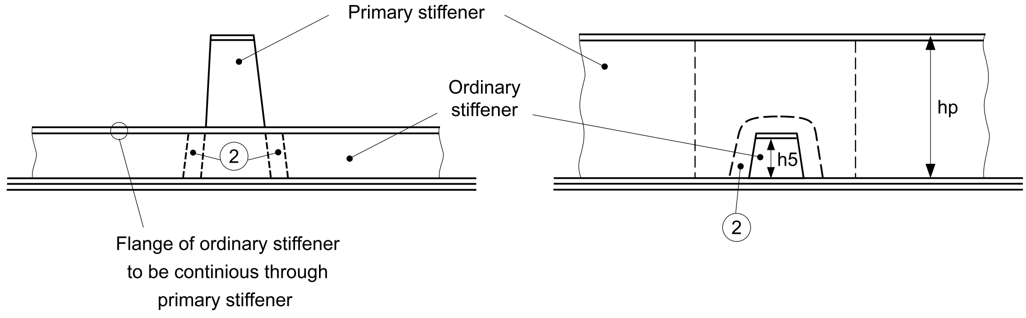
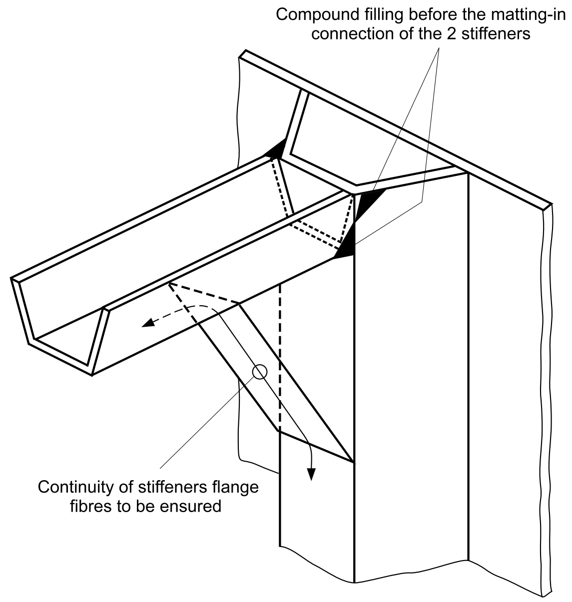


Figure 3 : Principal bracket arrangement



1.5.2 Where ordinary stiffeners are cut at primary supporting members, the ordinary flange stiffeners continuity is to be ensured by bracket or equivalent arrangement.

1.5.3 Bracket arrangement

As a general rule, the main principal bracket arrangement is to be based on the design shown on Fig 3, ensuring the continuity of the longitudinal fibres of stiffener flanges.

1.5.4 Cut-outs in stiffening structure

As a general rule, all openings carried out in a laminate panel (bulkhead, stiffener web...) are to be protected against damage caused by water and/or humidity.

This protection can be ensured by one or more laminate product laminated on the opening edge.

The location of cut-outs in secondary and/or primary structure are to be located in area where the shear forces are minimum.

The cut-outs in some area such as, for example, intersection between primary stiffeners, are to be avoided.

2 Ordinary stiffeners sustaining lateral pressure

2.1 Load point

2.1.1 Lateral pressure for longitudinal stiffener

Unless otherwise specified, lateral pressure is to be calculated at mid-span of the ordinary stiffener considered.

2.1.2 Lateral pressure for transversal stiffener

Unless otherwise specified, lateral pressure is to be calculated at the lower point and at the upper point of the ordinary stiffener considered.

2.2 Bending and shear check

2.2.1 As a general rule, the bending check of ordinary stiffeners sustaining lateral pressure is carried out according to the following process:

- Estimation of the flexural bending moment M induced by lateral pressure, in kN.m, and shear force T in kN, at the edges:

$$M = coeff \frac{p_M \cdot s \cdot \ell^2}{m}$$

$$T = coeft \frac{p_T \cdot s \cdot \ell}{2}$$

where

ℓ : Span of the stiffener, in m, measured as indicated in Ch 4, Sec 4, [3]

s : Spacing between stiffeners, in m

p_M : Lateral pressure, in kN/m², as given

1) For hydrodynamic loads

a) For longitudinal stiffeners,

$p_M = p_S$

as defined in Ch 7, Sec 1 taken into account [2.1.1]

b) For transversal stiffeners,

$p_M = 3\ p_{S\ lower} + 2\ p_{S\ upper}$

where $p_{S\ lower}$ and $p_{S\ upper}$ are defined in Ch 7, Sec 1, taken into account [2.1.2]

2) For bottom slamming loads

$p_M = p_{sl}$, as defined in Ch 7, Sec 2

3) For impact pressure on side shell

$p_M = p_{Smin}$, as defined in Ch 7, Sec 1, [2.3]

p_T : Lateral pressure, in kN/m^2, as given

1) For hydrodynamic loads

a) For longitudinal stiffeners,

$p_T = p_S$

as defined in Ch 7, Sec 1 taken into account [2.1.1]

b) For transversal stiffeners,

$p_T = (0,7\ p_{S\ lower} + 0,3\ p_{S\ upper})$

where $p_{S\ lower}$ and $p_{S\ upper}$ are defined in Ch 7, Sec 1 , taken into account [2.1.2]

2) For bottom slamming loads

$p_T = p_{sl}$, as defined in Ch 7, Sec 2

3) For impact pressure on side shell

$p_T = p_{Smin}$, as defined in Ch 7, Sec 1, [2.3]

m : Coefficient depending on load type and/or end conditions :

- m = 60 for load type p_M as defined in 1) b)
- m = 12, 10 or 8 for types p_M as defined in 1) a), 2), 3), and depending on end conditions, as defined in Ch 4, Sec 4, [3.3.3].

coeff : Reduction coefficient equal to:

- $(1 - s/2\ell) \geq 0$ in general case
- $(3\ell^2 - 0,36)\cdot 0,3/\ell^3$ for ordinary side shell stiffeners in the case where p is taken equal to the impact pressure on side shell p_{Smin} as defined in Ch 7, Sec 1, [2.3], with ℓ being taken not less than 0,6 m
- 1 for decks ordinary stiffener

coeft : Reduction coefficient equal to:

- $(1 - s/2\ell) \geq 0$ in general case
- $0,6/\ell$, without being taken superior to 1, for ordinary side shell stiffeners in the case where p is taken equal to the minimum pressure on side shell as defined in Ch 7, Sec 1, [2.3]
- 1 for decks ordinary stiffener

- Estimation of the neutral axis and the inertia of the stiffener as defined in Ch 12, Sec 4, [6.2.1] and Ch 12, Sec 4, [6.2.2]
- Estimation of the strains and the stresses induced by the moment M and by the shear force T, as defined in Ch 12, Sec 4, [6.2.3] to Ch 12, Sec 4, [6.2.5]
- Estimation of tensile or compressive stresses and shear stresses in each individual layer of each element of the stiffener, as defined in Ch 12, Sec 4, [6.2.4] and Ch 12, Sec 4, [6.2.5]
- Examination of safety factor for each element of the stiffener (composite attached plating, web and flange) in relation to minimum safety factors defined in Ch 4, Sec 3, [5.4].

2.2.2 Attention is to be particularly paid on the location where the strains are calculated. For an analysis at the edges:

- the flange is to be in compression (negative strain)
- the attached plating is to be in traction (positive strain).

3 Primary supporting members sustaining lateral pressure

3.1 General

3.1.1 The primary supporting members are designed as indicated in [2] for ordinary stiffeners, without taking into account the coefficients coeff and coeft, with lateral loads depending on primary member under consideration:

- bottom primary members: hydrodynamic loads as given in Ch 7, Sec 1, [2.2] and Ch 7, Sec 2.
- side primary members: hydrodynamic loads as given in Ch 7, Sec 1, [2.2]
- decks primary members: minimum sea loads as given in Ch 7, Sec 1, [3].

For deck primary structure exposed to sea pressure, the lateral loads taken into account can be reduced by the following coefficients:

- 0,8 for primary structure of exposed superstructure deck;
- $(1 - 0,05\ell) > 0,8$ for primary structure of exposed deck.

4 Curved primary supporting members

4.1 General

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

4.1.2 Model principles

In case of 2-D or 3-D beam structural model, the curved primary supporting members are to 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 knuckles equivalent springs is considered as unaffecting the local bending moment and shear forces distribution where the angle between two successive beams is not more than 3°.

5 Calculation program

5.1 Stiffener analysis

5.1.1 The stiffener analysis can be carried out with Bureau Veritas program defined in Ch 1, Sec 4.

5.2 Curvate primary stiffener analysis

5.2.1 The curvate primary stiffener analysis can be carried out with Bureau Veritas program defined in Ch 1, Sec 4.

SECTION 5 BOTTOM STRUCTURE

1 General

1.1 Application

1.1.1 The requirements of this Section apply to longitudinally or transversely framed single and double bottom structures.

1.1.2 The requirements of the present section are given for guidance. Any other arrangement may be considered.

1.2 General arrangement

1.2.1 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.

1.2.2 In case of a charter yacht of more than 12 passengers being considered by the Flag Administration as a passenger ship, it might be necessary to provide a continuous double bottom. In such a case, the relevant requirements of the Ship Rules, Part B, are applicable.

1.2.3 Adequate tapering is to be provided between double bottom and adjacent single bottom structures. Similarly, adequate continuity is to be provided in the case of height variation in the double bottom. Where such a height variation occurs within 0,6 L amidships, the inner bottom is generally to be maintained continuous by means of inclined plating.

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

2 Single bottom

2.1 Longitudinal framing

2.1.1 As a general rule, longitudinally framed single bottom yachts are to be fitted with a centre girder.

Intercostal centre girders are to be aligned and bounded to floors.

2.1.2 Where side girders are fitted in lieu of centre girder, the scarfing is to be adequately extended and additional stiffening of the centre bottom may be required. Arrangements similar to [2.1.1] are to be provided.

2.1.3 When the heights of floors and girders are the same, the web and flange of the stiffer member are generally to be continuous.

2.1.4 Centre and side girders are to be extended as far aft and forward as practicable.

2.1.5 As a rule, longitudinal girders are to be fitted in way of each line of pillars.

If not, pillars are to be located in way of a local longitudinal member.

2.1.6 Longitudinal ordinary stiffeners are generally to be continuous when crossing primary members.

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

These openings are to be protected as described on Ch 9, Sec 4, [1.4].

2.2 Transverse framing

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

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

In some particular cases, it may be accepted that floors end at side on a longitudinal member of the side shell or the bottom.

2.2.3 Openings and cut-outs in web of floors are to be taken into account for shear analysis of floors.

These openings are to be protected as described in Ch 9, Sec 4, [1.4].

3 Double bottom

3.1 Double bottom height

3.1.1 The double bottom height is to be sufficient to ensure access to all parts and, in way of the centre girder, is to be not less than 0,7 m.

3.1.2 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 laminated plate floors.

Where this is impossible, suitable longitudinal structures such as partial girders, longitudinal brackets etc., fitted across the knuckle are to be arranged.

3.2 Floors

3.2.1 Laminate plate floors are to be fitted:

- in way of transverse watertight bulkheads
- in way of double bottom steps.

3.2.2 Where the double bottom height exceeds 0,9 m, watertight floors are to be fitted with stiffeners having a scantling not less than that required for tank bulkhead vertical stiffeners.

3.3 Bottom and inner bottom longitudinal ordinary stiffeners

3.3.1 Bottom and inner bottom longitudinal ordinary stiffeners are generally to be continuous through the floors.

Openings in floors are to be protected throughout floor thickness.

4 Bottom structure in way of bulb keel of sailing yachts

4.1 General

4.1.1 The loads induced by the bulb keel on the bottom structure are given in Ch 10, Sec 7.

4.1.2 As a rule, the reinforced structural members of the bottom in way of the bulb keel are checked by direct calculations.

4.2 Keel bolted to the bottom structure

4.2.1 As a rule, bottom laminate rule scantling calculated according to Ch 9, Sec 3 is to be increased by 50% in case of keel fin bolted to bottom structure.

4.2.2 Bolts are to be high strength bolts.

4.2.3 Sizing of bolts is to be designed according to Ch 10, Sec 7.

4.2.4 Floors located at fore end and aft end of the keel fin are to be designed to sustain the loads defined in Ch 10, Sec 7, [2] and corresponding to the load case of keel grounding, as defined in Ch 10, Sec 7, [4].

SECTION 6 SIDE STRUCTURE

1 General

1.1 Application

1.1.1 The requirements of this Section apply to longitudinally or transversally framed side structures.

1.2 General

1.2.1 Structures of sides with transverse framing system are made of transverse frames, possibly supported by horizontal stringers.

1.2.2 Structures of sides with longitudinal framing system are made of ordinary longitudinal stiffeners supported by vertical primary supporting members.

2 Structure arrangement

2.1 Stiffeners

2.1.1 The ordinary stiffeners are normally to be continuous through the primary supporting members.

Otherwise, the detail of the connection is examined by the Society on a case by case basis.

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

2.1.3 Web frames and ordinary side frames are to be attached to floors by brackets, or any other equivalent structure.

2.2 Openings in the shell plating

2.2.1 Openings in the yacht sides are to be well rounded at the corners, located well clear of superstructure ends and protected as mentioned in Ch 9, Sec 4, [1.4].

2.2.2 Openings for stabiliser fins are considered by the Society on a case by case basis. The laminate of sea chests is generally to be that of the local shell plating.

2.2.3 Openings of considerable size are to be adequately compensated by means of increased lamination. Such compensation is to be partial or total depending on the stresses occurring in the area of the openings.

2.2.4 Ordinary stiffeners cut in way of openings are to be attached to local structural member supported by continuous adjacent ordinary stiffeners.

2.3 Side shell laminate plating in way of chain plates of sailing yachts

2.3.1 As a general rule, chainplates cannot be directly bonded on sandwich laminate plate (side shell, bulkhead...).

The local bonding between chainplate and hull structure should be carried out on a monolithic hull element structure.

2.3.2 Local reinforcements may be requested on the side shell, to distribute adequately the secondary loads induced by the chain plate. These local reinforcements are to be connected to the stiffening system of the side shell.

2.3.3 Chain plates scantlings are to be according to Ch 10, Sec 6.

2.4 Upper brackets of frames

2.4.1 The scantling of upper brackets connecting frames to deck beams is to be examined by direct calculation taking into account the flexural moment and shear force as defined in Ch 9, Sec 4, [2].

2.4.2 The principle for connections of perpendicular stiffeners located in the same plane or connections of stiffeners located in perpendicular planes are to be equivalent to:

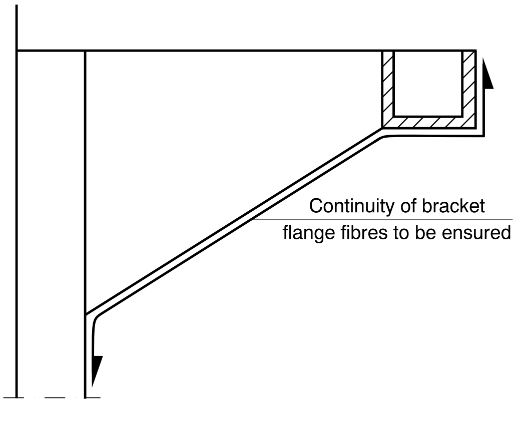
- for stiffeners in the same plane: as defined in Ch 9, Sec 4, Fig 3,
- for stiffeners in the perpendicular plane: as defined in Fig 1, hereafter.

2.5 Lower brackets of frames

2.5.1 In general, frames are to be continuous or to be bracketed to the bottom floors.

2.5.2 The scantling of lower brackets connecting frames to bottom floor is to be examined by direct calculation as indicated for upper brackets in [2.4].

Figure 1 : Connections of stiffeners located in perpendicular planes



SECTION 7 DECK STRUCTURE

1 General

1.1 Application

1.1.1 The requirements of this Section apply to longitudinally or transversely framed deck structures.

1.2 General

1.2.1 The deck supporting structure consists of ordinary stiffeners (beams or longitudinals), longitudinally or transversely arranged, supported by primary supporting members which may be sustained by pillars or bulkheads.

1.2.2 Adequate continuity of strength is to be ensured in way of:

- stepped strength decks
- changes in the framing system.

Details of structural arrangements are to be submitted for review to the Society.

1.2.3 Deck supporting structures under cranes and king posts are to be adequately stiffened.

1.2.4 Pillars or other supporting structures are generally to be fitted under heavy concentrated loads.

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

1.2.6 Where beams are fitted in a hatched deck, these are to be effectively supported by at least two longitudinal girders located in either side of the deck opening.

1.2.7 As a rule, the buckling strength of decks is to be checked under global hull girder loads.

1.2.8 The buckling strength of decks may also be requested to be checked under transverse loads:

- in way of mast of sailing yacht. The loads to consider are the horizontal transversal compression force induced by the traction in the shrouds
- in way of transverse bulkheads of cross deck of catamarans. The loads to consider are induced by the global torque exerted on the cross deck.

2 Structure arrangement

2.1 Stiffeners

2.1.1 Deck longitudinals are to be continuous in way of deck transverses and transverse bulkheads.

Other arrangements may be considered, provided adequate continuity of longitudinal strength is ensured.

2.2 Openings

2.2.1 The deck openings are to be as much spaced apart as possible.

As practicable, they are to be fitted as far as possible from highly stressed deck areas or from stepped deck areas.

2.2.2 An increase of lamination plate or additional reinforcements may be requested where deck openings are located:

- in the area of mast foot on sailing yachts
- in the areas of standing rigging chain plates on sailing yachts
- close to the primary transverse cross bulkheads on catamarans
- in areas of deck structural singularities (cockpit, stepped deck...)
- in way of the fixing of out-fittings.

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

The laminate cut out is to be protected as mentioned in Ch 9, Sec 4, [1.4].

2.2.4 Corner radiusing, in the case of the arrangement of two or more openings athwartship in one single transverse section, is considered by the Society on a case by case basis.

3 Pillars

3.1 General

3.1.1 Pillars are to be connected to the inner bottom at the intersection of girders and floors and at deck at the intersection of deck beams and deck girders.

3.1.2 Where pillars are not connected to the intersection of primary supporting members, partial floors, partial girders, partial deck beams or partial deck girders, an other appropriate structure is to be fitted to support the pillars.

3.1.3 Local high density core in stiffeners may be required in way where pillars are attached at their heads and heels.

3.1.4 Manholes may not be cut in the girders and floors below the heels of pillars.

3.1.5 Tight or non-tight bulkheads may be considered as pillars, provided that their scantlings comply with [3.2].

3.2 Scantling

3.2.1 The scantlings of pillars are to comply with the requirements of Ch 8, Sec 10 (for steel or aluminium pillars) or Ch 9, Sec 10 (for composite material pillars).

SECTION 8 BULKHEAD STRUCTURE

1 General

1.1 Application

1.1.1 The requirements of this Section apply to longitudinal or transverse bulkhead structures.

1.2 General

1.2.1 Bulkheads may be horizontally or vertically stiffened.

Horizontally framed bulkheads consist of horizontal ordinary stiffeners supported by vertical primary supporting members.

Vertically framed bulkheads consist of vertical ordinary stiffeners which may be supported by horizontal girders.

1.2.2 The number and location of watertight bulkheads are to be in accordance with the relevant requirements of damage stability criteria, when applicable, as defined in Part B, Chapter 3.

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

1.2.4 As a rule, openings may not be cut in the collision bulkhead below the freeboard deck(m) (Refer also to Ch 2, Sec 1, [2]).

The number of openings in the collision bulkhead above the freeboard deck(m) is to be kept to the minimum compatible with the design and proper working of the yacht.

All such openings are to be fitted with means of closing to weathertight standards.

1.2.5 Certain openings below the freeboard deck(m) are permitted in the other bulkheads, but these are to be kept to a minimum compatible with the design and proper working of the yacht and to be provided with watertight doors having strength such as to withstand the head of water to which they may be subjected.

1.2.6 As a general rule, the transverse bulkheads are to be stiffened in way of deck primary girders by vertical stiffeners in line with the deck girder or by an equivalent system. Where the deck primary girder is not continuous, the vertical stiffener supporting the end of the deck girder is to be strong enough to sustain the bending moment at end of the deck girder.

2 Structural arrangement

2.1 Watertight bulkheads

2.1.1 The crossing of transverse watertight bulkheads and bottom, side shell or deck longitudinal stiffeners are to be watertight.

2.1.2 Ordinary stiffeners of watertight bulkheads are to end in way of hull structure members, and to be connected to hull structure members.

2.1.3 Where requirement of [2.1.2] is made not possible by hull lines, any other solution may be accepted provided the embedding of bulkhead ordinary stiffeners is satisfactorily achieved.

2.1.4 Watertight bulkheads are to be fitted with watertight doors in way of passage.

2.1.5 The scantling of watertight doors is to be not less than that of the adjacent bulkhead, taking account of their actual spacing.

2.1.6 Where vertical stiffeners are cut in way of watertight doors, reinforced stiffeners are to be fitted on each side of the door and suitably overlapped; cross-bars are to be provided to support the interrupted stiffeners.

2.2 Non-tight bulkheads

2.2.1 As a rule, the total area of openings in wash bulkheads fitted in tanks is to be between 10% and 30% of the total area of the wash bulkhead.

2.3 Bulkheads acting as pillars

2.3.1 Non-tight bulkheads acting as pillars (i.e. those that are designed to sustain the loads transmitted by a deck structure) are to be provided as a general rules with vertical stiffeners.

2.3.2 As a general rule, a vertical stiffening member is to be fitted on the bulkhead, in line with the deck primary supporting member transfering the load from the deck to the bulkhead.

This vertical stiffener, in association with a width of plating equal to 35 times the plating thickness, is to comply with the applicable requirements for pillars, the load supported being determined in accordance with the same requirements.

2.4 Bracketed ordinary stiffeners

2.4.1 Where bracketed ordinary stiffeners are fitted, their arrangement are to be provided on the principles defined in Ch 9, Sec 4, [1.5.3].

The bracket scantlings are carried out by direct calculation taking into account the flexural moment and shear force acting on the stiffener in way of the bracket.

2.4.2 The connection between the stiffener and the bracket is to be such that the section modulus of the connection is not less than that of the stiffener.

SECTION 9 SUPERSTRUCTURES

1 General

1.1 Application

1.1.1 The requirements of this Section apply to front, side and aft bulkheads and decks of superstructures and deckhouses as defined in Ch 2, Sec 2, [2.2.2], which may or may not contribute to the longitudinal strength.

1.2 General

1.2.1 The pressures acting on on superstructures are given in Ch 7, Sec 1, [3] for decks and Ch 7, Sec 1, [4] for side and front walls.

In addition, for superstructures contributing to the hull girder longitudinal strength, global loads according to Part B, Chapter 6 are also to be considered

1.2.2 The strength of laminate and stiffeners of superstructures is to be checked according to Ch 9, Sec 3 and Ch 9, Sec 4 respectively.

In addition, for superstructures contributing to the hull girder longitudinal strength, overall strength is also to be checked according to Ch 9, Sec 2.

2 Structural arrangement

2.1 Connections of superstructures and deckhouses with the hull structure

2.1.1 Superstructure and deckhouse frames are to be fitted as far as practicable as extensions of those underlying and are to be effectively connected to both the latter and the deck beams above.

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.

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

2.1.3 The side plating at ends of superstructures is to be tapered into the bulwark or sheerstrake of the strength deck.

Where a raised deck is fitted, this arrangement is to extend over at least 3 frame spacings.

2.2 Structural arrangement of superstructures and deckhouses

2.2.1 Strengthening in way of superstructures and deckhouses

Web frames, transverse partial bulkheads or other equivalent strengthening are to be fitted inside deckhouses of at least 0,5B in breadth extending more than 0,15L in length within 0,4L amidships. These transverse strengthening reinforcements are to be spaced approximately 9 m apart and are to be arranged, where practicable, in line with the transverse bulkheads below.

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

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

2.2.2 Openings

Continuous coamings are to be fitted above and below doors or similar openings.

2.2.3 Access and doors

Access openings cut in sides 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 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.

2.2.4 Strengthening of deckhouses in way of tenders and liferafts

Stiffening of sides of deckhouses in way of tenders and liferafts, if any, is to be compatible with the launching operation. Deckhouses in way of launching appliances are to be adequately strenghtened.

2.2.5 Constructional details

Lower tier stiffeners are to be attached to the decks at their ends.

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

SECTION 10 PILLARS IN COMPOSITE MATERIAL

1 General

1.1 Application

1.1.1 The requirements of this Section apply to pillars (independent profiles or bulkheads stiffeners) made of composites.

1.1.2 The present Section deals with the buckling check of the pillars.

The general requirements relating to pillars arrangement is given in Ch 9, Sec 7, [3].

2 Buckling of pillars subjected to compression axial load

2.1 Compression axial load

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

The weighting factor depends on the relative position of each pillar with respect to that considered.

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 m², of the portion of the deck or the platform supported by the pillar considered

p_s : Pressure on deck, in kN/m², as defined in Ch 7, Sec 1, [3]

r : Coefficient which depends on the relative position of each pillar above the one considered, to be taken equal to:

- r = 0,9 for the pillar immediately above that considered
- $r = 0{,}9^i$ for the i^{th} pillar of the line above the pillar considered, to be taken not less than 0,478

Q_i : Vertical load, in kN, from the i^{th} pillar of the line above the pillar considered, if any.

2.2 Hollow tubular pillars

2.2.1 Critical column buckling load of hollow tubular pillars

The critical column buckling load of hollow tubular pillars is to be obtained, in kN, from the following formula:

$$F_{CR1} = \frac{\pi^2 I E}{(f\ell)^2} 10^{-5}$$

where:

I : Minimum moment of inertia, in cm⁴, of the pillar

$$I = \frac{\pi(d^4_{EXT} - d^4_{INT})}{64}$$

d_{EXT}, d_{INT} : External and internal diameter, in cm, of the pillar

ℓ : Span, in m, of the pillar

f : Coefficient, to be obtained from Tab 1

E : Young's modulus, in N/mm², of the global laminate in the longitudinal direction of the pillar, as defined in Ch 12, Sec 4, [5.1.2].

2.2.2 Global checking criteria

The composite pillars loaded by the compression axial load F_A defined in [2.1.1] are first to respect the following condition:

$$F_A \le F_{CR}/SF_G$$

where:

SF_G : Safety factor, equal to: $SF_G = 3\ C_F$

with C_F as defined in Ch 4, Sec 3, [5.4.1]

F_{CR1} : Critical column buckling load, in kN, as defined in [2.2.1]

2.2.3 Local checking criteria

Each individual layer of the laminate is to resist locally to load compression and to respect the following condition:

$$\varepsilon_A \le \varepsilon_{BR,k}/SF$$

where

SF : Safety factor of the individual layer as defined in Ch 4, Sec 3, [5.4.1]

$\varepsilon_{BR,k}$: Theoretical breaking strain, in compression in the longitudinal axis of the pillar, of the individual layer k, as defined in Ch 12, Sec 3, Tab 5

ε_A : Global strain, in percent, in compression in the longitudinal axis of the pillar, of the laminate, equal to:

$$\varepsilon_A = \frac{4F_A}{E\pi(d^2_{EXT} - d^2_{INT})} 10^3$$

d_{EXT}, d_{INT} : Extrenal and internal diamater, in cm, of the pillar

E : Young's modulus, in N/mm², of the global laminate in the longitudinal direction of the pillar, as defined in Ch 12, Sec 4, [5.1.2].

F_A : As defined in [2.1.1]

2.3 Hollow rectangular pillars

2.3.1 Critical column buckling load of hollow rectangular pillars

The critical column buckling load of hollow rectangular pillars is to be obtained, in kN, from the following formula:

$$F_{CR2} = \frac{\pi^2 I E}{(f\ell)^2} 10^{-5}$$

where:

- I : Minimum moment of inertia, in cm^4, of the pillar

$$I = \left(\frac{bh^3}{12} - \frac{(b-2t)(h-2t)^3}{12}\right) 10^{-4}$$

- b : Length, in mm, of the shorter side of the section
- h : Length, in mm, of the longer side of the section
- t : Laminate thickness, in mm, of all the side of the section
- ℓ : Span, in m, of the pillar
- f : Coefficient, to be obtained from Tab 1
- E : Young's modulus, in N/mm^2, of the global laminate in the longitudinal direction of the pillar, as defined in Ch 12, Sec 4, [5.1.2].

2.3.2 Global checking criteria

The composite pillars loaded by the compression axial load F_A defined in [2.1.1] are first to respect the following condition:

$$F_A \leq F_{CR2} / SF_G$$

where:

- SF_G : Safety factor, equal to: $SF_G = 3\ C_F$
  with C_F as defined in Ch 4, Sec 3, [5.4.1]
- F_{CR2} : Critical column buckling load, in kN, as defined in [2.2.1]

2.3.3 Local checking criteria

Each individual layer of the laminate is to resist locally to load compression and to respect the following condition:

$$\varepsilon_A \leq \varepsilon_{BR,k} / SF$$

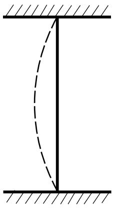
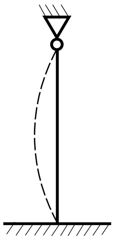
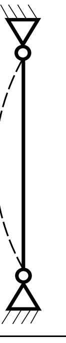
where

- SF : Safety factor of the individual layer as defined in Ch 4, Sec 3, [5.4.1]
- $\varepsilon_{BR,k}$: Theoretical breaking strain, in compression in the longitudinal axis of the pillar, of the individual layer k, as defined in Ch 12, Sec 3, Tab 5
- ε_A : Global strain, in percent, in compression in the longitudinal axis of the pillar, of the laminate, equal to:

$$\varepsilon_A = \frac{F_A}{2Et(h+b-2t)} 10^5$$

- b : Length, in mm, of the shorter side of the section
- h : Length, in mm, of the longer side of the section
- t : Laminate thickness, in mm, of all the side of the section
- E : Young's modulus, in N/mm^2, of the global laminate in the longitudinal direction of the pillar, as defined in Ch 12, Sec 4, [5.1.2].
- F_A : As defined in [2.1.1].

Table 1 : Coefficient f

Boundary conditions of the pillar	f
Both ends fixed 	0,5
One end fixed, one end pinned 	$\frac{\sqrt{2}}{2}$
Both ends pinned 	1,0

SECTION 1 EQUIPMENT IN ANCHORS AND CHAIN CABLES

Symbols

EN : Equipment Number defined in [2]

σ_{ALL} : Allowable stress, in N/mm^2, used for the Yielding check in [3.7], to be taken as the lesser of:

- $\sigma_{ALL} = R_{eH}$
- $\sigma_{ALL} = 0,64\ R_m$

R_{eH} : Minimum Yield stress, in N/mm^2, of the material, defined in the Rule Note NR216 Materials and Welding

R_m : Tensile strength, in N/mm^2, of the material, defined in the Rule Note NR216 Materials and Welding.

1 General

1.1 Design assumptions for anchoring equipment

1.1.1 The requirements in [2] and [3] only apply to temporary mooring of a ship within a harbour or sheltered area, where the yacht is awaiting for berth, tide, etc.

The attention of owners, shipyards and designers is drawn to the fact that loads on anchoring equipment due to emergencies increase to such a degree that its components may be damaged or lost owing to high energy forces generated, particularly in large yachts.

1.1.2 The equipment complying with the requirement [2] and [3], is not designed to hold a yacht off fully exposed coast in rough weather or for stopping the yacht which is moving or drifting. In this conditions the loads on anchoring equipment increase to such a degree that its components be damaged or lost owing to high energy forces generated, particularly in large yachts.

1.1.3 The Equipment Number (EN) formulae for anchoring equipment, as stipulated in [2] are based on following assumptions:

- Wind speed of 25 m/s
- Current speed of 2,5 m/s
- Scope of chain cable between 6 and 10, the scope being the ratio between length of chain paid out and water depth.

  A length of chain cable greater than the one obtained from [2.1.1] may be accepted by the Society, on the basis of justificative calculation submitted by the shipyard.

1.1.4 For yachts where frequent anchoring in open sea is expected, owner's, shipyard's and designer's attention is drawn to the fact that anchoring equipment should be provided in excess to the requirements of this Rules.

1.1.5 The equipment complying with the requirements in [2] to [3] is intended for holding a ship in good holding sea bottom, where the conditions are such as to avoid dragging of the anchor. In poor holding sea bottom, the holding power of the anchors is to be significantly reduced.

1.1.6 For small ships, equipement in anchors and cables may be reduced on a case-by-case basis. Nevertheless, it belongs to designer and/or shipyard to submit all the relevant information demonstrating that reduced equipement - its configuration - and all its components, fully copes with the energy forces most frequently encountered during service.

1.1.7 It is assumed that under normal circumstances a yacht will use one anchor only.

1.1.8 Towline and mooring lines are not required as a condition of classification.

1.1.9 Anchors and mooring line components - chain cable and its accessories, wire rope, etc - are to be manufactured in accordance with relevant requirements of the Rule Note NR216 Materials and Welding.

1.1.10 The bow anchors, connected to their own chain cables, are to be so stowed as to always be ready for use. For small ships, other arrangements of equivalent provision in security and safety may be foreseen, they are subjected to Society's agreement.

Hawse pipes are to be of a suitable size and so arranged as to create, as far as possible, an easy lead for the chain cables and efficient housing for the anchors.

For this purpose, chafing lips of suitable form with ample lay-up and radius adequate for the size of the chain cable are to be provided at the shell and deck. The shell plating at the hawse pipes is to be reinforced as necessary.

2 Equipment Number

2.1 General

2.1.1 All yachts are to be provided with equipement in anchors and cables - chain cable or ropes - to be obtained from Tab 1 based on their Equipment Number EN.

2.1.2 All yachts are to be equiped with High Holding Power - HHP - or Very High Holding Power anchors - VHHP - anchors. Anchors are to be of an Approved Type.

2.1.3 For ships having a navigation notation coastal area the equipement in anchors and cables may be reduced. This reduction consists of entering in Tab 1 one line higher, based on their Equipement Number EN.

Table 1 : Equipment

Equipment Number EN		HHP bow anchor		Stud link chain cable for bow anchor		
A < EN ≤ B		Mass of each anchor, in kg	Number of anchors **(2)**	Total length, in m	Diameter **(1)**	
A	B				grade Q2 steel, in mm	grade Q3 steel, in mm
10	12	8	2	75,0	(6,0)	(5,5)
12	14	10	2	80,0	(6,0)	(5,5)
14	16	11	2	85,0	(6,0)	(5,5)
16	18	13	2	95,0	(8,0)	(7,0)
18	20	14	2	100,0	(8,0)	(7,0)
20	22	16	2	105,0	(8,0)	(7,0)
22	24	18	2	110,0	(8,0)	(7,0)
24	26	19	2	115,0	(8,0)	(7,0)
26	28	21	2	120,0	(8,0)	(7,0)
28	30	23	2	125,0	(8,0)	(7,5)
30	34	26	2	130,0	(10)	(9,0)
34	38	30	2	137,5	(10)	(9,0)
38	42	35	2	137,5	(10)	(9,0)
42	46	40	2	152,0	(10)	(9,0)
46	50	45	2	165,0	11,0	(10,0)
50	58	50	2	165,0	11,0	(10,0)
58	66	62	2	180,0	12,5	11,0
66	74	75	2	192,5	12,5	11,0
74	82	85	2	192,5	14,0	12,5
82	102	110	2	220,0	16,0	14,0
102	122	145	2	220,0	16,0	14,0
122	142	185	2	247,5	17,5	16,0
142	162	230	2	275,0	19,0	17,5
162	182	280	2	275,0	20,5	19,0
182	202	340	2	275,0	22,0	20,5
202	222	400	2	302,5	22,0	20,5
222	242	465	2	302,5	24,0	22,0
242	262	535	2	302,5	24,0	22,0
262	288	620	2	302,5	26,0	24,0
288	318	680	2	330,0	28,0	26,0
318	348	750	2	330,0	28,0	26,0
348	378	820	2	357,5	30,0	28,0
378	408	880	2	357,5	30,0	28,0
408	438	950	2	385,0	32,0	28,0
438	468	1020	2	385,0	32,0	30,0
468	498	1090	2	385,0	34,0	30,0
498	528	1150	2	412,5	36,0	32,0
528	556	1220	2	412,5	36,0	32,0
556	584	1280	2	412,5	36,0	32,0
584	616	1350	2	412,5	38,0	34,0
616	656	1430	2	440,0	38,0	34,0
656	696	1520	2	440,0	40,0	36,0
696	736	1610	2	440,0	42,0	38,0
736	776	1700	2	467,5	42,0	38,0
776	816	1790	2	467,5	44,0	40,0
816	876	1900	2	467,5	44,0	40,0
876	956	2060	2	495,0	46,0	42,0
956	1046	2250	2	495,0	48,0	42,0
1046	1140	2460	2	495,0	50,0	46,0

(1) Values of chain cable diameters shown in brackets are given only to allow determination of the corresponding studless chain cable.

(2) For yachts and charter yachts with anchors weighing not more than 20 kg it may be accepted to have only one anchor and relevant chain cable length ready for use. In such case the second anchor and the relevant mooring line are to be so located that they can be easily accessed and handled.

2.1.4 For ships having a EN greater than 1140, the determination of the equipement will be considered by the Society on a case-by-case basis.

2.1.5 For yachts of special design or for yachts engaged in special services or on special voyage the Society may consider equipment other than that in Tab 1.

2.2 Equipment number calculation

2.2.1 Additional Service features approach

a) For yachts granted with service notation charter yacht-motor or yacht-motor:

$EN_m = EN$

where EN is to be calculated as per defined in [2.2.2] and [2.2.3] as relevant.

b) For yachts granted with service notation charter yacht-sailing or yacht-sailing:

$EN_S = EN + EN_E$

Where:

- EN is to be calculated as per defined in [2.2.2] to [2.2.3], as relevant.
- EN_E is to be calculated as per defined in [2.2.4].

2.2.2 Monohull yacht

The equipment number EN is to be calculated as follows:

$$EN = \Delta^{2/3} + 2 \cdot \left[a \cdot B + \sum_i (b_i \cdot h_i \cdot \sin\Theta_i)\right] + 0,1 \cdot A$$

where:

Δ	:	Maximum displacement, in t
a	:	Distance, in m, from summer load waterline amidships to the upper deck at side
h_i	:	Height, in m, on the centreline of each tier of deck houses having an actual breadth b_i greater than B/4, where B is the breadth, in m, as defined in Ch 1, Sec 2, [3.5]
Θ_i	:	Angle of inclination aft of each front bulkhead, as shown on Fig 1
A	:	Area, in m^2, in profile view of the hull, superstructures and deck houses above the summer load waterline, which is within the rule length of the yacht defined in Ch 1, Sec 2, [3.2] and with a breadth greater than B/4.

In the measurement of h_i, sheer and trim are to be ignored.

If a deck house broader than B/4 is placed on top of another deck house equal to or less than B/4 in breadth, only the widest is to be considered and the narrowest may be ignored.

Windscreens or bulwarks more than 1,5 m in height above the deck at side are to be regarded as parts of superstructures and houses where determining h_i and A. The height of hatch coamings may be ignored in the evaluation of h_i and A.

In the calculation of A, where a bulwark is more than 1,5 m in height, the cross hatched area of Fig 1 is to be considered.

2.2.3 Multihull yacht

The equipment number is to be calculated as follows:

$$EN = K_m \cdot \Delta^{2/3} + 2 \cdot \left[a \cdot B + \sum_i (b_i \cdot h_i \cdot \sin\Theta_i) - S_t\right] + 0,1 \cdot A$$

where:

- for yacht with N identical hulls:

  $K_m = N^{1/3}$

  i.e.:
  - for catamarans: $K_m = 1,26$
  - for trimarans: $K_m = 1,44$
  - for quadrimarans: $K_m = 1,59$
- for yacht with one mid hull and 2 · n non-identical lateral hulls (N = 2 · n+1):

$$K_m = \frac{(B_o \cdot T_o)^{2/3} + 2 \cdot \sum_{i=1}^{n} (B_i \cdot T_i)^{2/3}}{\left(B_o \cdot T_o + 2 \cdot \sum_{i=1}^{n} B_i \cdot T_i\right)^{2/3}} \quad \text{(N odd)}$$

- for yacht with non-identical hulls, but of an even number (N = 2 · n):

$$K_m = 2^{1/3} \cdot \frac{\sum_{i=1}^{n} (B_i \cdot T_i)^{2/3}}{\left(\sum_{i=1}^{n} B_i \cdot T_i\right)^{2/3}} \quad \text{(N even)}$$

S_t	:	Transverse area, amidships, of the tunnel(s) existing between the hulls and the waterline
B_o, T_o	:	Breadth and draught, in m, of the mid full hull (if any), measured amidship (see Fig 2)
B_i, T_i	:	Breadth and draught, in m, of the lateral hulls, measured amidship (see Fig 2)
N	:	Total number of yacht hulls
n	:	Number of lateral hulls on one side of the longitudinal symmetry plane of the yacht
Δ	:	Total displacement of the yacht, in t.

Other symbols are defined in [2.2.2].

2.2.4 Windage effect on mast and standing rigging

For yachts granted with service notation charter yacht-sailing or yacht-sailing, the additional Eolian equipment number terme EN_E, is to be calculated by direct calculation according to point a) below. However, where information is missing EN_E may be calculated according to point b) below

Special consideration will be given in case of unusual mast and standing rigging arrangement.

a) Direct calculation

$$EN_E = 2 \cdot \sum_{i=1}^{n} h_i \cdot b_{Yi} \cdot \frac{C_{TXi}}{1,22} + 0,1 \cdot \sum_{i=1}^{n} h_i \cdot b_{xi} \cdot \frac{C_{TYi}}{1,22}$$

where:

h_i	:	Height, in m, of the i-th mast measured from the implantation point at deck
b_{Yi}	:	Average width, in m, of the i-th mast, measured in the Y direction of the yacht as defined in Ch 1, Sec 2, [4]

C_{TXi} : Longitudinal drag coefficient of the i-th mast in the X direction of the yacht as defined in Ch 1, Sec 2, [4]

Note 1: Where no information is available, C_{TXi} may be taken equal to 1.

Note 2: Drag coefficient C_{TXi} is to be taken such as

$$1 \le C_{TXi} \le 2,05$$

b_{Xi} : Average width, in m, of the i-th mast, measured in the X direction of the yacht as defined in Ch 1, Sec 2, [4]

C_{TYi} : Longitudinal drag coefficient of the i-th mast, in the Y direction of the yacht as defined in Ch 1, Sec 2, [4]

Note 3: Where no information is available, C_{TYi} may be taken equal to 1.

Note 4: Drag coefficient C_{TYi} is to be taken such as

$$1 \le C_{TYi} \le 2,05$$

i : Designates the i-th mast. Index one for the first mast up to index n for the last mast of the yacht

$$1 \le 2 \le \ldots \le i \le \ldots \le n$$

b) Gross calculation

- For L_{WL} not greater than 40 m:

$$EN_E = EN$$

- For L_{WL} greater than 40 m:

$$EN_E = EN \cdot [(13/9) - (L_{WL}/90)]$$

where:

EN : Relevant Equipement Number as per defined in [2.2.2] and [2.2.3]

L_{WL} : Waterline length, in m, defined in Ch 1, Sec 2, [2.1.1].

3 Equipment

3.1 Shipboard fitting and supporting hull structures associated with towing and mooring

3.1.1 Additional Service features approach

a) For yachts granted with service notation charter yacht-motor or yacht-motor, all relevant requirements of this sub-article are to be complied with.

b) For yachts granted with service notation charter yacht-sailing or yacht-sailing, all relevant Regulations of this subarticle are to be complied with. Additionnally, if sailing winches are used as towing fittings, all relevant regulations of this sub-article apply.

Figure 1 :

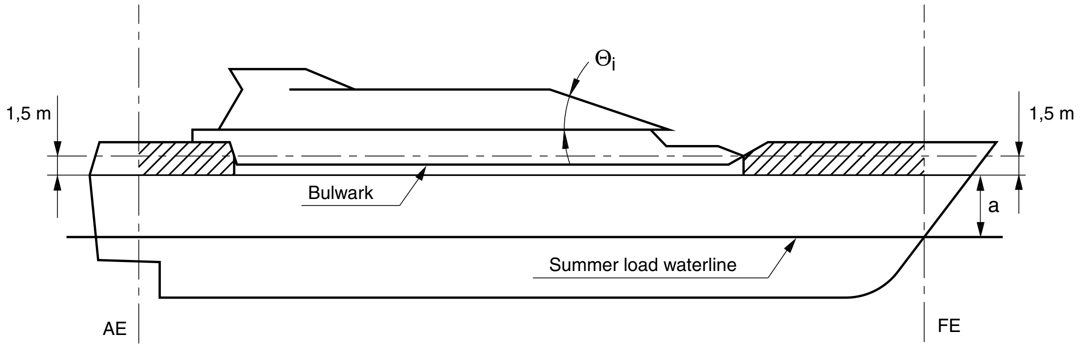
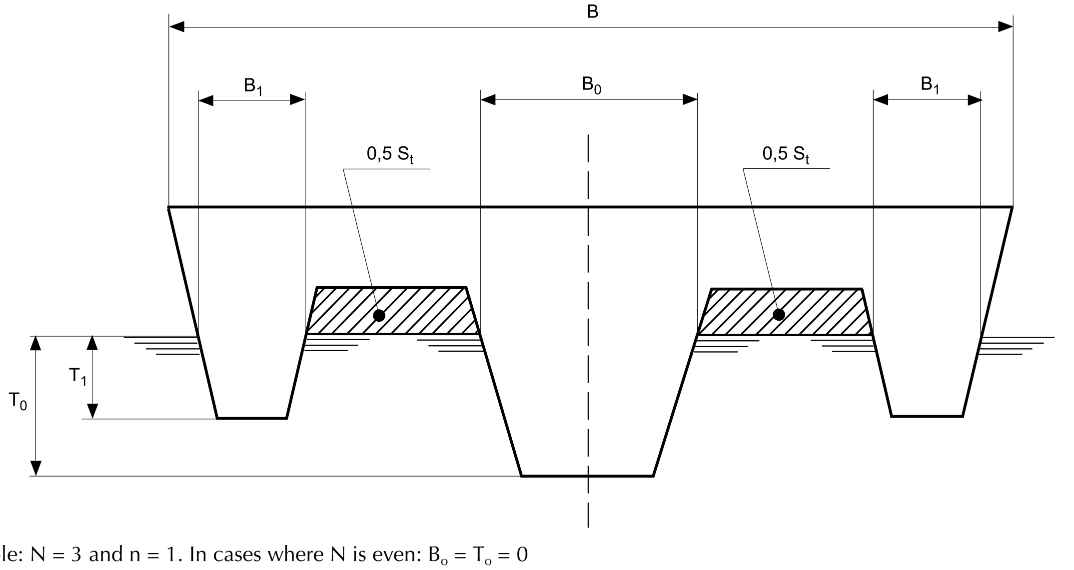


Figure 2 :



In this example: N = 3 and n = 1. In cases where N is even: $B_o = T_o = 0$

3.1.2 Definitions and applications

Requirements under the present sub-article apply to yachts of 500 GT and above. Nevertheless, they may be considered for yachts below 500 GT.

Shippyard fittings are limited to the following components used for normal mooring of the yachts and similar components used for towing and emergency towing of the yachts:

- Bitts and bollards
- Fairleads
- Stand rollers
- Chocks.

Other components such as capstans, winches, etc. are not covered by the present requirements. Nevertheless, hull structure supporting these components are to comply with [3.1.7].

Welded or bolted equivalent device connecting the shipyboard fitting to the supporting structure is a part of the shipboard fitting and subject to recognised standard applicable to the shipboard fitting.

3.1.3 Arrangements

Shipyard fittings for towing are to be located on longitudials, beams and/or girders, which are a part of the deck construction so as to facilitate efficient distribution of the towing load. Equivalent provision arrangements may be accepted.

3.1.4 Load

The force, in kN, acting on shipboard fittings at the attachement point of the towline or mooring lines, is to be taken as 1,25 times the Breaking Load BL, in kN, of the towline and mooring line, anticipated to be used throughout the service life of the yacht.

3.1.5 Shipboard fittings

The selection of shipboard fittings is to be made by the shipyard in accordance with a recognised standard accepted by the Society. Whatever is the selection methode of the shipboard fitting, the design load used to assess its strength and its attachment to the ship is to be in accordance with [3.1.4].

3.1.6 Towing and mooring arrangements

They are to be such that any surface against which the towing cable may chafe (for example, fairleads) is of sufficient radius to prevent the cable being damaged where under load.

Where necessary, suitable fairleads, bitts and mooring ropes shall be provided.

Adequate storage space for mooring lines shall be provided such that they are readily available and secured against the high relative wind speeds and accelerations which may be experienced.

3.1.7 Supporting Hull Structures

a) Arrangement

   The arrangement of reinforced members (carling) beneath shipboard fittings is to consider any variation of direction laterally and vertically, of the towing forces, which are to be calculated in accordance with [3.1.4]

b) Admissible stresses

   Where assessing the supporting hull structure, the allowable stresses are to be considered as follows:

   - For metallic materials
     - Bending stress: 100% of the minimum specified material yield stress
     - Shear stress: 60% of the minimum specified material yield stress
   - For composite structures

     Case-by-case basis. Details to be submitted for review.

3.1.8 Safe working Load (SWL)

The following requirements on SWL, applicable for a single post basis, i.e. no more than one turn of the cable, are to be considered:

- The SWL is not to exceed one half of the design load defined in [3.1.4]
- The SWL of each shipboard fitting is to be marked by weld bead or equivalent, at the place of deck fittings used for towing
- The SWL with its intended use, for normal and/or emergency conditions, for each shipboard fitting is to be noted in the towing and mooring arrangement plan or in any other available document on board, for guidance of the Master. This arrangement plan is to explicitly prohibit the use of mooring and/or towing lines outside of their intended use and fonction and/or having different characteristics.

3.2 Anchors

3.2.1 General

Normally “high holding power anchor” (HHP) or “Very high holding power anchors” (VHHP) are to be used. Possible use of ordinary anchors will be specially considered by the Society.

Anchors are to be from an Approved Type.

3.2.2 Mass of anchors

Tab 1 indicates the mass of a “high holding power anchor” (HHP) i.e. anchor having a holding power greater than that of a Society’s Type Approved ordinary anchor.

“Very high holding power anchors” (VHHP), i.e. anchors having a holding power equal to, at least, four times that of a Society’s Type Approved ordinary anchor, may be used.

The individual mass of each anchor may vary within (+7, – 3) per cent from the individual mass required in Tab 1, provided that the total mass of anchors is not less than the total mass required in Tab 1.

The mass of a VHHP anchor is to be not less than 2/3 of the mass required for the HHP anchor it replaces.

3.2.3 Anchor design and performance tests

Anchors are to be from an Approved Type. Therefore, Holding power - performance - assessment, Desing review and Tests and examination on manufactured product are to be carried-out.

Anchors are to have appropriate shape and scantlings in compliance with Society requirements. Moreover, they are to be constructed in compliance with Society requirements.

A high or very high holding power anchor is to be suitable for use on board without any prior adjustment or special placement on the sea bottom.

For approval and/or acceptance as a high or very high holding power anchor, the anchor is to have a holding power equal, respectively, to at least twice or four times that of an Type Approved ordinary stockless anchor of the same mass.

Holding power is to be assessed by full-scale comparative tests.

For very high holding power anchors, the holding power test load is to be less than or equal to the proof load of the anchor, specified in the Rule Note NR216 Materials and Welding, Ch 4, Sec 1, [1.5.2].

Comparative tests on Type Approved Ordinary stockless anchors are to be carried out at sea and are to provide satisfactory results on various types of seabeds.

Alternatively sea trials by comparison with a previously approved HHP anchor may be accepted as a basis for approval.

Such tests are to be carried out on anchors whose masses are, as far as possible, representative of the full range of sizes proposed for the approval.

At least two anchors of different sizes are to be tested. The mass of the greatest anchor to be approved is not to be in excess of 10 times that of the maximum size tested and the mass of the smallest is to be not less than 0,1 times that of the minimum size tested.

Tests are normally to be carried out by means of a tug, but, alternatively, shore-based tests may be accepted.

The length of the chain cable connected to the tested anchor, having a diameter appropriate to its mass, is to be such that the pull acting on the shank remains practically horizontal. For this purpose a scope of chain cable equal to 10 is deemed normal; however lower values may be accepted.

Three tests are to be carried out for each anchor and type of sea bottom. Three are the types of sea bottoms in which tests are to be performed, e.g. soft mud or silt, sand or gravel and hard clay or similar compounded.

The pull is to be measured by means of a dynamometer; measurements based on the bollard pull against propeller's revolutions per minute curve may be accepted instead of dynamometer readings.

Anchor stability and its ease of dragging are to be noted down, whenever possible.

Upon satisfactory outcome of the above tests, the Society will issue a certificate declaring the compliance of high or very high holding power anchors with its relevant Rules.

3.2.4 Manufacturing and materials

Manufacturing and materials are to comply with relevant requirements of the Rule Note NR216 Materials and Welding.

3.2.5 Test and examination

Tests and examination requirements are to comply with the Rule Note NR216 Materials and welding Ch 4, Sec 1, [1.5].

3.3 Chain cables

3.3.1 Chain cables arrangements

Bow anchors are to be used in connection with stud link chain cables whose scantlings and steel grades are to be in accordance with the requirements of the Society.

Normally grade Q2 or grade Q3 stud link chain cables are to be used with HHP anchors. In case of VHHP anchors, grade Q3 chain cables are to be used.

Proposal for use of grade Q1 chain cables connected to ordinary anchors will be specially considered by the Society.

For yacht with an Equipment Number $EN \leq 82$, studless short link chain cables may be used, provided that:

- steel grade of the studless chain is to be equivalent to the steel grade of the stud chains it replaces, i.e., referring to ISO standard 1834:
  - Class M (4) [grade 400], i.e. grade SL2 as defined in the Rule Note NR216 Materials and welding, Ch 4, Sec 1, [3] , in lieu of grade Q2
  - Class P (5) [grade 500], i.e. grade SL3 as defined in the Rule Note NR216 Materials and Welding, Ch 4, Sec 1 [3] in lieu of grade Q3
- equivalence in strength is to be based on proof load (not on breaking load)
- the studless chain cable meets the requirements of the Society.

The proof loads PL and breaking loads BL, in kN, required for the studless link chain cables are given by the following formulae, where d, in mm, is the required diameter of grade Q2 and grade Q3 stud chain cables taken from Tab 1:

- grade Q2:

  $PL_2 = 9{,}807\ d^2\ (44 - 0{,}08\ d)\ 10^{-3}$

  $BL_2 = 2\ PL_2$
- grade Q3:

  $PL_3 = 13{,}73 \cdot d^2 \cdot (44 - 0{,}08 \cdot d) \cdot 10^{-3}$

  $BL_3 = 2 \cdot PL_3$

The method of manufacture of chain cables and the characteristics of the steel used are to be approved by the Society for each manufacturer. The material from which chain cables are manufactured and the completed chain cables themselves are to be tested in accordance with the appropriate requirements.

Chain cables are to be made of unit lengths (“shots”) of 27,5 m minimum joined together by Dee or lugless shackles.

3.4 Synthetic fibre ropes

3.4.1 Synthetic fibre ropes may be used as an alternative to stud link chain cables required in Tab 1 where relevant EN (EN_s or EN_m calculated according to [2.2]) is not greater than 60, provided that the following requirements are complied with.

Fibre ropes are to be made of polyamide or other equivalent synthetic fibres, excluding polypropylene.

The length L_{sfr}, in m, of the synthetic fibre rope is to be equal to the Total lenght, in m, of Stud link chain cable for bow anchors required by Tab 1.

The effective breaking load P_s, in kN, of the synthetic fibre rope is to be not less than the following value:

$P_s = 2,2 \cdot BL^{8/9}$

where BL, in kN, is the required breaking load of the chain cable replaced by the synthetic fibre rope (BL can be determined by the formulae given in [3.3]).

A short length of chain cable having scantlings complying [3.3] with is to be fitted between the synthetic fibre rope and the bow anchor. The length of this chain part is not to be less than 12,5 m or the distance from the anchor to its stowed position to the windlass whichever is the lesser. In any case this lenght is to be less than 6,25 m.

3.5 Attachement pieces

3.5.1 Both attachment pieces and connection fittings for chain cables are to be designed and constructed in such a way as to offer the same strength as the chain cable and are to be tested in accordance with the appropriate requirements.

3.6 Hawse pipe and bow sheave

3.6.1 They are to be of a subtancial construction. Their position slope and arrangement are to be arranged so as to facilitate the housing and dropping of the anchors and avoid damage of the hull during these operations. The parts on which the chains, ropes and/or cables - as relevant - may bear are to be rounded to a suitable radius.

3.6.2 All mooring units and accessories, such as timbler riding and trip stoppers are to be secured to surveyors satisfaction.

3.7 Windlass

3.7.1 The windlass is to be power driven and suitable for the size of chain cable, and is to have the characteristics stated below.

The windlass is to be fitted in a suitable position in order to ensure an easy lead of the chain cable to and through the hawse pipe; the deck, at the windlass, is to be suitably reinforced.

The windlass is to be able to supply, for at least 30 minutes, a continuous duty pull P_C, in N, corresponding to the grade of the chain cables, given by the following formulae:

- for grade Q2 chain cables:

  $P_C = 42,5 \cdot d^2$
- for grade Q3 chain cables:

  $P_C = 47,5 \cdot d^2$

where d is the stud link chain cable diameter of the intended steel grade, in mm.

The windlass unit prime mover is to provide the necessary temporary overload capacity for breaking out the anchor.

The temporary overload capacity or “short term pull” is to be not less than 1,5 times the continuous duty pull P_C for at least two minutes.

The speed in this overload period may be lower than the nominal speed specified above.

The nominal speed of the chain cable where hoisting the anchor and cable may be a mean speed only and is to be not less than 0,15 m/s.

The speed is to be measured over two shots of chain cable during the entire trip; the test is to commence with 3 shots (82,5 m) of chain fully submerged, or with the longest practicable submerged chain length where the chain length does not allow 3 shots to be paid out.

The windlass is to be provided with a brake having sufficient capacity to stop chain cable and anchor where paying out, even in the event of failure of the power supply.

Windlass and brake not combined with a chain stopper have to be designed to withstand a pull of 80% of the breaking load of the chain cable without any permanent deformation of the stressed parts and without brake slip.

Windlass and brake combined with a chain stopper have to be designed to withstand a pull of 45% of the breaking load of the chain cable.

The stresses on the parts of the windlass, its frame and brake are to be below the yield point of the material used.

The windlass, its frame and the brake are to be efficiently anchored to the deck.

Performance criteria and strength of windlasses are to be verified by means of workshop testing according to the Society Rules.

Anchoring sea trails are to be carried out as per [3.10].

3.8 Chain stoppers

3.8.1 A chain stopper is normally to be fitted between the windlass and the hawse pipe in order to relieve the windlass of the pull of the chain cable where the ship is at anchor.

The deck at the chain stopper is to be suitably reinforced to withstand load defined is [3.8.2].

However, fitting of a chain stopper is not compulsory.

Chain tensioners or lashing devices supporting the weight of the anchor where housed in the anchor pocket are not to be considered as chain stoppers.

Where the windlass is at a distance from the hawse pipe and no chain stopper is fitted, suitable arrangements are to be provided to lead the chain cable to the windlass.

3.8.2 Load

A chain stopper with all its parts is to be capable of withstanding a pull of 80% of the breaking load of the chain cable; the deck at the chain stopper is to be suitably reinforced.

3.8.3 Yielding check

The equivalent von Mises stress s_E, in N/mm^2 induced in the chain stopper by a load equal to the load defined in [3.8.2] is to comply with the following formula:

$\sigma_E \leq \sigma_{ALL}$

Where chain stoppers are analysed by through fine mesh finite element models, the allowable stress may be taken as $1,1 \cdot s_{ALL}$.

3.9 Chain locker

3.9.1 The chain locker is to be of a capacity adequate to stow all chain cable equipment and provide an easy direct lead to the windlass.

Where two anchor lines are fitted, the port and starboard chain cables are to be separated by a steel bulkhead in the locker.

The inboard ends of chain cables are to be secured to the structure by a fastening able to withstand a force not less than 15% nor more than 30% of the breaking load of the chain cable.

In an emergency, the attachments are to be easily released from outside the chain locker.

Where the chain locker is arranged aft of the collision bulkhead, its boundary bulkheads are to be watertight and a drainage system provided.

3.10 Anchoring sea trials

3.10.1 General

The anchoring sea trials are to be carried out on board in the presence of a Society surveyor.

3.10.2 Single windlass arrangement

The test is to demonstrate that the windlass complies with the requirements given in [3.7] particulary that it works adequately and has sufficient power to simultaneously weigh the two anchors - excluding the housing in the house pipe - where both are suspended to a 55 m of chain cable in not more than 6 min.

3.10.3 One windlass per mooring line arrangement

Where two windlasses operating separately on each chain cable are adopted , the weighing test is to be carried out for both, weighing an anchor suspended to 82,5 m of chain cable and verifying that the time required for the weighing - excluding the housing on the hawse pipe - does not exceeds 9 min.

3.10.4 The brake is to be tested during lowering operations.

SECTION 2 RUDDER STOCK AND RUDDER BLADE

Symbols

V1 : Maximum ahead service speed, in knots, at maximum displacement in still water.

V_{AV} :
- For all Yachts except high speed motor yachts as defined in Ch 5, Sec 1, [2.1.1], V_{AV} is defined by the following formula:

$$V_{AV} = V_1 \quad \text{if} \quad V_1 \geq 10$$

$$V_{AV} = \frac{V_1 + 20}{3} \quad \text{if} \quad V_1 < 10$$

- For high speed motor yachts as defined in Ch 5, Sec 1, [2.1.5], V_{AV} is defined by the following formula:

$$V_{AV} = \min\left[V_1, \frac{2}{3} \cdot (V_1 + 2\sqrt{L})\right]$$

V_{AD} : Maximum astern speed, in knots, to be taken not less than 0,5 V_{AV}

A : Total area of the rudder blade, in m², bounded by the blade external contour, including the mainpiece and the part forward of the centreline of the rudder pintles, if any

k : Material factor, defined in [1.4.1]

C_R : Rudder force, in N, acting on the rudder blade, defined in [2.1.2]

M_{TR} : Rudder torque, in N.m, acting on the rudder blade, defined in [2.1.3] and [2.2.3]

M_B : Bending moment, in N.m, in the rudder stock, to be calculated according to [3].

1 General

1.1 Application

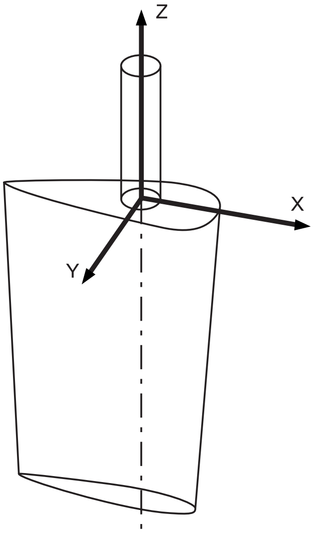
1.1.1 Requirements of this Section apply to arrangement and the component of the rudder and also to their scantlings. It is assumed that requirements apply to yachts correctly used by a competent and qualified crew.

For this section, system of reference is considered as follow:

- X axis : longitudinal axis aligned with chord of the rudder profile as described on Fig 1
- Y axis : transversal axis perpendicular to XZ plan
- Z axis : vertical axis aligned with Z axis from reference co-ordinate system of the Yacht.

1.1.2 Requirements of this section apply to ordinary profile rudders without any special arrangement for increasing the rudder force. Other type of rudder are to be considered by the Society on a case-by-case basis. Rudder forces are to be calculated by designer for the most severe combination between orientation angle and ship speed.

Figure 1 :



1.1.3 Rudder system is to have a rotation limitation system made with mechanical or physical means for maximum angulation of the rudder.

As a rule, maximum orientation of the rudder is limited to 35°. Angles greater than 35° are accepted for manoeuvres or navigation with an appropriate reduced speed. When the maximum speed is limited to an angle smaller than 35° by physical or software devices, the Society may accept reductions of scantlings, on a case by case basis.

1.2 Arrangement

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

1.2.2 Suitable arrangements are to be provided to prevent the rudder from lifting. In addition, structural rudder stops of suitable strength are to be provided, except where the steering gear is provided with its own rudder stopping devices, as detailed in Pt C, Ch 1, Sec 3, [3].

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

1.3 Documents to be submitted

1.3.1 Following drawings and documents are to be submitted for examination by the Society:

- Rudder arrangement including location of rudder stock, bearings, pintles, rudder carrier, and steering gear (speed V_{AV} and V_{AR} to be specified)
- Rudder blade structure including details of pintles, bearings, stiffenings, connection to rudder stock
- Rudder horn if any
- For all component of the rudder system types of materials and their mechanical characteristics are to be specified.

1.4 Materials

1.4.1 Rudder made of steel

a) Rudder stocks, pintles, coupling bolts, keys and cast parts of rudders are to be made of rolled steel, steel forging or steel castings according to applicable requirements of the Rule Note NR216 Materials and Welding, Chapter 2

b) The material used for rudder stocks, pintles, keys and bolts is to have a minimum yield stress not less than 200 N/mm²

c) The requirements relevant to the determination of scantlings contained in this section apply to steels having yield stress equal to 235 N/mm². Scantlings calculated with the formulae contained in the requirements of this section are to be modified, as indicated, depending on the material factor k, to be obtain from the following formula:

$$k = \frac{235 \cdot c}{R_{eH}}$$

where:

c : material factor taken equal to:
- 1 for steel elements except stainless steel
- 0,9 for aluminium alloy, stainless steel or other materials elements non affected by corrosion

R_{eH} : Design yield stress, in N/mm², calculated as follow:
If $R_m > 1{,}4\ R_{p0,2}$ $R_{eH} = R_{p0,2}$
If $Rm < 1{,}4\ R_{p0,2}$ $R_{eH} = 0{,}417(R_{p0,2} + R_m)$

$Rp_{0,2}$: Minimum guaranteed yield strength, in N/mm², of the steel used

R_m : Minimum guaranteed ultimate tensile strength, in N/mm², of the steel used.

d) Significant reductions in rudder stock diameter due to the application of steels with yield stresses greater than 235 N/mm² may be accepted by the Society subject to the results of a check calculation of the rudder stock deformations. In this case rudder stock slope in way of bearing is subject to an additional check to make sure that those slopes are acceptable regarding lengths and bearing clearances as described respectively in [8.2.4]

e) Welded parts of rudders are to be made of approved rolled hull materials. For these members, the material factor k defined in Ch 4, Sec 3 is to be used.

1.4.2 Rudder made of aluminium

a) Materials for rudder socks, rudder plate, are to comply with requirements of the Rule Note NR216 Materials and Welding, Ch 3, Sec 2

b) The materials used for rudder stocks, pintles, keys and bolts is to have a minimum yield stress of not less than 200 N/mm². Selection of materials is to be carefully made to avoid any risk of galvanic corrosion

c) Requirements relevant to the determination of scantlings contained in this section apply to aluminium alloys described in Ch 4, Sec 3, Tab 3

d) The material factor k for aluminium alloys is to be obtain from the following formula:

$$k = \frac{100}{R'_{lim}}$$

where:

R'lim : Minimum of $R'_{p0,2}$ and $0{,}7R'_m$ as defined in Ch 4, Sec 3, [4.3.1].

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

e) The loss of mechanical properties of some aluminium alloys (6000 series) induced by welding operation is to be taken into account for scantling.

1.4.3 Rudder made of composite

a) Materials for rudder stocks, rudder plates, are to comply with requirements of Part B, Chapter 12

b) Calculations for scantling of such type of rudder are to be made in accordance with Ch 4, Sec 3, [5].

2 Force and torque acting on the rudder

2.1 Rudder blade without cut-outs

2.1.1 Rudder blade description

A rudder blade without cut-outs may have trapezoidal or rectangular contour.

2.1.2 Rudder force

The rudder force C_R is to be obtained, in N, from the following formula:

$$C_R = \frac{1}{2} \cdot \rho \cdot A \cdot V^2 \cdot c$$

where:

r : Specific gravity of sea water, taken equal to 1025 kg/m³

A : Area, in m², of the rudder blade as defined at beginning of the present Section

V : V_{AV} or V_{AD}, depending on the condition under consideration

c : coefficient equal to:

$$c = 0{,}514^2 \cdot r_1 \cdot r_2 \cdot r_3$$

where:

r_1 : Shape factor, to be taken equal to:

$$r_1 = \frac{\lambda + 2}{3}$$

λ : Coefficient, to be taken equal to:

$$\lambda = \frac{h^2}{A_T}$$

and not greater than 2

h : Mean height, in m, of the rudder area to be taken equal to (see Fig 2):

$$h = \frac{z_3 + z_4 - z_2}{2}$$

AT : Area, in m², to be calculated by adding the rudder blade area A to the area of the rudder post or rudder horn, if any, up to the height h

r_2 : Maximum lifting coefficient of rudder profile to be obtained from Tab 1 could be reduced according that rudder angles is limited by physical means to value less than 35°. Other value of r2 based on designer justification could be accepted on case by case basis

r_3 : Coefficient to be taken equal to:

- r_3 = 0,8 for rudders outside or far from the propeller jet (more than L/5)
- r_3 = 1,15 for rudders behind a fixed propeller nozzle
- r_3 = 1,0 inside propeller jet

2.1.3 Rudder torque

The rudder torque M_{TR}, for both ahead and astern conditions, is to be obtained, in N.m, from the following formula:

$$M_{TR} = C_R \cdot r$$

where:

r : Lever of the force C_R, in m, equal to:

$$r = b\left(\alpha - \frac{A_F}{A}\right)$$

and to be taken not less than 0,1 b for the ahead condition

where:

b : Mean breadth, in m, of rudder area to be taken equal to (see Fig 2):

$$b = \frac{x_2 + x_3 - x_1}{2}$$

α : Coefficient to be taken equal to:

- α = 0,33 for ahead condition
- α = 0,66 for astern condition

For rudder parts located behind a fixed structure such as a rudder horn, α is to be taken equal to:

- α = 0,25 for ahead condition
- α = 0,55 for astern condition

Other values of α provided by designers may be taken. Those values are to be considered by Society on a case by case basis

A_F : Area, in m², of the rudder blade portion afore the centreline of rudder stock (see Fig 2).

Table 1 : Values of coefficient r_2 (given for an angle of attack of profile equal to 35°)

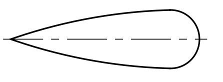
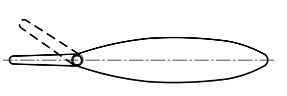
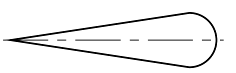
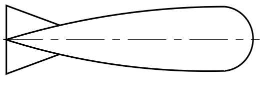
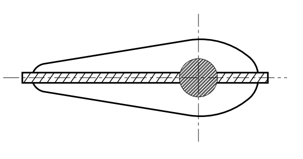
Rudder profile type	r_2 for ahead condition	r_2 for astern condition
NACA profile 	1,20	0,80
High lift 	1,7	1,3
Flat side 	1,10	0,90
Fish tail 	1,40	0,80
Single plate 	1,00	1,00

Figure 2 : Geometry of rudder blade without cut-outs

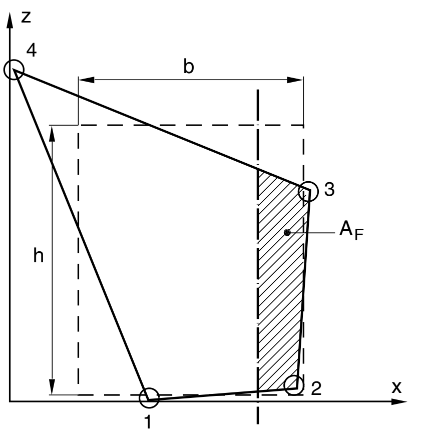
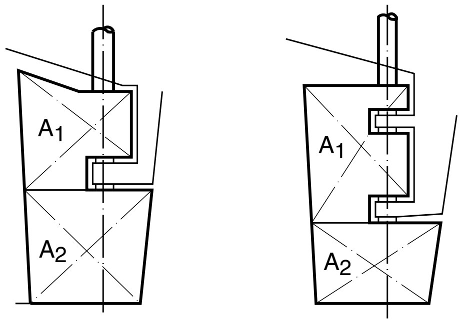


Figure 3 : Rudder blades with cut-outs



Trapezoidal rudder blade
Semi-spade rudder with
rudder horn - 2 bearings

Trapezoidal rudder blade
Semi-spade rudder with
rudder horn - 3 bearings

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

2.2.1 Rudder blade description

A rudder blade with cut-outs may have trapezoidal or rectangular contour, as indicated in Fig 3.

2.2.2 Rudder force

The rudder force C_R , in N, acting on the blade is to be calculated in accordance with [2.1.2].

2.2.3 Rudder torque

The rudder torque M_{TR}, in N.m, is to be calculated in accordance with the following procedure.

The rudder blade area A is to be divided into two rectangular or trapezoidal parts having areas A_1 and A_2, defined in Fig 3, so that:

$A = A_1 + A_2$

The rudder forces C_{R1} and C_{R2} , acting on each part A_1 and A_2 of the rudder blade, respectively, are to be obtained, in N, from the following formulae:

$$C_{R1} = C_R \frac{A_1}{A}$$

$$C_{R2} = C_R \frac{A_2}{A}$$

The levers r_1 and r_2 of the forces C_{R1} and C_{R2} , respectively, are to be obtained, in m, from the following formulae:

$$r_1 = b_1\left(\alpha - \frac{A_{1F}}{A_1}\right)$$

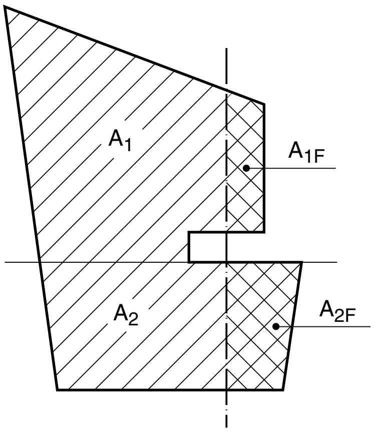
$$r_2 = b_2\left(\alpha - \frac{A_{2F}}{A_2}\right)$$

where:

b_1, b_2 : Mean breadths of the rudder blade parts having areas A_1 and A_2, respectively, to be determined according to [2.1.3]

A_{1F}, A_{2F} : Areas, in m^2, of the rudder blade parts, defined in Fig 4

Figure 4 : Geometry of rudder blade with cut-outs



α : Coefficient to be taken equal to:

- $\alpha = 0,33$ for ahead condition
- $\alpha = 0,66$ for astern condition

For rudder parts located behind a fixed structure such as a rudder horn, α is to be taken equal to:

- $\alpha = 0,25$ for ahead condition
- $\alpha = 0,55$ for astern condition.

Other values of α provided by designers may be taken. Those values are to be considered by Society on case by case basis.

The torques M_{TR1} and M_{TR2} , relevant to the rudder blade parts A_1 and A_2 respectively, are to be obtained, in N.m, from the following formulae:

$M_{TR1} = C_{R1}\, r_1$

$M_{TR2} = C_{R2}\, r_2$

The total torque M_{TR} acting on the rudder stock, for both ahead and astern conditions, is to be obtained, in N.m, from the following formula:

$M_{TR} = M_{TR1} + M_{TR2}$

For the ahead condition only, M_{TR} is to be taken not less than the value obtained, in N.m, from the following formula:

$$M_{TR,MIN} = 0,1\, C_R \frac{A_1 b_1 + A_2 b_2}{A}$$

3 Rudder types, relevant loads, moments and forces acting on the rudder structure for direct calculations

3.1 General

3.1.1 Loads per rudder category - basic assumptions

Depending on the shape of the rudder blade and arrangement of the rudder, four types of rudders are considered. In case of different arrangement, special examination on case by case basis is to be carried out.

3.1.2 Loads, forces, and moments acting on the rudder

The force and torque acting on rudders as defined in [2], may induce the following loads in the rudder structure:

- bending moment and torque in the rudder stock
- support reactions at pintle and rudder stock bearings
- bending moment, shear force and torque in the rudder body
- bending moment, shear force and torque in rudder horns and solepieces.

These loads are calculated according to formulae given from [3.2] to [3.5] as appropriate. Alternatively loads calculation derived from direct beam analysis may be accepted, provided corresponding calculations are submitted for information.

3.2 Rudder type 1

3.2.1 Description

Type 1 rudders are considered as follow: 4 bearings including 3 pintle bearings and 1 rudder bearing as described in Fig 5.

3.2.2 Bending moment, shear forces and reactions

a) Bending moment

- in rudder stock:

$$M_B = 0$$

- in the rudder blade for streamlined rudder:

$$M_R = \frac{C_R \cdot L_{10}}{24}$$

where:

M_R : Moment in the rudder blade, in N.m

C_R : Lifting force, in N, as calculated in [2.1.2]

L_{10} : Length, in m, as defined on Fig 5.

b) Reaction at supports

- at upper bearing:

$$R_{40} = 0$$

- at lower bearing:

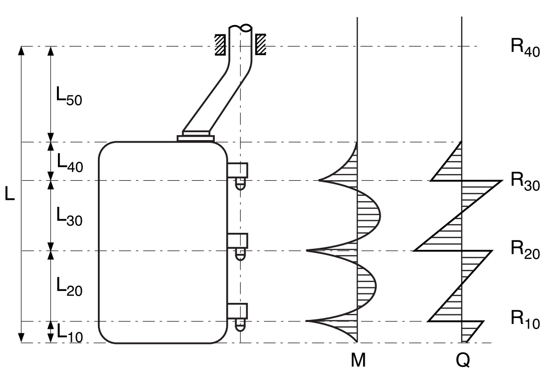
$$R_{10} = R_{20} = R_{30} = \frac{C_R}{3}$$

where:

R_i : Reaction, in N, at supports as defined in Fig 5

C_R : Lifting force, in N, as calculated in [2.1.2].

Figure 5 : Rudder type 1



3.3 Rudder type 5

3.3.1 Description

Type 5 rudders are considered as follow: 3 bearings including 1 pintle bearing and 2 rudder stock bearing as described in Fig 6.

Note 1: When the scantling of the solepiece is not sufficient to procure a fixed support in way of the pintle bearing, a direct calculation taking into account the solepiece rigidity is to be carried out to determine the bending moment and shear force in the rudder stock.

3.3.2 Bending moment, shear forces and reactions at supports

For this rule requirement, rudder structure is to be calculated according to the following approximate formula with assumption on lower pintle which is considered as a fixed support:

a) Bending moment

- at lower bearing:

$$M_{BLOSB} = \frac{p \cdot L_{10}^{\ 2}}{8} \cdot \left(\frac{L_{10}}{L_{10} + L_{20}}\right)$$

where:

M_{MBLOSB} : Bending moment, in N.m, in way of lower bearing

L_{10}, L_{20} : Lengths, in m, as defined on Fig 6

p : Linear pressure, in N/m, acting on rudder blade defined as follow:

$$p = \frac{C_R}{A} \cdot b$$

where:

C_R : Lifting force, in N, as calculated in [2.1.2]

A : Total area of rudder blade, in m^2

b : Mean breadth, in m of rudder blade as defined in [2.1.3].

- at upper bearing:

$$M_{BUpSB} = 0$$

- At pintle:

$$M_{BPib} = 0$$

Figure 6 : Rudder type 5

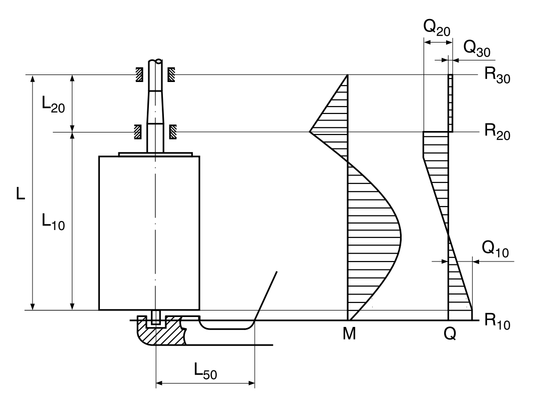
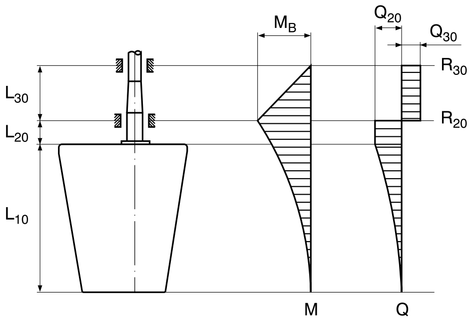


Figure 7 : Rudder type 6



b) Shear force in N

- at upper bearing

$$Q_{30} = \frac{M_{BLoSB}}{L_{20}}$$

- at lower bearing

$$Q_{20} = \frac{p \cdot L_{10}}{2} + \frac{M_{BLoSB}}{L_{10}}$$

- at pintle:

$$Q_{10} = \frac{p \cdot L_{10}}{2} - \frac{M_{BLoSB}}{L_{10}}$$

where:

Qi : Shear forces, in N, as described in Fig 6

M_{BLOSB} : Bending moment, in N.m as defined in [3.3.2] a)

L_{10}, L_{20} : Length, in m, as defined on Fig 6

p : Linear pressure in N/m as defined in [3.3.2] a).

c) Reaction at supports in N

- at upper bearing

$$R_{30} = Q_{30}$$

- at Lower bearing

$$R_{20} = Q_{20} + Q_{30}$$

- at neck

$$R_{10} = Q_{10}$$

where:

R_{10}, R_{20}, R_{30} : Reaction at supports, in N

Q_{10}, Q_{20}, Q_{30} : Shear forces, in N, as calculated in [3.3.2] b).

3.4 Rudder type 6

3.4.1 description

Type 6 rudders are considered as follow: 2 rudder stock bearings as described in Fig 7.

3.4.2 Bending moment, shear forces and reactions

a) Bending moment

- In rudder stock:

$$M_B = \frac{C_R \cdot (L_{10} + 2 \cdot L_{20})}{2}$$

where:

M_B : Maximum bending moment, in N.m, in the rudder stock

C_R : Lifting force, in N, applied on rudder blade

L_{10} : Length, in m, as defined in Fig 7

L_{20} : Length, in m, as defined in Fig 7.

b) Shear force

- In the rudder stock, at upper bearing

$$Q_{30} = \frac{M_B}{L_{30}}$$

- in the rudder stock, at lower bearing

$$Q_{20} = C_R$$

where:

Q_i : Shear force, in N, acting on rudder stock as shown on Fig 7

C_R : Lifting force, in N, applied on rudder blade

M_B : Maximum bending moment, in N.m, in the rudder stocks calculated in [3.4.2] a)

L_{30} : Length, in m, as defined in Fig 7.

c) Reaction at supports

- at upper bearing

$$R_{30} = \frac{M_B}{L_{30}}$$

- at Lower bearing

$$R_{20} = C_R + \frac{M_B}{L_{30}}$$

where:

R_i : Reactions at supports, in N, as described on Fig 7

C_R : Lifting force, in N, applied on rudder blade

M_B : Maximum bending moment, in N.m, in the rudder stock as calculated in [3.4.2] a)

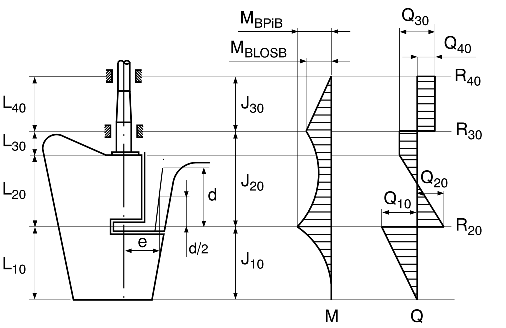
L_{30} : Length, in m, as defined in Fig 7.

3.5 Rudder type 7

3.5.1 description

Type 7 rudders are considered as follow: 3 bearings semi-spade rudder, including 1 pintle bearing and 2 rudder stock bearings, as described in Fig 8.

Figure 8 : Rudder type 7



3.5.2 Bending moment, shear forces and reactions at supports

a) Bending moment

- at lower stock bearing:

$$M_{BLoSB} = \frac{p_1 \cdot (L_{20}^2 - L_{30}^2) \cdot \left[\frac{1}{2} + \frac{u}{8}\right] + p_2 \cdot L_{10}^2 \cdot \left[\frac{1}{2} + \frac{L_{20}}{L_{10}} - \frac{u}{4}\right]}{1 + u \cdot \left[1 + \frac{L_{40}}{L_{20}} \cdot \frac{J_{20}}{J_{40}} \cdot \frac{E_{20}}{E_{40}}\right]}$$

Where:

L_{10}, L_{20},L_{30}, L_{40} : Lengths, in m, as defined on Fig 8

J_{10}, J_{20}, J_{30} : Moments of inertia about X axis, in cm^4 of the different parts constituting the rudder system having L_{10}, L_{20} and L_{30}, L_{40} respectively for lengths

$$p_1 = \frac{C_R \cdot \left(A_1 + \frac{A_2}{2}\right)}{A \cdot L_{20}}$$

$$p_2 = \frac{C_R \cdot \left(A_3 + \frac{A_2}{2}\right)}{A \cdot L_{10}}$$

$$u = \frac{L_{20}^3}{3 \cdot J_{20} \cdot E_{20} \cdot d \cdot \left[\frac{e^2}{G_{50} \cdot K_{50}} + \frac{d^2}{3 \cdot J_{50} \cdot E_{50}}\right]}$$

where:

C_R : Lifting force, in N, as calculated in [2.1.2]

A_1, A_2, A_3: Areas, in m^2, as defined in Fig 8

G_{50}, E_{50} : Respectively shear and elastic modulus, in N/mm^2, of the rudder horn

K_{50}, J_{50} : Respectively torsional (about z axis) and flexural (about x axis) inertia, in cm^4, of rudder horn

e : Torsion lever, in m, of rudder horn as defined in Fig 8

d : Flexural lever, in m, of rudder horn as defined in Fig 8

- at pintle bearing:

$$M_{BPiB} = \frac{p_2 \cdot L_{10}^2}{2}$$

Where:

M_{BPiB} : Bending moment, in N.m at pintle bearing

C_R : Lifting force, in N, applied on rudder blade

L_{10} : Length, in m as defined on Fig 8

b) Shear force

- At upper bearing:

$$Q_{40} = \frac{M_{BLoSB}}{L_{40}}$$

- At lower bearing:

$$Q_{30} = \frac{M_{BLoSB}}{(L_{20} + L_{30})} + \frac{p_1 \cdot (L_{20} + L_{30} - L_{40})^2}{2 \cdot (L_{20} + L_{30})} - \frac{M_{BPiB}}{L_{20}}$$

- at pintle bearing:

$$Q_{20} = C_R + Q_{40} - Q_{30} - (p_2 \cdot L_{10})$$

$$Q_{10} = p_2 \cdot L_{10}$$

where:

Q_i : Shear forces, in N, as shown on Fig 8

M_{BPiB} : Bending moment, in N.m, at pintle bearing as defined in [3.5.2] a)

M_{BLoSB} : Bending moment, in N.m, in way of lower bearing as defined in [3.5.2] a)

L_i : Distances, in m, between lower bearing and upper bearing as defined in Fig 8

p_1, p_2 : Value as defines in [3.5.2] a)

c) Reactions at supports:

- at upper bearing:

$$R_{40} = Q_{40}$$

- at lower bearing:

$$R_{30} = Q_{30} + Q_{40}$$

- at pintle bearing:

$$R_{20} = Q_{20} + Q_{10}$$

where:

R_i : Reactions at supports in N.

4 Rudder stock scantlings

4.1 General

4.1.1 Suitable tapering is to be carried out in case of significant change in the cross section of rudder stock, to avoid hard points. Abrupt changes in cross section of rudder stock may be accepted by Society on case by case basis.

4.1.2 Tiller or quadrant is to be fitted as far as practicable, such in a way that they will not induce secondary moment or reaction in the rudder stock. If any, bending moment and torque, respectively MB and Mtr, are to be corrected for the calculation of rudder stock scantling.

4.1.3 As a rule, for rudder stock made in composites, section is to be designed either as a ring or as hollow square.

In case of hollow square, angle of the square is to be rounded with a minimum radius of 5 mm.

4.2 Basic formulation

4.2.1 The scantling of the rudder stock diameter is based on direct calculations regarding each corresponding stress induced by combined bending moment MB and torque Mtr acting on rudder stock.

They are given by the following formulae:

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

$$\sigma_B = \frac{M_B}{w_B}$$

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

$$\tau_T = \frac{M_{TR}}{w_{TR}}$$

where:

W_B : Section modulus of rudder stock, in cm^3, to be obtained from the following formula:

$$w_B = \frac{I_{xx}}{v_y}$$

W_{TR} : Section modulus of rudder stock, in cm^3, to be obtained from the following formula:

$$w_{TR} = \frac{I_{zz}}{v_z}$$

with:

I_{XX} : Moment of inertia about x axis, in cm^3, of rudder stock corresponding to M_B

I_{ZZ} : Torsional inertia about z axis, in cm3, of rudder stock corresponding to M_{tr}

v_Y : Greatest distance taken along y axis between yy' neutral axis and the most external point of the section

v_Z : Greatest distance, in cm, between zz' neutral axis and the most external point located of the section.

4.3 Combination of stresses

4.3.1 Metallic rudder stock

For the check of steel rudder stock, calculations are based on the Von Mises equivalent criterion, σ_E, in N/mm^2, calculated for this state of stress, is to be in compliance with the following formula:

For bending moment M_B not equal to 0:

$$\sigma_E \leq \sigma_{E,all}$$

For null bending moment M_B:

$$\tau_T \leq \tau_{all}$$

with:

$$\sigma_E = \sqrt{\sigma_B^2 + 3\tau_T^2}$$

- For steel rudder stock:

$$\sigma_{E,all} = \frac{118}{k}$$

$$\tau_{all} = \frac{68}{k}$$

- For aluminium rudder stock

$$\sigma_{E,all} = \frac{56}{k}$$

$$\tau_{all} = \frac{32}{k}$$

The rudder stock diameter is to be not less than value the value obtained, in mm, from the following formula:

- For steel rudder stock

$$d_{TFi} = 4,2(M_{TR}k)^{1/3} \cdot \left[1 + \frac{4}{3}\left(\frac{M_{Bi}}{M_{TR}}\right)^2\right]^{1/6}$$

- For aluminium rudder stock

$$d_{TFi} = 5,4(M_{TR}k)^{1/3} \cdot \left[1 + \frac{4}{3}\left(\frac{M_{Bi}}{M_{TR}}\right)^2\right]^{1/6}$$

where M_{Bi} is to be obtained according to [3].

Diameter of rudder stock subject to torque and bending may be gradually tapered above the lower stock bearing so as to reach, from d_{TF} value in way of lower bearing part, the value d_T (equal to d_{TF} with null bending moment) in way of upper bearing.

If not otherwise specified, the notation d_1 used in this Section is equivalent to d_{TF}.

4.3.2 Composite rudder stock

For the scantling of composites rudder stocks, special consideration are to be taken: breaking criterion are to be taken from Ch 4, Sec 3, [5.3].

Calculations given in this part are given for the analysis of type 6 rudder with rudder stock made with an hollow square section. For other type of rudder than type 6 or if rudder stock is made with hollow circular section, examination will be based on case by case basis.

a) Loading of the side parts of rudder stock

As a rule, for the scantlings of sides of rudder stock, assumptions are made by considering the mechanical behaviour of the sides stock as a sandwich beam constituted by two skins and a thickness core with quasi-null mechanical properties.

Assumption is made on torque which neglected in the calculation of stress at lower bearing.

In way of lower bearing the loading is to be made with the two following formulae.

$$M_X = \frac{M_B}{L_X}$$

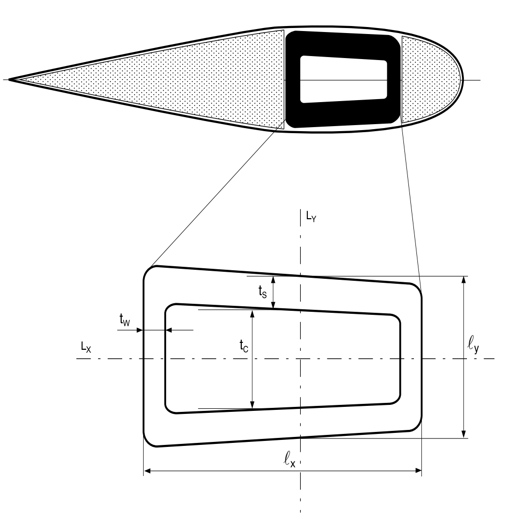
Where:

M_X : Bending moment, in kN.m/m, for loading of side parts of stock in bending according to input of BV composites software specified in Ch 1, Sec 4, [2.2]

M_B : Bending moment, in N.m, applied on rudder stock as defined in [3.4.2] for the corresponding type of rudder

L_X : Distance, in mm, as described in Fig 9

Figure 9 : Typical section of composite rudder stock



b) Loading of web part of rudder stock

Web parts of the rudder stock are subject to the load due to the bending moment and bending torque. For the loading, each skin constituting of the web parts of rudder stock is to be considered separately.

Calculations of each web parts are to be made in way of the upper bearing and lower bearing.

1) Loading in way of lower bearing:

$$N_{XY} = \frac{Q_{20}}{2 \cdot L_Y}$$

where:

- N_{XY} : In plain shear load, in kN/m applied in front web or aft web of rudder stock
- Q_{20} : shear force in way of lower bearing, in N, as defined in [3.4.2]
- L_Y : Dimension, in mm, of rudder stock section as shown on Fig 9.

2) Loading in way of upper bearing:

$$N_{XY} = \frac{Q_{30} + M_{TR}/L_Y}{2 \cdot L_Y}$$

where:

- N_{XY} : In plain shear load, in kN/m applied on front web or aft web of rudder stock
- M_{TR} : Rudder torque, in N.m, as defined in [2.1.3]
- L_Y : Dimension, in mm, of rudder stock section as shown on Fig 9
- Q_{30} : Shear force in way of upper bearing , in N, applied on rudder stock as defined in [3.4.2]

c) Check of rudder stock:

On each layer of rudder stock laminate, check is to be made with the breaking criterion defined in Ch 4, Sec 3, [5.3]:

For maximum stress criterion check, safety coefficients are to be not less than those calculated in the following formula:

$$\frac{\sigma_{br1}}{\sigma_1} \geq 1,1 \cdot SF \qquad \frac{\tau_{br12}}{\tau_{12}} \geq SF$$

$$\frac{\sigma_{br2}}{\sigma_2} \geq 1,1 \cdot SF \qquad \frac{\tau_{brIL}}{\tau_{13} \, or \, \tau_{23}} \geq SF$$

with:

- σ_1 : Single layer or core longitudinal tensile or compression stresses, calculated according to Ch 12, Sec 4, [6.2.4] and Ch 12, Sec 4, [6.2.5]
- σ_2 : Single layer or core transversal tensile or compression stresses, calculated according to Ch 12, Sec 4, [6.2.4] and Ch 12, Sec 4, [6.2.5]
- τ_{12} : Single layer or core in plane shear stresses, calculated according to Ch 12, Sec 4, [6.2.4] and Ch 12, Sec 4, [6.2.5]
- τ_{13} and τ_{23} : Single layer interlaminar shear stresses (out of plane), calculated according to Ch 12, Sec 4, [4.3.2]
- σ_{br1} : Single layer or core longitudinal breaking stress (in tensile or in compression modes) calculated with requirements of Ch 12, Sec 4, [5.2]
- σ_{br2} : Single layer or core transversal breaking stress (in tensile or in compression modes) calculated with requirements of Ch 12, Sec 4, [5.2]
- τ_{br12} : Single layer or core in plane breaking shear stress calculated with requirements of Ch 12, Sec 4, [5.2]
- τ_{brIL} : Single layer interlaminar breaking shear stress calculated with requirements of Ch 12, Sec 4, [5.2]
- SF : Safety coefficient as defined in Ch 4, Sec 3, [5.4]

5 Rudder blade scantlings

5.1 General

5.1.1 Application

The requirements from [5.1] to [5.3] apply to streamlined rudders and, when applicable, to rudder blades of single plate rudders.

5.1.2 Rudder blade structure

The structure of the rudder blade is to be such that stresses are correctly transmitted to the rudder stock and pintles.

To this end, for metallic rudder blade, horizontal and vertical web plates are to be provided. Horizontal and vertical webs acting as main bending girders of the rudder blade are to be suitably reinforced.

For composite rudder blade, scantling of the skin constituting the rudder blade is to be sufficient to allow a good transmission of loads form rudder blade to stock. Cohesion between this two part is to be ensure either by gluing or laminating. Other system of connecting will be examined on case by case basis.

5.1.3 Dismounting

Dismounting system on every type of rudder is provided.

The corners of openings intended for the passage of the rudder horn heel and for the dismantling of pintle or stock nuts are to be rounded off with a radius as large as practicable.

On metallic rudder, where the access to the rudder stock nut is closed with a welded plate, a full penetration weld is to be provided.

5.1.4 Connection of the rudder blade to the trailing edge and nose for rudder blade area

- On metallic rudder, where the rudder blade area is greater than 6 m², the connection of the rudder blade plating to the trailing edge is to be made by means of a forged or cast steel fashion piece, a flat or a round bar.
- For composite rudder, where the rudder blade area is greater than 3 m², reinforcements made by laminate are provided (e.g. unidirectional tapes).

Table 2 : Allowable stresses for steel rudder blade scantlings

Type of rudder blade	Allowable bending stress σ_{ALL} in N/mm²	Allowable shear stress τ_{ALL} in N/mm²	Allowable equivalent stress $\sigma_{E,ALL}$ in N/mm²
Without cut-outs	110 / k	50 / k	120 / k
With cut-outs (see Fig 3)	75 / k	50 / k	100 / k

5.2 Metallic rudder blade

5.2.1 Bending stresses

For the generic horizontal section of the rudder blade it is to be checked that the bending stress σ, in N/mm², induced by the loads defined in [3.1], is in compliance with the following formula:

$\sigma \leq \sigma_{ALL}$

where:

σ_{ALL} : Allowable bending stress, in N/mm², specified in Tab 2 and Tab 3

5.2.2 Shear stresses

For the generic horizontal section of the rudder blade it is to be checked that the shear stress τ, in N/mm², induced by the loads defined in [3.1], is in compliance with the following formula:

$\tau \leq \tau_{ALL}$

where:

τ_{ALL} : Allowable shear stress, in N/mm², specified in Tab 2 and Tab 3

5.2.3 Combined bending and shear stresses

For the generic horizontal section of the rudder blade it is to be checked that the equivalent stress, σ_E, is in compliance with the following formula:

$\sigma_E \leq \sigma_{E,ALL}$

where:

σ_E : Equivalent stress induced by the loads defined in [3.1], to be obtained, in N/mm², from the following formula:

$$\sigma_E = \sqrt{\sigma^2 + 3\tau^2}$$

σ : Bending stress, in N/mm²

τ : Shear stress, in N/mm²

$\sigma_{E,ALL}$: Allowable equivalent stress, in N/mm², specified in Tab 2 and Tab 3.

5.2.4 Plating

As a rule, rule thickness of metallic plates sustaining lateral pressure is given, in mm, by the formula:

$$t = 22,4 \cdot coeff \cdot \mu \cdot s \cdot \sqrt{\frac{p}{\sigma_{am}}}$$

where:

coeff : Coefficient equal to:

- In case of uniformly distributed hydrodynamic loads, as defined here above:

  coeff = 1

μ : Aspect ratio coefficient of the elementary plate panel, equal to:

$$\sqrt{1,1 - \left(0,5 \cdot \frac{s^2}{\ell^2}\right)}$$

without being taken more than 1, where:

- ℓ : Longer side, in m, of the elementary plate panel
- s : Smaller side, in m, of the elementary plate panel

σ_{am} : Rule admissible stress, in N/mm², defined in Ch 4, Sec 3, Tab 2 or Ch 4, Sec 3, Tab 4 respectively for steel and aluminium as hydrodynamic load for plating

p : Pressure, in kN/m², acting on rudder blade to be calculated with the following formula:

$$p = 9,807 \cdot \rho \cdot z + \frac{C_R}{A} \cdot 10^{-3}$$

z : Vertical distance, in m, from calculation point to the full load water line. Calculation point is to be taken at mid-height of the elementary panel

r : Specific gravity of sea water taken equal to 1025 kg/m3

C_R : Lifting force applied on rudder blade as defined in [2.1.2]

A : Total area of the rudder blade, in m², as defined in [2.1.2].

The thickness of the top and bottom plates of the rudder blade is to be taken as the maximum of:

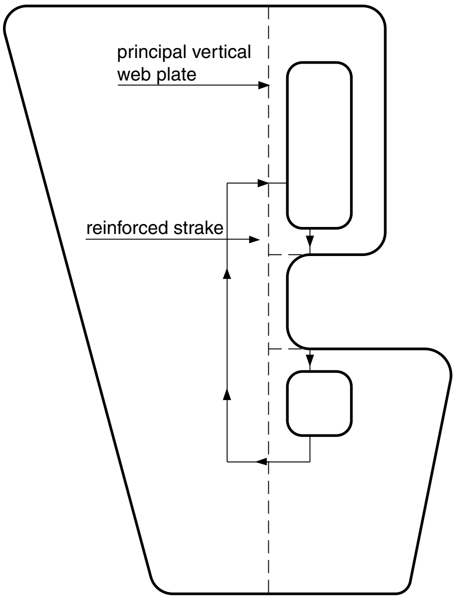
- the thickness t_F defined in [5.2.4], by considering the relevant values of s and ℓ, for both the top and bottom plates
- 1,2 times the thicknesses obtained for the attached side platings around the top and bottom plates, respectively, calculated according to [5.2.4], by considering the relevant values of s and ℓ

Where the rudder is connected to the rudder stock with a coupling flange, the thickness of the top plate which is welded in extension of the rudder flange is to be not less than 1,1 times the thickness calculated above.

Table 3 : Allowable stresses for aluminium rudder blade scantlings

Type of rudder blade	Allowable bending stress σ_{ALL} in N/mm²	Allowable shear stress τ_{ALL} in N/mm²	Allowable equivalent stress $\sigma_{E,ALL}$ in N/mm²
Without cut-outs	52 / k	23/ k	56 / k
With cut-outs (see Fig 3)	35 / k	23 / k	47 / k

Figure 10 : Reinforced strake extension for semi-spade rudders



5.2.5 Stiffeners

a) Arrangement of stiffeners

The spacing between horizontal web plates is to be not greater than 1,20m.

Vertical webs are to have a spacing not greater than twice that horizontal spacing.

b) Web thickness

Web thickness is to be at least 70% of that required for rudder plating except for the upper and lower horizontal webs, for which the requirements in [5.2.4] apply.

When the design of the rudder does not incorporate a mainpiece and the rudder stock is not continuous, this is to be replaced by two vertical webs closely spaced, having thickness not less than that obtained from Tab 4. In rudders having area less than 6 m^2, one vertical web only may be accepted provided its thickness is at least twice that of normal webs.

c) Thickness of side plating and vertical web plates welded to a solid part or to rudder flanges

The thickness, in mm, of the vertical web plates welded to the solid part where the rudder stock is housed, or welded to the rudder flange, as well as the thickness of the rudder side plating under this solid part, or under the rudder coupling flange, is to be not less than the value obtained, in mm, from Tab 4.

d) Reinforced strake of semi-spade rudders

A reinforced strake is to be provided in the lower pintle zone of semi-spade rudders. Its thickness is to be not less than 1,6 t_F, where t_F is defined in [5.2.4]. This strake is to be extended forward of the main vertical web plate (see Fig 10).

e) Main vertical webs of semi spade rudders

The thickness of the main vertical web plate in the area between the rudder blade upper part and the pintle housing of semi-spade rudders is to be not less than 2,6 t_F, where t_F is defined in [5.2.4].

Under the pintle housing the thickness of this web is to be not less than the value obtained from Tab 4.

Where two main vertical webs are fitted, the thicknesses of these webs are to be not less than the values obtained from Tab 4 depending on whether the web is fitted in a rudder blade area without opening or if the web is along the recess cut in the rudder for the passage of the rudder horn heel.

f) Welding:

The welded connections of blade plating to vertical and horizontal webs are to be in compliance with the applicable requirements of the Rule Note NR216 Materials and Welding.

Where the welds of the rudder blade are accessible only from outside of the rudder, slots on a flat bar welded to the webs are to be provided to support the weld root, to be cut on one side of the rudder only.

5.2.6 Connections of rudder blade structure with solid parts in forged or cast steel

a) General

Solid parts in forged or cast steel which ensure the housing of the rudder stock or of the pintle are in general to be connected to the rudder structure by means of two horizontal web plates and two vertical web plates.

b) minimum section modulus of the connection with rudder stock housing

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

$$w_S = c_S d_1^3 \left(\frac{H_E - H_X}{H_E}\right)^2 \frac{k}{k_1} 10^{-4}$$

where:

- c_S : Coefficient, to be taken equal to:
  - c_S = 1,0 if there is no opening in the rudder plating
  - c_S = 1,5 if there is an opening in the considered cross-section of the rudder
- d_1 : Rudder stock diameter, in mm, defined in [4.3.1]
- H_E : Vertical distance, in m, between the lower edge of the rudder blade and the upper edge of the solid part
- H_X : Vertical distance, in m, between the considered cross-section and the upper edge of the solid part
- k, k_1 : Material factors, defined in [1.4], for the rudder blade plating and the rudder stock, respectively.

c) calculation of the actual section modulus

The actual section modulus of the cross-section of the structure of the rudder blade which is connected with the solid part where the rudder stock is housed is to be calculated with respect to the symmetrical axis of the rudder.

The breadth of the rudder plating to be considered for the calculation of this actual section modulus is to be not greater than that obtained, in m, from the following formula:

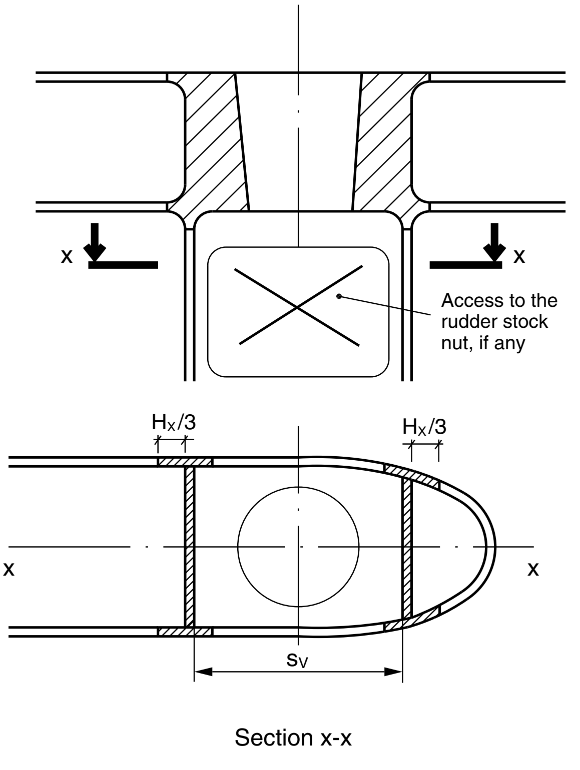
$$b = s_V + 2\frac{H_X}{m}$$

where:

- s_V : Spacing, in m, between the two vertical webs (see Fig 11)
- H_X : Distance defined in [5.2.6] b)
- m : Coefficient to be taken, in general, equal to 3.

Where openings for access to the rudder stock nut are not closed by a full penetration welded plate according to [5.1.3], they are to be deducted (see Fig 11).

Figure 11 : Cross-section of the connection between rudder blade structure and rudder stock housing



d) thickness of horizontal web plates

In the vicinity of the solid parts, the thickness of the horizontal web plates, as well as that of the rudder blade plating between these webs, is to be not less than the greater of the values obtained, in mm, from the following formulae:

$t_H = 1,2\ t_F$

$$t_H = 0,045\frac{d_S^2}{s_H}$$

where:

- t_F : Defined in [5.2.4]
- d_S : Diameter, in mm, to be taken equal to:
  - d_1 for the solid part connected to the rudder stock
  - d_A for the solid part connected to the pintle
- d_1 : Rudder stock diameter, in mm, defined in [4.3.1]
- d_A : Pintle diameter, in mm, defined in [8.4.1]
- s_H : Spacing, in mm, between the two horizontal web plates.

Different thickness may be accepted when justified on the basis of direct calculations submitted to the Society for approval.

e) Thickness of side plating and vertical web plates welded to solid part.

The thickness of the vertical web plates welded to the solid part where the rudder stock is housed as well as the thickness of the rudder side plating under this solid part is to be not less than the values obtained, in mm, from Tab 4.

f) Solid part protrusions

The solid parts are to be provided with protrusions. Vertical and horizontal web plates of the rudder are to be butt welded to these protrusions.

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

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

Table 4 : Thickness of the vertical webs and rudder side plating welded to solid part or to rudder flange

Type of rudder	Thickness of vertical web plates, in mm		Thickness of rudder plating, in mm	
	Rudder blade without opening	At opening boundary	Rudder blade without opening	Area with opening
Hinged rudders on pintles type 1 rudder	t_F	$1,3\ t_F$	t_F	$1,2\ t_F$
Rudder without intermediate pintle type 5 rudder	$1,2\ t_F$	$1,6\ t_F$	$1,2\ t_F$	$1,4\ t_F$
Spade and semi spade type 6 and 7 rudders	$1,4\ t_F$	$2,0\ t_F$	$1,3\ t_F$	$1,6\ t_F$
t_F : Defined in [5.2.4].				

5.2.7 Connection of the rudder blade with the rudder stock by means of horizontal flanges

a) Minimum section modulus of the connection

The section modulus of the cross-section of the structure of the rudder blade which is directly connected with the flange, which is made by vertical web plates and rudder blade plating, is to be not less than the value obtained, in cm^3, from the following formula:

$$w_S = 1,3\ d_1^3\ 10^{-4}$$

where d_1 is the rudder stock diameter d_{TF}, in mm, to be calculated in compliance with [4.3.1], taking k equal to 1.

b) Section modulus of the connection

The section modulus of the cross-section of the structure of the rudder blade which is directly connected with the flange is to be calculated with respect to the symmetrical axis of the rudder.

For the calculation of this actual section modulus, the length of the rudder cross-section equal to the length of the rudder flange is to be considered.

Where the rudder plating is provided with an opening under the rudder flange, the actual section modulus of the rudder blade is to be calculated in compliance with [5.2.6] c).

c) Welding of the rudder blade structure to the rudder blade flange

The welds between the rudder blade structure and the rudder blade flange are to be full penetrated (or of equivalent strength) and are to be 100% inspected by means of non-destructive tests.

Where the full penetration welds of the rudder blade are accessible only from outside of the rudder, a backing flat bar is to be provided to support the weld root.

The external fillet welds between the rudder blade plating and the rudder flange are to be of concave shape and their throat thickness is to be at least equal to 0,5 times the rudder blade thickness.

Moreover, the rudder flange is to be checked before welding by non-destructive inspection for lamination and inclusion detection in order to reduce the risk of lamellar tearing.

d) Thickness of side plating and vertical web plates welded to the rudder flange

The thickness of the vertical web plates directly welded to the rudder flange as well as the plating thickness of the rudder blade upper strake in the area of the connection with the rudder flange are to be not less than the values obtained, in mm, from Tab 4.

5.2.8 Single plate rudders

a) Main piece diameter

The mainpiece diameter is to be obtained from the formulae in [4.3.1].

In any case, the mainpiece diameter is to be not less than the stock diameter.

For spade rudders the lower third may taper down to 0,75 times the stock diameter.

b) Blade thickness

The blade thickness is to be not less than the value obtained, in mm, from the following formula:

$$t_B = (1{,}5\,s\,V_{AV} + 2{,}5)\sqrt{k}$$

where:

s : Spacing of stiffening arms, in m, to be taken not greater than 1 m (see Fig 12).

c) Arms

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

The section modulus of the generic section is to be not less than the value obtained, in cm^3, from the following formula:

$$Z_A = 0,5\ s\ C_H^2\ V_{AV}^2\ k$$

where:

C_H : Horizontal distance, in m, from the aft edge of the rudder to the centreline of the rudder stock (see Fig 12)

s : Defined in item b).

5.3 Composite rudder blade

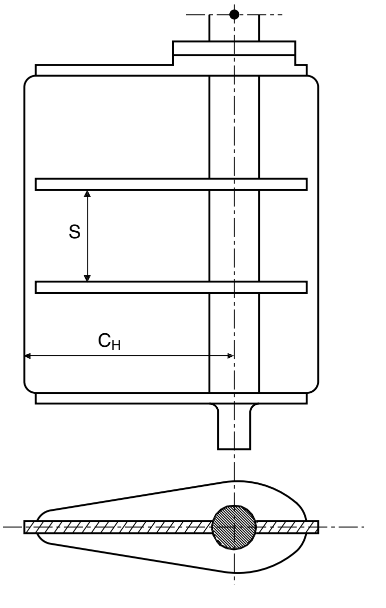
5.3.1 General

As a rule rudders made of composite materials, are streamlined rudders. Skins constituting the rudder blade are made of single skin laminate separated by a core.

For the generic horizontal section of the rudder blade, check are to be made on:

- Skins constituting the rudder blade loaded under bending induced by the rudder torque. Check will be made with breaking criterion defined in Ch 4, Sec 3, [5.3]
- Core constituting the inner web of rudder blade loaded under shearing induced by lifting force.

Figure 12 : Single plate rudder



5.3.2 Checking criteria

On each layer of rudder blade laminate, check is to be made with breaking criterion defined in Ch 4, Sec 3, [5.3]:

For maximum stress criterion check, safety coefficients are to be not less than those calculated in the following formula:

$$\frac{\sigma_{br1}}{\sigma_1} \geq 1,1SF \qquad \frac{\tau_{br12}}{\tau_{12}} \geq SF$$

$$\frac{\sigma_{br2}}{\sigma_2} \geq 1,1SF \qquad \frac{\tau_{brIL}}{\tau_{13} or \tau_{23}} \geq SF$$

with:

- σ_1 : Single layer or core longitudinal tensile or compression stresses, calculated according to Ch 12, Sec 4, [6.2.4] and Ch 12, Sec 4, [6.2.5]
- σ_2 : Single layer or core transversal tensile or compression stresses, calculated according to Ch 12, Sec 4, [6.2.4] and Ch 12, Sec 4, [6.2.5]
- τ_{12} : Single layer or core in plane shear stresses, calculated according to Ch 12, Sec 4, [6.2.4] and Ch 12, Sec 4, [6.2.5]
- τ_{13} and τ_{23} : Single layer interlaminar shear stresses (out of plane), calculated according to Ch 12, Sec 4, [4.3.2]
- σ_{br1} : Single layer or core longitudinal breaking stress (in tensile or in compressive modes) calculated with requierements of Ch 12, Sec 3, [5.2]
- σ_{br2} : Single layer or core transversal breaking stress (in tensile or in compression modes) calculated with requirements of Ch 12, Sec 3, [5.2]
- τ_{br12} : Single layer or core in plane breaking shear stress calculated with requirements of Ch 12, Sec 3, [5.2]
- τ_{brIL} : Single layer interlaminar breaking shear stress calculated with requirements of Ch 12, Sec 3, [5.2]
- SF : Safety coefficient as defined in Ch 4, Sec 3, [5.4].

5.3.3 Plating

As a rule, for each skin, laminates constituting the blade plating are to be check with the following formulae:

$$M_Y = \frac{M_{TR}}{L_{10}} \cdot 10^3$$

where:

- M_y : Moment, in kN.m/m, for the loading of plating with BV software
- M_{TR} : Rudder torque, in N.m, as defined in [2.1.3] [2.1.3]
- L_{10} : Dimension, in mm, of rudder stock section as shown on Fig 7.

6 Couplings between rudder stock and rudder blade

6.1 Coupling between metallic stock and blade

6.1.1 General

As a rule, coupling between rudder stock and rudder blade is to be made by horizontal stiffening. Other system will be considered on case by case basis.

Coupling flange and rudder stock could be build up by forging, manufacturing or assembled by welding. the rudder stock are to be forged from a solid piece.

6.1.2 Coupling with non continuous rudder stock

a) forged or manufactured pieces for coupling flange and rudder stock

The coupling flange is to have a thickness at least equal to one-quarter of the rule diameter of the stock lower part. A shoulder radius as large as practicable is to be provided for between the rudder stock and the coupling flange. This radius is to be not less than 0,15 d_1, where d_1 is defined in [4.3.1].

b) Welded coupling flanges

Where the rudder stock diameter does not exceed 350 mm, the coupling flange may be welded onto the stock, provided that its thickness is increased by 10% and that the weld extends through the full thickness of the coupling flange and that the assembly obtained is subjected to heat treatment. This heat treatment is not required if the diameter of the rudder stock is less than 75 mm.

Where the coupling flange is welded, the grade of the steel used is to be of weldable quality, with a carbon content not exceeding 0,23% on laddle analysis and a carbon equivalent CEQ not exceeding 0,41. The welding conditions (preparation before welding, choice of electrodes, pre- and post-heating, inspection after welding) are to be defined to the satisfaction of the Society. The throat weld at the top of the flange is to be concave shaped to give a fillet shoulder radius as large as practicable. This radius:

- is to be not less than 0,15d_1 , where d_1 is defined as in [4.3.1]
- may be obtained by grinding. If disk grinding is carried out, score marks are to be avoided in the direction of the weld
- is to be checked with a template for accuracy. Four profiles at least are to be checked. A report is to be submitted to the Surveyor.

The inspection is to include full non destructive tests at weld location (dye penetrant or magnetic particle test and ultrasonic test).

6.1.3 Couplings by continuous rudder stock welded to the rudder blade

When the rudder stock extends through the upper plate of the rudder blade and is welded to it, the thickness of this plate in the vicinity of the rudder stock is to be not less than 0,20 d_1, where d_1 is defined in [4.3.1].

The welding of the upper plate of the rudder blade with the rudder stock is to be made with a full penetration weld and is to be subjected to non-destructive inspection through dye penetrant or magnetic particle test and ultrasonic test.

The throat weld at the top of the rudder upper plate is to be concave shaped to give a fillet shoulder radius as large as practicable. This radius:

- is to be not less than $0,15d_1$, where d_1 is defined in [4.3.1]
- may be obtained by grinding. If disk grinding is carried out, score marks are to be avoided in the direction of the weld
- is to be checked with a template for accuracy. Four profiles, at least, are to be checked. A report is to be submitted to the Surveyor.

6.1.4 Connection between rudder blade and coupling flange

a) By bolts

Flange couplings are to be connected by fitted bolts having a diameter not less than the value obtained, in mm, from the following formula:

$$d_B = 0,62\sqrt{\frac{d_1^3 k_B}{n_B e_M k_S}}$$

where:

- d_1 : Rudder stock diameter, in mm, defined in [4.3.1]
- k_S : Material factor k for the steel used for the rudder stock
- k_B : Material factor k for the steel used for the bolts
- e_M : Mean distance, in mm, of the bolt axes from the centre of the bolt system
- n_B : Total number of bolts, which is to be not less than: 6 if d>75mm and 4 if less than 75 mm

A suitable locking device on nuts is to be provided.

The distance from the bolt axes to the external edge of the coupling flange is to be not less than 1,2 d_B.

b) Other coupling system

Connection made by other system than described in [6.1.4] a) will be examined on case by case basis and are subject to direct calculation.

6.1.5 Coupling flange

The thickness of the coupling flange is to be not less than the value obtained, in mm, from the following formula:

$$t_P = d_B\sqrt{\frac{k_F}{k_B}}$$

where:

- d_B : Bolt diameter, in mm, calculated in accordance with [6.1.4], where the number of bolts n_B is to be taken not greater than 8
- k_F : Material factor k for the metallic material used for the flange
- k_B : Material factor k for the metallic material used for the bolts

In any case, the thickness t_P is to be not less than 0,9 d_B.

6.2 Coupling between composite rudder stock and composite rudder blade

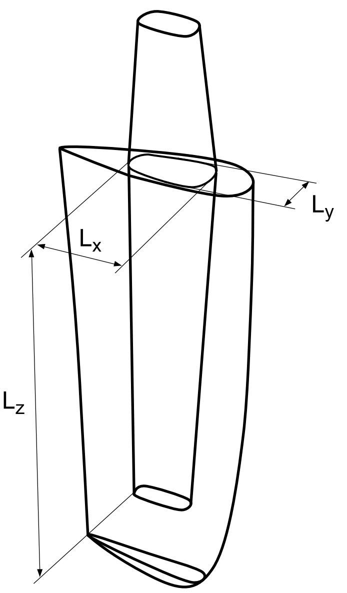
6.2.1 General

As a rule, composite rudder stock are to have flat surfaces for the part integrated in the rudder blade as described in Fig 13. The rudder blade for such type of arrangement is constituted of skins made of composite and a core made of foam glued on flat surfaces of the rudder stock. Other systems of coupling is to be considerated by Society on case by case basis.

For coupling between composite rudder stock to composite rudder blade the following ratio are to be checked:

- ratio between Shear stress in the glue due to applied shear force and shear breaking stress of glue
- Ratio between shear stress in the web due to applied shear force and shear breaking stress of the web.

Figure 13 : Coupling for composite rudder



6.2.2 Calculation of shear force

The shear Force acting on connection between rudder stock and rudder blade is to be calculated with the following formula:

$$T = \frac{M_{TR}}{L_Y}$$

with:

- M_{TR} : Torsional moment, in N.m as defined in [2.1.3]
- L_Y : Dimension, in mm, of rudder stock on Y axis.

6.2.3 Shear stress

a) Shear stress in the gluing surface between rudder stock and rudder blade.

The surface considered for the calculations of the shear stress is the lateral projected area (in XZ plan) of the rudder stock. Shear stress in the glue is to be calculated as indicated in the following formula:

$$\tau_g = \frac{T}{S_g}$$

with:

τ_g : Shear stress in the glue in N/mm²

T : Shear force, in N, calculated as [6.2.2]

S_g : Contact surface, in mm²

and Sg to be calculated as follow:

$S_g = L_Z L_X$

with:

- L_Z: Length, in mm, of rudder stock inserted in rudder blade
- L_X: Dimension, in mm, in x axis direction, of rudder stock to be taken at mid-length of L_Z

b) Shear stress in the rudder blade

Once shear force is transmitted through the gluing materials, the surface considered for the calculations of the shear stress is the frontal projected area (in YZ plan) of the rudder stock. Shear stress in the core is to be calculated as indicated in the following formula:

$$\tau_C = \frac{T}{S_C}$$

with:

τ_C : Shear stress in N/mm²

T : Shear force, in N, calculated as [6.2.2]

S_C : Contact surface, in mm²

and S_C to be calculated as follow:

$S_C = L_Z L_Y$

with:

- L_Z: Length, in mm, of rudder stock inserted in rudder blade
- L_Y: Dimension, in mm, in Y axis direction, of rudder stock to be taken at mid-length of L_Z.

6.2.4 Calculation of ratio

Ratio are to be calculated as follow and are to be not less than security factors:

$$\frac{\tau_{brg}}{\tau_g} \geq SF$$

$$\frac{\tau_{brC}}{\tau_C} \geq SF$$

with:

τ_g : Shear stress, in N/mm², in the gluing surface (XZ plan)

τ_{brg} : Shear breaking stress of the glue, in N/mm²

τ_C : Shear stress, in N/mm², in the core (YZ plan)

τ_{brc} : Shear breaking stress of the core, in N/mm²

Values of SF are listed in Ch 4, Sec 3, [5.4.1] shear stress in the core.

6.3 Coupling between metallic rudder stock and composite rudder blade

6.3.1 General

As a rule, for this type of system, arms are fitted on rudder stock and are perpendicular to the axis of rotation of rudder stock.

Connection between arms and rudder blade is to be sufficient to ensure a good transmission of rudder torque. In case where arms of rudder stock are not in contact with rudder blade, coupling material is to be checked. Special care must be taken for the fitting of arms on rudder stock if welded.

For aluminium rudder stock, mechanical properties for the check of rudder stock and arms are to be made with the properties of the metal as in welded condition (see Ch 4, Sec 3, Tab 3).

6.3.2 Check of couplings arms between rudder stock and rudder blade

Depending of the connection between rudder stock and arms check is to be made in accordance with the following requirements:

a) Bending check

As a rule for metallic arms fitted on metallic rudder stock, check is to be made on stress, obtained from the following formula:

$$\sigma_{am} \geq \frac{M_{TR}}{n} \times \frac{1}{w_z}$$

where:

σ_{am} : Admissible stress, in N/mm², taken from Ch 4, Sec 3, Tab 2 and Ch 4, Sec 3, Tab 4 as a stiffeners local stress induced by local hydrodynamic loads

M_{TR} : Rudder torque, in N.m, applied on rudder blade as defined in [2.1.3]

n : Number of arms connected to the rudder stock

w_z : Minimum arms section modulus, in cm3, around z axis.

b) Shearing check

As a rule, the design shear area Ash, in cm², of metallic arms fitted on metallic rudder stock is given by the following formula:

$$\tau_{Am} \geq \frac{C_R}{n} \times \frac{1}{A_{sh}} \cdot 10^2$$

where:

τ_{Am} : Admissible stress, in N/mm², taken from Ch 4, Sec 3, Tab 2 and Ch 4, Sec 3, Tab 4 as a stiffeners local stress induced by local hydrodynamic loads

A_{sh} : Minimum arms shear section in cm²

C_R : Lifting force, in N, applied on rudder blade

n : Number of arms connected to the rudder stock.

7 Rudder trunks

7.1 Arrangement

7.1.1 As a rule rudder trunks are to be fitted in a such way that lower end of rudder trunk is flush with hull plating.

7.1.2 The steel grade used for the rudder trunk is to be of weldable quality, with a carbon content not exceeding 0,23% on laddle analysis and a carbon equivalent CEQ not exceeding 0,41.

7.1.3 Connection between rudder trunk and shell plating

As far as practicable, a shoulder radius is provided at the connection between rudder trunk and shell plating.

a) For steel and aluminium rudder trunks

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

The fillet shoulder radius r is to be as large as practicable and to comply with the following formulae:

r = 60 mm when

$\sigma \geq 40/\,k$ N/mm² for steel, and

$\sigma \geq 19/\,k$ N/mm² for aluminium

$r = 0{,}1\ d_1$ when

$\sigma < 40\,/\,k$ N/mm² for steel, and

$\sigma < 19/\,k$ N/mm² for aluminium

without being less than 30 mm,

where d_1 is defined in [4.3.1].

The radius may be obtained by grinding. If disk grinding is carried out, score marks are to be avoided in the direction of the weld.

The radius is to be checked with a template for accuracy. Four profiles at least are to be checked. A report is to be submitted to the Surveyor.

b) For composite rudder trunks

Connection between rudder trunk and shell plating is to be made with a radius, made of compliant resin, which is to be as large as practicable.

7.1.4 Before welding is started, a detailed welding procedure specification is to be submitted to the Society covering the weld preparation, welding positions, welding parameters, welding consumable, preheating, post weld heat treatment and inspection procedures. This welding procedure is to be supported by approval tests in accordance with the applicable requirements of the Rule Note NR216 Materials and Welding, Ch 5, Sec 4.

The manufacturer is to maintain records of welding, subsequent heat treatment and inspections traceable to the welds. These records are to be submitted to the Surveyor.

Non destructive tests are to be conducted at least 24 hours after completion of the welding. The welds are to be 100% magnetic particle tested and 100% ultrasonic tested. The welds are to be free from cracks, lack of fusion and incomplete penetration. The non destructive tests reports are to be handed over to the Surveyor.

7.1.5 The thickness of the shell or of the bottom plate is to be compatible with the trunk thickness.

8 Rudder stock and pintle bearings

8.1 Forces on rudder stock and pintle bearings

8.1.1 Support forces R_i , for i = 1, 2, 3, on pintles are to be obtained according to [3.2.2], depending on the rudder type.

8.1.2 Supporting structure in way of bearing is to be examined with loads as in defined in [3]. This examination will be based on direct calculation.

8.2 Rudder stock bearing

8.2.1 The mean bearing pressure acting on the rudder stock bearing is to be in compliance with the following formula:

$p_F \leq p_{F,ALL}$

where:

p_F : Mean bearing pressure acting on the rudder stock bearings, in N/mm², equal to:

$$p_F = \frac{R_i}{d_m h_m}$$

R_i : Support force acting on the rudder stock bearing, in N

d_m : Actual inner diameter, in mm, of the rudder stock bearings (contact diameter)

h_m : Bearing length, in mm (see [8.2.3])

$p_{F,ALL}$: Allowable bearing pressure, in N/mm², defined in Tab 5

Values greater than those given in Tab 5 may be accepted by the Society on the basis of specific tests.

8.2.2 An adequate lubrication of the bearing surface is to be ensured.

8.2.3 As a rule the length/diameter ratio of the bearing surface is not to be greater than 1,2. Other ratio could be accepted and will be considered on case by case basis.

Table 5 : Allowable bearing pressure

Bearing material	$p_{F,ALL}$, in N/mm²
Lignum vitae	2,5
White metal, oil lubricated	4,5
Synthetic material with hardness between 60 and 70 Shore D **(1)**	5,5
Steel, bronze and hot-pressed bronze-graphite materials **(2)**	7,0

(1) Indentation hardness test at 23°C and with 50% moisture to be performed according to a recognised standard. Type of synthetic bearing materials is to be approved by the Society.
(2) Stainless and wear-resistant steel in combination with stock liner approved by the Society.

8.2.4 The manufacturing clearance t_0 on the diameter of metallic supports is to be not less than the value obtained, in mm, from the following formula:

$$t_0 = \frac{d_m}{1000} + 1$$

In the case of non-metallic supports, the clearances are to be carefully evaluated on the basis of the thermal and distortion properties of the materials employed. In any case, for non metallic supports, the clearance on support diameter is to be not less than 1,5 mm.

8.3 Pintle bearings

8.3.1 The mean bearing pressure acting on the gudgeons is to be in compliance with the following formula:

$p_F \le p_{F,ALL}$

where:

p_F : Mean bearing pressure acting on the gudgeons, in N/mm², equal to:

$$p_F = \frac{R_i}{d_{AC} h_L}$$

R_i : Support force acting on the pintle, in N

d_{AC} : Actual diameter, in mm, of the rudder pintles (contact diameter)

h_L : Bearing length, in mm (see [8.3.3])

$p_{F,ALL}$: Allowable bearing pressure, in N/mm², defined in Tab 5

Values greater than those given in Tab 5 may be accepted by the Society on the basis of specific tests.

8.3.2 An adequate lubrication of the bearing surface is to be ensured.

8.3.3 As a rule the length/diameter ratio of the bearing surface is to not be greater than 1,2 and to be not less than 1. Other ratio could be accepted and will be considered on case by case basis.

8.3.4 The manufacturing clearance t_0 on the diameter of metallic supports is to be not less than the value obtained, in mm, from the following formula:

$$t_0 = \frac{d_{AC}}{1000} + 1$$

In the case of non-metallic supports, the clearances are to be carefully evaluated on the basis of the thermal and distortion properties of the materials employed. In any case, for non-metallic supports, the clearance on support diameter is to be not less than 1,5 mm.

8.4 Pintles

8.4.1 Rudder pintles are to have a diameter not less than the value obtained, in mm, from the following formula:

$$d_A = \frac{0{,}38 V_{AV}}{V_{AV} + 3} \sqrt{R_i k} + f_C$$

where:

R_i : Reaction, in N, induced by loading of rudder blade acting on the pintle, as specified in [3]

f_C : Coefficient depending on corrosion, whose value may generally be obtained from the following formula:

$$f_C = 30\sqrt{k}$$

The Society may accept lower values of f_C, considering the ship's dimensions and satisfactory service experience of corrosion control systems adopted.

8.4.2 Suitable tapering is provided on pintles.

8.4.3 The length of the pintle housing in the gudgeon is to be not less than the value obtained, in mm, from the following formula:

$$h_L = 0{,}35\sqrt{R_i k}$$

where:

R_i : Force, in N, acting on the pintle, as specified in [3]

The thickness of pintle housing in the gudgeon, in mm, is to be not less than 0,25 d_A, where d_A is defined in [8.4.1].

9 Metallic rudder horn and solepiece scantlings

9.1 General

9.1.1 The weight of the rudder is normally supported by a carrier bearing inside the rudder trunk.

In the case of unbalanced rudders having more than one pintle, the weight of the rudder may be supported by a suitable disc fitted in the solepiece gudgeon.

Robust and effective structural rudder stops are to be fitted, except where adequate positive stopping arrangements are provided in the steering gear compartment, in compliance with the applicable requirements of Pt C, Ch 1, Sec 3.

Structure in way of rudder horn or solepiece is to extend as far as possible inside the hull, and if possible, up to an horizontal stiffener.

Connecting radius between outer shell of the hull and rudder horn or solepiece is to be as large as possible.

9.2 Metallic Rudder horn

9.2.1 General

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

9.2.2 Loads

The following loads acting on the generic section of the rudder horn are to be considered:

- bending moment
- shear force
- torque.

Bending moment, shear forces and torque are to be calculated according to [3], depending on the relevant type of rudder.

9.2.3 Shear stress check for metallic rudder horn

For the generic section of the rudder horn it is to be checked that:

$\tau_S + \tau_T \le \tau_{ALL}$

where:

τ_S , τ_T : Shear and torsional stresses, in N/mm², to be obtained according to [3]

τ_{ALL} : Allowable torsional shear stress, in N/mm²:

τ_{ALL} = 48/ k for steel

τ_{ALL} = 23/ k for aluminium.

9.2.4 Combined stress strength check for metallic rudder horn

For the generic section of the rudder horn, it is to be checked that:

$\sigma_E \le \sigma_{E,ALL}$

$\sigma_B \le \sigma_{B,ALL}$

where:

σ_E : Equivalent stress to be obtained, in N/mm², from the following formula:

$$\sigma_E = \sqrt{\sigma_B^2 + 3(\tau_S^2 + \tau_T^2)}$$

σ_B : Bending stress, in N/mm², to be obtained from [3], depending on the rudder type

τ_S , τ_T : Shear and torsional stresses, in N/mm², to be obtained according to [3]

$\sigma_{E,ALL}$: Allowable equivalent stress, in N/mm², equal to:

$\sigma_{E,ALL}$ = 115 / k for steel

$\sigma_{E,ALL}$ = 55 / k for aluminium

$\sigma_{B,ALL}$: Allowable bending stress, in N/mm², equal to:

$\sigma_{B,ALL}$ = 80 / k $_{\text{for steel}}$

$\sigma_{B,ALL}$ = 38 / k $_{\text{for aluminium}}$

9.2.5 Rudder horn calculation for type 7 rudder

a) Bending moment

The bending moment acting on the generic section of the rudder horn is to be obtained, in N.m, from the following formula:

$M_H = R_{20}\, z$

where:

R_{20} : Support force at the rudder horn lower-pintle, in N, according to [3.5.2] c)

z : Distance, in m, defined in Fig 14, to be taken less than the distance d.

b) Shear force

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

$Q_H = R_{20}$

where:

R_{20} : Support force at the rudder horn lower-pintle, in N, according to [3.5.2] c)

c) Torque

The torque acting on the generic section of the rudder horn is to be obtained, in N.m, from the following formula:

$M_T = R_{20}\, e_{(z)}$

where:

R_{20} : Support force at the rudder horn lower-pintle, in N, to be obtained according [3.5.2] c)

$e_{(z)}$: Torsion lever, in m, defined in Fig 14

d) Stress calculations for metallic rudder horn

For the generic section of the rudder horn within the length d, defined in Fig 14, the following stresses are to be calculated:

σ_B : Bending stress to be obtained, in N/mm², from the following formula:

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

M_H : Bending moment at the section considered, in N.m, defined in [9.2.5] a)

W_X : Section modulus, in cm³, around the horizontal axis X (see Fig 14)

τ_S : Shear stress to be obtained, in N/mm², from the following formula:

$$\tau_S = \frac{R_{20}}{A_H}$$

R_{20} : Support force at the rudder horn lower-pintle, in N, to be obtained according [3.5.2] c)

A_H : Effective shear sectional area of the rudder horn, in mm², in y-direction

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

$$\tau_T = \frac{M_{TR} 10^3}{2 F_T t_H}$$

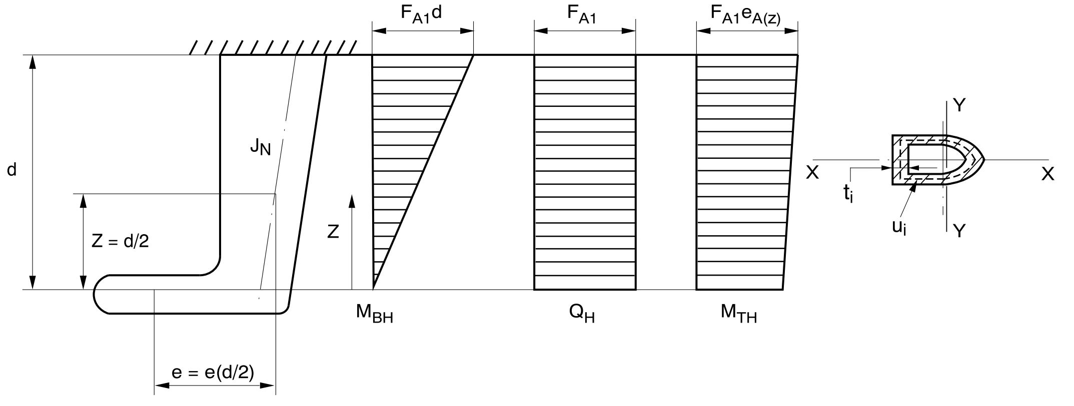
For solid rudder horn, τ_T is to be considered by the Society on a case-by-case basis.

M_{TR} : Torque, in N.m, defined in [2.1.3] and [2.2.3]

F_T : Mean of areas enclosed by outer and inner boundaries of the thin walled section of rudder horn, in m²

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

Figure 14 : Rudder horn geometry



9.3 Metallic Solepieces

9.3.1 Strength checks

For the generic section of the solepiece, it is to be checked that:

$\sigma_E \le \sigma_{E,ALL}$

$\sigma_B \le \sigma_{B,ALL}$

$\tau \le \tau_{ALL}$

where:

σ_E : Equivalent stress, in N/mm², to be obtained from the following formula:

$$\sigma_E = \sqrt{\sigma_B^2 + 3\tau^2}$$

σ_B : Bending stress, in N/mm², to be obtained according to [4.2.1]

τ : Shear stress, in N/mm², to be obtained according to [9.3.3] b)

$\sigma_{E,ALL}$: Allowable equivalent stress, in N/mm², equal to:

$\sigma_{E,ALL}$ = 115 / k for steel solepiece

$\sigma_{E,ALL}$ = 55 / k for aluminium solepiece

$\sigma_{B,ALL}$: Allowable bending stress, in N/mm², equal to:

$\sigma_{B,ALL}$ = 80 / k for steel

$\sigma_{B,ALL}$ = 38 / k for aluminium

τ_{ALL} : Allowable torsional shear stress, in N/mm²:

τ_{ALL} = 48 / k for steel component

τ_{ALL} = 23 / k for aluminium.

9.3.2 Minimum section modulus around the horizontal axis

The section modulus around the horizontal axis Y (see Fig 15) is to be not less than the value obtained, in cm³, from the following formula:

$W_Y = 0,5\ W_Z$

where:

W_Z : Section modulus, in cm³, around the vertical axis Z (see Fig 15)

9.3.3 Calculation of the solepiece for type 5 rudder

a) Bending moment

The bending moment acting on the generic section of the solepiece is to be obtained, in N.m, from the following formula:

$M_S = R_{10}\ x$

R_{10} : Supporting force, in N, in the pintle bearing, to be determined according to [3.2.2] c)

where:

x : Distance, in m, defined in Fig 15.

b) Stress calculations for metallic solepiece

For the generic section of the solepiece within the length ℓ_{50}, defined in Fig 15, the following stresses are to be calculated:

sb : Bending stress to be obtained, in N/mm², from the following formula:

$$\sigma_B = \frac{M_S}{W_Z}$$

τ : Shear stress to be obtained, in N/mm², from the following formula:

$$\tau = \frac{R_{10}}{A_S}$$

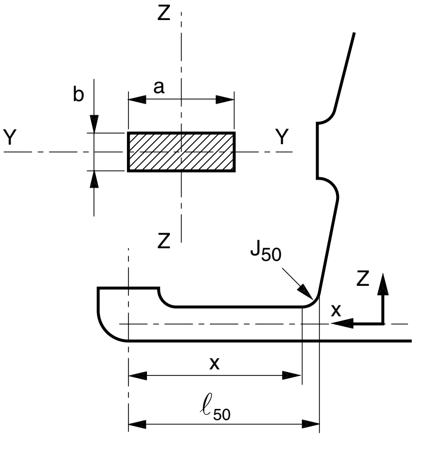
M_S : Bending moment, in N.m, at the section considered, as defined in [9.3.3] a)

R_{10} : Supporting force, in N, in the pintle bearing, to be determined according to [3.3.2] c)

W_Z : Section modulus, in cm³, around the vertical axis Z (see Fig 15)

A_S : Shear sectional area, in mm², in a plane perpendicular to the X axis of the solepiece.

Figure 15 : Solepiece geometry



9.4 Rudder horn and solepiece made of composites

9.4.1 General

For rudder horn and solepiece made in composite, direct calculation will be carried out.

9.4.2 Rudder horn

a) For rudder horn made of composites, calculations will be made with the following loads:
   - Bending moment MH as defined in [9.2.5] a)
   - Shear force QH as defined in [9.2.5] b)
   - Torque MT as defined in [9.2.5] c)

b) Analysis

   Analysis will be carried out on the following basis:
   - rudder horn behaviour is considered as a cantilever beam fitted on the hull
   - Section of the beam considered is the generic section as defined in Fig 14

     Analysis of the surrounding structure (e.g. hull structure) is, also, to be carried out

c) Check

   Calculation is to be made with formulae written in Ch 12, Sec 4, [6]. Check of the results is to be made with Ch 4, Sec 3, [5.3] for breaking criterion and Ch 4, Sec 3, [5.4] for safety coefficients.

9.4.3 Rudder solepiece

a) Loads

   For solepiece made of composite, calculation will be made with the following load:
   - Bending moment M_S as defined [9.3.3] a)
   - Shear force Q_S equal to R_{10}

b) Analysis

   Analysis will be carried out on the following basis:
   - Solepiece behaviour is considered as a cantilever beam
   - Section of the beam considered is the generic section within the length L_{50}

     Analysis of the surrounding structure (e.g. hull structure) is, also, to be carried out

c) Check

   Calculation is to be made with formulae written in Ch 12, Sec 4, [6]. Check of the results is to be made with Ch 4, Sec 3, [5.3] for breaking criterion and Ch 4, Sec 3, [5.4] for safety coefficients.

10 Coupling between rudder stock and tillers or quadrants

10.1 Arrangement

10.1.1 general

Coupling of rudder stock and tillers could be made by key or by flat areas on rudder stock in way of tiller or quadrants.

The tillers or quadrants are to be efficiently tightened on the rudder stock by means such as:

- Bolting (split or two half tillers)
- Tapered connecting on steel rudder stock
- Cylindrical connecting with shrink fit on steel rudder stock.

The requirements of this sub-article apply in addition to those specified in Pt C, Ch 1, Sec 3, [2].

10.2 Cone coupling on steel rudder stock

10.2.1 General

The entrance edge of the tiller bore and that of the rudder stock cone are to be rounded or bevelled.

The right fit of the tapered bearing is to be checked before final fit up, to ascertain that the actual bearing is evenly distributed and at least equal to 80% of the theoretical bearing area; push-up length is measured from the relative positioning of the two parts corresponding to this case.

The required push-up length is to be checked after releasing of hydraulic pressures applied in the hydraulic nut and in the assembly.

10.2.2 Materials

The requirements specified in [10.2.3] and [10.2.4] apply to solid rudder stocks in steel and to tiller bosses, either in steel or in SG iron, with constant external diameter. Solid rudder stocks others than those above will be considered by the Society on a case-by-case basis, provided that the relevant calculations, to be based on the following criteria, are submitted to the Society:

System made with materials other than those described in this requirement, will be examined on case by case basis

- Young's modulus:
  - $E = 2{,}06.10^5$ N/mm² for steel
  - $E = 1{,}67.10^5$ N/mm² for SG iron
- Poisson's ratio:
  - $\nu = 0{,}30$ for steel
  - $\nu = 0{,}28$ for SG iron
- Frictional coefficient:
  - $\mu = 0{,}15$ for contact steel/steel
  - $\mu = 0{,}13$ for contact steel/SG iron
- Torque C_T transmissible through friction:

  $C_T \geq \eta\ M_{TR}$

  where η is defined in [10.2.3]
- Combined stress in the boss:

  $(\sigma_R^2 + \sigma_T^2 + \sigma_R\ \sigma_T) \leq (0{,}5 + 0{,}2\ \eta)\ R_{eH}$

  where σ_R and σ_T are, in N/mm², the radial compression stress and tangent tensile stress, respectively, induced by the grip pressure, considered as positive, and calculated at the bore surface ($\sigma_R = p_F$, where p_F is the grip pressure in the considered horizontal cross-section of the boss)
- Where the rudder stock is hollow, the following strength criterion is to be complied with at any point of the rudder stock cross-section:

  $(\sigma_R^2 + \sigma_T^2 - \sigma_R\ \sigma_T + 3\ \tau^2) \leq 0{,}7\ R_{eH}$

  where:

σ_R, σ_T : Radial and tangent compression stresses, respectively, in N/mm², induced by the grip pressure, considered as positive

τ : Shear stress, in N/mm², induced by the torque M_{TR}

10.2.3 Push-up length of cone couplings with hydraulic arrangements for assembling and disassembling the coupling

It is to be checked that the push-up length Δ_E, in mm, of the rudder stock tapered part into the tiller boss is in compliance with the following formula:

$\Delta_0 \le \Delta_E \le \Delta_1$

where:

$$\Delta_0 = 6,2\frac{M_{TR}\eta\gamma}{c d_M t_S \mu_A \beta}10^{-3}$$

$$\Delta_1 = \frac{2\eta + 5}{1,8}\frac{\gamma d_0 R_{eH}}{c}10^{-6}$$

η : Coefficient to be taken equal to:

- $\eta = 1$ for keyed connections
- $\eta = 2$ for keyless connections

c : Taper of conical coupling measured on diameter, to be obtained from the following formula:

$c = (d_U - d_0) / t_S$

t_S, d_U, d_0 : Geometrical parameters of the coupling, defined in Fig 16

β : Coefficient to be taken equal to:

$$\beta = 1 - \left(\frac{d_M}{d_E}\right)^2$$

d_M : Mean diameter, in mm, of the conical bore, to be obtained from the following formula:

$d_M = d_U - 0,5\ c\ t_S$

d_E : External boss diameter, in mm

μ_A : Coefficient to be taken equal to:

$$\mu_A = \sqrt{\mu^2 - 0,25c^2}$$

μ, γ : Coefficients to be taken equal to:

- for rudder stocks and bosses made of steel:
  $\mu = 0,15$
  $\gamma = 1$
- for rudder stocks made of steel and bosses made of SG iron:
  $\mu = 0,13$
  $\gamma = 1,24 - 0,1\ \beta$

R_{eH} : Defined in [1.4].

10.2.4 Boss of cone couplings with hydraulic arrangements for assembling and disassembling the coupling

The scantlings of the boss are to comply with the following formula:

$$\frac{1,8}{2\eta + 5} \cdot \frac{\Delta_E c}{\gamma d_0}10^6 \le R_{eH}$$

where:

Δ_E : Push-up length adopted, in mm

c, η, γ : Defined in [10.2.3]

d_0 : Defined in Fig 16

R_{eH} : Defined in [1.4.1]

10.2.5 Cylindrical couplings by shrink fit

It is to be checked that the diametral shrinkage allowance δ_E, in mm, is in compliance with the following formula:

$\delta_0 \le \delta_E \le \delta_1$

where:

$$\delta_0 = 6,2\frac{M_{TR}\eta\gamma}{d_U t_S \mu \beta_1}10^{-3}$$

$$\delta_1 = \frac{2\eta + 5}{1,8}\gamma d_U R_{eH} 10^{-6}$$

η, μ, γ, c : Defined in [10.2.3]

d_U : Defined in Fig 16

β_1 : Coefficient to be taken equal to:

$$\beta_1 = 1 - \left(\frac{d_U}{d_E}\right)^2$$

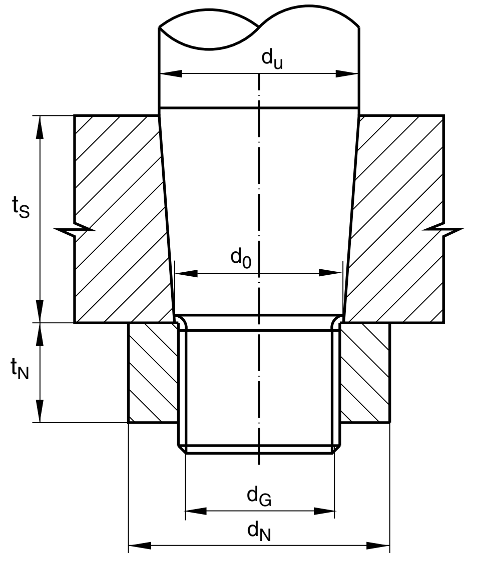
R_{eH} : Defined in [1.4.1].

10.2.6 Keyless couplings through special devices

The use of special devices for frictional connections, such as expansible rings, may be accepted by the Society on a case-by-case basis provided that the following conditions are complied with:

- evidence that the device is efficient (theoretical calculations and results of experimental tests, references of behaviour during service, etc.) are to be submitted to the Society
- the torque transmissible by friction is to be not less than 2 M_{TR}
- design conditions and strength criteria are to comply with [10.2.2]
- instructions provided by the manufacturer are to be complied with, notably concerning the pre-stressing of the tightening screws.

Figure 16 : Geometry of cone coupling



10.3 Coupling made by key

10.3.1 General

As a rule, this type of system is only allowed on metallic solid rudder stock.

As a rule, keys are to be fitted in way of a tiller or quadrants or a reinforced parts of the tiller or quadrant boss.

The ends of the keyways in the rudder stocks and in the tiller or quadrant are to be rounded and corners at the bottom of the keyway are to be provided.

The key is to be embedded at half thickness in the metallic solid rudder stock.

Material constituting the key is to be such as his yield stress is not less than that of the rudder stock and that of tiller or quadrant.

10.3.2 Check of the key

As a rule, stresses induced either by rudder blade or steering gear on the key are to comply with the following formula:

$$\tau_{ALL} > \frac{2 \cdot M_{TR}}{d_T \cdot S_K} \cdot 10^3$$

where:

τ_{AAA} : Allowable shear stress, in N/mm², of key material to be taken not less than:

- 70/k for steel
- 30/k for aluminium alloy

M_{TR} : Torque, in N.m, as defined in [2.1.3]

d_T : Rules diameter, in mm, of rudder stock calculated with null bending moment as defined in [4.3.1] for steel and aluminium

S_K : Surface, in mm², subject to shear force of the key.

10.4 Other coupling systems

10.4.1 General

Other type of couplings between rudder stock and tiller may be accepted by the Society on a case by case basis, provided relevant justification is submitted.

SECTION 3 WINDOWS AND SIDESCUTTLES

1 Sidescuttles and windows

1.1 General

1.1.1 Application

The requirements of this Section apply to sidescuttles and windows providing light and air, located in positions which are exposed to the action of sea and/or bad weather.

Arrangements of sidescutles and windows have to be made in accordance with Ch 2, Sec 2, [3.3].

1.1.2 Sidescuttle definition

As a general rule, sidescuttles are openings with an area not exceeding 0,16 m^2.

1.1.3 Window definition

Windows are openings with an area exceeding 0,16 m^2, having a radius at each corner relative to the window size in accordance with recognised national or international standards.

1.1.4 Number of openings in the shell plating

The number of openings in the shell plating are to be reduced to the minimum compatible with the design and proper working of the ship.

1.1.5 Material and scantlings

Sidescuttles and windows together with their glasses, deadlights and storm covers, if fitted, are to be of approved design and substantial construction in accordance with, or equivalent to, recognised national or international standards.

1.1.6 Means of closing and opening

The arrangement and efficiency of the means for closing any opening in the shell plating are to be consistent with its intended purpose and the position in which it is fitted is to be generally to the satisfaction of the Society.

1.2 Windows and sidescuttles arrangement

1.2.1 General

The strength of openings is to be equivalent to the strength of the surrounding structure.

1.2.2 Non-opening sidescuttle type are to be provided:

- where they become immersed by any intermediate stage of flooding or the final equilibrium waterplane in any required damage case for ships subject to damage stability regulations
- in the first tier of superstructures and deckhouses considered as being buoyant in the stability calculations.

1.2.3 Ships with several decks

In ships having several decks above the freeboard deck[(m)], the arrangement of sidescuttles and rectangular windows is considered by the Society on a case by case basis.

Particular consideration is to be given to the ship side up to the upper deck and the front bulkhead of the superstructure.

1.2.4 Automatic ventilating scuttles

Where automatic ventilating sidescuttles are fitted, refer to Ch 2, Sec 2, [3.2]

1.3 Materials

1.3.1 Glasses

In general, toughened glasses with frames of special type are to be used in compliance with, or equivalent to, recognised national or international standards.

1.3.2 Other materials

The use of any other material for openings is considered by the Society on a case by case basis.

1.4 Scantlings

1.4.1 The design loads to take into account for the windows and sidescuttles are the local loads of the adjacent structure supporting the windows and the sidescuttles as defined in Ch 7, Sec 1, [2.2], Ch 7, Sec 1, [2.3] and Ch 7, Sec 1, [4].

1.4.2 Thickness of monolithic glazings

The following formulae are only valid for monolithic panes. Where laminated material is used, the thickness is considered by the Society on a case by case basis.

The thickness of glazings, where supported, is to be not less than that obtained, in mm, from the following formula:

$$t = 27,4 \cdot coeff \cdot \mu \cdot s \cdot \sqrt{\frac{p}{R_m / S_f}}$$

The thickness of glazings, where clamped, is to be not less than that obtained, in mm, from the following formula:

$$t = 22,4 \cdot coeff \cdot \mu \cdot s \cdot \sqrt{\frac{p}{R_m / S_f}}$$

where:

coeff : Coefficient equal to:

- In case of uniformly distributed hydrodynamic loads, as given in Ch 7, Sec 1:

  coeff = 1
- In case of impact pressure on side shells (loads distributed on a part only of the elmentary plate panel), as given in Ch 7, Sec 1, [2.3]:

- coeff = 1, if

$$\frac{\ell}{0,6} \le 1 + s$$

- coeff = $(1+s)^{-1/2}$, if

$$\frac{\ell}{0,6} > 1 + s$$

s : Equal to:

- Smaller side, in m, for rectangular panes
- Diameter, in m, for circular panes
- Minor axis, in m, for oval panes

μ : Aspect ratio coefficient of the elementary plate panel, equal to:

$$\sqrt{1,1 - \left(0,5 \cdot \frac{s^2}{\ell^2}\right)}$$

without being taken more than 1, where:

ℓ : Equal to:

- Longer side, in m, for rectangular panes
- Major side, in m, for oval panes

R_m : Guaranteed minimum flexural strength, in MPa, of material used. For guidance only, the guaranteed minimum flexural strength R_m for monolithic andd laminated glasses are:

- Thermally toughened = 180 MPa
- Chemically toughened = 250 MPa

S_f : Safety factors

- Monolithic toughened glass = 5
- Poly (MethylMethAcrilate) = 4,5
- Poly (carbonate) = 4,5

Where curved panes are used, a coefficient of curvature may be taken into account by the Society on a case by case basis.

1.4.3 Thickness of glasses forming screen bulkheads or internal boundaries of deckhouses

The thickness of glasses forming screen bulkheads on the side of enclosed promenade spaces and that for rectangular windows in the internal boundaries of deckhouses which are protected by such screen bulkheads are considered by the Society on a case by case basis.

The Society may require both limitations on the size of rectangular windows and the use of glasses of increased thickness in way of front bulkheads which are particularly exposed to heavy sea.

1.4.4 Deadlight scantling

Strength of deadlights is to be equal to the strength of the surrounding structure.

SECTION 4 PROPELLER SHAFT BRACKETS

1 Propeller shaft brackets

1.1 General

1.1.1 Propeller shafting is either enclosed in bossing or independent of the main hull and supported by shaft brackets.

1.1.2 Scantling methods

Two different methods are used to check the shaft brackets according to the type of yacht:

- The calculation of the working rate in the shaft brackets takes into account an "unbalance" caused by the absence of one propeller blade. This unbalance causes a centrifugal force which is assimilated to the centrifugal force of the missing blade F_C
- A second method may be used instead of the calculation here before if the moments in each arm of the shaft bracket M_1, M_2 or M, as defined in [3.2.2] and [3.3.3] are more than 20 kN.m

  This alternative calculation takes into account a moment caused by friction between the shaft propeller and the shaft brackets, caused by unexpected seizing.

2 Loss of a blade

2.1 General

2.1.1 This way of calculation concerns great yachts which are more often equipped of double arm propeller shaft brackets. The case with single arm propeller shaft brackets is developed for information.

2.2 Double arm propeller shaft brackets

2.2.1 General

This type of propeller shaft bracket consists in two arms arranged, as far as practicable, at right angles and converging in the propeller shaft bossing.

Exceptions to this will be considered by the Society on a case by case basis.

2.2.2 Scantlings of arms

The moment in the arm, in kN.m, is to be obtained from the following formula:

$$M = \frac{F_C}{\sin\alpha}\left(\frac{L}{\ell}d_1\cos\beta + L - \ell\right)$$

where:

F_C : Force, in kN, taken equal to:

$$F_C = \left(\frac{2\pi N}{60}\right)^2 R_P P$$

P : Mass of a propeller blade, in t

If this value is unknown, it is to be equal to:

$P = P_{PROP} / (n+1)$

P_{PROP} : Total mass of the propeller (hub included), in t

n : Number of propeller blades

N : Number of revolution per minute of the propeller

R_P : Distance, in m, of the centre of gravity of a blade in relation to the rotation axis of the propeller

If this value is unknown, it is to be equal to:

$R_P = D / 3$

D : Diameter of the propeller, in m

α : Angle between the two arms

β : Angle defined in Fig 1

d_1 : Distance, in m, defined in Fig 1

L, ℓ : Lengths, in m, defined in Fig 2.

Figure 1 : Angle β and length d_1

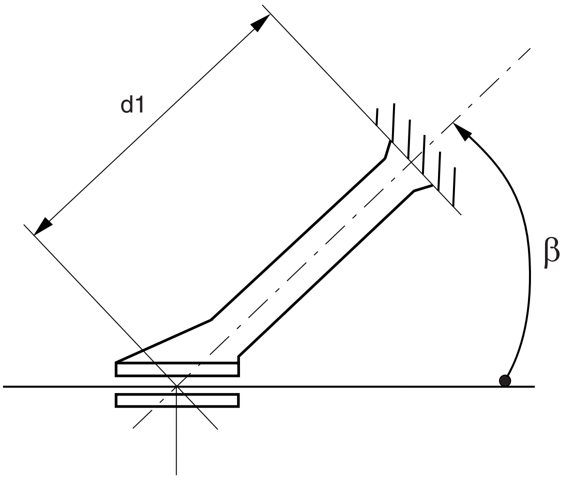
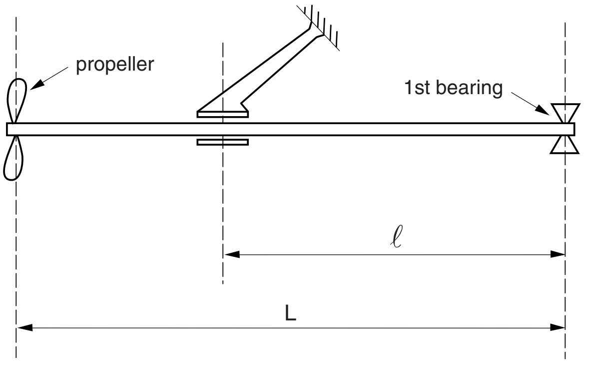


Figure 2 : Lengths L and ℓ



It is to be checked that the bending stress σ_F, the compression stress σ_N and the shear stress τ are in compliance with the following formula:

$$\sqrt{(\sigma_F + \sigma_N)^2 + 3\tau^2} \le \sigma_{ALL}$$

where:

$$\sigma_F = \frac{M}{w_A} 10^3$$

$$\sigma_N = 10 F_C \frac{L \sin\beta}{A \ell \sin\alpha}$$

$$\tau = 10 F_C \frac{L \cos\beta}{A_S \ell \sin\alpha}$$

σ_{ALL} : Allowable stress, in N/mm², equal to:

$$\sigma_{ALL} = \frac{70}{\chi}$$

where

χ : Material factor, as given below:

$\chi = 1$ for steel

$\chi = 2.3$ for aluminium

L : Rule length, in m, as defined in Ch 1, Sec 2, [3.2]

w_A : Section modulus, in cm³, of the arm at the level of the connection to the hull with respect to a transversal axis

A : Sectional area, in cm², of the arm

A_S : Shear sectional area, in cm², of the arm.

2.2.3 Allowable stress

A higher admissible stress may be considered by the Society in case by case, according to the type of yacht, its motorization (two independent shaft lines, sailing yacht...).

2.2.4 Scantlings of propeller shaft bossing

The length of the propeller shaft bossing is to be not less than the length of the aft sterntube bearing bushes (see Pt C, Ch 1, Sec 2, [4.3.5]).

The thickness of the propeller shaft bossing is to be not less than 0,33 d_P, where d_P is the propeller shaft diameter, in mm, measured inside the liner, if any.

2.2.5 Bracket arm attachments

In way of bracket arms attachments, the thickness of deep floors or girders is to be suitably increased. Moreover, the shell plating is to be increased in thickness and suitably stiffened.

The securing of the arms to the hull structure is to prevent any displacement of the brackets with respect to the hull.

2.3 Single arm propeller shaft brackets

2.3.1 General

This type of propeller shaft bracket consists of one arm generally used only in very small ships.

2.3.2 Scantling of arm

The moment in case of a single arm, in kN.m, is to be obtained from the following formula:

$$M = F_C \frac{L}{\ell} d_2$$

F_C : Force, in kN, as defined in [2.2.2]

d_2 : Length of the arm, in m, measured between the propeller shaft axis and the hull

L, ℓ : Lengths, in m, defined in Fig 2.

It is to be checked that the bending stress σ_F, the compression stress σ_N and the shear stress τ are in compliance with the following formula:

$$\sqrt{\sigma_F^2 + 3\tau^2} \le \sigma_{ALL}$$

where:

$$\sigma_F = \frac{M}{w_B} 10^3$$

$$\tau = 10 F_C \frac{L}{A_S \ell}$$

where:

A, A_S, σ_{ALL}: as defined in [2.2.2]

w_B : Section modulus, in cm³, of the arm at the level of the connection to the hull with respect to a longitudinal axis.

2.3.3 Scantlings of propeller shaft bossing

The length of the propeller shaft bossing is to be not less than the length of the aft sterntube bearing bushes (see Pt C, Ch 1, Sec 2, [4.3.5]).

The thickness of the propeller shaft bossing is to be not less than 0,33 d_P (d_P defined in [2.2.4]).

2.3.4 Bracket arm attachments

In way of bracket arms attachments, the thickness of deep floors or girders is to be suitably increased. Moreover, the shell plating is to be increased in thickness and suitably stiffened.

The securing of the arms to the hull structure is to prevent any displacement of the brackets with respect to the hull.

2.4 Bossed propeller shaft brackets

2.4.1 General

Where bossed propeller shaft brackets are fitted, their scantlings are to be considered by the Society on a case by case.

2.4.2 Scantling of the boss

The length of the boss is to be not less than the length of the aft sterntube bearing bushes (See Pt C, Ch 1, Sec 2, [4.3.5]).

The thickness of the boss, in mm, is to be not less than 0,33 d_P (d_P defined in [2.2.4]).

The aft end of the bossing is to be adequately supported.

2.4.3 Scantling of the end supports

The scantlings of end supports are to be specially considered. Supports are to be adequately designed to transmit the loads to the main structure.

End supports are to be connected to at least two deep floors of increased thickness or connected to each other within the ship.

2.4.4 Stiffening of the boss plating

Stiffening of the boss plating is to be specially considered. At the aft end, transverse diaphragms are to be fitted at every frame and connected to floors of increased scantlings.

At the fore end, web frames spaced not more than four frames apart are to be fitted.

3 Alternative calculation seizing

3.1 General

3.1.1 Application

As indicated in [1.1.2], this alternative method is applicable if the moments in each arm of the shaft bracket M_1, M_2 or M as defined in [3.2.2] and [3.3.2] are greater than 20 KNm.

3.1.2 The seizing phenomenon is caused by friction between the propeller shaft and the propeller shaft bossing, supported by the shaft brackets.

It is considered that the propeller torque M_P is transmitted in full to the shaft bracket. The propeller torque M_P, in kN.m, is to be obtained from the following formula:

$$M_P = \frac{P_P}{\frac{2\pi N}{60}}$$

where:

N : Number of revolution per minute of the propeller

P_P : Power transmitted to the propeller, in kW

3.1.3 The angle β defined in Fig 1 is neglected if it is not less than 80°. If this condition is not respected, direct calculation will have to be made on a case by case.

3.2 Double arm propeller shaft brackets

3.2.1 General

This type of propeller shaft bracket consists in two arms arranged, as far as practicable, at right angles and converging in the propeller shaft bossing.

Exceptions to this will be considered by the Society on a case by case basis.

3.2.2 Scantlings of arms

The moment in each arm, in kN.m, at the attachment with the shaft propeller is to be obtained from the following formulae:

$$M_1 = \frac{M_P}{1 + \frac{E_2 I_2 d_1}{E_1 I_1 d_2}}$$

$$M_2 = \frac{M_P}{1 + \frac{E_1 I_1 d_2}{E_2 I_2 d_1}}$$

where:

M_P : Propeller torque, in kN.m,as estimated in [3.1.2]

E_1,E_2 : Young's modulus of each arm, in N/mm²

I_1,I_2 : Inertia of each arm, in cm⁴

d_1,d_2 : Length of each arm, in m, measured between the propeller shaft axis and the hull

Note 1: $M_1 + M_2 = M_P$

In each arm, it is to be checked that the bending stresses σ_{F1} and σ_{F2}, the compressive stresses σ_{N1} and σ_{N2} and the shear stresses τ_1 and τ_2 are in compliance with the following formulae:

$$\sqrt{(\sigma_{F1} + \sigma_{N1})^2 + 3\tau_1^2} \le \sigma_{ALL,S}$$

$$\sqrt{(\sigma_{F2} + \sigma_{N2})^2 + 3\tau_2^2} \le \sigma_{ALL,S}$$

where:

$$\sigma_{F1} = \frac{M_1}{w_{B,1}} 10^3$$

$$\sigma_{F2} = \frac{M_2}{w_{B,2}} 10^3$$

$$\sigma_{N1} = 10,\frac{3}{2A_1 \sin\alpha}\left(\frac{M_2}{d_2} + \frac{M_1}{d_1}\cos\alpha\right)$$

$$\sigma_{N2} = 10,\frac{3}{2A_2 \sin\alpha}\left(\frac{M_1}{d_1} + \frac{M_2}{d_2}\cos\alpha\right)$$

$$\tau_1 = 10\frac{3M_1}{2d_1 A_{S,1}}$$

$$\tau_2 = 10\frac{3M_2}{2d_2 A_{S,2}}$$

where:

$\sigma_{ALL,S}$: Allowable stress, in N/mm², equal to:

$$\sigma_{ALL,S} = 0,8 \cdot \frac{235}{k}$$

where

k : Material factor, as defined in Ch 4, Sec 3, [3.1]

$w_{B,1}$, $w_{B,2}$: Section modulus, in cm³, of each arm at the level of the connection to the hull with respect to a longitudinal axis

A_1, A_2 : Sectional area, in cm², of each arm

$A_{S,1}$, $A_{S,2}$: Shear sectional area, in cm², of each arm.

3.2.3 Scantlings of propeller shaft bossing

The length of the propeller shaft bossing is to be not less than the length of the aft sterntube bearing bushes (see Pt C, Ch 1, Sec 2, [4.3.5]).

The thickness of the propeller shaft bossing is to be not less than 0,33 d_P -(d_P defined in [2.2.4]).

3.2.4 Bracket arm attachments

In way of bracket arms attachments, the thickness of deep floors or girders is to be suitably increased. Moreover, the shell plating is to be increased in thickness and suitably stiffened.

The securing of the arms to the hull structure is to prevent any displacement of the brackets with respect to the hull.

3.3 Single arm propeller shaft brackets

3.3.1 General

This type of propeller shaft bracket consists of one arm used only in very small ships.

3.3.2 Scantling of arm

The moment in case of a single arm, in kN.m, is to be obtained from the following formula:

$$M = M_P$$

where:

M_P : As defined in [3.2.2]

It is to be checked that the bending stress σ_F is less than the admissible stress:

$$\sigma_F \le \sigma_{ALL,S}$$

where:

$$\sigma_F = \frac{M}{w_B} 10^3$$

w_B : As defined in [2.3.2]

σ_{ALL} : As defined in [2.2.2].

3.3.3 Scantlings of propeller shaft bossing

The length of the propeller shaft bossing is to be not less than the length of the aft sterntube bearing bushes (see Pt C, Ch 1, Sec 2, [4.3.5]).

The thickness of the propeller shaft bossing is to be not less than 0,33 d_P (d_P defined in [2.2.4]).

3.3.4 Bracket arm attachments

In way of bracket arms attachments, the thickness of deep floors or girders is to be suitably increased. Moreover, the shell plating is to be increased in thickness and suitably stiffened.

The securing of the arms to the hull structure is to prevent any displacement of the brackets with respect to the hull.

3.4 Bossed propeller shaft brackets

3.4.1 General

Where bossed propeller shaft brackets are fitted, their scantlings are to be considered by the Society on a case by case.

3.4.2 Scantling of the boss

The length of the boss is to be not less than the length of the aft sterntube bearing bushes (See Pt C, Ch 1, Sec 2, [4.3.5]).

The thickness of the boss, in mm, is to be not less than 0,33 d_P (d_P defined in [2.2.4]).

The aft end of the bossing is to be adequately supported.

3.4.3 Scantling of the end supports

The scantlings of end supports are to be specially considered. Supports are to be adequately designed to transmit the loads to the main structure.

End supports are to be connected to at least two deep floors of increased thickness or connected to each other within the ship.

3.4.4 Stiffening of the boss plating

Stiffening of the boss plating is to be specially considered. At the aft end, transverse diaphragms are to be fitted at every frame and connected to floors of increased scantlings.

At the fore end, web frames spaced not more than four frames apart are to be fitted.

SECTION 5 INDEPENDENT TANKS

Symbols

L : Rule length as defined in Ch 1, Sec 2, [3.2]

x : Longitudinal position, in m, taken from the aft end AE as defined in Ch 1, Sec 2, [3.4.2].

1 General

1.1 Application

1.1.1 The present section deals with scantlings of independent tanks, in steel, aluminium alloys or composites.

1.2 General

1.2.1 The connections to reinforced hull structures of independent tanks are to be able to withstand the reactions induced by the tank weight.

For that purpose, the dynamic amplification due to behaviour of yacht at sea is to be taken into account for high speed motor yachts as defined in Ch 5, Sec 1, [2] and for monohull sailing yachts. For such yachts, the tank weight is to be taken as W_D, where:

- W_D : Dynamic weight of the tank, taken equal to $(1 + 0{,}4\ a_V)$

  W : Maximum static weight of the tank

  a_V : Vertical acceleration resulting from effect of heave and pitch, equal to:

  $a_v = 2\ .\ x/L\ .\ a_{CG}$, for high speed motor yacht, without being less than a_{CG} , where a_{CG} is defined in Ch 5, Sec 1, [2.1.7]

  $a_v = a_H + a_P$, for monohull sailing yacht , where a_H and a_P are defined in Ch 5, Sec 1, [2.2].

2 Steel and aluminium tanks

2.1 General

2.1.1 In case of gas-oil or diesel-oil aluminium tanks, it is reminded that careful attention is to be paid to welds, as repairs are made very difficult due to degreasing difficulty.

2.2 Plating

2.2.1 The rule thickness of independent tank plates is given, in mm, by the formulae:

$$t = 22{,}4 \cdot \mu \cdot s \cdot \sqrt{\frac{p}{\sigma_{ad}}}$$

where:

s : Smaller side, in m, of the elementary plate panel

μ : Aspect ratio coefficient of the elementary plate panel, equal to:

$$\sqrt{1{,}1 - \left(0{,}5 \cdot \frac{s^2}{\ell^2}\right)}$$

without being taken more than 1, where:

ℓ : Longer side, in m, of the elementary plate panel

p : Design pressure, or testing pressure, in kN/m², given in Ch 7, Sec 1, [5]

σ_{ad} : Rule admissible stress, in N/mm², defined in Ch 4, Sec 3, Tab 2 or Ch 4, Sec 3, Tab 4 whatever the case

Checking of plate thickness against design pressure is to be performed with admissible local bending stress induced by local hydrodynamic loads.

Checking of plate thickness against testing pressure is to be performed with admissible local bending stress induced by tank testing loads.

2.2.2 A local increase in plating thickness is generally required in way of pipe penetration.

2.3 Stiffeners

2.3.1 As a rule, the design section modulus Z, in cm³, of independent tank ordinary stiffeners is given by the formulae:

$$Z = 1000 \cdot \left(1 - \frac{s}{2 \cdot l}\right) \cdot \frac{p \cdot s \cdot l^2}{m \cdot \sigma_{ad}}$$

where:

ℓ : Span of the siffener, in m, measured as indicated in Ch 4, Sec 4, [3]

s : Spacing between siffeners, in m

p : design pressure, or testing pressure, in kN/m², as given in Ch 7, Sec 1, [5]

σ_{ad} : Rule admissible stresses, in N/mm², defined in Ch 4, Sec 3, Tab 2 or Ch 4, Sec 3, Tab 4 whatever the case

Checking of stiffener section modulus against design pressure is to be performed with admissible local bending stress induced by local hydrodynamic loads.

Checking of stiffener section modulus against testing pressure is to be performed with admissible local bending stress induced by tank testing loads.

m : Coefficient depending on end conditions, equal to 12, 10 or 8, as defined in Ch 4, Sec 4, [3.2.5].

2.3.2 As a rule, the design shear area A_{sh}, in cm^2, of independent tanks stiffeners is given by the formulae:

$$A_{sh} = 10 \cdot \left(1 - \frac{s}{2 \cdot l}\right) \cdot \frac{p \cdot s \cdot l}{\tau_{ad}}$$

where:

p, s, ℓ : As indicated in [2.3.1]

τ_{ad} : Rule admissible shear stress, in N/mm^2, as defined in Ch 4, Sec 3, Tab 2 or Ch 4, Sec 3, Tab 4 as appropriate

Checking of stiffener shear area against design pressure is to be performed with admissible local shear stress induced by local hydrodynamic loads.

Checking of stiffener section modulus against testing pressure is to be performed with admissible local shear stress induced by tank testing loads.

2.3.3 The end connections of stiffeners with supporting structures are also to be carefully checked.

2.3.4 In independent tanks made of steel and intended for fresh water or sea water, the fillet welds connecting the stiffeners to the attached plate are to be double continuous fillet welds, to avoid corrosion.

However, in independent tanks made of steel and intended for gas-oil, it is accepted to have intermittent fillet welds.

3 Composites tanks

3.1 General

3.1.1 The mechanical characteristics of the composite laminates used for the tanks is described in Ch 12, Sec 4.

3.2 Plating

3.2.1 The rule scantlings of independent tank in composites material is to be checked according to Ch 9, Sec 3, [7], with

p : Design pressure, or testing pressure, in kN/m^2, given in Ch 7, Sec 1, [5]

SF : Safety coefficients between the applied stresses (see Ch 12, Sec 4, [4]) and the theoretical breaking stresses (see Ch 12, Sec 3, [5]), to be compared with Rule safety factor defined in Ch 4, Sec 3, [5.4].

3.2.2 A local increase in plating laminate is generally required in way of pipe penetration.

3.3 Stiffeners

3.3.1 The rule flexural modulus and shear areas of independent tank composites stiffeners are is to be checked according to Ch 9, Sec 4, [2], with:

p : Design pressure, or testing pressure, in kN/m^2, given in Ch 7, Sec 1, [5]

SF : Safety coefficients between the applied stresses and (see Ch 12, Sec 4, [6]) and the theoretical breaking stresses (see Ch 12, Sec 3, [5]), to be compared with Rule safety factor defined in Ch 4, Sec 3, [5.4].

3.3.2 The end connections of stiffeners with supporting structures are also to be carefully checked.

SECTION 6 STANDING RIGGING CHAINPLATES

1 General

1.1 Application

1.1.1 The present Section defines structural requirements for the scantling of chainplates or all other element connecting standing rigging, their structural connection to the hull's substructure and local hull reinforcement.

2 Chainplates and local hull structure

2.1 Design Loads

2.1.1 General

Loads induced by the standing rigging (stays, backstays and vertical/lower shrouds) are to be submitted by the designer or the Yard.

These loads can be:

a) The design loads defined for the various sailing conditions taking into account the different sail configuration for all wind heading from head wind to down wind and sail reductions

a) When the design load defined in a) are not submitted, the load taken into consideration are the breaking load of stays and shrouds.

2.1.2 Loads on chainplates

As a general rule, the loads F_S to take into account for the chain plate scantling, in N, is:

$$F_S = F_D \cdot C_i$$

where:

F_D : Design load, in N, defined in [2.1.1] a)

C_i : Safety coefficient taken equal to 3

When the design load defined in [2.1.1]a) is not submitted, the value of F_S, in N, is to be taken equal to:

$$F_S = F_D \cdot C_I$$

where:

F_D : Breaking load, in N, defined in [2.1.1] b)

C_I : Safety coefficient taken equal to 1,2

In case of several shrouds or stays connected to the same chainplate, the applied load will be equal to the sum of F_S of the stronger shroud and of 0,8 times the F_S of the others.

2.1.3 Loads to apply on local hull structure

The design load to apply to the local hull structure supporting chainplates is to be taken equal to 1,6 times the load F_S defined in [2.1.2].

2.2 Allowable stresses

2.2.1 The scantling of chainplates or all other element connecting standing rigging, their structural connection to the hull's substructure and local hull reinforcement defined in this section are based on forces defined in [2.1] associated to:

- admissible stresses taken equal to the minimum guaranteed tensile strength of the materials for steel or aluminium structure

Note 1: For aluminium, the effect of welding in the heat affect zone is to be taken into account for the determination of the minimum guaranteed strength.

- for composite materials, safety coefficient applied on the theoretical breaking strength and equal to:

  $$SF = C_V \cdot C_F$$

  where C_V and C_F are defined in Ch 4, Sec 3, [5.4.1].

Note 2: Breaking criteria for layers of composite structures are defined in Ch 12, Sec 3, [5].

2.3 Scantling of chainplates

2.3.1 General

This sub article gives the requirements for scantling of chainplates.

2.3.2 Metallic chainplates

The actual tensile stress $\sigma_{tensile}$, in MPa, in the chainplate is to be less than the allowable stress defined in [2.2.1] and is obtain from the following formula:

$$\sigma_{tensile} = F_S / A_t$$

where:

F_S : Load, in N, defined in [2.1.2]

A_t : Total cross section, in mm², solicited in tensile

The actual shear stress τ_{shear}, in MPa, in the chainplate is to be less than the allowable stress defined in [2.2.1] and is obtain from the following formula:

$$\tau_{shear} = F_S / A_S$$

where:

F_S : Load, in N, defined in [2.1.2]

A_S : Total shear section, in mm², solicited in shear

The actual diametral pressure $\sigma_{bearing}$, in MPa, in way of the chainplate eye is to be less than the allowable stress defined in [2.2.1] and is obtain from the following formula:

$$\sigma_{bearing} = F_S / (D \cdot th_C)$$

F_S : Load, in N, defined in [2.1.2]

D : Diameter, in mm, of the chainplate eye

th_C : Thickness, in mm, of the chain plate in way of the eye.

2.3.3 Composite chainplates

The review of chainplates made of composite materials is to be performed on a case by case basis.

2.4 Scantling of local hull structures in way of chainplates

2.4.1 Application

The main types of connection between chainplates and their supporting structures considered in this rules are bolted connection, welded connection and bonded connection.

In case of other type of connection, the Society may accept the connection on a case by case basis.

2.4.2 General

Supporting structures are to be designed in such a way that they sustain load defined in [2.1.3] within allowable stresses' level defined in [2.2].

2.4.3 Bolted connection

Material and grade of bolts are to be submitted for information.

Bolts are to be designed to sustain shear forces, induced by load defined in [2.1.3]. The scantling of the bolts is to be carried out taking into account the allowable stresses defined in [2.2].

Where applicable, bolts may be pre-stressed in compliance with appropriate standards. In such a case, the grade of bolts is to be selected accordingly and details of pre-stressing process are to be submitted.

The tightening of bolts is to be suitably checked.

Bolting system is to be so design as to allow taking off for inspection.

Where a backplate is provided, its thickness is to be at least equal to 0,25 times the bolt's diameter

Where there is no backplate, nut is to be fitted with a washer for each bolt.

Dimensions of washers cannot be taken smaller than the following:

- Diameter to be, at least, equal to 4 times the bolt's diameter
- Thickness to be, at least, equal to 0,25 times the bolt's diameter.

For metallic hulls, bolting system is to be protected from galvanic corrosion where materials of nuts and washers are made of different metallic materials.

2.4.4 Welded connections

Where welded connections of metallic chainplates to metallic hulls are used, they are to comply with all requirements relating to weldings, as defined in Part B, Chapter 11.

2.4.5 Bonded connection

The bonded connections are mainly defined by the shear surface of bonding, capable of sustaining the applied loads defined in [2.1.3].

The type of adhesive used depends on the type of materials of the supporting structures and of chainplates. All requirements for surface's preparation and adhesives' use are defined in Ch 12, Sec 2, [5].

The minimum bonding surface S_{min}, in mm^2, is to be not less than:

$$S_{min} = \frac{F}{\tau_{am}}$$

where:

F : Load, in N, defined in [2.1.3]

τ_{am} : Allowable shear stress, in MPa, of the adhesive used

Mechanical properties of adhesive have to be provided by manufacturers.

Where not given, the allowable stress of adhesives, whatever their type, is usually taken equal to 5 MPa.

Mechanical test may be requested by the Society in order to check that the bounded connection as produced by the Yard is, at least, equivalent to the theoretical properties. In this case, the sample tests are to be performed according to Ch 12, Sec 5, [4].

SECTION 7 SOLID KEEL FOR SAILING YACHTS

1 General

1.1 Application

1.1.1 The present Section defines structural requirements for the scantling of keels and local bottom hull reinforcement of sailing yachts. Where existing, attachments of bulbs to fin keels are also in scope of the review.

1.1.2 Moveable keels (lifting and canting) and centreboards are reviewed on a case-by-case basis.

1.2 Materials

1.2.1 Keels made of steel

All structural parts of keels are to be made of rolled steel, steel forging or steel casting according to applicable requirements of the Rule Note NR216 Materials and Welding.

Keels fabrication by welding is to be carried out in compliance with the applicable Society Rules and in particular in compliance with Chapter 5, Section 1 of the Rule Note NR216 Materials and Welding.

1.2.2 Keels made of aluminium

Aluminium material used for structural parts of keels are to comply with requirements of the Rule Note NR216 Materials and Welding.

In case of welding of two different aluminium alloys, the material factor k to be taken for the scantling is to be the greater material factor of the aluminium alloys of the assembly

The loss of mechanical properties of some aluminium alloys (6000 series) induced by welding operation is to be taken into account for scantling.

Where aluminium alloys of 6000 series are used, protection from sea water by permanent coating is to be provided. Details of coating are to be submitted for information.

1.2.3 Keels made of composite

All composite parts of keels are to comply with Part B, Chapter 12.

The Society can request that mechanical tests e carried out as defined in Ch 12, Sec 5.

1.2.4 Bolts materials

Bolts and washers are to be of stainless steel or equivalent sea water corrosion resistant materials.

2 Design Loads

2.1 Application

2.1.1 As a general Rule, design loading cases to apply on keels and supporting structures are those where sailing yacht is at a heel angle of 30° with respect to vertical and a trim angle of 10° with respect to horizontal.

2.1.2 Design loading cases defined in [2.1.1] are also applicable on movable keel's arrangements.

2.1.3 In addition to forces and bending moments generated by loading cases defined in [2.1.1], torsional moments can be caused where the centre of gravity of bulb, at lower end of keel, is significantly apart from the torsional axis of the keel.

2.2 Loads induced by heel

2.2.1 The design load due to roll motion of yacht, in KN, are to be taken equal to:

$$F_{hheel} = P \cdot (1 + a_H) \cdot \sin 30$$

$$F_{vheel} = P \cdot (1 + a_H) \cdot \cos 30$$

where:

- F_{hheel} : Horizontal component of the keel weight, in KN
- F_{vheel} : Vertical component of the keel weight, in KN
- P : Total weight of keel, in KN
- a_H : Heave vertical acceleration, in g, as defined in Ch 5, Sec 1, [2.2.2].

2.2.2 The bending moment M_{heel} , in KNm, induced by keel due to roll motion of yacht at hull bottom is to be taken equal to:

$$M_{heel} = F_{hheel} \cdot Z_{keel}$$

where:

- F_{hheel} : Design load due to roll motion, in KN, as defined in [2.2.1]
- Z_{keel} : Distance, in m, between the external side of hull's bottom and the center of gravity of the keel.

2.3 Loads induced by pitch

2.3.1 The design load F_{pitch} due to pitch motion of yacht, in KN, is to be taken equal to:

$$F_{pitch} = P(1 + a_H) \sin 10 (L_{WL} - X_K)(1 + a_{PFP}) / Z_{keel}$$

where:

- P : Total weight of keel, in KN

a_H : Heave vertical acceleration, in g, as defined in Ch 5, Sec 1, [2.2.2]

a_{PFP} : Pitch vertical acceleration, in g, as defined in Ch 5, Sec 1, [2.2.3]

L_{WL} : Yacht waterline length, in m, as defined in Ch 1, Sec 2, [2.1.1]

X_K : Longitudinal distance, in m, between the aft perpendicular as define in Ch 1, Sec 2, [3.4.2] and the center of gravity of the keel

Z_{keel} : Distance, in m, between the external side of hull's bottom and the center of gravity of the keel.

2.3.2 The bending moment M_{pitch} , in KNm, induced by keel due to pitch motion of yacht at hull bottom is to be taken equal to:

$$M_{pitch} = F_{pitch} \cdot Z_{keel}$$

with F_{pitch} and Z_{keel} as defined in [2.3.1].

3 Allowable stresses

3.1 Steel and aluminium

3.1.1 Requirements relevant to the determination of scantling contained in this section are based on allowable stresses as defined in Ch 4, Sec 3.

3.2 Composite materials

3.2.1 Requirements relevant to the determination of scantling contained in this section are based on theoretical individual breaking strength criteria as defined in Ch 12, Sec 3, [5] and safety coefficients as defined in Ch 4, Sec 3, [5.4].

4 Keel's arrangements

4.1 General

4.1.1 The type of keel dealt in this section are the keel bolted to the hull bottom structure or the keel completely integrated to the hull structure.

4.1.2 Keel's arrangement is to be designed in such a way that it simultaneously sustains forces and moments defined in [2], within allowable stresses' level as defined in [3].

4.1.3 Bottom structural arrangements of stiffeners and plating are to be designed in such a way that distributions of forces and moments, defined in [2], induce stresses within allowable stresses level, as defined in [3].

4.1.4 For moveable keels, attachments of keel's operating system to side and/or deck are to be designed in such a way that distributions of forces and moments, defined in [2], induce stresses within allowable stresses level, as defined in [3].

4.2 Bolting system

4.2.1 General

All bolting systems have to comply with the following requirements:

a) Bolts are to be of stainless steel or equivalent sea-corrosion resistant material. The back plate, washers, nuts... are to be made of the same materials or of a compatible material of the keel bolts

b) As a rule, a large back plate extending from one bolt to the symmetrical bolt is to be provided. The thickness of this back plate is not to be less than 0,25 times the bolt diameter

c) Washers are to be provided under the nut head of each keel bolt. The diameter of the washer is not to be less than 4 times the bolt diameter, and its thickness is not to be less than 0,25 times the bolt diameter

d) Bolting system is to be in such a way that taking off can be handled for inspection

e) Nuts of bolting system are to be so arranged as to allow inspection

f) Where applicable, bolts may be pre-stressed in compliance with appropriate standards. In such a case, the grade of bolts is to be selected accordingly and details of pre-stressing process are to be submitted.

4.2.2 Bolts

The bolts are to be designed to sustain tensile and shear forces, induced by loads defined in [2].

For each bolt i, the total tensile stress σ_i, in MPa, can be estimated by the following formula (see Fig 1):

$$\sigma_i = \frac{M_{heel} X_i 10^2}{I_{X'X'}} + \frac{M_{pitch} Y_i 10^2}{I_{Y'Y'}} + \frac{F_{vheel} 10^3}{A_{SH}}$$

where:

M_{heel} : As defined in [2.2.2]

M_{pitch} : As defined in [2.3.2]

F_{vheel} : As defined in [2.2.1]

$I_{X'X'}$: Total inertia of all bolts, in cm^4, with respect to global axis XX' as defined in Fig 1

$I_{Y'Y'}$: Total inertia of all bolts, in cm^4, with respect to global axis YY' as defined in Fig 1

X_i : Distance, in mm, of the considered bolt i to the global axis XX'

Y_i : Distance, in mm, of the considered bolt i to the global axis YY'

A_{SH} : Total cross section, in mm^2, of all bolts

Note 1: X'X' axis is defined in Fig 1 where X', in m, is equal to $b_{i\,max}/2$, with $b_{i\,max}$ equal to the greater value of the distances between bolts b_i.

Y'Y' axis is defined as the neutral fibre of the global cross section of all the bolts (see Fig 1).

For each bolt i, the shear stress τ_i, in MPa, can be estimated by the following formula:

$$\tau_i = \frac{F_{hheel} 10^3}{A_{SH}}$$

where:

F_{hheel} : As define in [2.2.1]

A_{SH} : Total cross section, in mm², of all bolts.

For each bolt, the Von Mises combined stress is to be less than 0,5 time R_{eH}, where R_{eH} is the minimum guaranteed yield strength of bolts, in MPa.

5 Keel grounding

5.1 General

5.1.1 Keel grounding is considered by the Society only where controlled.

5.1.2 Uncontrolled keel grounding is not covered by the Class Society.

5.2 Controlled keel grounding

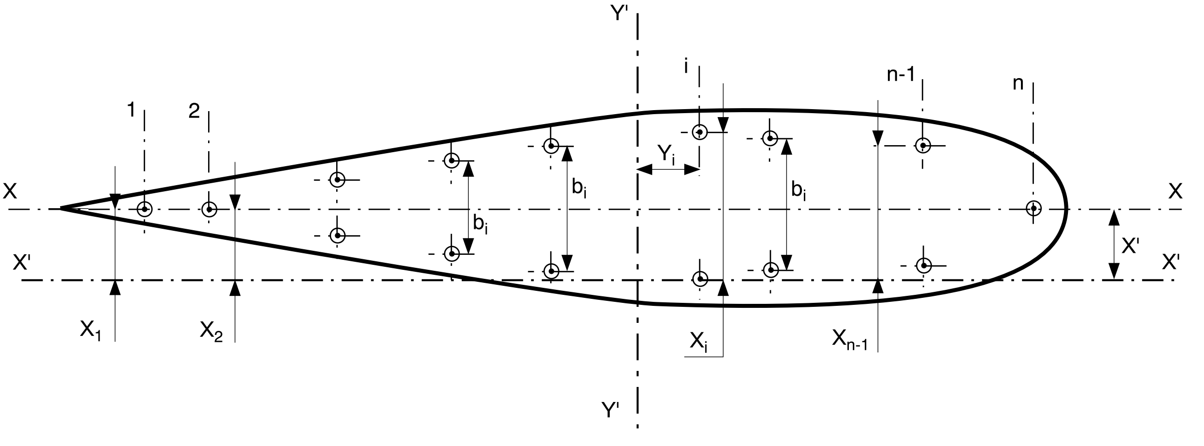
5.2.1 Application

Controlled keel grounding is:

- considered by the Society only where yacht's structural design allows this type of operation
- reviewed on a case by case basis.

Specific hull design is to be submitted.

Figure 1 : Keel bolting arrangement



SECTION 1 GENERAL REQUIREMENTS

1 General

1.1 Characteristics of the materials

1.1.1 The characteristics of the steel or aluminium materials to be used in the construction of ships are to comply with the applicable requirements of the Rule Note NR216 Materials and Welding.

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

1.2 Testing of materials

1.2.1 Materials are to be tested in compliance with the applicable requirements of the Rule Note NR216 Materials and Welding.

1.3 Manufacturing processes

1.3.1 The requirements of this Chapter presumes that welding and other cold or hot manufacturing processes are carried out in compliance with current sound working practice and the applicable requirements of the Rule Note NR216 Materials and Welding:

- parent material and welding processes are to be within the limits stated for the specified type of material for which they are intended
- specific preheating may be required before welding
- welding or other cold or hot manufacturing processes may be need to be followed by an adequate heat treatment.

1.3.2 Requirements for welding and weld connections are given in Ch 11, Sec 2 and Ch 11, Sec 3 .

1.3.3 Qualification of welders

The welders hired by the yard are to be duly qualified and their qualification duly checked, according to the requirements of the Rule Note NR216 Materials and Welding.

1.3.4 Qualification of welding procedures

The welding procedures used for the construction are to be qualified by qualification tests carried out under the Surveyor's supervision, according to the requirements of the Rule Note NR216 Materials and Welding.

SECTION 2 WELDING CONNECTIONS FOR STEEL

1 General

1.1 Application

1.1.1 The requirements of this Section apply for the preparation, execution and inspection of welded connections in steel hull structures of yachts.

They are to be complemented by the criteria given in [2], to which reference is made. These criteria being given as recommendations, minor departures may be accepted by the Society, on a case by case basis.

The general requirements relevant to fabrication by welding and qualification of welding procedures are given in the Rule Note NR216 Materials and Welding, Chapter 5.

1.1.2 Weld connections are to be executed according to the approved plans. Any detail not specifically represented in the plans is, if any, to comply with the applicable requirements.

1.1.3 It is understood that welding of the various types of steel is to be carried out by means of welding procedures approved for the purpose, even though an explicit indication to this effect may not appear on the approved plans.

1.1.4 The quality standard adopted by the shipyard is to be submitted to the Society and applies to all constructions unless otherwise specified on a case by case basis.

1.2 Base material

1.2.1 The requirements of this Section apply for the welding of hull structural steels of the types considered in the Rule Note NR216 Materials and Welding, or other types accepted as equivalent by the Society.

1.2.2 The service temperature is intended to be the ambient temperature, unless otherwise stated.

1.3 Welding consumable and procedures

1.3.1 Approval of welding consumable and procedures

Welding consumable and welding procedures adopted are to be approved by the Society.

The requirements for the approval of welding consumable are given in the Rule Note NR216 Materials and Welding, Ch 5, Sec 2.

The requirements for the approval of welding procedures for the individual users are given in the Rule Note NR216 Materials and Welding, Ch 5, Sec 4 and Ch 5, Sec 5.

The approval of the welding procedure is not required in the case of manual metal arc welding with approved covered electrodes, except in the case of one side welding on refractory backing (ceramic).

1.3.2 Consumable

The minimum consumable grades to be adopted are specified in Tab 1 depending on the steel grade.

Consumable used for manual or semi-automatic welding (covered electrodes, flux-cored and flux-coated wires) of higher strength hull structural steels are to be at least of hydrogen-controlled grade H15 (H). Where the carbon equivalent Ceq is not more than 0,41% and the thickness is below 30 mm, any type of approved higher strength consumable may be used at the discretion of the Society.

Especially, welding consumable with hydrogen-controlled grade H15 (H) and H10 (HH) shall be used for welding hull steel forgings and castings of respectively ordinary strength level and higher strength level.

Table 1 : Consumable grades

Steel grade	Consumable minimum grade	
	Butt welding, partial and full T penetration welding	Fillet welding
A	1	1
B - D	2	
E	3	
AH32 - AH36 DH32 - DH36	2Y	2Y
EH32 - EH36	3Y	

Note 1:
Welding consumable approved for welding higher strength steels (Y) may be used in lieu of those approved for welding normal strength steels having the same or a lower grade; welding consumable approved in grade Y having the same or a lower grade.
Note 2:
In the case of welded connections between two hull structural steels of different grades, as regards strength or notch toughness, welding consumable appropriate to one or the other steel are to be adopted.

1.4 Personnel and equipment

1.4.1 Welders

Manual and semi-automatic welding is to be performed by welders certified by the Society in accordance with the Rule Note NR476 “Approval testing of welders”, unless otherwise agreed with the Society. The welders are to be employed within the limits of their respective approval.

1.4.2 Automatic welding operators

Personnel manning automatic welding machines and equipment are to be competent and sufficiently trained.

1.4.3 Organisation

The internal organisation of the shipyard is to be such as to ensure compliance in full with the requirements in [1.4.1] and [1.4.2] and to provide for assistance and inspection of welding personnel, as necessary, by means of a suitable number of competent supervisors.

1.4.4 NDE operators

Non-destructive tests are to be carried out by qualified personnel, certified by the Society, or by recognised bodies in compliance with appropriate standards.

The qualifications are to be appropriate to the specific applications.

1.4.5 Technical equipment and facilities

The welding equipment is to be appropriate to the adopted welding procedures, of adequate output power and such as to provide for stability of the arc in the different welding positions.

In particular, the welding equipment for special welding procedures is to be provided with adequate and duly calibrated measuring instruments, enabling easy and accurate reading, and adequate devices for easy regulation and regular feed.

Manual electrodes, wires and fluxes are to be stored in suitable locations so as to ensuring their preservation in proper condition. Especially, where consumable with hydrogen-controlled grade are to be used, proper precautions are to be taken to ensure that manufacturer's instructions are followed to obtain (drying) and maintain (storage, maximum time exposed, re-backing, ...) hydrogen-controlled grade.

1.5 Documentation to be submitted

1.5.1 The structural plans to be submitted for approval, according to Ch 1, Sec 3, are to contain the necessary data relevant to the fabrication by welding of the structures and items represented as far as class is concerned.

1.5.2 Where several steel types are used, a plan showing the location of the various steel types is to be submitted at least for outer shell, deck and bulkhead structures.

1.6 Design

1.6.1 General

For the various structural details typical of welded construction in shipbuilding and not dealt with in this Section, the rules of good practice, recognised standards and past experience are to apply as agreed by the Society.

1.6.2 Plate orientation

The plates of the shell and strength deck are generally to be arranged with their length in the fore-aft direction. Possible exceptions to the above will be considered by the Society on a case by case basis.

1.6.3 Prefabrication sequences

Prefabrication sequences are to be arranged so as to facilitate positioning and assembling as far as possible.

The amount of welding to be performed on board is to be limited to a minimum and restricted to easily accessible connections.

1.6.4 Distance between welds

Welds located too close to one another are to be avoided. The minimum distance between two adjacent welds is considered on a case by case basis, taking into account the level of stresses acting on the connected elements.

2 Type of connections and preparation

2.1 General

2.1.1 The type of connection and the edge preparation are to be appropriate to the welding procedure adopted, the structural elements to be connected and the stresses to which they are subjected.

2.2 Butt welding

2.2.1 General

In general, butt connections of plating are to be full penetration, welded on both sides.

Connections different from the above may be accepted by the Society on a case by case basis; in such cases, the relevant detail and workmanship specifications are to be approved.

2.2.2 Welding of plates with different thicknesses

In the case of welding of plates with a difference in thickness equal to or greater than:

- 3 mm, if the thinner plate has a thickness equal to or less than 10 mm
- 4 mm, if the thinner plate has a thickness greater than 10 mm

a taper having a length of not less than 4 times the difference in thickness is to be adopted for connections of plating perpendicular to the direction of main stresses. For connections of plating parallel to the direction of main stresses, the taper length may be reduced to 3 times the difference in thickness.

When the difference in thickness is less than the above values, it may be accommodated in the weld transition between plates.

For large thicknesses (e.g. 25mm), other criteria may be considered on a case by case basis, when deemed equivalent.

2.2.3 Edge preparation, root gap

Typical edge preparations and gaps are indicated in Tab 2 and Tab 3.

The acceptable root gap is to be in accordance with the adopted welding procedure and relevant bevel preparation.

Table 2 : Typical butt weld plate edge preparation (manual welding) - See Note 1

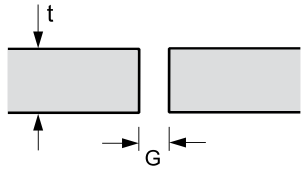
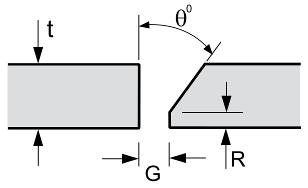
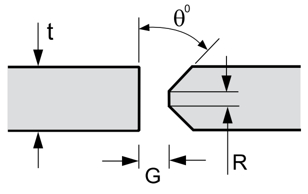
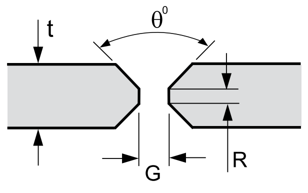
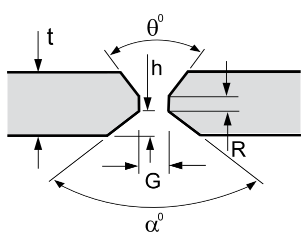
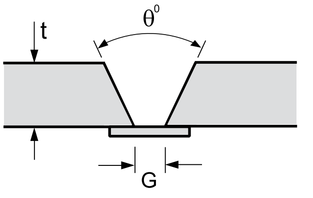
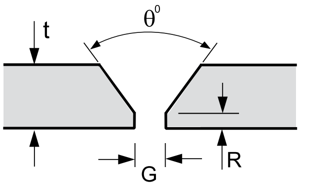
Detail	Standard
Square butt 	t ≤ 5 mm G = 3 mm
Single bevel butt 	t > 5 mm G ≤ 3 mm R ≤ 3 mm 50° ≤ θ ≤ 70°
Double bevel butt 	t > 19 mm G ≤ 3 mm R ≤ 3 mm 50° ≤ θ ≤ 70°
Double vee butt, uniform bevels 	G ≤ 3 mm R ≤ 3 mm 50° ≤ θ ≤ 70°
Double vee butt, non-uniform bevels 	G ≤ 3 mm R ≤ 3 mm 6 ≤ h ≤ t/3 mm θ = 50° α = 90°
Note 1: Different plate edge preparation may be accepted or approved by the Society on the basis of an appropriate welding procedure specification.	

Table 3 : Typical butt weld plate edge preparation (manual welding) - See Note 1

Detail	Standard
Single vee butt, one side welding with backing strip (temporary or permanent) 	3 ≤ G ≤ 9 mm 30° ≤ θ ≤ 45°
Single vee butt 	G ≤ 3 mm 50° ≤ θ ≤ 70° R ≤ 3 mm
Note 1: Different plate edge preparation may be accepted or approved by the Society on the basis of an appropriate welding procedure specification.	

2.2.4 Butt welding on permanent backing

Butt welding on permanent backing, i.e. butt welding assembly of two plates backed by the flange or the face plate of a stiffener, may be accepted where back welding is not feasible or in specific cases deemed acceptable by the Society.

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 and an adequate connection to the stiffener as required.

2.2.5 Section, bulbs and flat bars

When lengths of longitudinals of the shell plating and strength deck within 0,6 L amidships, or elements in general subject to high stresses, are to be connected together by butt joints, these are to be full penetration. 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, this requirement applies to work done on board or in conditions of difficult access to the welded connection. Special measures may be required by the Society.

2.3 Fillet welding

2.3.1 General

In general, ordinary fillet welding (without bevel) may be adopted for T connections of the various simple and composite structural elements.

2.3.2 Fillet welding types

Fillet welding may be of the following types:

- continuous fillet welding, where the weld is constituted by a continuous fillet on each side of the abutting plate
- intermittent fillet welding, which may be subdivided into:
  - chain welding
  - scallop welding
  - staggered welding.

2.3.3 Continuous fillet welding

Continuous fillet welding is to be adopted:

- for watertight connections
- for connections of brackets, lugs and scallops
- at the ends of connections for a length of at least 75mm
- where intermittent welding is not allowed, according to [2.3.4].

Continuous fillet welding may also be adopted in lieu of intermittent welding wherever deemed suitable, and it is recommended where the spacing p, calculated according to [2.3.4], is low.

2.3.4 Intermittent welding

The spacing p and the length d, in mm, of an intermittent weld, shown in:

- Fig 1, for chain welding
- Fig 2, for scallop welding
- Fig 2, for staggered welding

are to be such that:

$$\frac{p}{d} \leq \varphi$$

where the coefficient φ is defined in Tab 4 for the different types of intermittent welding, depending on the type and location of the connection.

In general, staggered welding is not allowed for connections subjected to high alternate stresses.

In addition, the following limitations are to be complied with:

- chain welding (see Fig 1):

  d ≥ 75 mm

  p-d ≤ 200 mm

- staggered welding (see Fig 2):

  d ≥ 75 mm

  p-2d ≤ 300 mm

  p ≤ 2d for connections subjected to high alternate stresses.

Figure 1 : Intermittent chain welding

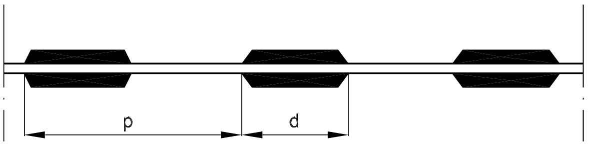
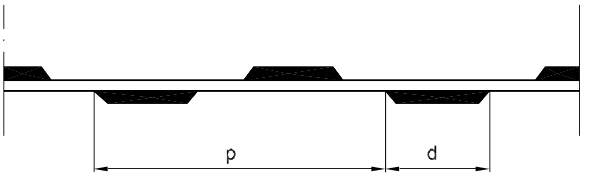


Figure 2 : Intermittent staggered welding



2.3.5 Throat thickness of fillet weld T connections

The throat thickness of fillet weld T connections is to be obtained, in mm, from the following formula:

$$t_T = w_F t \frac{p}{d}$$

where:

w_F : Welding factor, defined in Tab 4 for the various hull structural connections; for connections of primary supporting members and not mentioned in Tab 4, w_F is defined in Tab 6

t : Actual thickness, in mm, of the structural element which constitutes the web of the T connection

p, d : Spacing and length, in mm, of an intermittent weld, defined in [2.3.4].

For continuous fillet welds, p/d is to be taken equal to 1.

In no case may the throat thickness be less than:

- 3,0 mm, where the gross thickness of the thinner plate is less than 6 mm
- 3,5 mm, otherwise.

The throat thickness may be required by the Society to be increased, depending on the results of structural analyses.

The leg length of fillet weld T connections is to be not less than 1,4 times the required throat thickness.

2.3.6 Throat thickness of welds between cut-outs

The throat thickness of the welds between the cut-outs in primary supporting member webs for the passage of ordinary stiffeners is to be not less than the value obtained, in mm, from the following formula:

$$t_{TC} = t_T \frac{\varepsilon}{\lambda}$$

where:

t_T : Throat thickness defined in [2.3.5]

ε, λ : Dimensions, in mm, to be taken as shown in Fig 3, for continuous welding.

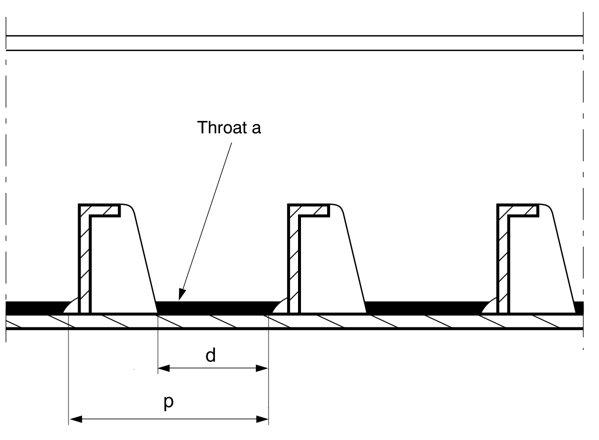
Table 4 : Welding factors w_F and coefficient φ for the various hull structural connections

Hull area	Connection of	Connection to		w_F (1)	φ (2) (3) CH	φ (2) (3) ST
General, unless otherwise specified in the table	watertight plates	boundaries		0,35		
	webs of ordinary stiffeners	plating		0,13	3,5	4,6
Bottom and double bottom	longitudinal ordinary stiffeners	bottom and inner bottom plating		0,13	3,5	4,6
	centre girder	keel plate		0,25	1,8	
		inner bottom plating		0,20	2,2	
	side girders	bottom and inner bottom plating		0,13	3,5	4,6
		floors (interrupted girders)		0,20	2,2	
	floors	bottom and inner bottom plating	in general	0,13	3,5	4,6
			at ends (20% of span) for longitudinally framed double bottom	0,25	1,8	
		inner bottom plating in way of brackets of primary supporting members		0,25	1,8	
		girders (interrupted floors)		0,20	2,2	
	partial side girders	floors		0,25	1,8	
Side	ordinary stiffeners	side plating		0,13	3,5	4,6
Deck	ordinary stiffeners	deck plating		0,13	3,5	4,6
	strength deck	side plating		Partial penetration welding		
	non-watertight decks	side plating		0,20	2,2	
Bulkheads	ordinary stiffeners	bulkhead plating	in general **(5)**	0,13	3,5	4,6
			at ends (25% of span), where no end brackets are fitted	0,35		
	tank bulkhead structures	tank bottom	plating and ordinary stiffeners (plane bulkheads)	0,45		
		boundaries other than tank bottom		0,35		
	watertight bulkhead structures	boundaries		0,35		
	transverse bulkheads between floats of catamarans	boundaries		0,35		
Structures located forward of 0,75 L from the AE	bottom longitudinal ordinary stiffeners	bottom plating		0,20	2,2	
	floors and girders	bottom and inner bottom plating		0,25	1,8	
	side frames	side plating		0,20	2,2	
	side girders	side plating		0,25	1,8	
After peak	internal structures	each other		0,20		
	side ordinary stiffeners	side plating		0,20		
	floors	bottom and inner bottom plating		0,20		
Machinery space of motor yachts	girders	bottom and inner bottom plating	in way of main engine foundations	0,45		
			in way of seating of auxiliary machinery	0,35		
			elsewhere	0,20	2,2	
	floors (except in way of main engine foundations)	bottom and inner bottom plating	in way of seating of auxiliary machinery	0,35		
			elsewhere	0,20	2,2	
	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	1,8	

Hull area	Connection			w_F **(1)**	φ **(2) (3)**	
	of	to			CH	ST
Superstructures and deckhouses	external bulkheads	deck		0,35		
	internal bulkheads	deck		0,13	3,5	4,6
	ordinary stiffeners	external and internal bulkhead plating		0,13	3,5	4,6
Pillars	pillars	deck	pillars in compression	0,35		
			pillars in tension	Full penetration welding		
Ventilators	coamings	deck		0,35		
Rudders	horizontal and vertical webs directly connected to solid parts	each other		0,45		
	other webs	each other		0,20		
	webs	plating	in general	0,20		
			top and bottom plates of rudder plating	0,35		
		solid parts or rudder stock		According to Ch 10, Sec 2, [6]		

(1) In connections for which $w_F \geq 0{,}35$, continuous fillet welding is to be adopted.
(2) For coefficient φ, see [2.3.4]. In connections for which no φ value is specified for a certain type of intermittent welding, such type is not permitted and continuous welding is to be adopted.
(3) CH = chain welding, ST = staggered welding.
(4) Ends of ordinary stiffeners means the area extended 75 mm from the span ends. Where end brackets are fitted, ends means the area extended in way of brackets and at least 50 mm beyond the bracket toes.
(5) In tanks intended for the carriage of ballast or fresh water, continuous welding with $w_F = 0{,}35$ is to be adopted.

Figure 3 : Continuous fillet welding between cut-outs



2.3.7 Throat thickness of welds connecting ordinary stiffeners with primary supporting members

The throat thickness of fillet welds connecting ordinary stiffeners and collar plates, if any, to the web of primary supporting members is to be not less than $0{,}35t_W$, where t_W is the web thickness, in mm.

In general, the resistant weld section A_W, in cm^2, connecting the ordinary stiffeners to the web of primary members, is not to be less than:

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

where:

φ : Coefficient as indicated in Tab 5

p : Design pressure, in kN/m^2, acting on the secondary stiffeners, as defined in Ch 7, Sec 1 and Ch 7, Sec 2

s : Spacing of ordinary stiffeners, in m

ℓ : Span of ordinary stiffeners, in m

K : Greatest material factor of ordinary stiffener and primary member, as defined in Ch 4, Sec 3, [3].

Table 5 : Coefficient φ

Case	Weld	φ
1	Parallel to the reaction exerted on primary member	100
2	Perpendicular to the reaction exerted on primary member	75

2.4 Lap-joint welding

2.4.1 General

Lap-joint welding may be adopted for:

- peripheral connection of doublers
- internal structural elements subjected to very low stresses.

Elsewhere, lap-joint welding may be allowed by the Society on a case by case basis, if deemed necessary under specific conditions.

Continuous welding is generally to be adopted.

2.4.2 Gap

The surfaces of lap-joints are to be in sufficiently close contact.

Table 6 : Welding factors w_F and coefficient φ for connections of primary supporting members

Primary supporting member	Connection of	Connection to		w_F (1)	φ (2) (3) CH	SC	ST
General	web, where A < 65 cm^2	plating and face plate	at ends	0,20			
			elsewhere	0,15	3,0	3,0	
	web, where A ≥ 65 cm^2	plating		0,35			
		face plate	at ends	0,35			
			elsewhere	0,25	1,8	1,8	
	end brackets	face plate		0,35			
In tanks, where A < 65 cm^2 **(5)**	web	plating	at ends	0,25			
			elsewhere	0,20	2,2	2,2	
		face plate	at ends	0,20			
			elsewhere	0,15	3,0	3,0	
	end brackets	face plate		0,35			
In tanks, where A ≥ 65 cm^2	web	plating	at ends	0,45			
			elsewhere	0,35			
		face plate		0,35			
	end brackets	face plate		0,45			

(1) In connections for which w_F ≥ 0,35, continuous fillet welding is to be adopted.
(2) For coefficient φ, see [2.3.4]. In connections for which no φ value is specified for a certain type of intermittent welding, such type is not permitted.
(3) CH = chain welding, SC = scallop welding, ST = staggered welding.
(4) For primary supporting members in tanks intended for the carriage of ballast or fresh water, continuous welding is to be adopted.
(5) In tanks intended for the carriage of ballast or fresh water, continuous welding with w_F = 0,35 is to be adopted.
Note 1: A is the face plate sectional area of the primary supporting member, in cm^2.
Note 2: Ends of primary supporting members means the area extended 20% of the span from the span ends. Where end brackets are fitted, ends means the area extended in way of brackets and at least 100 mm beyond the bracket toes.

2.4.3 Dimensions

The dimensions of the lap-joint are to be specified and are considered on a case by case basis. Typical details are given in Tab 7.

2.5 Slot welding

2.5.1 General

Slot welding may be adopted in very specific cases subject to the special agreement of the Society.

In general, slot welding of doublers on the outer shell and strength deck is not permitted within 0,6L amidships. Beyond this zone, slot welding may be accepted by the Society on a case by case basis.

Slot welding is, in general, permitted only where stresses act in a predominant direction. Slot welds are, as far as possible, to be aligned in this direction.

2.5.2 Dimensions

Slot welds are to be of appropriate shape (in general oval) and dimensions, depending on the plate thickness, and may not be completely filled by the weld.

Typical dimensions of the slot weld and the throat thickness of the fillet weld are given in Tab 7.

The distance between two consecutive slot welds is to be not greater than a value which is defined on a case by case basis taking into account:

- the transverse spacing between adjacent slot weld lines
- the stresses acting in the connected plates
- the structural arrangement below the connected plates.

2.6 Plug welding

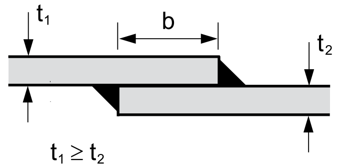
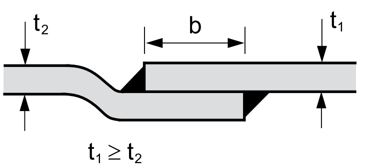
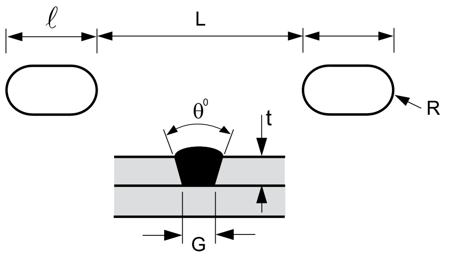
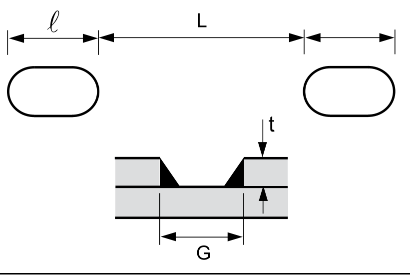
2.6.1 Plug welding may be adopted only when accepted by the Society on a case by case basis, according to specifically defined criteria. Typical details are given in Tab 7.

3 Workmanship

3.1 Welding procedures and consumable

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

Table 7 : Typical lap joint, plug and slot welding (manual welding)

Detail	Standard	Remark
Fillet weld in lap joint  $t_1 \geq t_2$	$b = 2\ t_2 + 25$ mm	location of lap joint to be approved by the Society
Fillet weld in joggled lap joint  $t_1 \geq t_2$	$b \geq 2\ t_2 + 25$ mm	
Plug welding 	• $t \leq 12$ mm $\ell = 60$ mm $R = 6$ mm $40° \leq \theta \leq 50°$ $G = 12$ mm $L > 2\ \ell$ • 12 mm $< t \leq 25$ mm $\ell = 80$ mm $R = 0{,}5\ t$ mm $\theta = 30°$ $G = t$ mm $L > 2\ \ell$	
Slot welding 	• $t \leq 12$ mm $G = 20$ mm $\ell = 80$ mm $2\ \ell \leq L \leq 3\ \ell$, max 250 mm • $t > 12$ mm $G = 2\ t$ $\ell = 100$ mm $2\ \ell \leq L \leq 3\ \ell$, max 250 mm	

3.2 Welding operations

3.2.1 Weather protection

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

In welding procedures using bare, cored or coated wires with gas shielding, the welding is to be carried out in weather protected conditions, so as to ensure that the gas outflow from the nozzle is not disturbed by winds and draughts.

3.2.2 Butt connection edge preparation

The edge preparation is to be of the required geometry and correctly performed. In particular, if edge preparation is carried out by flame, it is to be free from cracks or other detrimental notches.

Recommendations for edge preparation are given in the "Guide for welding".

3.2.3 Surface condition

The surfaces to be welded are to be free from rust, moisture and other substances, such as mill scale, slag caused by oxygen cutting, grease or paint, which may produce defects in the welds.

Effective means of cleaning are to be adopted particularly in connections with special welding procedures; flame or mechanical cleaning may be required.

The presence of a shop primer may be accepted, provided it has been approved by the Society.

Shop primers are to be approved by the Society for a specific type and thickness according to the Rule Note NR216 Materials and Welding, Ch 5, Sec 3.

3.2.4 Assembling and gap

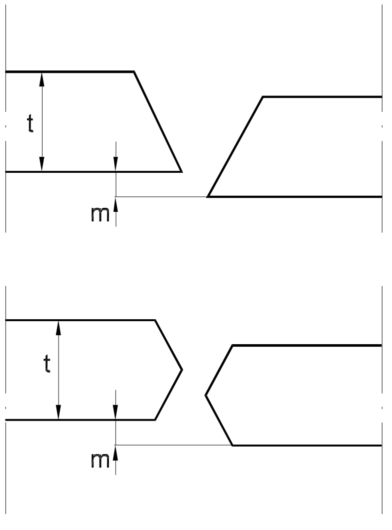
The setting appliances and system to be used for positioning are to ensure adequate tightening adjustment and an appropriate gap of the parts to be welded, while allowing maximum freedom for shrinkage to prevent cracks or other defects due to excessive restraint.

The gap between the edges is to comply with the required tolerances or, when not specified, it is to be in accordance with normal good practice.

3.2.5 Plate misalignment in butt connections

The misalignment m, measured as shown in Fig 4, between plates with the same gross thickness t is to be less than 0,15t, without being greater than 3 mm.

Figure 4 : Plate misalignment in butt connections

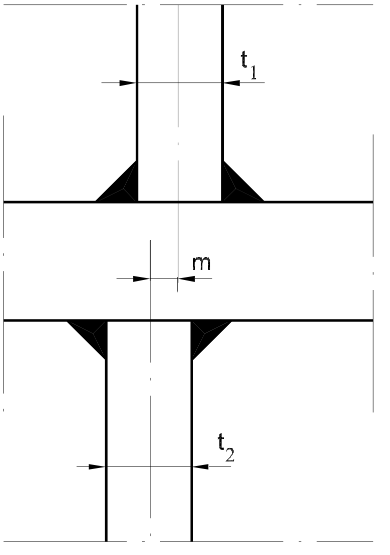


3.2.6 Misalignment in cruciform connections

The misalignment m in cruciform connections, measured on the median lines as shown in Fig 5, is to be less than:

- t/2, in general, where t is the gross thickness of the thinner abutting plate.

Figure 5 : Misalignment in cruciform connections



The Society may require lower misalignment to be adopted for cruciform connections subjected to high stresses.

3.2.7 Welding sequences

Welding sequences and direction of welding are to be determined so as to minimise deformations and prevent defects in the welded connection.

All main connections are generally to be completed before the ship is afloat.

Departures from the above provision may be accepted by the Society on a case by case basis, taking into account any detailed information on the size and position of welds and the stresses of the zones concerned, both during ship launching and with the ship afloat.

3.2.8 Interpass cleaning

After each run, the slag is to be removed by means of a chipping hammer and a metal brush; the same precaution is to be taken when an interrupted weld is resumed or two welds are to be connected.

SECTION 3 WELDING AND OTHER CONNECTIONS MEANS FOR ALUMINIUM ALLOYS

1 General

1.1 Application

1.1.1 The requirements of this Section apply for the preparation, execution and inspection of welded connections or riveting connections in aluminium hull structures of yachts.

They are to be complemented by the criteria given [2]. These criteria being given as recommendations, minor departures may be accepted by the Society, on a case by case basis.

The general requirements relevant to fabrication by welding and qualification of welding procedures are given in the Rule Note NR216 Materials and Welding, Chapter 5.

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

1.1.3 Weld connections are to be executed according to the approved plans. Any detail not specifically represented in the plans is, if any, to comply with the applicable requirements.

1.1.4 It is understood that welding of the various types of aluminium alloys is to be carried out by means of welding procedures approved for the purpose, even though an explicit indication to this effect may not appear on the approved plans.

1.1.5 The quality standard adopted by the shipyard is to be submitted to the Society and applies to all constructions unless otherwise specified on a case by case basis.

1.2 Welding filler products

1.2.1 The choice of 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.

1.2.2 Welding filler products are generally to be approved by the Society.

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

2 Welding - type of connections and preparation

2.1 General

2.1.1 The types and dimensions of the welds, their preparation and performing conditions, their field of use are dealt with hereafter.

2.1.2 Other types and dimensions may be considered, subject to the review by the Society.

2.1.3 Assembly conditions, other than those provided for hereafter, are to be agreed upon with the Surveyor.

2.1.4 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.

It is reviewed during the qualification of welding procedure as defined in the Rule Note NR 216 Materials and Welding.

2.1.5 The Surveyor is to be provided with the following information:

- location of prefabrication joints welded at workshop
- location of joints carried out on the building slip for assembly of the prefabricated panels
- welding sequences
- sequence of assembly of prefabricated panels
- general information on the welding operations.

2.1.6 The welding procedure, filler products and the design of joints are to be described in a welding booklet.

Moreover, the welding booklet is to indicate, for each type of joint, the preparations and various welding parameters.

The welding booklet is to define, for each type of assembly, the nature and the extent of the inspections proposed and, in particular, of the non-destructive testing (dye-penetrant tests and, if needed, radiographic inspection).

2.1.7 The welding booklet is to be submitted for review by the Society Surveyor.

2.2 Butt weld

2.2.1 As a rule, butt welding is to be used for plate and section butts; it 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).

2.2.2 Permissible root gap j is to be defined during qualification tests of welding procedures and indicated in the welding booklet.

2.2.3 In the case of assembly of two plates of different thicknesses, the thickest plate is to be tapered with a maximum slope of 1/4, where:

for $e_1 \leq 10$ mm and $e_2 - e_1 \geq 3$ mm

for $e_1 > 10$ mm and $e_2 - e_1 \geq 4$ mm

where:

e_1 : Thickness of the thinnest plate, in mm

e_2 : Thickness of the thickest plate, in mm.

On the thickest plate, tapering can be carried out on one face or on both faces, as shown in Fig 1 and Fig 2.

2.2.4 In the case of unsupported butt welds, a backweld is recommended for thicknesses greater than or equal to 4 mm.

Figure 1 : Tapering on one face

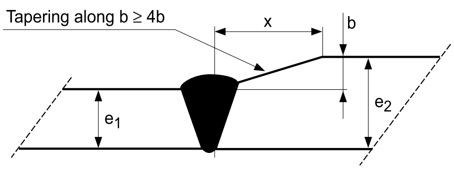
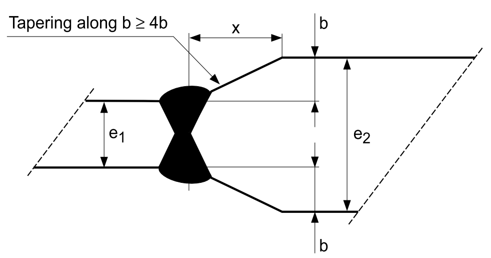


Figure 2 : Tapering on both faces



2.3 Fillet weld in a lap joint

2.3.1 Fillet weld in a lap joint may be used only for members submitted to moderate stresses.

2.3.2 Rule throats of fillet welds are shown in Fig 3 and Fig 4.

The width b, in mm, of overlapping is not to be less than:

$b \geq 1,5\ (e_1 + e_2) + 20$

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.

Figure 3 : Fillet weld in lap joint

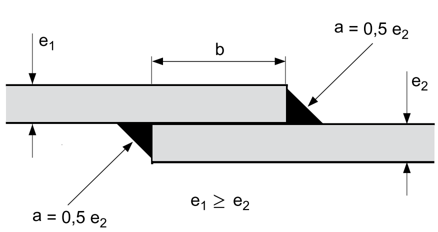
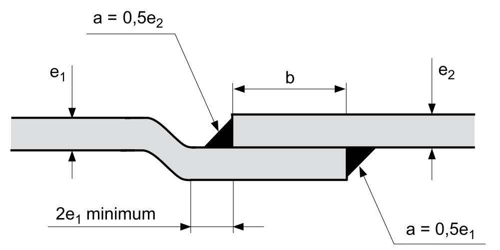


Figure 4 : Fillet weld in joggled lap joint



2.4 Butt welds on permanent backing

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

2.4.2 The type of bevel and the root gap between the members to be assembled are to be such as to ensure a proper penetration of the weld on its backing.

2.4.3 The gap, in mm, in the bottom of the groove, as shown in Fig 5, is not to exceed:

- for $e \leq 6$:

  $\alpha = 0^o$

  $j = e$

  $e_1 = e + 1 \leq 6$ mm

- for $6 < e \leq 20$:

  $\alpha = 20^o$

  $j = 6$ mm

  $e_1 = 6$ mm

- for $e > 20$:

  $\alpha = 15^o$

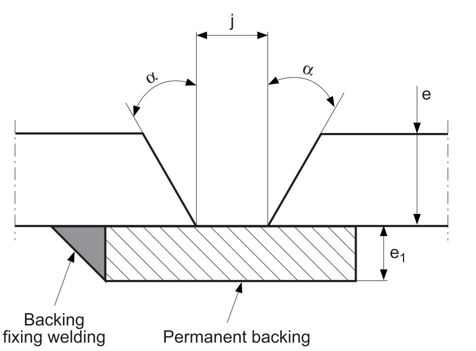
  $j = 10$ mm

  $e_1 = 10$ mm

2.4.4 The scantlings of permanent backing are to be determined in accordance with the importance of the welding of the parts assembled.

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

Figure 5 : Butt weld on permanent backing



2.5 Butt welding on temporary backing

2.5.1 Preparation before welding of the butt welds carried out on temporary backing is to be defined during the qualification of welding procedures.

2.6 Slot welding

2.6.1 Slot welding may be used where fillet welding is not possible.

2.6.2 The shape is shown in Fig 6 and Fig 7, depending on the plate thickness.

2.6.3 Slot welding is not to be completely filled by the weld. As much distance as possible is to be allowed between the two fillet roots.

2.6.4 The distance L_b between extremities of two consecutive slot welds, as shown in Fig 8, is to be such that:

$10\ e \leq L_b \leq 200$

where e is the plate thickness, in mm.

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

2.6.5 The width of the opening is to be such as to allow easy fillet weld along its perimeter.

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

Figure 6 : Slot welding for e ≤ 12 mm

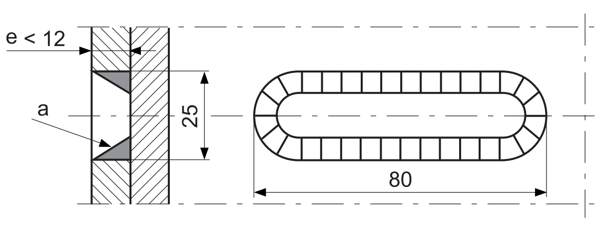


Figure 7 : Slot welding for e > 12 mm

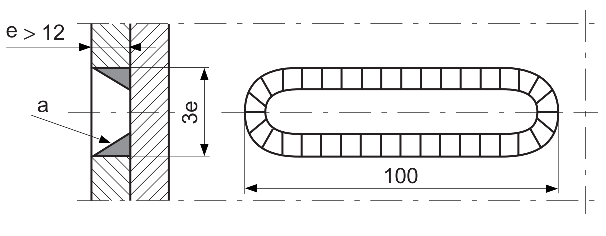
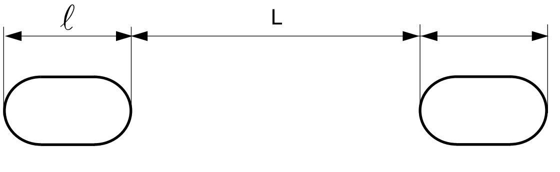


Figure 8 : Distance between slot welds



2.7 Plug welding

2.7.1 Plug weld is to be used exceptionally as a substitute to slot welding.

2.7.2 Plug welding is to be completely filled by the welding.

2.7.3 Weld preparation and execution procedures are to be submitted for the review by the Surveyor.

2.8 Fillet weld

2.8.1 The scantlings of fillet weld assemblies for hull members are given in Tab 1. The scantlings may be increased for particular loading conditions.

Where the members to be assembled have different thicknesses, their connection is to be specially considered by the Society.

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, defined in Tab 1 for the various hull structural connections
- t : Actual thickness, in mm, of the thinner plate of the assembly

Throat t_T is not to be greater than 1,5 t.

As a rule, the throat thickness of fillet welds is not to be less than 4 mm.

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

2.8.2 The clearance j is to be as follows:

$j \leq 1$ mm for $e \leq 8$ mm

$j \leq 2$ mm for $e > 8$ mm

For greater clearances, the throat thickness is to be increased by half the clearance j, as shown in Fig 9.

2.8.3 Where the thickness exceeds 8 mm, a preparation may be recommended, as shown in Fig 10 and Fig 11.

In any case, a blocking device of 3 mm minimum is to be provided.

Figure 9 : Clearance

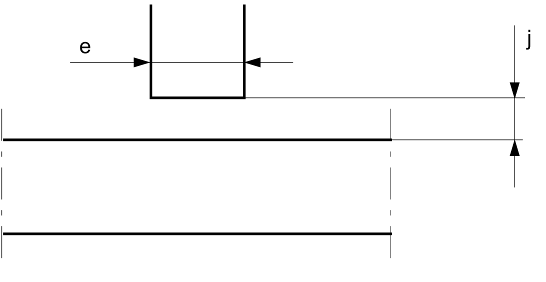


Figure 10 : Clearance and preparation

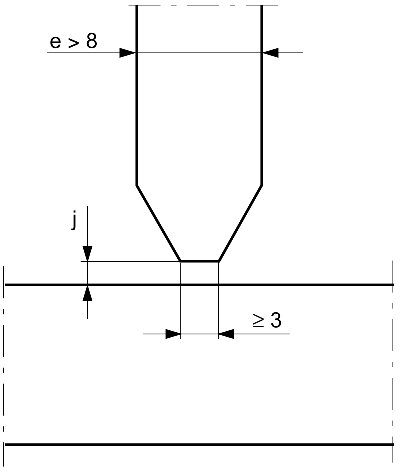


Figure 11 : Clearance and preparation

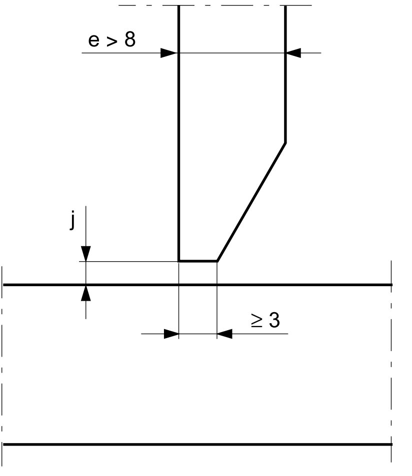


Table 1 : Welding factors w_F for the various hull structural connections

Hull area	Connection of	Connection to		w_F (1)
General, unless otherwise specified in the table	watertight plates	boundaries		0,35
	webs of ordinary stiffeners	plating		0,13
Bottom and double bottom	longitudinal ordinary stiffeners	bottom and inner bottom plating		0,13
	centre girder	keel plate		0,25
		inner bottom plating		0,20
	side girders	bottom and inner bottom plating		0,13
		floors (interrupted girders)		0,20
	floors	bottom and inner bottom plating	in general	0,13
			at ends (20% of span) for longitudinally framed double bottom	0,25
		inner bottom plating in way of brackets of primary supporting members		0,25
		girders (interrupted floors)		0,20
	partial side girders	floors		0,25
Side	ordinary stiffeners	side plating		0,13
Deck	ordinary stiffeners	deck plating		0,13
	strength deck	side plating		Partial penetration welding
	non-watertight decks	side plating		0,20
Bulkheads	ordinary stiffeners	bulkhead plating	in general(3)	0,13
			at ends (25% of span), where no end brackets are fitted	0,35
	tank bulkhead structures	tank bottom	plating and ordinary stiffeners (plane bulkheads)	0,45
		boundaries other than tank bottom		0,35
	watertight bulkhead structures	boundaries		0,35
	transverse bulkheads between floats of catamarans	boundaries		0,35

Hull area	Connection			w_F **(1)**
	of	to		
Structures located forward of 0,75 L from the AE	bottom longitudinal ordinary stiffeners	bottom plating		0,20
	floors and girders	bottom and inner bottom plating		0,25
	side frames	side plating		0,20
	side girders	side plating		0,25
After peak	internal structures	each other		0,20
	side ordinary stiffeners	side plating		0,20
	floors	bottom and inner bottom plating		0,20
Machinery space of motor yachts	girders	bottom and inner bottom plating	in way of main engine foundations	0,45
			in way of seating of auxiliary machinery	0,35
			elsewhere	0,20
	floors (except in way of main engine foundations)	bottom and inner bottom plating	in way of seating of auxiliary machinery	0,35
			elsewhere	0,20
	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
Ventilators	coamings	deck		0,35
Rudders	horizontal and vertical webs directly connected to solid parts	each other		0,45
	other webs	each other		0,20
	webs	plating	in general	0,20
			top and bottom plates of rudder plating	0,35
		solid parts or rudder stock		According to Ch 10, Sec 2

(1) In connections for which $w_F \geq 0,35$, continuous fillet welding is to be adopted.
(2) Ends of ordinary stiffeners means the area extended 75 mm from the span ends. Where end brackets are fitted, ends means the area extended in way of brackets and at least 50 mm beyond the bracket toes.
(3) In tanks intended for the carriage of ballast or fresh water, continuous welding with $w_F = 0,35$ is to be adopted.

2.8.4 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.

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

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

without exceeding 1,5 e

where:

t_T : Throat, in mm, of the double continuous fillet weld, obtained from the Tab 1

p : Pitch, in mm, of the fillet welds positioned on the same side, measured as shown from Fig 13 to Fig 15 , according to the types of welds

d_e : Efficient length, in mm, of the fillet welds, defined in [2.8.4].

2.8.6 Staggered welds are to comply with the following requirements:

$d \geq 75$ mm

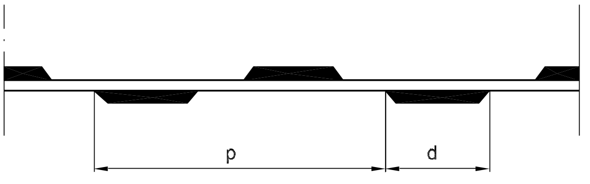
$p \leq 3\ d$

where:

p, d : As shown in Fig 12.

To reduce deformations, it is recommended to choose the values of d according to the thickness.

Figure 12 : Staggered welds



For members subjected to dynamic loads, staggered welds with overlap may be accepted, subject to the following requirements:

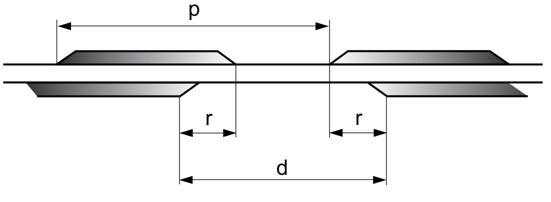
$d \geq 75$ mm

$r \geq 20$ mm

where:

d, r : As shown in Fig 13.

Figure 13 : Staggered weld subjected to dynamic loads



2.8.7 Chain welds are to comply with the following requirements:

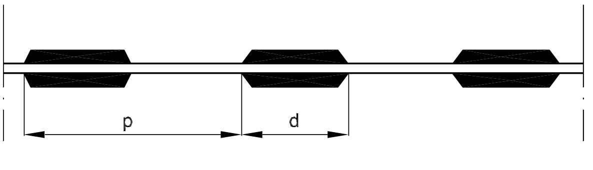
$d \geq 75$ mm

$p - d \leq 200$ mm

where:

p, d : As shown in Fig 14.

Figure 14 : Chain weld



2.8.8 In way of cut-outs for the passage of stiffeners, the throat thickness of the continuous fillet welds located between cut-outs is to not be less than:

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

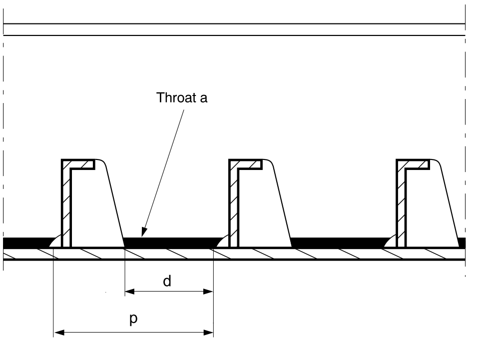
where:

d_e : Efficient length, defined in [2.8.4]

p, d : As shown in Fig 15.

In the case of connections ensuring the continuity of the strength members on each side of a continuous member, the throat thickness is to be determined with respect to the thinnest intermittent member.

Figure 15 : Fillet weld in way of cut-outs



2.8.9 Throat thickness of welds connecting ordinary stiffeners with primary supporting members

The throat thickness of fillet welds connecting ordinary stiffeners and collar plates, if any, to the web of primary supporting members is to be not less than $0,35t_W$, where t_W is the web thickness, in mm.

In general, the resistant weld section A_W, in cm^2, connecting the ordinary stiffeners to the web of primary members, is to be not less than:

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

where:

φ : coefficient as indicated in Tab 2

p : design pressure, in kN/m^2, acting on the secondary stiffeners, as defined in Ch 7, Sec 1 and Ch 7, Sec 2

s : spacing of ordinary stiffeners, in m

ℓ : span of ordinary stiffeners, in m

K : greatest material factor of ordinary stiffener and primary member, as defined in Ch 4, Sec 3, [3].

Table 2 : Coefficient φ

Case	Weld	φ
1	Parallel to the reaction exerted on primary member	200
2	Perpendicular to the reaction exerted on primary member	160

2.9 Particular conditions applying to bilge keels

2.9.1 Connection of the bilge keel 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.

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 defects in way of the scallop and, where necessary, the defects are to be ground.

2.10 Welding - performing conditions

2.10.1 The items to be welded and the filler products are to be stored in a dry room sufficiently aired and free from condensation.

Welding operations in open air are to be avoided. It is recommended to carry out the welding of the greatest number possible of items under shelter.

2.10.2 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.

2.10.3 The metal is to be properly degreased prior to welding, by means of a solvent which is inert for the metal and legally acceptable.

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.

2.10.4 Preparation of edges and adjusting are to comply with the tolerances indicated in the welding booklet.

2.10.5 If sections 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 different heights, the strength continuity is to be restored.

2.10.6 It is recommended to start and end welded joints on appendices tack welded onto the ends. Restarting a discontinued weld, the end of the joint is to be carefully ground.

Overlapping of lines of welding over some 20 mm is necessary.

2.10.7 Whenever the thickness allows it, i.e. for thicknesses exceeding or equal to 4 mm, butt weld of hull plating or resistant members is to be carried out in two opposed runs minimum, in order to eliminate transverse flaws.

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

2.10.9 The provisions taken for the layout of joints, the adjustment of elements, the nature and execution order of welds, are to be such that they minimize the deformations.

3 Workmanship

3.1 Welding procedures and consumables

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

3.2 Welding operations

3.2.1 Weather protection

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

In welding procedures using bare, cored or coated wires with gas shielding, the welding is to be carried out in weather protected conditions, so as to ensure that the gas outflow from the nozzle is not disturbed by winds and draughts.

3.2.2 Butt connection edge preparation

The edge preparation is to be of the required geometry and correctly performed. In particular, if edge preparation is carried out by flame, it is to be free from cracks or other detrimental notches.

3.2.3 Surface condition

The surfaces to be welded are to be free from moisture and other substances, such as mill scale, slag caused by oxygen cutting, grease or paint, which may produce defects in the welds.

Effective means of cleaning are to be adopted particularly in connections with special welding procedures; flame or mechanical cleaning may be required.

The presence of a shop primer may be accepted, provided it has been approved by the Society.

Shop primers are to be approved by the Society for a specific type and thickness according to the Rule Note NR216 Materials and Welding, Ch 5, Sec 3.

3.2.4 Assembling and gap

The setting appliances and system to be used for positioning are to ensure adequate tightening adjustment and an appropriate gap of the parts to be welded, while allowing maximum freedom for shrinkage to prevent cracks or other defects due to excessive restraint.

The gap between the edges is to comply with the required tolerances or, when not specified, it is to be in accordance with normal good practice.

3.2.5 Plate misalignment in butt connections

Misalignment d before butt welding of plates of the same thickness is not to exceed:

for e ≤ 10 mm: d ≤ 1 mm

for 10 mm < e ≤ 20 mm: d ≤ 2 mm

for e > 20 mm: d ≤ 3 mm.

3.2.6 Misalignment in cruciform connections

In the case of cruciform joint as shown in Fig 16, misalignment d is not to be greater than:

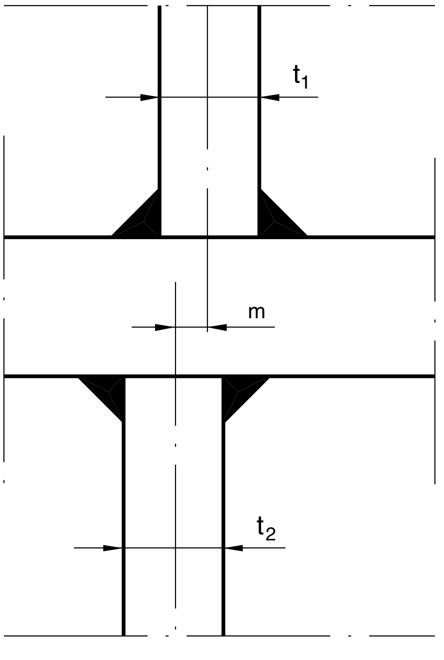
d ≤ e / 2

where:

e : Thickness of the thickest plate (e_1 or e_2).

Misalignment d may be limited even more in the case of highly stressed cruciform joints.

Figure 16 : Cruciform connection



3.2.7 Welding sequences

Welding sequences and direction of welding are to be determined so as to minimise deformations and prevent defects in the welded connection.

All main connections are generally to be completed before the ship is afloat.

Departures from the above provision may be accepted by the Society on a case by case basis, taking into account any detailed information on the size and position of welds and the stresses of the zones concerned, both during ship launching and with the ship afloat.

3.2.8 Interpass cleaning

After each run, the slag is to be removed by means of a metal brush and the grease is to be removed by appropriate cleaning ; the same precaution is to be taken when an interrupted weld is resumed or two welds are to be connected.

4 Riveting

4.1 General

4.1.1 This sub-article defines the conditions of riveting of hulls and structures made of aluminium alloy.

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, diameters of hole perforations, manufacturing tolerances and shape of the heads are given in Tab 2 and Tab 3 and in Fig 17 and Fig 18. The diameters of rivets are given versus the thickness of the thinner member.

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

Figure 17 : Manufactured heads

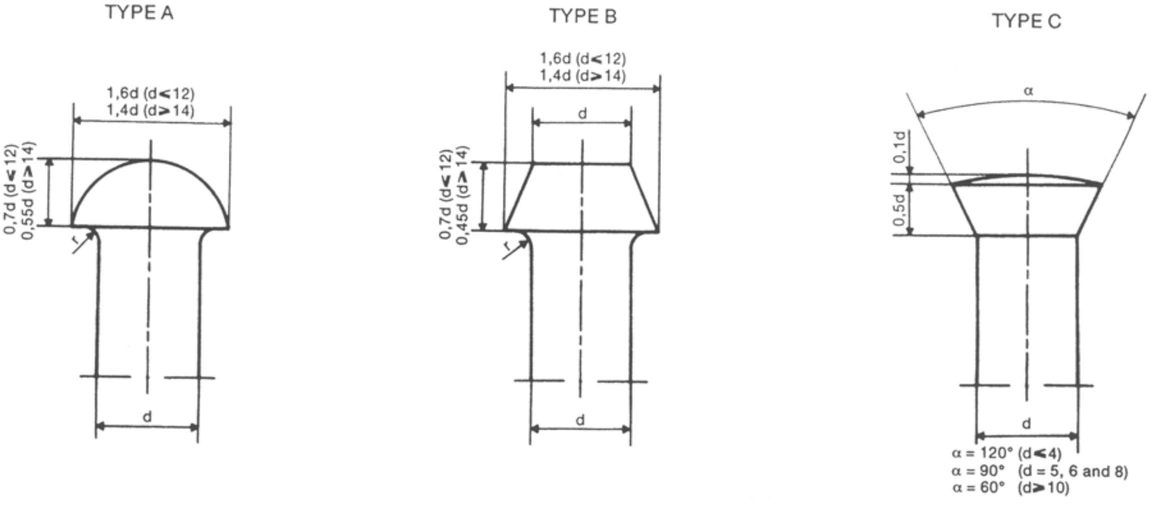


Figure 18 : Riveted heads

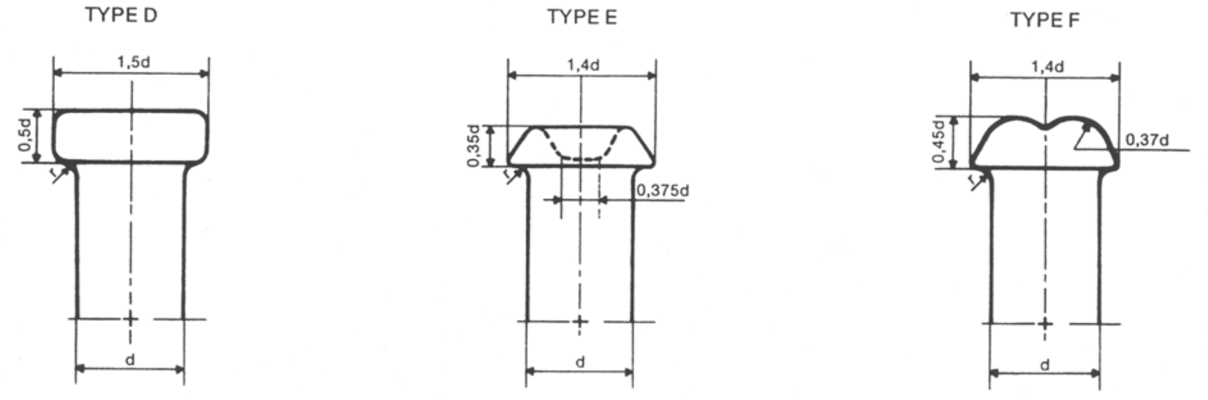


Table 3 : Rivets in aluminium alloy

Diameter of the rivets, in mm			Reaming of rivet holes, in mm		Thickness of plates and sections, in mm
nominal	minimum	maximum	minimum	maximum	
4	3,9	4,0	4,1	4,2	1,5 à 2
5	4,9	5,0	5,1	5,2	2 à 2,5
6	5,9	6,0	6,1	6,2	2,5 à 3
8	7,8	8,0	8,1	8,2	3 à 4
10	9,8	10,0	10,1	10,2	4 à 6
12	11,8	12,0	12,1	12,2	5 à 8
14	13,8	14,0	14,1	14,2	6 à 10
16	15,8	16,0	16,1	16,2	7 à 12
18	17,8	18,0	18,1	18,2	9 à 14
20	19,8	20,0	20,2	20,3	10 à 15
22	21,8	22,0	22,2	22,3	11 à 16
24	23,8	24,0	24,2	24,3	12 à 17
(1) Maximal diameter of rivet recommended for cold use.					

Table 4 : Rivets in aluminium alloy

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.						

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

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 depend on the relative strength required for the joint.

Pitch E is to be at least 2,5 d and at the most 6 d.

For riveting with several rows, the row spacing is to be, as a rule, equal to E for chain-riveting and to 0,75 E 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.

4.4.4 Any jointing system other than classical riveting (high performance fixation, etc.) is to be specially considered.

5 Heterogeneous assembly steel / aluminium alloy

5.1 General

5.1.1 This sub-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 [4.2] apply. Diameters of rivets are given in Tab 3 according to the thickness of the member in aluminium alloy.

5.2.4 Requirements of [4.3] 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 Transition joints are to be type-approved.

5.4.3 Qualification tests for welding procedures are to be carried out for each joint configuration.

5.4.4 A welding booklet giving, for each type of assembly, the preparations and various welding parameters is to be submitted for review.

SECTION 1 GENERAL REQUIREMENTS

1 General

1.1 Application

1.1.1 The characteristics of composite materials to be used in the construction of yachts within scope of Bureau Veritas classification are to comply with the present Chapter.

1.2 General

1.2.1 The composite's characteristics are directly depending on:

- type of resin
- type of fibre
- type of reinforcement fabric
- type of hull's manufacturing process.

All these particulars are taken into account in this Chapter:

- to characterize composite materials from a mechanical point of view
- to define the Bureau Veritas survey and inspection requested for granting the construction marks ✠ or • and for classing the yacht.

1.2.2 The following steps are to be examined within the scope of the classification of a composite yacht, from a structural point of view:

- Raw materials: homologation or equivalent process to grant the construction marks as defined in Ch 12, Sec 2, [6]
- Theoretical characterization of laminates as defined in Ch 12, Sec 3 (individual layer) and Ch 12, Sec 4 (laminate)
- Mechanical sample tests representative of the hull's structure to compare with theoretical analysis as defined in Ch 12, Sec 5, [4]
- Structure drawings examination, as defined in Ch 1, Sec 3
- Preliminary survey of the yard and survey at work as defined in Ch 12, Sec 5, [2] and Ch 12, Sec 5, [3].

1.2.3 The composite materials considered in this present chapter are basically those made from:

- Thermoset resin's systems
- Glass, carbon or para-aramid based reinforcement fabrics
- Manufacturing processes as lay-ups (spray and hand) or vacuums (infusion) or pre-pregs.

Composite materials made of other resin's systems, fibres or manufacturing processes may be accepted provided their specifications are submitted to the Society for approval.

2 Documents to be submitted

2.1 General

2.1.1 As a rule, the drawings and documents to be submitted for examination are listed in Ch 1, Sec 3, Tab 1.

2.2 Laminate

2.2.1 Following information are to be given on drawings:

- arrangement of laminate for the various structural elements: thickness, definition of the successive layers of reinforcement, mass per square meter in layers of reinforcement, proportion in mass of reinforcement of each layer, directions of roving layers and unidirectional reinforcements, decreasing in thicknesses between layers
- direction of laminate in relation with ship structure
- structure of oil tanks or other liquid tanks which are integrated to the hull
- details of connection between various structural elements and details of attachments to the hull of reinforcing supplementary elements
- pillars.

2.3 Individual layer

2.3.1 However, the technical specifications of suppliers with indication of types, trademarks and references of the resins and gel-coats, reinforcements, and core materials are to be supplied.

These specifications have to give the following information:

- for resins: system (polyester, vinylester or epoxy), density, Young modulus, shear modulus, Poisson coefficient, breaking strength and elongation at break
- for reinforcements (unidirectional reinforcements, woven rovings, chopped strand mats): quality (fibre's type, density with breaking strength of the elementary fibre, Young modulus and Poisson coefficient, in fibre direction and normal to fibre direction), mass per square meter, thickness and eventually weft-warp distribution
- for core materials: type and quality, density, tensile, compression and shear strength and elasticity moduli.

SECTION 2 RAW MATERIALS

1 General

1.1 Application

1.1.1 The mechanical characteristics of composite materials depend on raw materials' characteristics.

1.1.2 The present section gives general "state of the art" information about raw materials.

1.2 Definitions

1.2.1 The present chapter describes the main raw materials used in composite boat building.

The raw materials, used in boat building, are of four main types: resin systems, reinforcements, core materials, adhesives.

1.2.2 Resin systems

Also named matrix, resin systems are thermoset resins (initial liquid, hard and stiff cross linked material that does not return liquid when cured). Resin is used to:

- link reinforcements together
- protect them from impact, moisture and abrasion
- spread loads through reinforcements' layers.

Resin systems dealt with in this Chapter are polyester, vinylester and epoxy systems.

1.2.3 Reinforcements

Reinforcement fabrics are used to improve mechanical characteristics of composite materials.

Reinforcement fabrics may be constructed with interlaced yarns or without interlacing, named respectively woven rovings and stitched rovings.

Reinforcement fabrics dealt in this chapter are made of continuous yarns, manufactured with glass, carbon or para-aramid fibres.

1.2.4 Core materials

Core materials are used in composite sandwich structures to improve global moment of inertia of the whole laminate. Sandwich structures are made of two reinforced faces also named skins, separated by and jointed to a core.

Core materials dealt with in this chapter are synthetic foams, natural cores and honeycombs.

1.2.5 Adhesives

Adhesive materials are generally considered as resin systems, and are used to bond together different composite structures or to bond skins to core in sandwich structures.

2 Resin systems

2.1 General

2.1.1 Manufacturing and curing process

As a general rule, thermoset resin systems used in shipbuilding are obtained from a synthetic resin, also named polymer, made of long unsaturated chains of molecules.

The process, which allows to modify the arrangement of molecular chains from free independent chains to a three dimensional linked chains network, is called polymerisation or curing process.

This chemical reaction is observed where resin goes from its liquid state to its solid state. This reaction is accompanied by a heat discharge and is irreversible for thermoset resins.

The three dimensional network is obtained by different curing processes, according to the type of synthetic resin:

- for polyester and vinylester: by mixing synthetic resin with an unsaturated monomer (e.g. styrene) which creates the chemical links. In this case, the chemical reaction needs a catalyst to start the polymerisation process
- for epoxy: by adding a hardener which promotes the polymerisation process. In this case, macromolecular chains are directly linked to each other.

These two different chemical processes have an important effect on mechanical characteristics of the final resin system and particularly on the volumetric shrinkage during the polymerisation (source of stress concentration in the final composite between resin and fibre).

2.1.2 Glass Transition Temperature (Tg)

Glass Transition Temperature (Tg): the state of polymerisation may be appraised by measuring the Tg. This is the approximate temperature at which number of chemical links between molecular chains is significant to change mechanical properties of a cured resin.

The more polymerized is the resin, which means the greater is the number of chemical links between macromolecular chains, higher is the value of Tg.

Where Tg is measured, it is necessary to indicate the reference of the test method, taking into account that the measured value of Tg may vary from one method to another.

For epoxy resin systems in particular, Tg may be increased after the resin polymerisation by a post cure with an additional rise of temperature.

2.1.3 Speed of polymerisation

The speed of polymerisation process may be controlled:

- either by the amount of accelerators for polyester and vinylester resin systems
- or by the amount of a hardener for epoxy resin systems
- or by a controlled rise of temperature speed.

2.1.4 Resin system reference

The resin systems may be affected by:

- the chemical formulation of polymers used (basic resins, unsaturated monomers, catalysts or hardeners)
- the polymerisation process and the additive products used such as thixotropic or coloured agents.

Due to the above, resins are to be used within the limits fixed by the manufacturer. In this respect, the Surveyor may ask any useful justification to be submitted, such as:

- technical data sheet of resin system in a determined cured condition
- manufacturer guarantee for resin used in naval construction (stability regarding ageing in marine environment, resistance to hydrolysis...)
- type and proportion of catalyst, hardener and accelerator recommended by the manufacturer to be adjusted in the different circumstances of conditions of work (ambient atmosphere, i.e. temperature, relative humidity, dust)
- Type approval certificate for resin system granted by a recognized Society.

Note 1: As a general rule, mechanical tests are to be carried out on a panel laminate representative of the hull structure and polymerisation process as defined in Ch 12, Sec 5, [4].

These mechanical tests aim at examining the final performance of the resin system among others.

2.2 Resin systems type

2.2.1 Polyester system

Polyester resin systems are the result of mixing unsaturated polyester resin with an unsaturated monomer, also called co-polymer, and a catalyst. This reaction is named co-polymerisation.

- Monomer: the unsaturated monomer, generally styrene, is used to reduce the initial viscosity of the resin before polymerisation and to create the chemical links between chains of polyester macromolecules. The chemical reactive sites and so the chemical links are located all along the macromolecular chains of polyester.

  This chemical reaction between polyester and styrene leads to the emission of styrene over, not used in the polymerisation. The global chemical polymerisation is stopped where all the styrene over emission is fully completed or where reactive sites of polyester are fully linked.

- Catalyst: generally of organic peroxyde chemical family, catalyst is used to initiate the reaction between polyester and monomer. It does not take part in the chemical reaction.

  The catalyst proportion and its homogeneous mixing with the polyester/styrene resin before moulding are main parameters.

  Too low proportion of catalyst may result in an incomplete polymerisation reaction, which may affect the mechanical properties of the final laminate. The catalyst proportion is to be defined by the resin manufacturer.

- Accelerator: an accelerator may also be added to control the chemical speed of reaction, according to the workshop environment (temperature for example).

  Because the accelerator has no influence to initiate the polymerisation reaction, as long as there is no catalyst, it may be directly added by the manufacturer in the polyester resin system. This type resin is called pre-accelerated.

The polymerisation is carried out at room temperature and goes with an exothermic heat temperature.

The chemical network after polymerisation may be represented by Fig 1.

Two types of polyester resins are used in boat building: orthophtalic and isophtalic.

The mechanical characteristics and the water absorption resistance of isophtalic are higher than of orthophtalic polyester resin. Isophtalic polyester resin is then generally used for gelcoats and in the first layers located after the gelcoat.

The main physical characteristics of polyester resin systems are:

- a high volumetric shrinkage during polymerisation due to the great number of chemical links along polyester macromolecules and to styrene emission
- a moderate breaking strain due to the location of chemical links along polyester macromolecules
- a water absorption sensitivity due to ester functions in polyester macromolecules.

Figure 1 : Polyester

```
- P - RS - P - P - RS - P - RS - P -
      |            |       |
      S            S       S
      |            |       |
- P - RS - P - P - RS - RS - RS - P -
```

RS= Reactive Sites; P= Polyester; S= Styrene

2.2.2 Vinylester resin systems

Vinylester resin systems have the same polymerisation process than polyester systems.

Unsaturated vinylester resins differ from polyesters primary in their chemical structure by:

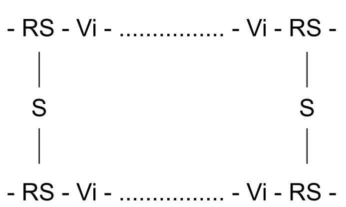
- the location of ester groups and reactive sites at ends of vinylester macromolecular chains
- the lower number of ester groups along chains
- the presence of epoxy groups along the chemical structure.

The chemical network after polymerisation may be represented by Fig 2.

The main physical characteristics of the vinylester resin systems are:

- Lower volumetric shrinkage during polymerisation than polyester, due to the lower number of chemical links between macromolecules
- a higher resistance to the water absorption due to the fewer ester functions along macromolecules of vinylester
- a higher breaking strain and ductility than polyester systems due to the location at ends and fewer number of reactive sites along the macromolecule
- high adhesive characteristics due to the presence, in macromolecules, of polarized molecules able to create non-chemical links (hydrogen type) between macromolecules.

Figure 2 : Vinylester



RS: Reactive site; Vi: Vinylester; S: Styrene.

2.2.3 Epoxy systems

Epoxy resins are made of long macromolecular chains of polymer with epoxy reactive sites located at ends of these chains. Epoxy resin systems polymerisation may be obtained by:

- mixing epoxy molecular chains with a hardener, generally polyamine or acid anhydride
- and/or rising curing temperature. In this case, epoxy sites may directly react during the polymerisation between each other, without need to add a hardener.

One of the two cases here above is necessary to initiate the reaction; and, in both cases, this chemical reaction is called polyaddition.

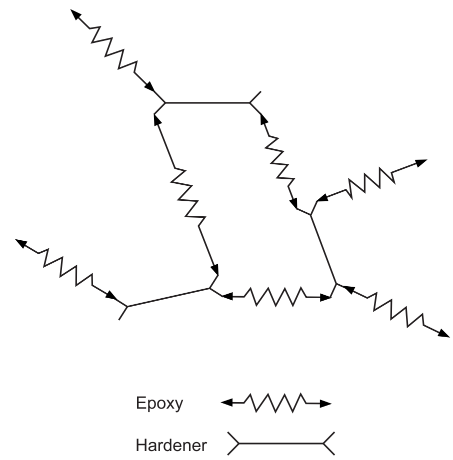
Taking into account that epoxy reactive sites do not need a co-polymer to create chemical links between themselves, the quality of a polymerisation may be increased by a second rise of temperature. This process is named post-cure.

The chemical network after polymerisation of polyepoxyde may be represented as shown in the Fig 3.

The main characteristics of epoxy resins are:

- a low volumetric shrinkage during polymerisation
- a higher breaking strain than polyester and vinylester ones due to the location of the chemical links at macromolecules ends and to the strong resistance of these links
- a high water absorption resistance due to the absence of ester group in the macromolecule
- very high adhesive properties.

Figure 3 : Epoxy



2.3 Homologation of resin systems

2.3.1 General

As a general rule, the resins used in the construction of a yacht are to be certified within the scope of Classification and in particular to assign the construction marks ✠ or •.

This resin system homologation process is described in [6].

2.4 Resins mechanical characteristics

2.4.1 General

As a general rule, the mechanical characteristics of the resin to take into account for laminate calculation are to be given by manufacturer and/or by mechanical test.

2.4.2 The minimum mechanical characteristics are given for information in Tab 1.

3 Reinforcements

3.1 General

3.1.1 As a general rule, the reinforcement fibres need to be arranged into fabric products to make handling possible.

These fabrics are textile structures made from continuous yarns, themselves made from an assembly of monofilaments.

In boat building, continuous yarns and monofilaments are generally named “fibres” and fabrics may also be named “rovings”.

The main mechanical characteristics of reinforcement fabrics taken into account in the present chapter depend on:

- fibre type
- yarns’ nature
- fabrics’ nature.

Table 1 : Resins' mechanical characteristics

	Polyester	Vinylester	Epoxy
Density ρ_m	1,2	1,1	1,25
Poisson coefficient ν_m	0,38	0,26	0,39
Tg (°C)	around 60°	around 100°	between 80° and 150° **(1)**
Tensile Young modulus (MPa) E_m	3550	3350	3100
Tensile or compressive breaking stress (MPa)	55	75	75
Tensile or compressive breaking strain (%)	1,8	2,2	2,5
Shear modulus (MPa) G_m	1350	1400	1500
Shear breaking stress (MPa)	around 50	around 65	around 80
Shear breaking strain (%)	3,8	3,7	5
(1) The actual value of Tg is depending on the polymerisation process used and in particular the temperature used in post-cure			

3.1.2 After fabrication of monofilaments and/or yarns, a surface treatment, named size, is carried on yarns in order to:

- create a cohesion between yarns
- improve the quality of the reinforcement/resin interface
- protect the yarns from manufacturing process.

This size plays a very important part to promote fibre/resin interfacial bond strength. In some cases (carbon and para-aramid fibres), size remains on yarns throughout the fabrics' manufacturing process. In other cases (glass fibre), a first size is applied during yarns' manufacturing to protect monofilaments and a second one is applied during fabric fabrication to improve fibre/resin interface bonding characteristics.

3.1.3 The linear density of a yarn, expressed in tex (g/km), has a direct influence on the strength of a yarn and then on final fabric.

3.1.4 Taking into account that a reinforcement may be affected by the nature of fibre, of yarn, of size or of fabric the Surveyor may ask any useful justification such as technical data sheets of used yarns and/or fabrics to be submitted.

3.1.5 As a general rule, mechanical tests are to be carry out on samples representative of hull laminate structure and polymerisation process as defined in Ch 12, Sec 5, [4].

At this stage, these tests aim at examining performance of yarns and fabrics as well as the fibre/resin interface bond strength.

3.2 Fibre type

3.2.1 Glass

Glass monofilaments are obtained by heating a mixture of silica and alumina up to approximately 1600 °C then by stretching the liquid through a die, made up of holes generally of 5 to 25 µm.

They have the same molecular arrangement than glass plates and then are considered as isotropic materials. It means that the mechanical properties are the same in lengthwise and crosswise directions.

The two main types of glass used in composite shipbuilding are the E and the R types. E-glass is the reference glass, generally used. R-glass has an higher mechanical resistance due to greater percentages of silica and alumina in its chemical composition.

Glass yarns have a standardized designation (ISO 2078), giving following information:

- type of glass
- type monofilament: C for Continuous and D for Discontinuous, commonly and respectively named strand and staple
- diameter of monofilaments in micrometer
- linear density in Tex.

For example, "EC15 800" means E-Glass made from Continuous monofilaments of 15 µm diameter and 800 Tex.

The main physical characteristics of the E-Glass are:

- a good tensile and compressive strength and stiffness
- a relatively poor impact resistance.

The main physical characteristics of R-Glass are the same than E-Glass with an improvement of roughly 20% as well as good interlaminar shear strength properties.

3.2.2 Carbon

Carbon monofilaments are mainly made from Poly-Acrylonitril) (PAN) precursor fibres.

PAN-precursor fibres are first oxidized (between 200°C and 300°C) and then carbonized under inert atmosphere (between 700°C and 1500°C). These steps rearrange the molecular structure into a network of aromatic carbon layers, which are all chemically linked. This chemical process makes the structure different in the lengthwise direction and in the crosswise direction, which explains the orthotropy of carbon monofilaments.

This first stage of fabrication gives the HS Carbon.

This Carbon may undergo an additional stage: a graphitization between 2000°C and 3000°C under inert gaz. This final stage increases the number of aromatic carbon layers and chemical links, which give the monofilaments a higher density and a higher Young modulus. Those types of Carbon are named IM and HM Carbon (respectively Intermediate Modulus and High Modulus).

Another type of Carbon, called Pitch Carbon, is also used in shipbuilding. Pitch-precursor carbon monofilaments are obtained by pitch fusion (between 350°C and 450°C), dying and high stretching. Stretching, which is in addition with the chemical process, gives monofilaments a higher anisotropic molecular arrangement than the HM carbon monofilaments then an even higher Young modulus.

Generally, one has to apply a size to carbon monofilaments in order to improve the quality of reinforcement/resin interface and to protect them from the different steps of reinforcements' fabrication.

The industrial designation of carbon multifilament is as follow. First one gives the type of carbon, then the number of monofilaments into the multifilament, expressed in thousands of monofilaments (e.g. HR-12k Carbon).

The main characteristics of carbon fibres are:

- very high tensile and compressive strength and stiffness
- a very low strength in the normal direction to the fibres' direction
- a relatively poor interlaminar shear strength and impact resistance.

3.2.3 Para-aramid

Aramid (Aromatic ether amid) fibres are organic man-made fibres. Para-aramid is the result of a polycondensation of a polyamine and an aromatic acid around 300°C.

Para-aramid monofilaments are obtained successively by hot-dying, cold-water solidification and "high-speed, high-temperature, dry-air" stretching. Stretching, which is a mechanical process, gives to para-aramid monofilaments a very high-oriented molecular organization in the "fibre" direction. Their behaviour and mechanical properties in transverse and "fibre" directions are then very different.

The main characteristics of the para-aramid fibres are:

- a very high impact resistance
- high tensile strength and stiffness and a poor compressive strength
- a very poor tensile and compressive resistance in transverse direction.

As a general rule, para-aramid are hard to wet by resin systems.

3.2.4 Mechanical characteristics

As a general rule, the mechanical characteristics of fibres to take into account for laminates calculations are to be submitted by manufacturer and/or are given by mechanical tests.

The minimum mechanical characteristics are given in Tab 2 for information.

Table 2 : fibres mechanical properties

		Glass		Carbon			Para-aramid
		E	R	HS	IM **(1)**	HM **(1)**	
Density ρ_f		2,57	2,52	1,79	1,75	1,88	1,45
Tensile in fibre direction	Poisson coefficient ν_f	0,238	0,2	0,3	0,32	0,35	0,38
	Young modulus $E_{f0°}$ (MPa)	73100	86000	238000	350000	410000	129000
	Breaking strain (%)	3,8	4	1,5	1,3	0,6	2,2
	Breaking stress (MPa)	2750	3450	3600	4500	4700	2850
Tensile normal to fibre direction	Poisson coefficient	0,238	0,2	0,02	0,01	0,01	0,015
	Young modulus $E_{f90°}$ (MPa)	73100	86000	15000	10000	13800	5400
	Breaking strain (%)	2,4	2,4	0,9	0,7	0,45	0,7
	Breaking stress (MPa)	1750	2000	135	70	60	40
Compressive in fibre direction	Breaking strain (%)	2,4	2,4	0,9	0,6	0,45	0,4
	Breaking stress (MPa)	1750	2000	2140	2100	1850	500
Shear	Modulus G_f (MPa)	30000	34600	50000	35000	27000	12000
	Breaking strain (%)	5,6	5,6	2,4	3	3,8	4
	Breaking stress (MPa)	1700	1950	1200	1100	1000	500

(1) Taking into account the large diversity of IM and HM carbon, the values presented in this table are given for general guidance only.

3.3 Reinforcement fabrics

3.3.1 General

Usually, reinforcing fibres are arranged into fabric products.

These fabrics may be made by:

- mechanical stitching of fibres (unidirectional fabrics)
- mechanical weaving of fibres (woven fabrics)
- chopped fibre chemically gathered into sheet
- combined fabrics mixing one or other previous described fabric product
- pre-preg fabrics.

Fabrics may be made of different types of fibre, one type of fibre per main fabric direction.

3.3.2 Mechanical characteristics

The mechanical characteristics will be influenced by the fibre type used for fabric products, by the direction and positioning of the fibre in the fabric products, but also by the various distortion of the fibre induced by weaving process, called waviness.

3.3.3 Unidirectionals (UD)

Unidirectionals are fabrics with fibres in one main direction, gathered by mechanical or chemical stitching, respectively with another fibre or a specific adhesive.

The main characteristics of unidirectionals are:

- high tensile and compressive strengths in the fibre direction, due to the high percentage of fibres in fibre direction and also to lack of waviness
- low tensile and compressive strengths in the crosswise fibre direction.

From a theoretical point of view, UD are used as reference for the calculations of elastic coefficients of the other fabric types.

3.3.4 Woven rovings

Woven rovings are made from two sets of fibres criss-crossing, which form a right angle. The one in the weaving direction is named warp, the other one weft. Weaving consists in repeating a basic interlace sequence between warp and weft rovings. This sequence is named basic weave.

The four main weave families used in composite shipbuilding are:

Plains : Each weft fibre passes alternatively under and over each warp fibre. This type of fabric is relatively difficult to drape due to its high stability. The fibres are strongly crisscrossed (high waviness)

Baskets : Similar to plains with an alternative pattern made up of 2 or more weft fibres alternatively interlaced with 2 or more warp fibres (high aviness)

Twills : One or more weft fibres pass alternatively under two or more warp fibres. The main interests of this fabric type are to make easier the drape process and to limit the bend fibre in the weaving process as well as to increase the wet operation, named wetting. This is a moderate waviness fabric

Satins : The weaving pattern is obtained by one or more weft fibres cross several warp fibres and then pass under only one warp fibre. Satins have the same interest than twills with a lower waviness and a higher wetting ability.

As a general rule, the weaving angle between weft and warp is equal to 90°.

The coefficient "woven balance" C_{eq}, indicates for each woven roving the amount of fibre laid in weft and warp direction.

3.3.5 Chopped Strand Mats (CSM)

Chopped strands mats (CSM) are made of fibres chemically gathered to form a web. As fibres are random assembled in the web, there is no main direction. That explains why CSM are considered as isotropic reinforcements.

Mats may be made of fibres shorter than 50mm (Chopped Strand Mats) or longer than 50mm (Continuous Strand Mats).

Chopped Strand Mats mechanical characteristics are low due to the short length of fibres and their non-alignment.

As a general rule, only continuous strands mats (with fibres longer than 50mm) are to be used.

The main characteristics of mats are the nature of fibre, the length of fibres and the area weight.

3.3.6 Combined fabrics

Combined fabrics mainly consist in the assembly by stitching together several reinforcement fabrics as for example:

- woven roving and CSM
- two woven rovings with different orientation (0° for one and 45° for the other) to make a combined fabric with main fibre orientation from -45°, 90°, 0° and 45°
- two UD with orientation equal to -45° and 45° to make a fabric named "bi-bias" or "biax"
- three UD with orientation equal to -45°, 0° and 45° to make a "three directional fabric".

3.3.7 Pre-pregs

The pre-pregs consist in reinforcement fabrics (usually UD, woven roving or combined fabrics) pre-impregnated with a resin system (itself pre-catalysed).

The main advantage of pre-preg fabrics is their accurate resin contents in the reinforcement fabrics.

As a general rule, it is necessary to initiate the polymerisation to activate the chemical reaction by rise in temperature.

3.4 Homologation of reinforcement fabrics

3.4.1 The reinforcements fabrics are to be used within limits fixed by the manufacturer, taking into account the resin systems and laminating process used by the yard.

In this respect, the Surveyor may ask any useful justification to be submitted, such as:

- technical data sheet of reinforcement fabrics, specifying the fibre nature and characteristics
- manufacturer guarantee for the use in shipbuilding.

As a general rule, the reinforcement fabrics in the construction of a yacht are to be certified within the scope of Classification and in particular to assign the construction marks ✠ or •.

The reinforcement fabrics homologation process is described in [6].

4 Core materials

4.1 General

4.1.1 Core materials are used in sandwich composite structures.

The aim of a core material in a composite is to increase the laminate stiffness by increasing its thickness. The core material acts similar to the web of a beam, and so is basically subject to shear forces.

The main characteristics of a core material are low density, shear strength and also capacity to take compressive and shear loading without buckling failure.

Three main families are used as core material:

- foam cores obtained from expanded synthetic resins
- natural material, mainly balsa wood
- manufactured material such as honeycombs.

4.2 Foam cores

4.2.1 General

Foam cores may be manufactured from a large variety of synthetic resins and in a large range of densities and thicknesses.

All the foam cores are to have closed cells to avoid water migration.

The foam cores are to be compatible with resin systems and adhesives used and must withstand to temperature when they are used for pre-pregs process or post-cure process.

Some foam cores need to be heat treated before use to reduce the amount of gassing given when they are submitted to temperature rising during laminating process such as post-cure or pre-preg work.

It is to the manufacturer responsibility to define the process of this operation.

The foam materials are to be used within the limits fixed by the manufacturer and in particular for their compatibility with resin and adhesive systems used and working process when rising temperature is provided.

The purpose of the present subarticle is to describe the main mechanical characteristics of the most used foam cores in shipbuilding.

4.2.2 PVC foam (PolyVinyl Chloride)

The main characteristics of PVC foams are highly resistant to water absorption, to many chemical products and in particular styrene used in polyester and vinylester resin systems.

There are two different types of PVC foams: cross linked PVC and uncross linked PVC (also named linear PVC). The linear PVC foam is more flexible and their mechanical properties are lower than cross linked ones. Cross linked PVC are however more brittle than uncrossed PVC.

4.2.3 PU foam (Polyurethan)

As a general rule, PU foams are only used for lightly loaded structures and as frame or girder formers.

Their mechanical characteristics are relatively low, and the interface between foam and skins may be subject to brittleness with ageing.

4.2.4 PMI foam (Polymethacrylimide)

The PMI foams are used for their high strength and stiffness. They are also used in construction process requiring temperature rising (pre-pregs for example) due to high dimensional stability.

4.2.5 SAN foam (Styrene Acrylo Nitrile)

The main SAN foam characteristic is highly resistant to impact loads.

Their mechanical characteristics are similar to cross linked PVC with higher elongation and toughness.

4.3 Homologation of foam cores

4.3.1 The foam cores are to be used within the limits fixed by the manufacturer.

In this respect, the Surveyor may ask any useful justification to be submitted, such as:

- technical data sheet of foam
- manufacturer guarantee regarding work process.

As a general rule, the foam cores used in the construction of a yacht are to be certified within the scope of Classification and in particular to assign the construction mark ✠ or •.

The foam cores homologation process is described in [6].

4.3.2 As a general rule, mechanical characteristics of the foam cores to take into account for sandwich calculations are to be given by manufacturer and/or are given by mechanical tests.

For information only, the standard mechanical characterisitcs of different types of foam cores in relation to their density are given in Tab 3.

Table 3 : Foams

	Voluminal mass (kg/m^3)	Modulus			Breaking Stresses			Poisson coefficient ν_{12} , ν_{21}
		Tensile E_1 , E_2 (MPa)	Compressive E_3 (MPa)	Shear G_{12} , G_{13} , G_{23} (MPa)	Tensile σ_1, σ_2 (MPa)	Compressive σ_1, σ_2 (MPa)	Shear τ_{12} , τ_{13} , τ_{23} (MPa)	
PVC Linear	50	21	18	8	0,7	0,3	0,3	0,36
	60	29	28	11	0,9	0,4	0,5	0,31
	70	37	38	14	1,1	0,6	0,7	0,27
	80	44	49	18	1,3	0,7	0,8	0,25
	90	52	59	21	1,4	0,9	1,0	0,24
	100	59	69	24	1,6	1,0	1,2	0,23
	110	67	79	27	1,8	1,2	1,3	0,22
	130	82	99	34	2,2	1,5	1,7	0,21
	140	89	109	37	2,4	1,6	1,9	0,21
PVC cross linked	50	37	40	18	1,0	0,6	0,6	0,02
	60	47	51	22	1,4	0,8	0,8	0,05
	70	57	63	27	1,8	1,1	1,0	0,07
	80	67	75	31	2,2	1,4	1,1	0,08
	90	78	88	36	2,5	1,7	1,3	0,09
	100	88	102	40	2,9	1,9	1,5	0,10
	110	98	116	44	3,3	2,2	1,6	0,11
	130	118	145	53	3,9	2,8	2,0	0,12
	140	129	161	57	4,3	3,0	2,2	0,12
	170	159	209	71	5,2	3,8	2,7	0,13
	190	180	243	79	5,8	4,4	3,0	0,13
	200	190	260	84	6,1	4,7	3,2	0,13
	250	241	352	105	7,4	6,0	4,1	0,14
SAN	50	52	29	13	0,9	0,4	0,7	0,11
	60	65	37	16	1,2	0,5	0,8	0,18
	70	78	44	18	1,5	0,6	0,9	0,20
	80	92	50	21	1,7	0,8	1,0	0,19
	90	107	55	23	1,9	0,9	1,1	0,17
	100	122	60	26	2,0	1,1	1,2	0,15
	110	137	64	29	2,2	1,2	1,3	0,12
	130	168	71	34	2,5	1,6	1,5	0,06
	140	184	74	36	2,6	1,8	1,6	0,03
	170	234	83	43	2,9	2,4	1,9	0,03
	190	268	88	48	3,1	2,8	2,1	0,03
	200	285	90	51	3,1	3,0	2,1	0,03
PMI	50	54	59	21	1.9	0.8	0.8	0.4
	60	69	76	24	2.1	1.1	1.0	0.6
	70	84	94	28	2.3	1.5	1.2	0.6
	80	101	112	33	2.6	1.9	1.5	0.7
	90	119	132	39	2.9	2.3	1.8	0.7
	100	137	152	45	3.2	2.7	2.1	0.7
	110	155	173	52	3.6	3.2	2.4	0.6
	130	195	217	71	4.5	4.2	3.1	0.5
	140	215	239	83	5.0	4.8	3.5	0.4
	170	280	311	131	6.8	6.7	4.7	0.2

The values presented in this table are given for general guidance only.

Note 1: τ_{13} and τ_{23} are identical to respectively τ_{IL2} and τ_{IL1}

Table 4 : Balsa

	Voluminal mass (kg/m^3)								
	80	96	112	128	144	160	176	192	240
Young modulus (MPa), parallel to sandwich in-plane E_1 , E_2	23	33	42	51	61	71	80	89	116
Young modulus (MPa), normal to sandwich in-plane E_3	1522	2145	2768	3460	4083	4706	5328	5882	7750
Shear modulus (MPa), normal to sandwich in-plane G_{13} , G_{23}	57	80	103	127	150	174	197	218	286
Shear modulus (MPa), parallel to sandwich in-plane G_{12}	40	55	70	90	105	120	140	150	200
Coefficient ν_{12} , ν_{21}	0,015	0,015	0,015	0,015	0,015	0,015	0,015	0,015	0,015
Breaking compressive (MPa), normal to sandwich in-plane σ_3	3,53	5,12	5,95	8,17	9,69	11,35	12,80	14,32	18,96
Breaking traction (MPa), parallel to sandwich in-plane σ_1 , σ_2	0,28	0,34	0,42	0,51	0,56	0,64	0,69	0,78	1
Breaking compressive (MPa), parallel to sandwich in-plane σ_1 , σ_2	0,48	0,58	0,71	0,87	0,95	1,1	1,17	1,33	1,7
Shear breaking (MPa), through sandwich thickness τ_{13} , τ_{23}	0,94	1,1	1,33	1,62	1,73	1,93	2,05	2,33	2,93
Shear breaking (MPa), parallel to sandwich in-plane τ_{12}	0,7	0,9	1,2	1,5	1,8	2	2,3	2,5	3,4
The values presented in this table are given for general guidance only. **Note 1:** τ_{13} and τ_{23} are identical to respectively τ_{IL2} and τ_{IL1}									

4.4 Natural materials

4.4.1 General

The natural material used is the wood, and so the mechanical characteristics of wood as core are intrinsically linked to the structure of wood used.

Two main technics are used to make sandwich with wood core which differ from the wood grain orientation in relation to the sandwich plane:

- wood grain running normal to the sandwich plane (balsa). In this case, the wood core behaviour is similar to foams or honeycombs.
- wood grain running parallel to the sandwich plane (cedar for example). In this case, in addition to ensuring stiffness and shear resistance of the sandwich, the wood core directly takes part to the global sandwich bending due to significant stiffness.

4.4.2 Balsa

The main mechanical characteristics of balsa are:

- high compressive and shear strength
- high stability where heated.

Balsa is available in a large range of density and thickness.

Where balsa is used with high density and thickness, the grain may be transversally solicited by the global sandwich bending.

For information, the standard mechanical characteristics of the balsa core material in relation to their density are given in Tab 4.

4.4.3 Red cedar

Red cedar is generally used in typical construction, named "strip planking". With its wood grain running parallel to the sandwich plane, the cedar is also participating to bending stress located perpendicular to the cedar grain where its resistance is weaker.

For information, the main mechanical characteristics of red cedar, for a voluminal mass equal to 350 kg/m^3, are in Tab 5.

Table 5 : Red cedar

Young modulus (MPa), parallel to grain E_1	6000
Young modulus (MPa), perpendicular to grain E_2 , E_3	300
Shear modulus (MPa) G_{12}	350
Shear modulus (MPa) G_{23}	250
Shear modulus (MPa) G_{13}	350
Coefficient ν_{12}	0,47
Coefficient ν_{21}	0,02
Breaking traction (MPa), parallel to grain direction σ_1	40
Breaking traction (MPa), perpendicular to grain direction σ_2	1,5
Breaking compressive (MPa), parallel to grain direction σ_1	25
Breaking compressive (MPa), perpendicular to grain direction σ_2	2,5
Breaking, shear stress (MPa) τ_{12} , τ_{13} , τ_{IL2}	5
Breaking, shear stress (MPa) τ_{23} , τ_{IL1}	10
The values presented in this table are given for general guidance only.	

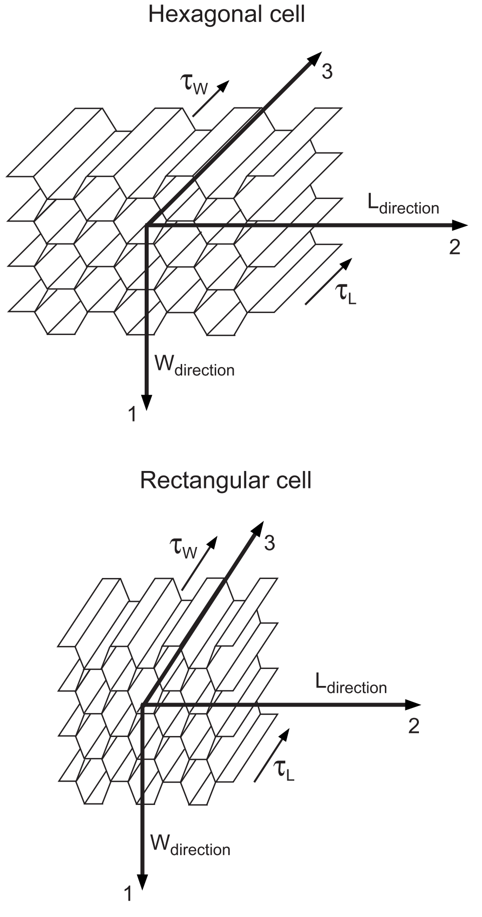
4.5 Honeycombs

4.5.1 General

Honeycombs are cores whose geometry is described as shown in Fig 4. Honeycomb cores are available in a large range of materials (meta-aramid, thermoplastic resins), cell shape and size thickness. The cells' shapes are closely linked to the manufacturing process of the honeycomb.

All these parameters act upon the final mechanical characteristics of the honeycomb core.

Figure 4 : Honeycombs



4.5.2 Thermoplastic honeycombs

The most common polymers used for thermoplastic honeycombs are polyethylen, polycarbonate and polypropylene.

As a general rule, these thermoplastic honeycomb cores have relatively low stiffness and mechanical characteristics and are difficult to bond with the sandwich skins.

The cell shape may be diverse due to the fact that these honeycomb cores are obtained by extrusion process.

The use of thermoplastic honeycombs is submitted to a special examination on a case by case basis due to the important diversity of these cores and their temperature sensitiveness.

Special examination is mainly carried out through mechanical tests to estimate the interface and shear resistance of the core in a sandwich construction.

4.5.3 Meta-aramid honeycombs

The meta-aramid honeycomb cores are obtained from an aramid paper, dipped in resin system.

The density of the aramid paper directly acts upon the shear characteristics while the dip operation in resin acts on the compressive characteristics of the honeycomb.

Note 1: Two honeycombs with same density may differ from a mechanical point of view (shear and compressive stresses) in relation to their respective paper thickness and number of dip operations in resin.

Two main cell shapes are available: hexagonal and rectangular. Second shape is being obtained from the hexagonal one with an over expand mechanical operation.

The main advantage of the rectangular cell shape is its curving ability.

From mechanical characteristics point of view, the two main particulars of honeycomb are:

- shear characteristics are different in the two directions of a honeycomb sheet
- for a given honeycomb, shear stress depends on its thickness.

Honeycomb cores are mainly used with pre-pregs process. Honeycomb sheets need to be heat-treated before use to reduce the amount of gassing where they are submitted to temperature rising during pre-preg process.

This material, relatively difficult to stick to sandwich skins must be dust-free and cleaned before use.

For information, the standard mechanical characteristics of meta-aramid honeycombs in relation to their density, cell size, and thickness are given in Tab 6.

Note 2: The failure mode under traction and compressive stresses along L and W directions as well as in plane shear stresses are not dependent on honeycomb characteristics only but also on the characteristics of the global sandwich laminates (core thickness and skins characteristics).

These failure modes are estimated on a case by case by mechanical tests as defined in Ch 12, Sec 5.

5 Structural adhesives

5.1 General

5.1.1 In the present article, the structural adhesive is used to create a structural connection between:

- two composite structures, already cured, as for example the deck/hull gluing
- one composite structure, already cured, with another element, not cured, as for example the stiffener matting-in with the hull
- two raw materials, as for example, the gluing of the foam core with a sandwich skin
- two elements of different kinds, as for example, the windows / hull assembly.

Table 6 : Meta-aramid honeycombs

Voluminal mass	Hexagonal								
	E_1 (in W direction)	E_2 (in L direction)	G_{12}	G_{13}	G_{23}	ν_{12}	ν_{21}	τ_{13} (in L direction), τ_{IL2}	τ_{23} (in W direction), τ_{IL1}
48	13	16	3	37	25	0,82	0,82	1,2	0,7
50	13,6	17	3,3	39	26	0,82	0,82	1,3	0,75
56	14	18	4,1	46	30	0,82	0,82	1,5	0,85
64	17	20	5	59	38	0,82	0,82	1,8	1
96	21	27	6	87	57	0,82	0,82	3	1,7

Voluminal mass	Rectangular								
	E_1 (in W direction)	E_2 (in L direction)	G_{12}	G_{13}	G_{23}	ν_{12}	ν_{21}	τ_{13} (in L direction), τ_{IL2}	τ_{23} (in W direction), τ_{IL1}
48	105	12,5	1,5	19	36	0,263	0,263	0,75	0,8
50	108	12,8	1,6	19,5	37	0,263	0,263	0,8	0,85
56	114	13	1,9	21	40	0,263	0,263	0,95	0,9
64	135	13,5	2,1	23,5	43,5	0,263	0,263	1,1	1
96	180	15,5	3,3	31	58	0,263	0,263	1,9	1,5

Note 1: The values presented in this table are given for general guidance only. The mechanical characteristics given by the supplier and taking into account the cell size and paper thickness of the honeyycombs are to be taken into account for rules calculations.
Note 2: τ_{13} and τ_{23} are identical to respectively τ_{IL2} and τ_{IL1}

5.1.2 The main mechanical characteristics of a structural gluing joint mainly depends on the following parameters:

- resin systems and additives such as thixotropic agents
- type of the components to be bonded as well as their surface preparation (abrasing, cleaning,...)
- geometry and thickness of the bonded joint
- curing process of the bonded joint.

5.2 Structural adhesive characteristics

5.2.1 The large range of adhesive resin systems, curing adhesive process, type of components to be bonded and the large variety of joint geometry do not permit to define typical mechanical characteristics.

As a general use, the mechanical values to take into account are given by the manufacturer, paying attention to the mechanical type tests context from which the mechanical values are taken from.

5.2.2 As a general rule, a maximum breaking shear stress from 5 N/mm^2 to 10 N/mm^2 (for high performance bonding) is usually considered.

6 Raw materials certification

6.1 Construction marks

6.1.1 Definition

Construction mark refers to the mode of survey of raw materials used in construction of a yacht and is granted in scope of classification.

6.1.2 The possible construction marks are:

- Construction mark ✠ where the principal raw materials are homologated or surveyed at works (or on reception at the yard) by the Society
- Construction mark • where the principal raw materials have not been surveyed by the Society under the terms of one of the previous schemes; in this case, the yard is responsible for ensuring that the raw materials comply with the Society's requirements.

6.1.3 Principle of assignment of construction marks

This article stipulates the arrangements to be adopted in assigning the construction marks ✠ or •.

Materials concerned by certification are:

- gel-coats and laminating resins
- reinforcement fabrics
- core materials for sandwich laminates.

Other materials may occasionally be submitted for Society approval (e.g. adhesives or structural plywoods).

Note 1: The purpose of survey of raw materials by the Society is to ensure compliance with the requirements of the relevant Society's Rules (within the framework of theoretical calculation of the mechanical properties of the composite). However, the findings of such surveys are not to be used as the only basis for the order specification. The Yard must issue a proper specification to its Supplier.

6.2 Assignment of construction mark ✠

6.2.1 General

The construction mark ✠ is assigned when one of the following modes of survey of raw materials is used:

- Homologation of raw materials

- Acceptance of specific mechanical tests carried out on raw materials used for construction
- Homologation already granted by another Society, recognized by Bureau Veritas.

6.2.2 Homologation of successive stages

The homologation of raw materials requests two successive stages:

- Type approval
- Homologation itself.

6.2.3 Type Approval

The Society ensures that certain technical data in the Supplier data sheets comply with the relevant requirements of the Society's Rules.

A test programme, drawn up jointly by the Supplier and the Society, is performed, and the results are examined, so that the declared properties may be confirmed.

For information, the standards' test programme is generally as follows:

- Gel coats:
  - Tensile test (modulus, elongation): ISO 527 or equivalent
  - Moisture absorbency: Standard ISO 62 or equivalent
- Resin:
  - Density: ISO 1675 or equivalent
  - Tensile test (modulus and breaking strength): ISO 527 or equivalent
  - compressive test (modulus and breaking strength): ISO 604 or equivalent
  - Shear test (modulus and breaking strength): ISO 1922 or equivalent
  - Voluminal shrinkage: ISO 3521 or equivalent
  - Glass Transition Temperature: ISO 11357 or ISO 11359 or equivalent
- Reinforcements fabrics:
  - Surface weight: ISO 3374 or equivalent
  - Tensile test: ISO 4604 and ISO 4606 or equivalent
- Prepregs:
  - Glass content: ISO 9782 or equivalent
  - Surface weight: ISO 10352 or equivalent
- Core materials - foams:
  - Density: ISO 845 or equivalent
  - Tensile test (modulus and breaking strength): ISO 1926 or equivalent
  - compressive test (modulus and breaking strength): ISO 844 or equivalent
  - Shear test (modulus and breaking strength): ISO 1922 or equivalent
- Core materials - balsa:
  - Density: ISO 3131 or equivalent
  - Shear strength: ISO 8905 or equivalent
- Core materials honeycombs: Test program to be defined with the Society.

Certain tests may be dropped from this list, and other additional tests requested, depending on the particular use of materials, or experience acquired with such materials.

Reports, issued in the forms stipulated in standards, are submitted to the Society for examination.

Tests are generally done either in laboratories recognized by Bureau Veritas, or in presence of the Surveyor. In the former case, the laboratory reference is stated.

Samples may be taken from the production line or from stocks at the Supplier. Sampling conditions must also be stated by the Supplier.

A type approval certificate is issued for each type of raw material.

6.2.4 Homologation of raw materials

During homologation, the Society checks that the Supplier of mass-produced raw materials is capable of reproducing satisfactory the products examined during type approval. For this purpose, the Supplier must submit documents on the various phases described below, as a basis for survey of the production line by the Surveyor:

- Organisation and means of production of raw materials for homologation
- Procedures for purchase, acceptance testing and storage of various materials used in the manufacture of the products
- Procedures for manufacturing of the products
- Survey procedures used during production phases
- Tests and surveys performed on completion of production.

6.2.5 Acceptance of specific mechanical tests

On a case by case basis, where raw materials are not homologated as defined in [6.3], specific mechanical tests, based on these defined in Ch 12, Sec 5, [4], may be accepted by the Society.

The raw material samples are to be defined in accordance with the Society.

6.3 Assignment of construction mark •

6.3.1 The construction mark • is assigned where one of the forms of survey of raw materials, described in [6.2], is not applied.

In this case, the yard is responsible for ensuring that the materials used in the construction meet the relevant requirements of the Society's Rules.

SECTION 3 INDIVIDUAL LAYER

1 General

1.1 Application

1.1.1 General

The present Section deals with the methodology to estimate the five elastic coefficients and the six breaking stresses requested to define the breaking strength of an individual layer.

The in-plane elastic coefficients to take into account are:

- a longitudinal Young's modulus
- a transverse Young's modulus
- two Poisson's coefficients
- a shear modulus.

The theoretical breaking stresses to estimate are:

- in-plane longitudinal tensile and compressive breaking stresses
- in-plane transverse tensile and compressive breaking stresses
- in-plane shear breaking stress
- interlaminar shear breaking stress.

Two geometric parameters are also to be defined:

- the individual layer's thickness
- the individual layer's density (or weight per surface unit).

1.1.2 Methodology

Coefficients, breaking stresses and geometric parameters defined in [1.1.1] are based on the Society experience and take into account:

- the type of raw material as defined in Ch 12, Sec 2
- the fibre/resin mix ratio
- the laminating and curing processes used for the composite work
- the type of stress in relation to the reinforcement's orientation.

Whatever the type of reinforcement making up the individual layer, the first step of the methodology consists in estimating the elastic coefficients of a unidirectional (UD) fabric having same raw materials and content of fibre than the considered individual layer to calculate.

Where unusual individual layers are used (due to specific raw materials or laminating process), the Society may request mechanical tests to be performed in order to evaluate elastic coefficients and/or breaking stresses and compare them to the present Rule theoretical approach.

1.1.3 Symbols

Symbols used in the formulae of the present Section are:

C_{eq} : Woven balance coefficient for woven rovings. See [3.2.2].

e : Individual layer thickness, in mm

$E_{f0°}$: Longitudinal Young's modulus of fibre, in MPa (see Note 1)

$E_{f90°}$: Transversal Young's modulus of fibre, in MPa (see Note 1)

E_m : Young's modulus of resin, in MPa (see Note 1)

G_f : Shear modulus of fibre, in MPa (see Note 1)

G_m : Shear modulus of resin, in MPa (see Note 1)

m : Total mass per square meter of individual layer, in gr/m^2

M_f : Content in mass of fibre in an individual layer, in %

M_m : Content in mass of resin in an individual layer, in %

P_f : Total mass per square meter of dry reinforcement fabric, in g/m^2

V_f : Content in volume of fibre in an individual layer, in %

V_m : Content in volume of resin in an individual layer, in %

ν_f : Poisson's coefficient of fibre

ν_m : Poisson's coefficient of resin

ρ : Density of an individual layer

ρ_f : Density of fibre

ρ_m : Density of resin.

Note 1: Minimum mechanical characteristics are given, for information only, in Ch 12, Sec 2, Tab 1and Ch 12, Sec 2, Tab 2.

2 Geometrical and physical properties of an individual layer

2.1 fibre/resin mix ratio

2.1.1 The fibre/resin mix ratio of an individual layer can be expressed in:

- mass or volume, and
- resin or reinforcement.

The contents in mass are obtained from the following formulae:

- M_f = fibres' mass (gr/m²)/individual layer's mass (gr/m²)
- M_m = resin's mass (gr/m²)/individual layer's mass (gr/m²)
- V_f and V_m are defined in [1.1.3].

$$V_f = \frac{(M_f / \rho_f)}{(M_f / \rho_f) + ((1 - M_f) / \rho_m)}$$

$$V_m = 1 - V_f$$

$$M_f = \frac{(V_f \times \rho_f)}{(V_f \times \rho_f) + ((1 - V_f) \times \rho_m)}$$

$$M_m = 1 - M_f$$

with all parameters defined in [1.1.3].

2.1.2 The resin/fibre mix ratio is to be specified by the shipyard and depends on the laminating process.

For information only, the common ratio values are given in Tab 1.

2.2 Individual layer's thickness

2.2.1 The individual layer's thickness, in mm, can be expressed from the fibre's content, in mass or in volume, by the following formulae:

$$e = \frac{\left(P_f \cdot \left(\frac{1}{\rho_f} + \frac{1 - M_f}{M_f \cdot \rho_m}\right)\right)}{1000}$$

$$e = \frac{P_f / (V_f \cdot \rho_f)}{1000}$$

with all parameters defined in [1.1.3].

2.3 Mass, voluminal mass and density of an individual layer

2.3.1 The density of an individual layer is obtained by the following formula:

$$\rho = \rho_f \times V_f + \rho_m \times (1 - V_f)$$

with all parameters defined in [1.1.3].

3 Elastic coefficient of an individual layer

3.1 Unidirectionals

3.1.1 Reference axis

The reference axis system for a unidirectional is as follows (see Fig 1):

- 1 : axis parallel to the fibre's direction
- 2 : axis perpendicular to the fibre's direction
- 3 : axis normal to plane containing axis 1 and 2, leading to direct reference axis system.

The reference axis for an elementary fibre is defined as follows (see Fig 2):

- 0° : Longitudinal axis of the fibre
- 90° : Transverse axis of the fibre.

Figure 1 : Reference axis for unidirectionals

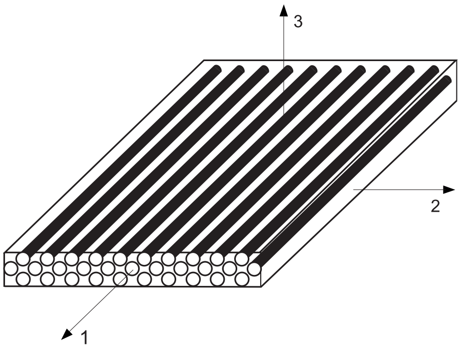
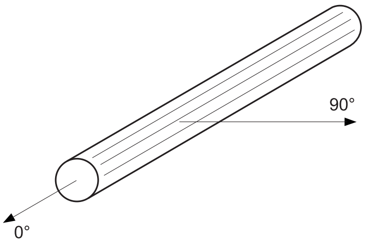


Figure 2 : Reference axis of an elementary fibre



3.1.2 Elastic coefficients

The elastic coefficients of an unidirectional are estimated by the following formulae, with all parameters defined in [1.1.3]:

- Longitudinal Young's modulus E_{UD1}, in MPa:

$$E_{UD1} = C_{UD1} \times (E_{f0°} \times V_f + E_m \times (1 - V_f))$$

- Transverse Young's moduli E_{UD2} and E_{UD3}, in MPa:

$$E_{UD2} = E_{UD3} = C_{UD2} \times \left(\left(\frac{E_m}{1 - \nu_m^2}\right) \times \frac{1 + 0{,}85 \cdot V_f^2}{(1 - V_f)^{1,25} + \frac{E_m}{E_{f90°}} \times \frac{V_f}{1 - \nu_m^2}}\right)$$

- Shear moduli, in MPa:

$$G_{UD12} = G_{UD13} = C_{UD12} \cdot G_m \times \frac{1 + \eta \cdot V_f}{1 - \eta \cdot V_f}$$

$$\text{with} \quad \eta = \frac{\left(\frac{G_f}{G_m}\right) - 1}{\left(\frac{G_f}{G_m}\right) + 1}$$

$$G_{UD23} = 0{,}7 \cdot G_{UD12}$$

- Poisson's coefficients:

$$\nu_{UD13} = \nu_{UD12} = C_{UD\nu} \times (\nu_f \times V_f + \nu_m \times (1 - V_f))$$

$$\nu_{UD21} = \nu_{UD31} = \nu_{UD12} \times \frac{E_{UD2}}{E_{UD1}}$$

$$\nu_{UD23} = \nu_{UD32} = C_{UD\nu} \times (\nu_f' \times V_f + \nu_m \times (1 - V_f))$$

$$\text{with} \quad \nu_f' = \nu_f \cdot \frac{E_{f90°}}{E_{f0°}}$$

The coefficients C_{UD1}, C_{UD2}, C_{UD12} and $C_{UD\nu}$ are experimental coefficients taking into account the specific characteristics of fibre's type. They are given in Tab 2.

Table 1 : Resin / fibre mix ratios (in %)

Laminating Process		V_f	M_f		
			Glass	Carbon	Para-aramid
Hand Lay-up	Mat	from 15 to 20	from 25 to 35	-	-
	Roving	from 25 to 40	from 40 to 60	from 35 to 50	from 30 to 45
	Unidirectional	from 40 to 50	from 60 to 70	from 50 to 60	from 45 to 55
Infusion		45	60	55	50
Pre-pregs		from 55 to 60	from 60 to 70	from 65 to 70	from 60 to 65

Table 2 : Coefficients C_{UD1} , C_{UD2}, C_{UD12} and C_{UDv}

	E-glass	R-Glass	Carbon HS	Carbon IM	Carbon HM	Para-aramid
C_{UD1}	1	0,9	1	0,85	0,9	0,95
C_{UD2}	0,8	1,2	0,7	0,8	0,85	0,9
C_{UD12}	0,9	1,2	0,9	0,9	1	0,55
C_{UDv}	0,9	0,9	0,8	0,75	0,7	0,9

3.2 Woven Rovings

3.2.1 Reference axis

The reference axis defined for woven rovings are the same than for unidirectionals with the following denomination:

- 1 : axis parallel to warp direction
- 2 : axis parallel to weft direction
- 3 : axis normal to plane containing axis 1 and 2, leading to direct reference axis system.

3.2.2 Woven balance coefficient C_{eq}

The woven balance coefficient is equal to the mass ratio of dry reinforcement in warp direction to the total dry reinforcement of woven fabric.

3.2.3 Elastic coefficients

The elastic coefficients of woven rovings as individual layers are estimated by the following formulae:

- Young's modulus in warp direction E_{T1}, in MPa:

$$E_{T1} = \frac{1}{e} \cdot \left(A_{11} - \frac{A_{12}^2}{A_{22}}\right)$$

- Young's modulus in weft direction E_{T2}, in MPa:

$$E_{T2} = \frac{1}{e} \cdot \left(A_{22} - \frac{A_{12}^2}{A_{11}}\right)$$

- Out-of-plane Young's modulus E_{T3}, in MPa:

$$E_{T3} = E_{UD3}$$

- Shear moduli G_{12}, G_{23} and G_{13}, in MPa:

$$G_{T12} = \frac{1}{e} \cdot A_{33} \quad \text{and} \quad G_{T23} = G_{T13} = 0,9 \cdot G_{T12}$$

- Poisson's coefficients:

$$\nu_{T12} = \frac{A_{12}}{A_{22}}$$

$$\nu_{T21} = \nu_{T12} \cdot \frac{E_{T2}}{E_{T1}}$$

$$\nu_{T32} = \nu_{T31} = (\nu_{UD32} + \nu_{UD31})/2$$

$$\nu_{T13} = (\nu_{UD23} + \nu_{UD13})/2$$

where:

$$A_{11} = e \cdot (C_{eq} \cdot Q_{11} + (1 - C_{eq}) \cdot Q_{22})$$

$$A_{22} = e \cdot (C_{eq} \cdot Q_{22} + (1 - C_{eq}) \cdot Q_{11})$$

$$A_{12} = e \cdot Q_{12}$$

$$A_{33} = e \cdot Q_{33}$$

with:

$$Q_{11} = E_{UD1}/(1 - (\nu_{UD12} \cdot \nu_{UD21}))$$

$$Q_{22} = E_{UD2}/(1 - (\nu_{UD12} \cdot \nu_{UD21}))$$

$$Q_{12} = (\nu_{UD21} \cdot E_{UD1})/(1 - (\nu_{UD12} \cdot \nu_{UD21}))$$

$$Q_{33} = G_{UD12}$$

Note 1: Parameters with suffix UD are defined in [3.1].

3.3 Chopped Strand Mats

3.3.1 General

A chopped strand mat is made of cut fibres, random arranged and supposed uniformly distributed in space. It is assumed as isotropic material.

3.3.2 Elastic coefficients

Isotropic assumption makes possible to define only three elastic coefficients obtained by the following formulae:

- Young's moduli, in MPa:

$$E_{mat1} = E_{mat2} = \frac{3}{8} \cdot E_{UD1} + \frac{5}{8} \cdot E_{UD2}$$

$$E_{mat3} = E_{UD3}$$

- Poisson's coefficient is as all isotropic materials:

$$\nu_{mat12} = \nu_{mat21} = \nu_{mat32} = \nu_{mat13} = 0,3$$

- Shear moduli, in MPa:

$$G_{mat12} = E_{mat1}/(2 \cdot (1 + \nu_{mat21}))$$

$$G_{mat23} = G_{mat31} = 0,7 \cdot G_{UD12}$$

Where parameter with suffix UD are defined in [3.1].

Note 1: Parameters with suffix UD are defined in [3.1].

3.4 Combined fabrics

3.4.1 Combined fabrics, as defined in Ch 12, Sec 2, [3.3.6], are to be considered as a series of individual layers such as unidirectionals, woven rovings or chopped strand mats. Each component is analysed as defined in [3.1], [3.2] or [3.3] accordingly to type of reinforcement fabric.

4 Rigidity and flexibility of an individual layer

4.1 In-plane characteristics

4.1.1 General

Rigidity and flexibility of an individual layer need to be determined to perform the mechanical calculations of a laminate, made of several individual layers, as defined in Ch 12, Sec 4.

4.1.2 Rigidity

The rigidity $\bar{R}$, defined in the individual layer coordinate system, is as follows:

$$[\sigma]_{1,2} = [\bar{R}] \cdot [\varepsilon]_{1,2}$$

where [σ] is the matrix of in-plane stresses, [ε] is the matrix of in-plane strains and [$\bar{R}$] local matrix of rigidity.

Or under matrix notation:

$$\begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{bmatrix} = \begin{bmatrix} \bar{R}_{11} & \bar{R}_{12} & 0 \\ \bar{R}_{21} & \bar{R}_{22} & 0 \\ 0 & 0 & \bar{R}_{33} \end{bmatrix} \cdot \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{bmatrix} \quad \text{with} \quad \bar{R} = \begin{vmatrix} \bar{R}_{11} & \bar{R}_{12} & 0 \\ \bar{R}_{21} & \bar{R}_{22} & 0 \\ 0 & 0 & \bar{R}_{33} \end{vmatrix}$$

Elements of matrix of rigidity are specific to types of reinforcement and define in Tab 3.

4.1.3 Flexibility

The flexibility $\bar{S}$, defined in the individual layer coordinate system, is as follow:

$$[\varepsilon]_{1,2} = [\bar{S}] \cdot [\sigma]_{1,2}$$

where σ and ε are defined in [4.1.2] and [$\bar{S}$] local individual layer flexibility matrix.

Or under matrix notation:

$$\begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{bmatrix} = \begin{bmatrix} \bar{S}_{11} & \bar{S}_{12} & 0 \\ \bar{S}_{21} & \bar{S}_{22} & 0 \\ 0 & 0 & \bar{S}_{33} \end{bmatrix} \cdot \begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{bmatrix} \qquad \bar{S} = \begin{vmatrix} \bar{S}_{11} & \bar{S}_{12} & 0 \\ \bar{S}_{21} & \bar{S}_{22} & 0 \\ 0 & 0 & \bar{S}_{33} \end{vmatrix}$$

Elements of matrix of flexibility are specific to types of reinforcement and are defined in Tab 4.

5 Individual layer breaking stress criteria

5.1 General

5.1.1 The individual layer breaking criteria are in relation with the elastic coefficients defined in [3], taking into account the type and the direction of the stresses.

5.2 Definitions

5.2.1 Breaking stresses

The individual layer breaking criteria are defined, in MPa, as the maximum breaking stresses of the individual layer in its local coordinate system, and are obtained by the following formulae:

$\sigma_{br1} = \varepsilon_{br1} \cdot E_1 \cdot Coef_{res}$

$\sigma_{br2} = \varepsilon_{br2} \cdot E_2 \cdot Coef_{res}$

$\tau_{br12} = \gamma_{br12} \cdot G_{12} \cdot Coef_{res}$

$\tau_{brIL1} = \gamma_{brIL23} \cdot G_{23} \cdot Coef_{res}$

$\tau_{brIL2} = \gamma_{brIL13} \cdot G_{13} \cdot Coef_{res}$

where :

E_1, E_2, G_{12}, G_{13}, G_{23} : Elastic coefficients defined in [3], in N/mm², for the individual layer considered according to type of reinforcement (unidirectionals, woven rovings, mats)

ε_{br1} : Theoretical breaking strain, in %, in traction or compressive, of an individual layer in the direction 1 of its local coordinate system

ε_{br2} : Theoretical breaking strain, in %, in traction or compressive, of an individual layer in the direction 2 of its local coordinate system

γ_{br12} : Theoretical in-plane breaking shear strain, in %, of an individual layer

γ_{brIL} : Theoretical interlaminar breaking shear strain, in %, of an individual layer

$Coef_{res}$: Coefficient taking into account the adhesive quality of the resin system.

All breaking strains and coefficients are given in Tab 5 or Tab 6, as applicable.

Table 3 : Elements of matrix of rigidity

	For Unidirectionals	For Woven Rovings	For Mats	Core material
$\bar{R}_{11}$	$E_{UD1}/(1-\nu_{UD12}\cdot\nu_{UD21})$	$E_{T1}/(1-\nu_{T12}\cdot\nu_{T21})$	$E_{mat}/(1-\nu_{mat}^2)$	$E_1/(1-\nu_{12}\cdot\nu_{21})$
$\bar{R}_{22}$	$E_{UD2}/(1-\nu_{UD12}\cdot\nu_{UD21})$	$E_{T2}/(1-\nu_{T12}\cdot\nu_{T21})$	$E_{mat}/(1-\nu_{mat}^2)$	$E_2/(1-\nu_{12}\cdot\nu_{21})$
$\bar{R}_{12}$	$\nu_{UD21}\cdot E_{UD1}/(1-\nu_{UD12}\cdot\nu_{UD21})$	$\nu_{T21}\cdot E_{T1}/(1-\nu_{T12}\cdot\nu_{T21})$	$\nu_{mat}\cdot E_{mat}/(1-\nu_{mat}^2)$	$\nu_{21}\cdot E_1/(1-\nu_{12}\cdot\nu_{21})$
$\bar{R}_{21}$	$\nu_{UD12}\cdot E_{UD2}/(1-\nu_{UD12}\cdot\nu_{UD21})$	$\nu_{T12}\cdot E_{T2}/(1-\nu_{T12}\cdot\nu_{T21})$	$\nu_{mat}\cdot E_{mat}/(1-\nu_{mat}^2)$	$\nu_{12}\cdot E_2/(1-\nu_{12}\cdot\nu_{21})$
$\bar{R}_{33}$	G_{UD12}	G_{T12}	G_{mat12}	G_{12}

Table 4 : Elements of matrix of flexibility

	For Unidirectionals	For Woven Rovings	For Mats	Core material
$\overline{S}_{11}$	$1/E_{UD1}$	$1/E_{T1}$	$1/E_{mat}$	$1/E_1$
$\overline{S}_{22}$	$1/E_{UD2}$	$1/E_{T2}$	$1/E_{mat}$	$1/E_2$
$\overline{S}_{12}$	$-\nu_{UD21}/E_{UD2}$	$-\nu_{T21}/E_{T2}$	$-\nu_{mat}/E_{mat}$	$-\nu_{21}/E_2$
$\overline{S}_{21}$	$-\nu_{UD12}/E_{UD1}$	$-\nu_{T12}/E_{T1}$	$-\nu_{mat}/E_{mat}$	$-\nu_{12}/E_1$
$\overline{S}_{33}$	$1/G_{UD12}$	$1/G_{T12}$	$1/G_{mat12}$	$1/G_{12}$

Table 5 : Theoretical breaking strains, in %

		Strains		Reinforcement fibres type					
				E Glass	R Glass	HS Carbon	IM Carbon	HM Carbon	Para-aramid
Reinforcement fabrics' type	Unidirectionals	Tensile	ε_{br1}	2.7	3.1	1.2	1.15	0.7	1.7
			ε_{br2}	0.42	0.35	0.85	0.65	0.4	0.65
		Compressive	ε_{br1}	1.8	1.8	0.85	0.65	0.45	0.35
			ε_{br2}	1.55	1.1	2.3	2.3	2.1	2
		Shear	γ_{br12}	1.8	1.5	1.6	1.7	1.8	2
			γ_{br13}, γ_{brIL2}	1.8	1.5	1.6	1.7	1.8	2
			γ_{br23}, γ_{brIL1}	2.5	1.8	1.9	1.85	1.8	2.9
	Woven	Tensile	ε_{br1}	1.8	2.3	1	0.8	0.45	1.4
			ε_{br2}	1.8	2.3	1	0.8	0.45	1.4
		Compressive	ε_{br1}	1.8	2.5	0.85	0.8	0.5	0.42
			ε_{br2}	1.8	2.5	0.85	0.8	0.5	0.42
		Shear	γ_{br12}	1.5	1.5	1.55	1.6	1.85	2.3
			γ_{br13}, γ_{brIL2}	1.8	1.8	1.55	1.6	1.85	2.9
			γ_{br23}, γ_{brIL1}	1.8	1.8	1.55	1.6	1.85	2.9
	Mats	Tensile	ε_{br1}	1.55	NA	NA	NA	NA	NA
			ε_{br2}	1.55	NA	NA	NA	NA	NA
		Compressive	ε_{br1}	1.55	NA	NA	NA	NA	NA
			ε_{br2}	1.55	NA	NA	NA	NA	NA
		Shear	γ_{br12}	2	NA	NA	NA	NA	NA
			γ_{br13}, γ_{brIL2}	2.15	NA	NA	NA	NA	NA
			γ_{br23}, γ_{brIL1}	2.15	NA	NA	NA	NA	NA

Table 6 : Coefficient $Coef_{res}$

Resin systems		
Polyester	Vinylester	Epoxy
0.8	0.9	1

5.2.2 As a general Rule, the mechanical characteristics of the individual layer are also depending on the laminating process. To simplify the breaking criteria, the influence of the process is taken into account by means of a dedicated safety coefficient defined in Ch 4, Sec 3, [5.4.1].

5.2.3 Other maximum breaking stresses of an individual layer may be taken into account, provided that representative mechanical tests are submitted to the Society.

The elastic coefficients and theoretical individual layer breaking criteria may be computed by the Bureau Veritas dedicated software, as defined in Ch 1, Sec 4.

SECTION 4 LAMINATES AND STIFFENERS

1 General

1.1 Definition

1.1.1 The purpose of this Chapter is to estimate the global laminate's elastic coefficients and the local distribution of stresses in the individual layers.

As a general rule, a laminate is made of stacked individual layers, which may differ in local orientation and in type.

1.2 General

1.2.1 The laminating process acts upon the mechanical characteristics of the final laminate. This influence is taken into account with the partial safety factor C_F as defined in Ch 4, Sec 3, [5.4.1].

1.2.2 All steps of laminating process are to be performed taking into account the recommendations of raw materials' manufacturers and of the requirements of Ch 12, Sec 5.

2 Determination of laminate's mechanical characteristics

2.1 General

2.1.1 The methodology to determine the mechanical characteristics of a laminate is described in Tab 1.

The aim of laminates' calculation approach defined in the present Rules is to determine, starting from external loads applied to a laminate, the local stresses in each individual layer in its own orthotropic axis system and to compare them with the local theoretical breaking stresses as defined in Ch 12, Sec 3, [5].

2.2 Software

2.2.1 All the calculations defined in the present chapter may be performed using the Society's program defined in Ch 1, Sec 4.

3 Laminate definition

3.1 Parameters

3.1.1 The laminate's main characteristics depend on:

- the type of individual layers
- the position of individual layers throught the laminate thickness
- the orientation of individual layers in relation to laminate's global axis.

3.2 Description

3.2.1 Type of individual layer

The type and properties of individual layers are defined in Ch 12, Sec 3.

Table 1 : Methodology

Step	Description	Rule's requirements
1	Estimation of elastic coefficients, mechanical and geometric characteristics of each individual layer in their local orthotropic axis	Ch 12, Sec 3, [2] and Ch 12, Sec 3, [3]
2	Description of the laminate to examine: • position of all individual layers • orientation of each layer in relation to the global laminate's in-plane axis	[3.2.2] and [3.2.3]
3	Calculation of rigidity and flexibility of individual layers in the laminate's global axis	[3.2.4]
4	For specific calculations (midship section modulus, global buckling or stiffeners), calculation of laminate's global elastic coefficients and mechanical characteristics in laminate's axis	[5]
5	Estimation of all external loads applied to the laminate	For panels: Ch 9, Sec 3 For stiffeners: Ch 9, Sec 4
6	Calculation of the laminate's global strain in its global axis, induced by loads estimated in previous step 5	[4.1]
7	Calculation of stresses and strains, for each individual layer, in the laminate's global axis	[4.2.1]
8	Calculation of stresses and strains, for each individual layer, in the individual layer's local axis	[4.2.2]
9	Estimation, for each individual layer, of the breaking criteria in their own local axis	Ch 12, Sec 3, [5]
10	Check of the safety coefficient (equal to the breaking stresses -step 9- divided by the local stresses in local axis -step 8-) in relation to Rule safety coefficients	Ch 4, Sec 3, [5.4]

3.2.2 Position of individual layer

Positions of all individual layers are described in Fig 1.

where:

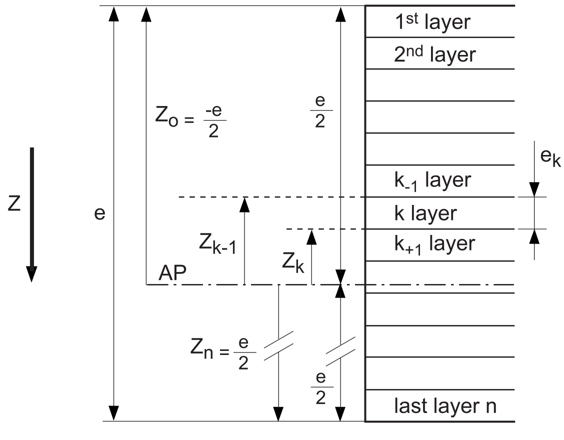
- AP : Median plane of the laminate, located at half the thickness of the laminate
- e : Laminate's thickness, in mm
- e_K : Thickness of individual layer K, in mm
- Z_K : Distance between AP and interface of layers K and K+1.

$$Z_K = \frac{-e}{2} + \sum_1^K e_i$$

- Z_{K-1} : Distance between AP and interface of layers K and K-1.

$$Z_{K-1} = \frac{-e}{2} + \sum_1^{K-1} e_i$$

Figure 1 : Position of individual layer



3.2.3 Orientation of individual layer

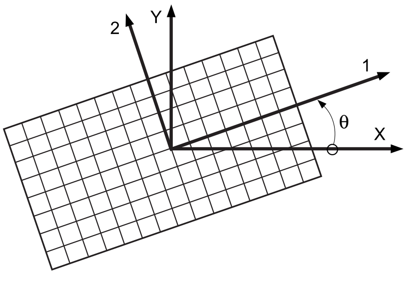
The orientation between each individual layer's local axis and laminate's global axis is defined in Fig 2.

As a general rule, laminate's global reference axis are taken similar to the ship's reference axis:

- X : Ship's longitudinal axis
- Y : Axis perpendicular to the ship's longitudinal axis in laminate's plane

Note 1: The angle θ is considered positive from global axis to local axis (See Fig 2).

Figure 2 : Orientation of individual layer in relation to laminate's global axis



3.2.4 This orientation enables to calculate rigidity and flexibility of all individual layers in the laminate's global axis. The conversion's calculation is obtained by the following formulae:

$$[R]_K = \begin{bmatrix} R_{XX} & R_{XY} & R_{XZ} \\ R_{YX} & R_{YY} & R_{YZ} \\ R_{ZX} & R_{ZY} & R_{ZZ} \end{bmatrix}_K = T[\bar{R}]_K T'^{-1}$$

$$[S]_K = \begin{bmatrix} S_{XX} & S_{XY} & S_{XZ} \\ S_{YX} & S_{YY} & S_{YZ} \\ S_{ZX} & S_{ZY} & S_{ZZ} \end{bmatrix}_K = T'[\bar{S}]_K T^{-1}$$

where:

- $[\bar{R}]_k$ and $[\bar{S}]_k$: Rigidity and flexibility matrix of an individual layer K in local axis as defined in Ch 12, Sec 3, [4.1.2] and Ch 12, Sec 3, [4.1.3]
- $[R]_k$ and $[S]_k$: Rigidity and flexibility matrix of an individual layer K in global axis
- T and T' : Transfer matrixes

$$T = \begin{bmatrix} (\cos\theta)^2 & (\sin\theta)^2 & -2\cos\theta\sin\theta \\ (\sin\theta)^2 & (\cos\theta)^2 & 2\cos\theta\sin\theta \\ (\cos\theta\sin\theta) & (-\cos\theta\sin\theta) & ((\cos\theta)^2 - (\sin\theta)^2) \end{bmatrix}$$

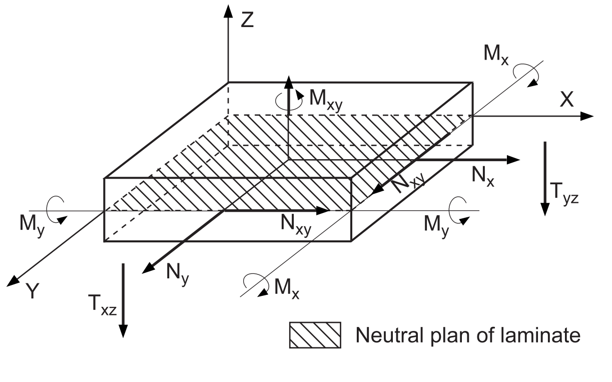
$$T' = \begin{bmatrix} (\cos\theta)^2 & (\sin\theta)^2 & -\cos\theta\sin\theta \\ (\sin\theta)^2 & (\cos\theta)^2 & \cos\theta\sin\theta \\ (2\cos\theta\sin\theta) & (-2\cos\theta\sin\theta) & ((\cos\theta)^2 - (\sin\theta)^2) \end{bmatrix}$$

4 Laminate analysis under external loading

4.1 Laminate in-plane strain under external loading

4.1.1 As a general rule, a laminate can be loaded by forces and moments as described in Fig 3.

Figure 3 : Forces and moments loading



These external loads are expressed as a function of the median plane of the laminate, per meter of width:

$$\begin{bmatrix} N_X \\ N_Y \\ N_{XY} \\ M_X \times 10^3 \\ M_Y \times 10^3 \\ M_{XY} \times 10^3 \end{bmatrix} = \begin{bmatrix} A & B \\ B & D \end{bmatrix} \cdot \begin{bmatrix} \varepsilon_x^0 \\ \varepsilon_y^0 \\ \gamma_{xy}^0 \\ K_x \\ K_y \\ K_{xy} \end{bmatrix}$$

where matrix [ABD] represents the global rigidity of the laminate:

A_{ij} : Tensile rigidity (matrix 3x3)

$$A_{ij} = \sum_1^n (R_{ij})_K \cdot e_K$$

B_{ij} : Coupling effect tensile and bending (matrix 3x3)

$$B_{ij} = \frac{1}{2} \cdot \sum_1^n (R_{ij})_K \cdot (Z_K^2 - Z_{K-1}^2)$$

D_{ij} : Bending rigidity (matrix 3x3)

$$D_{ij} = \frac{1}{3} \cdot \sum_1^n (R_{ij})_K \cdot (Z_K^3 - Z_{K-1}^3)$$

ε°_x : Tensile or compressive strain of the median plane of the laminate in X direction

ε°_y : Tensile or compressive strain of the median plane of the laminate in Y direction

γ°_{xy} : Shear strain of the median plane of the laminate in XY plan

K_x : Curvate deformation of the median plane of the laminate around Y axis

K_y : Curvate deformation of the median plane of the laminate around X axis

K_{xy} : Curvate deformation of the median plane of the laminate around Z axis

N_X, N_Y, N_{XY}: Used for specific calculation as defined in step 4 of Tab 1. Global loads applied at the median plane of the laminate (see Fig 3) induced by the global loadings applied to the hull girder structure as defined in Ch 9, Sec 2, [1].

For laminate loaded by local external pressure, N_X, N_Y and N_{XY} are to be taken equal to 0.

M_X, M_Y, M_{XY}: Local flexural moments applied to the laminate (see Fig 3) as defined in Ch 9, Sec 3, [7].

$M_{XY} = 0$ in general case.

4.1.2 Strains and curvate deformations can be expressed by reversing the matrix [ABD] by the following formula:

$$\begin{bmatrix} \varepsilon_x^0 \\ \varepsilon_y^0 \\ \gamma_{xy}^0 \\ K_x \\ K_y \\ K_{xy} \end{bmatrix} = \begin{bmatrix} A & B \\ B & D \end{bmatrix}^{-1} \cdot \begin{bmatrix} N_X \\ N_Y \\ N_{XY} \\ M_X \times 10^{-3} \\ M_Y \times 10^{-3} \\ M_{XY} \times 10^{-3} \end{bmatrix}$$

4.2 Analysis of an individual layer in a laminate

4.2.1 Individual layer's strains in laminate global axis

From laminate's membrane and bending strains, calculated in [4.1], the membrane and bending strains for each individual layer are given by the following formula:

$$\begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{bmatrix}_K = \begin{bmatrix} \varepsilon_x^0 \\ \varepsilon_y^0 \\ \gamma_{xy}^0 \end{bmatrix} + \begin{bmatrix} K_x \\ K_y \\ K_{xy} \end{bmatrix} \cdot \frac{Z_K + Z_{K-1}}{2}$$

Note 1: ε_x, ε_y, and γ_{xy} are calculated at mid-thickness of each individual layer, except for core materials where ε_x, and ε_y are to be calculated at each interface of the core.

4.2.2 Individual layer's strains and stresses in local axis

Strains of an individual layer can be defined in its local axis by the following formula:

$$\begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{bmatrix}_K = T'^{-1} \cdot \begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{bmatrix}_K$$

with T' defined in [3.2.4] for every individual layer.

The local stresses in an individual layer expressed in local axis, at mid-thickness, are defined by the following formula (except for core material, see [4.2.1], Note 1):

$$\begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{bmatrix}_K = [\overline{R}] \cdot \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{bmatrix}_K$$

where $[\overline{R}]$ is defined in [3.2.4] for every individual layer.

4.3 Laminate's interlaminar shear analysis

4.3.1 General

The interlaminar shear stresses τ_{yz} and τ_{xz}, located between each individual layers are induced by shear loads T_{YZ} and T_{XZ} normal to the median plane of the laminate, as defined in Fig 3.

4.3.2 The interlaminar shear stresses, in the global X and Y directions of the laminate, between two layers K and K-1, are determined by the following formulae:

$$\begin{bmatrix} \tau_{yz} \\ \tau_{xz} \end{bmatrix}_K = \begin{bmatrix} H_{44} & H_{45} \\ H_{54} & H_{55} \end{bmatrix}_K \cdot \begin{bmatrix} T_{yz} \\ T_{xz} \end{bmatrix}$$

where:

T_{YZ} and T_{XZ} : Applied shear loads, normal to the median plane of laminate (see Fig 3) and defined in Ch 9, Sec 3, [7].

$[H_{44}]_k$, $[H_{45}]_k$, $[H_{54}]_k$, $[H_{55}]_k$: Shear constants of layer k

$$H_{44} = \left[C_{yz}\right]_{k,5} - \left[R_{21}\ R_{22}\ R_{23}\right]_k \cdot \begin{bmatrix} Z_{k-1} \cdot B'_{12} + \frac{Z^2_{k-1}}{2} \cdot D'_{12} \\ Z_{k-1} \cdot B'_{22} + \frac{Z^2_{k-1}}{2} \cdot D'_{22} \\ Z_{k-1} \cdot B'_{32} + \frac{Z^2_{k-1}}{2} \cdot D'_{32} \end{bmatrix}$$

$$H_{45} = \left[C_{yz}\right]_{k,6} - \left[R_{21}\ R_{22}\ R_{23}\right]_k \cdot \begin{bmatrix} Z_{k-1} \cdot B'_{13} + \frac{Z^2_{k-1}}{2} \cdot D'_{13} \\ Z_{k-1} \cdot B'_{23} + \frac{Z^2_{k-1}}{2} \cdot D'_{23} \\ Z_{k-1} \cdot B'_{33} + \frac{Z^2_{k-1}}{2} \cdot D'_{33} \end{bmatrix}$$

$$H_{54} = \left[C_{xz}\right]_{k,6} - \left[R_{11}\ R_{12}\ R_{13}\right]_k \cdot \begin{bmatrix} Z_{k-1} \cdot B'_{13} + \frac{Z^2_{k-1}}{2} \cdot D'_{13} \\ Z_{k-1} \cdot B'_{23} + \frac{Z^2_{k-1}}{2} \cdot D'_{23} \\ Z_{k-1} \cdot B'_{33} + \frac{Z^2_{k-1}}{2} \cdot D'_{33} \end{bmatrix}$$

$$H_{55} = \left[C_{xz}\right]_{k,4} - \left[R_{11}\ R_{12}\ R_{13}\right]_k \cdot \begin{bmatrix} Z_{k-1} \cdot B'_{11} + \frac{Z^2_{k-1}}{2} \cdot D'_{11} \\ Z_{k-1} \cdot B'_{21} + \frac{Z^2_{k-1}}{2} \cdot D'_{21} \\ Z_{k-1} \cdot B'_{31} + \frac{Z^2_{k-1}}{2} \cdot D'_{31} \end{bmatrix}$$

$[C_{YZ}]_k$, $[C_{XZ}]_k$: Local coefficients of each individual layer k

$$\left[C_{yz}\right]_k = \left[C_{yz}\right]_{k-1} + (\left[R_2\right]_k - \left[R_2\right]_{k-1}) \cdot \left[M\right]_k$$

$$\left[C_{xz}\right]_k = \left[C_{xz}\right]_{k-1} + (\left[R_1\right]_k - \left[R_1\right]_{k-1}) \cdot \left[M\right]_k$$

where:

$$\left[M\right]_k = \left[\left(Z_{k-1} \cdot A' + \frac{Z^2_{k-1}}{2} \cdot C'\right)\left(Z_{k-1} \cdot B' + \frac{Z^2_{k-1}}{2} \cdot D'\right)\right]$$

$[C_{xz}]_k$ and $[C_{yz}]_k$: Shear distribution coefficient (matrix [1x6]) for the layer k

$[C_{xz}]_{k-1}$ and $[C_{yz}]_{k-1}$: Shear distribution coefficient (matrix [1x6]) for the layer k-1

$[R_1]_k$ and $[R_1]_{k-1}$: First line of matrix of rigidity [R] for layers k and k-1 as defined in [3.2.4]

$[R_2]_k$ and $[R_2]_{k-1}$: Second line of matrix of rigidity [R] for layers k and k-1 as defined in [3.2.4]

A′, B′, C′ and D′ : Obtained by reversing matrix [ABD] defined in [4.1.1] according the following formula:

$$\begin{bmatrix} A' & B' \\ C' & D' \end{bmatrix} = \begin{bmatrix} A_{ij} & B_{ij} \\ B_{ij} & D_{ij} \end{bmatrix}^{-1}$$

Note 1: For the first layer (k=1), coefficients are as follows:

$$\left[C_{yz}\right]_{k-1} = \left[C_{xz}\right]_{k-1} = 0$$

$$\left[R_2\right]_{k-1} = \left[R_1\right]_{k-1} = 0$$

4.3.3 The interlaminar stresses (expressed in the local orthotropic axis of the individual layer) between two layers k and k-1 are calculated by the following formula:

$$\begin{bmatrix} \tau_{23} \\ \tau_{13} \end{bmatrix}_k = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \cdot \begin{bmatrix} \tau_{yz} \\ \tau_{xz} \end{bmatrix}_k$$

Transfer matrix T is defined in [3.2.4].

Note 1: τ_{23} and τ_{13} are identical to the interlaminar shear stresses τ_{IL1} and τ_{IL2} located between layers k and k_{-1}.

5 Global laminate parameters for specific calculation

5.1 Global rigidity

5.1.1 General

Global tensile and shear rigidity expressed in the present Article are used for specific calculations such as stiffeners or midship section modulus.

Main directions X and Y of the global laminate are defined in [3.2.3].

5.1.2 Tensile and shear rigidity

The global tensile rigidity of a laminate can be expressed in its two main directions X and Y by the following formulae:

- In X direction:

$$E_x = \frac{1}{(A'_{11} \times th)}$$

- In Y direction:

$$E_y = \frac{1}{(A'_{22} \times th)}$$

The global shear rigidity of a laminate can be expressed in its plane by the following formula:

$$G_{xy} = \frac{1}{(A'_{33} \times th)}$$

The distances V_x and V_y between the global neutral axis of a laminate and the edge of the first individual layer, in mm, are defined in its two main directions X and Y by the following formulae:

$$V_x = \left(\sum E_{xi} \cdot th_i \cdot Z_i\right) / \left(\sum E_{xi} \cdot th_i\right)$$

$$V_y = \left(\sum E_{yi} \cdot th_i \cdot Z_i\right) / \left(\sum E_{yi} \cdot th_i\right)$$

with:

A'_{11}, A'_{22}, A'_{33} : defined in [4.3.1]

th : Laminate's total thickness, in mm

E_{xi} : Tensile rigidity of each individual layer in X direction in global reference axis system, in N/mm², equal to $1/S_{XX}$ as defined in [3.2.4]

E_{yi} : Tensile rigidity of each individual layer in Y direction in global reference axis system, in N/mm², equal to $1/S_{YY}$ as defined in [3.2.4]

th_i : Thickness of each individual layer, in mm, as defined in Ch 12, Sec 3, [2.2.1]

Zi : Distance between edge of the laminate and mid-thickness of layer i, in mm.

5.1.3 Bending rigidity

The global bending rigidity of a laminate can be expressed, in N.mm²/mm, in its two main directions X and Y by the following formulae.

- In X direction:

$$[EI]_x = \frac{1}{D'_{11}}$$

- In Y direction:

$$[EI]_y = \frac{1}{D'_{22}}$$

with:

D'_{11}, D'_{22} : defined in [4.3.1].

5.2 Laminate's weight

5.2.1 The total laminate weight per square meter of a laminate, in kg/m², is equal to:

$$W = \sum_1^n \frac{P_{fi}}{M_{fi}}$$

with:

P_{fi} : Mass per square meter of dry reinforcement fabric of each individual layer, defined in Ch 12, Sec 3, [1.1.3] of the present chapter.

M_{fi} : Content in mass of fibre for each individual layer, defined in Ch 12, Sec 3, [2.1.1] of the present chapter.

6 Stiffener's analysis

6.1 General

6.1.1 As a general rule, a composite stiffener is made of an attached plating, a web and a flange. All these elements are to be considered as independent laminate characterized by their own:

- global tensile rigidity E_{xi} and shear rigidity G_{XYi}, defined in [5.1], in the longitudinal direction of the stiffener
- thickness th_i,
- global neutral axis position V_{xi}, as defined in [5.1],
- width for associated platings and flanges, height for webs.

Note 1: Where associated plating is a sandwich structure, its rigidity is to be calculated without taking into account the sandwich core.

6.2 Calculations' parameters

6.2.1 Neutral axis

The neutral axis V, in mm, of a stiffener is to be calculated by the following formula:

$$V = \sum E_{xi} \cdot S_i \cdot Z_{xi} / \sum E_{xi} \cdot S_i$$

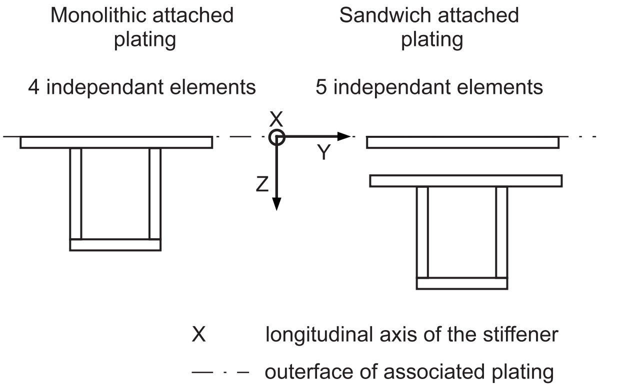
where:

E_{xi} : Global tensile rigidity of each element (flange, web and associated plating) of a stiffener, in N/mm², in the longitudinal direction of the stiffener

S_i : Section of each element of the stiffener, in mm²

Z_{xi} : Distance, in mm, between outer-face of associated plating and neutral axis of each element of the stiffener (see Fig 4).

Figure 4 : Stiffener model



6.2.2 Bending rigidity and global inertia of stiffener

The rigidity, in N.mm², of the stiffener is given by the following formula:

$$[EI] = \sum E_{xi} \cdot (I_i + S_i \cdot d_i^2)$$

where:

d_i : Distance, in mm, between neutral axis of each element of a stiffener and the stiffener's one.

$$d_i = Z_{xi} - V$$

S_i : Section, in mm², as defined in [6.2.1]

I_i : Proper inertia of each element of the stiffener, in mm⁴, in relation to the longitudinal axis of the stiffener X.

6.2.3 Strains

The strain of each element of a stiffener submitted to a bending moment M is estimated in the longitudinal direction of the stiffener, in percent by:

$$\varepsilon_{xi} = \frac{M \cdot d_i}{[EI]} \cdot 10^8$$

where:

E_{xi} : As defined in [6.2.1]

d_i : As defined in [6.2.2]

[EI] : As defined in [6.2.2]

M : Bending moment, in kN.m, applied to the stiffener as defined in Ch 9, Sec 4, [2.2].

Note 1: Attention is to be paid to the sign of the bending moment which condition the type of stresses (tensile or compressive) in the attached the plating and the flange of the stiffener.

6.2.4 Strains and stresses in attached plating and flange induced by moments

As a general rule, the stains and tensile or compressive stresses induced by flexural moment are only determined in the attached plating and the flange of the stiffener. These local strains, in %, and stresses, in MPa, in each layer of each element of a stiffener are given by the following formulae:

$\varepsilon_1 = (\cos\theta)^2\, \varepsilon_{xi}$

$\varepsilon_2 = (\sin\theta)^2\, \varepsilon_{xi}$

$\gamma_{12} = -2 \sin\theta \cos\theta\, \varepsilon_{xi}$

and

$\sigma_1 = (\overline{R_{11}} \cdot \varepsilon_1 + \overline{R_{12}} \cdot \varepsilon_2)/100$

$\sigma_2 = (\overline{R_{21}} \cdot \varepsilon_1 + \overline{R_{22}} \cdot \varepsilon_2)/100$

$\tau_{12} = (\overline{R_{33}} \cdot \gamma_{12})/100$

$\overline{R}_{11}$, $\overline{R}_{12}$, $\overline{R}_{21}$ and $\overline{R}_{22}$ are defined in Ch 12, Sec 3, [4.1.2].

θ is the orientation of an individual layer in relation to the logitudinal axis X of the stiffener as shown in Fig 4.

6.2.5 Strains and stresses in web induced by shear force

As a general rule, shear strain, in percent, is only calculated in the web of the stiffener and is given by the following formula:

$$\gamma_{xy} = \frac{T}{\left(\sum S_i \cdot G_{XYi}\right) 10^5}$$

where:

T : Shear force applied to the stiffener as defined in Ch 9, Sec 4, [2.2], in kN

S_i : Shear area of each part of the webs contributing to the stiffener shear strength, in mm^2

G_{XYi} : Shear rigidity of each part of the webs contributing to shear strength in global axis, in N/mm^2.

Strains and stresses of the individual layers of the web contributing to shear strength of the stiffener are given by the following formulae:

$\varepsilon_1 = \sin\theta \cdot \cos\theta \cdot \gamma_{xy}$

$\varepsilon_2 = -\sin\theta \cdot \cos\theta \cdot \gamma_{xy}$

$\gamma_{12} = ((\cos\theta)^2 - (\sin\theta)^2) \cdot \gamma_{xy}$

and

$\sigma_1 = (\overline{R_{11}} \cdot \varepsilon_1 + \overline{R_{12}} \cdot \varepsilon_2)/100$

$\sigma_2 = (\overline{R_{21}} \cdot \varepsilon_1 + \overline{R_{22}} \cdot \varepsilon_2)/100$

$\tau_{12} = (\overline{R_{33}} \cdot \gamma_{12})/100$

Note 1: ε_1, ε_2 and σ_1, σ_2 are only calculated under the shear strain of web.

7 Transverse ship section analysis

7.1 General

7.1.1 The main characteristics of a transverse ship section can be estimated with the same approach than defined in [6] for a stiffener.

In this case, all typical laminates constituing the transverse section is to be considered as independent laminate characterized as defined in [6.1.1].

For shear strength calculation, vertical section or vertical projection of all parts of transverse ship section have to be taken into account.

SECTION 5 WORKING PROCESS AND MECHANICAL TEST

1 General

1.1 Scope

1.1.1 As indicated in Ch 12, Sec 1, [1.2.2], the following three steps are necessary within the scope of yacht classification:

- Preliminary survey at yard
- Survey at work
- Samples' mechanical tests.

These three steps are described in the present section.

2 Preliminary survey at yard

2.1 Application

2.1.1 General

The preliminary survey is to be carried out for Shipyards not known to the Society.

This survey is intended to provide for the Society general information on the shipyard, so that production plant of composite hulls can be assessed.

The different information to document are described in the following requirements.

2.1.2 Shipyards

- Production sites
- Design office and production workforces
- Capacity (total and net surface areas)
- Production capacity (number of units per year, number of types, sizes)
- Total number of hull units already built
- Yard lay-out (showing zones assigned to different operations).

2.1.3 Raw materials used

- List of raw materials (gel-coats, resins, catalysts/ accelerators and/or hardeners, reinforcements, core materials, adhesives, etc.) with their reference and supplier's identification
- References of existing homologation and type approval certificates (Bureau Veritas or other), with copies
- Raw material data sheets, containing in particular the supplier's recommendations on storage and use, if available.

2.1.4 Storage site for raw materials

- Identification of storage site on yard lay-out plan (specifying all separated storage sites, the storage site equipped with ventilation and/or air conditioning system)
- Packaging of delivered consignments
- Storage conditions:
  - Summer maximum temperature and relative humidity
  - Winter minimum temperature and relative humidity
- Temperature monitoring (i.e. recording)
- Other environmental factor (hygrometry)
- Keeping and presence of logbook (e.g. consignment number, dates) for inventory control.

2.1.5 Raw material preparation units

- Resins and gel-coats:
  - Identification of preparation unit on lay-out plan
  - Manufacturer's specifications and recommendations
  - Resin blending method
  - Temperature monitoring
  - Preparation procedure
  - Method of supplying workstations
  - Accompanying data sheet.
- Reinforcement fabrics and core materials:
  - Identification of preparation area on lay-out plan
  - Preparation procedure
  - Method of supplying workstations
  - Accompanying data sheet.
- Gel-coating unit:
  - Locations with details of means of separation from other workshops
  - Equipment in gel-coating units (air conditioning, ventilation, dust extraction)
  - Hygrometry and temperature monitoring: number of hygrometers/thermometers, positioning, recording and height about ground level
  - Laying procedure
  - Moulds: type of mould, storage of moulds, preparation procedure (e.g. heating, cleaning, waxing)
  - Accompanying data sheet.
- Laminating unit:
  - Identification of laminating site on lay-out plan
  - Laminating method (e.g. hand or spray lay-up, prepregs, etc.)
  - Average time elapsing between application of layers
  - Hygrometry and temperature monitoring: minima and maxima of temperature and hygrometry
  - Location of hygrometer and thermometer in laminating unit.

- Assembly operations:
  - Types of assembly (e.g. glue-assembly, matting-in connection)
  - Physico-chemical preparations of parts for assembly
  - Areas of completion of such preparations (where such operations generate large amounts of dust, for instance, details are needed of precautions to limit teh effects on assembly work or other operations performed nearby, such as gel-coating or laminating).
- Traceability:
  - Data to ensure traceability of raw materials and equipment covered by the Society's Rules (from purchase order to installation or placing on vessel)
  - Data to ensure traceability of production means (describing different steps such as inspection or recording, during production)
  - Handing of non-conformities (from reception of materials or equipment to the end of construction)
  - Dealing with client complaints and returns to after-sales department.

3 Survey at work

3.1 General

3.1.1 Surveys at work by the Society during yacht hull construction are intended to ensure that method of production of composite hull complies with the Society and raw materials' suppliers requirements.

3.1.2 The surveys, carried out by Society's Surveyor, can only focus on the construction stage in progress during the survey and only permit a restricted visual examination on the completed construction stage coming before the survey.

It is necessary that the yard presents to the Surveyor a manufacturing plan ensuring traceability of hull construction progress.

A general lay-out for drafting this manufacturing plan, corresponding to the different important stages of construction, is proposed hereafter.

3.2 Content of manufacturing plan for Survey

3.2.1 Raw materials reference

The yard must draw up an exhaustive list of all raw materials used in manufacturing parts of composite hulls covered by the Society's Rules (shell plating, structural counter-moulds, bulkheads, stiffeners and, in general, all elements contributing to hull strength).

These main materials comprise:

- gel-coats
- laminating or bonding resins
- reinforcements
- core materials for sandwich laminates
- glues and adhesives.

Yard documents contain the following information for each type of raw material:

- maker's name
- product supplier references
- Bureau Veritas product homologation references (number and date of validity of type approval certificates)
- homologation references from another classification Society (name and same information as in preceding point)
- supplier's special requirements, including at least:
  - minimum and maximum storage temperatures
  - minimum and maximum storage hygrometry
  - product packaging for delivery
  - packaging for storage
  - maximum shelf life of product
  - type of checks to be performed on incoming products and properties to be tested by yard before use.

3.2.2 Raw materials traceability

The raw materials' traceability must permit to identify the raw material batch reference used during each laminating stage of the hull as well as the preparation of raw materials before laminating, as for example:

- For gel-coats, resins and adhesives:
  - Amounts of various components necessary to prepare the resin systems in relation to the temperature in the laminating unit
  - Date and time of laminating.
- For reinforcement fabrics:
  - Precaution taken to prevent condensation caused by temperature difference
  - Identification of reinforcement fabrics and location in the hull
  - Date and time of laminating.
- For core materials:
  - Precaution taken to prevent condensation and to reduce the amount of gazing
  - Identification of core materials and adhesives used for laminating
  - Date and time of laminating.

3.2.3 Laminating

The different stages of the laminating process must be listed, indicating:

- Date and time of operation
- Temperature and hygrometry during operation
- Raw materials reference used
- Reference of laminating drawing used
- Directions of fabrics reinforcement
- Bubbles elimination operation
- Preparation of laminated zone intended for subsequent re-laminating or gluing.

3.2.4 Other laminating operations

The various laminating process as given hereafter are to be listed on the same basis than described in [3.2.3] for the following operations:

- Installation of internal structural components such as bulkheads, stiffeners
- chainplates when applicable
- connection between hull and deck.

3.3 Non Destructive Testing (NDT)

3.3.1 Application

Non destructive testing can be implemented by the yard.

The main testing processes used in yacht building are:

- Ultra-sonic testing
- Spectroscopy
- Differential Scanning Calorimetry
- Radiography.

4 Mechanical tests

4.1 General

4.1.1 Application

The present Article specifies the mechanical and physico-chemical tests to be performed on a test panel.

This test panel, which is representative of the construction of the hull, is used for mechanical tests, in order to check that the laminate produced by yard manufacturing methods possesses properties at least equivalent to the theoretical properties calculated on the basis of the requirements of the relevant Society's Rules, Ch 12, Sec 4.

Consequently, to be representative of yard production methods and of the hull under Classification, each test panel is to be:

- manufactured from the same raw materials as the hull for Classification
- manufactured by the same methods as the hulls for Classification and in the same environment
- of an similar composition as the hull scantling (arrangement of layers).

These tests are done in the laboratory of the Society, or a laboratory recognized by Bureau Veritas.

Note 1: It can be requested that where reinforcement fabrics are provided with direction different from 0°/90° in the hull, these fabrics can be replaced by 0°/90°direction to avoid test panel disruption.

4.2 Types of tests to be performed

4.2.1 General

Tests comprise destructive mechanical and physico-chemical tests.

The laminate panels are packaged, and test pieces prepared and dimensionally checked, in accordance with recognized standards.

4.2.2 Application

Tests are done on test pieces taken from the panel in two perpendicular directions. The number of test pieces in each direction depends on the reference standard (usually five in each direction for each test).

Each test piece is to be identified and must specify:

- the test piece direction in relation to the main longitudinal and transverse axis of the hull
- the layers' arrangement.

4.2.3 Types

For each set of test pieces to be tested, and for each result, the value to be recorded is the average for the number of tes pieces, provided that the minimum result is not less than 0,9 times the average. Otherwise, the Society decides which result is to be taken, on the basis of test conditions and the range of results.

In general, the following are to be performed:

- monolithic laminates: tensile tests and/or three points bending tests, measurement of density and percentage of reinforcement in weight
- sandwich laminates: three or four points bending tests; and for each skin, tensile tests, measurement of density and percentage of reinforcement in weight.

Bending tests are carried out with the load applied on the gel-coat side or on the opposite side. The side is to be chosen in agreement with the Society, in such a way that the test piece will break in a way representative of the relevant shell plating scantling.

The Tab 1 shows the types of tests to be performed, relevant standards and dimensions of test pieces and panels.

Additional or different tests, compared with those in Tab 1 may be requested, where the results are unsatisfactory, or in particular cases (e.g. structural components subject to high shear stresses).

Some specific mechanical tests may be requested by the Society where it is necessary to characterize particular laminating process such as structural gluing.

4.2.4 Reports

A report is issued on test results.

The values of the tests breaking bending moments and breaking tensile forces allow to estimate the test breaking stresses and strains and to compare them with the theoretical breaking criteria defined in Ch 12, Sec 3.

Table 1 : Testing of laminate test panels

	Test type - Standards	Quantity of test pieces	Size of test pieces **(1)**	Panels' number and dimensions (in mm)
Monolithic panels	Tensile test: ISO 527, or equivalent	- 5 lengthwise direction of panel - 5 crosswise direction of panels - 2 test pieces for calibration	Length = 400 mm Width = • 25 mm where thickness < 25 mm • 30 mm where thickness < 30 mm • etc.	All dimensions are described in standard ISO 1268, from item 1 to item 9. Each item corresponds to a way of laminating. **(1)**
	Bending test 3 points (ISO 14125 may be additionally used for determining the Interlaminar shear strength)	- 5 lengthwise direction of panel - 5 crosswise direction of panels - 2 test pieces for calibration	Length = 200 mm Width = • 25 mm where thickness < 25 mm • 30 mm where thickness < 30 mm • etc.	
	Measurement of density and reinforcement's content in weight: ISO 1172, (Nota2)	4 samples	30mm x 30mm	
Sandwich panels	Bending test 3 points (ISO 14125 may be additionally used for determining the Interlaminar shear strength)	- 5 lengthwise direction of panel - 5 crosswise direction of panels - 2 test pieces for calibration	Length = 1000 mm Width = 2 x thickness	Pre-cut test pieces to be delivered after Society agreement on sizes
	Skins' tensile test (for both skins): ISO 527, or equivalent	• 5 lengthwise direction of panel • 5 crosswise direction of panels • 2 test pieces for calibration		According to ISO. **(1)**
	Measurement of density and reinforcement's content in weight: ISO 1172, (Nota2)			

Note 1: Where both skins of the sandwich panel are fairly similar, tensile and density tests may be confined to one of the two skins.
Note 2: This test cannot be carried out when laminate tests panels are reinforced with carbon and/or para-aramid fibres.
Note 3: Equivalence of standards is to only assessment of the class Society.
Note 4: Equivalence of standards is to only assessment of the class Society.
(1) The Society may request additional tests with other sizes of test pieces.

4.2.5 Scope of test panel application

A test panel is produced in the following cases:

- Submission of a new composite hull for classification
- Changes in raw materials, arrangement of layers or manufacturing processes for new hull when the yard already classed similar hull
- At regular intervals, for mass-produced hulls. In this precise case, the frequency of production of test panels is to be agreed with the Society.

Note 1: Where a new type of model for classification is under construction in the yard, production of test panels may not be required, if the new model is considered to be fairly similar to a composite hull already classed by the Society, and which has not been in production for a too long period.