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Small craft — Hull construction and scantlings —

Part 10:
Rig loads and rig attachment in sailing craft

Petit navires — Construction de la coque et échantillonnage —

Partie 10: Charges dans le gréement et points d'attache du gréement dans les bateaux à voiles

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by ISO/TC 188, *Small craft*.

A list of all parts in the ISO 12215 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The reason underlying the preparation of the ISO 12215 series is that scantlings rules and recommended practices for small craft differ considerably, thus limiting the general worldwide acceptability of craft.

This document has been set towards the minimal requirements of the current practice.

The dimensioning according to this document is regarded as reflecting current practice, provided the craft is correctly handled in the sense of good seamanship and equipped and operated at a speed appropriate to the prevailing sea state.

This document is not a design standard and designers/builders are strongly cautioned from attempting to design craft such that nearly all structural components only just comply.

The connection between the rig attachment and the structure is required to be stronger than the rig attachment itself. It is therefore considered that unforeseen overload will not entail its detachment from the structure, and that the watertight integrity will be maintained.

Small craft — Hull construction and scantlings —

Part 10:
Rig loads and rig attachment in sailing craft

1 Scope

This document specifies methods for the determination of:

— the design loads and design stresses on rig elements; and

— the loads and scantlings of rig attachments and mast steps/pillars;

on monohull and multihulls sailing craft.

It also gives, in Annexes, "established practices" for the assessment of mast steps/pillars or chainplates

NOTE 1 Other engineering methods can be used provided the design loads and design stresses are used.

This document is applicable to craft with a hull length L_H up to 24 m but it can also be applied to craft up to 24 m load line length.

NOTE 2 The load line length is defined in the OMI "International Load Lines Convention 1966/2005", it is smaller than L_H. This length also sets up, at 24 m, the lower limit of several IMO conventions.

Scantlings derived from this document are primarily intended to apply to recreational craft, including charter vessels.

This document is not applicable to racing craft designed only for professional racing.

This document only considers the loads exerted when sailing. Any loads that may result from other situations are not considered in this document.

Throughout this document, and unless otherwise specified, dimensions are in (m), areas in (m^2), masses in (kg), forces in (N), moments in (N m), stresses and elastic modulus in N/mm^2 (1 N / mm^2 = 1 Mpa). Unless otherwise stated, the craft is assessed in fully loaded ready for use condition.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 12215-5:2019, *Small craft — Hull construction and scantlings — Part 5: Design pressures for monohulls, design stresses, scantlings determination*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
design categories
description of the sea and wind conditions for which a craft is assessed to be suitable

Note 1 to entry: The design categories are defined in ISO 12217 (all parts).

Note 2 to entry: The definitions of the design categories are in line with the European Recreational Craft Directive 2013/53/EU.

[SOURCE: ISO 12215-5:2019, 3.1]

3.2
loaded displacement
m_{LDC}
mass of water displaced by the craft, including all appendages, when in the fully loaded ready-for-use condition

Note 1 to entry: The fully loaded ready-for-use condition is further defined in ISO 8666.

[SOURCE: ISO 12215-5:2019, 3.2]

3.3
sailing craft
craft for which the primary means of propulsion is wind power

Note 1 to entry: It is further defined in ISO 8666.

[SOURCE: ISO 12215-5:2019, 3.3, modified — Note 2 to entry deleted.]

3.4
monohull
craft with only one hull

3.5
multihull
craft with two or more hulls with a connecting wet deck/platform or beams above the loaded waterline, as opposed to a tunnel boat or scow

3.6
mast step
element fitted at the bottom of the mast that supports the mast compression and transmits it to the rest of the structure

3.7
mast pillar
pillar
in a deck stepped rig, structural element that transmits the mast compression to the rest of the structure

3.8
chainplate
rig attachment
component(s) to which the rig elements are attached, transmitting their load to the rest of the structure, including tie rods where relevant

EXAMPLE Metal chainplate, strapped composite chainplate,

Note 1 to entry: See Annex D.

3.9
connection
<of mast step, pillar or chainplate to the structure> all elements or group of elements connecting the rig attachment to the structure of the craft

EXAMPLE Bolts, lamination.

Note 1 to entry: Some of these elements can be part of the chainplate.

3.10
***m_{LDC}* condition**
maximum load condition corresponding to the *loaded displacement* (3.2)

4 Symbols

Unless specified otherwise, the symbols, factors and parameters given in Table 1 apply.

Table 1 — Symbols, factors, parameters

Symbol	Unit	Designation/Meaning of symbol	Reference
1 - Main dimensions of the craft			
B_{CB}	m	Beam between centers of buoyancy: between center of buoyancy of hulls, for catamarans; and between C_B of center hull and C_B of float, for trimarans	Table 5, Fig 3
B_{CP}	m	Beam between chainplates (from port to starboard)	Table C.1, Fig 3
B_H	m	Beam of hull	It 1 of Table 5
GZ_{30}	m	Righting lever at 30° heel for monohulls	Table 5
L_{WL}	m	Length of waterline in m_{LDC} condition	7.5, Table 10
V_{CG}	m	Height of craft center of gravity above T_C bottom	Table 5, Fig 3
m_{LDC}	kg	Loaded displacement mass (3.2) or condition (3.10)	3.2, Clause 13
n_{PH}	1	Number of persons hiking	It 1 of Table 5
T_C	m	Draught of canoe body	Table 5, Fig 3
2 - Main dimensions of the rig and connected data			
A_i	m²	Sail area, index i defining the sail name or combination	Tables 5 to 8 etc.
F_{Ai}	N	Aerodynamic force, index i defining which force it corresponds to	Tables 5 to 8
F_{DMC}	N	Design compression force on single mast step/pillar	8.4. Annex C
F_{DMCi}	N	Design compression force on mast step/pillar of two-masted rig where index i = 1 or 2	8.4. Annex C
M_D	Nm	Design moment under sail	Tables 5 and 6
M_{Hi}	Nm	Heeling moment, where index i = $_{UP, MAX, BROACH, DOWN,}$	Tables 5 and 6
M_{Ri}	Nm	Righting moment, where index i = $_{UP}$, $\phi_{UP, MAX}$	Table 5
$V_{ACEK\ i}$	knots	Design apparent wind speed, in knots, at the center of area of sails, where index i stands for sail configuration S_{Ci}	Tables 5 and 7
$V_{ACEM\ i}$	m/s	Design apparent wind speed, in m/s, at the center of area of sails, where index i stands for sail configuration S_{Ci}	Tables 5 and 7
$V_{AMT\ i}$	m/s (knots)	Design apparent wind speed at mast top, where index i stands for sail configuration S_{Ci}	Note 5 in Table 5
See Table 8 for detailed dimensions of rig, areas, etc.			

Table 1 *(continued)*

Symbol	Unit	Designation/Meaning of symbol	Reference
3 - Factors			
k_{DCR}	1	Design category factor for rig	It 5 of Table 3
k_{DSR}	1	Dynamic sail and rig factor	It 1 of Table 10
k_{HF}	1	Foresail center of pressure height factor	It 1of Table 9
k_{HMS}	1	Mainsail center of pressure height factor	It 3 of Table 9
k_{LC}	1	Load case factor	Tables 3 and 7
k_{MAT}	1	Material factor	It 3 of Table 3
k_{ROACH}	1	Roach factor	Table 8
k_{SAGF}	1	Forestay or inner forestay sag factor = stay sag sagitta/stay length	It 3 of Table 10
k_{SAGM}	1	Mainsail leech sag factor	It 3 of Table 10
k_{ϕ}	1	Factor assessing heel angle of multihulls	It 1 of Table 5
4 - Other variables			
S_{Ci}	1	Sail configuration where *i* is the configuration index	Table 7
S_{Fi}	1	Safety factor against *i*, the index *i* being y (yield) or u (ultimate)	Table 4
σ_i, τ_i	N/mm^2	Direct or shear stress, where *i* may be LIM, u, uw, yw, uc, ut, uf	Table 3
ϕ	degree	Heel angle, which may be 30° for monohulls or ϕ_{LIM} for multihulls	Table 5

5 Application of the document

5.1 General

This document allows the determination of the design loads and design stresses on rig elements of sailing small craft and to assess the design loads on mast step/pillar and chainplates and their connection to the craft's structure:

1) by a simplified method, or

2) by a developed method.

These methods are defined step by step in Table 2.

The developed method also allows to determine the rig loads needed to assess the global loads in the structure of multihulls in ISO 12215-7:2020.

5.2 The simplified method

Clause 14 requires that the mast/rig manufacturer provide the design load on mast steps/pillars and on each rig element, the dimensions of end fittings, etc. assessed according to 7.1.3. If this information is not available, the "Simplified method" applies through "Established practice" Annexes: Annex C for "basic" or "enhanced" methods for mast steps/pillars, or Annex D for chainplates or their connections.

5.3 The developed method

This method involves the full determination of the design loads on mast steps/pillars and on each rig element, the dimensions of end fittings, etc. assessed according to Clause 7. The assessment of the mast step(s), mast pillar(s), chainplates, and their connections to the craft shall then be checked either by the

"Established practice" methods of Annexes C and D or by any relevant engineering method, including finite elements methods (FEM).

NOTE The actual dimensioning of mast and rig being a complex mast bending and buckling problem, where the tuning of rig elongation is paramount, mast scantlings are purposely left out of the scope of this document, even if the values of the loads defined is a useful information.

5.4 Steps of the methods and corresponding clauses of this document

Table 2 sums up the steps for both methods and gives the corresponding Clauses of this document.

Table 2 — Assessment methods

Step	Methods	Clause & Table
	1- SIMPLIFIED METHOD for mast step/pillar or chainplate	5.2
1.1	Design stress determination	Clause 6 and Table 3
1.2	If no information is available from the mast/rig manufacturer/provider, the "Established practice" methods of Annex C -"basic" or "enhanced"- allow a simple determination of the design compression force F_{DMC} and scantlings of mast steps/pillars and their connections to the structure. Tables C.4 and C.5 also give examples of mast step/pillar floor calculation according to the design force.	Annex C
1.3	For chainplates and their connection, use the "Established practice" of Annex D	Annex D
1.4	Structural components to be assessed – mast step or chainplate	Clause 9
1.5	Use of the Annexes for the simplified method	Clause 10
1.6	Application of this document and application sheet	Clause 12, Annex A
1.7	Information in the owner's manual	Clause 13
1.8	Information to be given to the boatbuilder from rig/mast manufacturer/provider	Clause 14
	2- DEVELOPED METHOD for rig load, mast step/pillar or chainplate Computation of all the loads in the rig	5.3
2.1	Design stress determination	Clause 6 and Table 3
2.2	Developed method - General assessments, design moment Determination of the design moments/forces according to sail configuration S_{Ci}: — Formulas for the determination of upwind design moments and forces — Formulas for the determination of downwind design moments and forces — Sail configurations, design heeling/righting moments and apparent wind speed — Rig dimensions and default values for dimensions, areas and point of application — Transverse forces on sails	Clause 7 and: 7.2 and Table 5 7.2 and Table 6 7.2 and Table 7 7.3 and Table 8 7.5 and Table 9
2.3	Design loads in rigging elements: — Forces in forestay, inner forestay, mainsail leech and halyards — Forces in backstay or running backstay or equivalent	Clause 8 and: 8.2 and Table 10 8.3 and Table 10
2.4	Structural components to be assessed – mast step or chainplate	Clause 9
2.6	Application of the developed method	Clause 11
2.7	Application of this document and application declaration	Clause 12, Annex A
2.8	Information in the owner's manual	Clause 13
2.9	Information to the boatbuilder	Clause 14

6 Simplified and developed methods — Design stresses

6.1 General

The design stresses defined in Table 3 shall be used.

NOTE They are similar to those used in ISO 12215-9:2012, except that the dynamic factor for rig k_{DSR} increases the loads for light craft and therefore have a "dynamic behavior", see Item 1 of Table 10.

This document differentiates two types of load cases: "Normal" and "Exceptional", see 7.1, which means two different design stresses.

The stresses are obtained by multiplying, where relevant, see Tables 2 and 3, the actual stresses σ_{act}, τ_{act}, etc. by k_{DSR}, and they shall not be greater than the design stresses σ_d, τ_d, etc.

The "limit" stresses σ_{LIM} or τ_{LIM} are given in Table 3 and correspond to the following stress states:

— for metals, the one-letter subscripts for the stresses below are: y, for yield, and u, for ultimate; the second character of the two-letter subscripts is w, for welded state within heat affected area (see table footnote a in Table 3),

— for FRP and wood, the second character of the subscripts, u, means ultimate stress; the first character respectively is t, for tensile, c, for compressive, and f, for flexural or bearing stress.

The sources for the values of these stresses, i.e. σ_y, σ_u or τ_u for non-welded metals, or σ_{yw}, σ_{uw} or τ_{uw} for welded metals in heat affected zones, or σ_{tu}, σ_{cu}, σ_{fu}, σ_{bu} or τ_u for wood and FRP shall be:

— either the "default" values according to Annexes B or D or to written data provided by the rig manufacturer/provider;

— for other metals than the ones used in rig, according to Annex B for the listed metals, or documented values for other metals, from a recognized standard, or from tests made according to a recognized standard;

— for FRP or wood/plywood, respectively according to Annexes C or F of ISO 12215-5:2019.

Table 3 — Design stress and adjustment factors

1 - Design stress		
σ_d or τ_d	$\sigma_d = \sigma_{LIM} \times k_{MAT} \times k_{LC} \times k_{DCR}$, or $\tau_d = \tau_{LIM} \times k_{MAT} \times k_{LC} \times k_{DCR}$ at yield, or ultimate, and bearing, as relevant, see 6.1 where the adjustments factors are defined below	
2 – Limit stress		
Limit stress	**Material / designation**	**Value**
σ_{LIM} or τ_{LIM}	Metals, unwelded or well clear of heat affected zones[a,b,c]	$\sigma_{LIM} = \min(\sigma_y; 0{,}5\ \sigma_u)$ or $\tau_{LIM} = \min(\tau_y; 0{,}5\ \tau_u)$
	Metals, within heat affected zones, in welded condition[a,b,c]	$\sigma_{LIM} = \min(\sigma_{yw}; 0{,}5\ \sigma_{uw})$ or $\tau_{LIM} = \min(\tau_{yw}; 0{,}5\ \tau_{uw})$
	Wood or FRP as dictated by sense of applied stress	(σ_{uc}, σ_{ut}, σ_{uf} and τ_u)[c] as relevant
3 - Stress factor for material k_{MAT}		
k_{MAT}	Metals with elongation at break $\varepsilon_R \geq 7$ %	$k_{MAT} = 0{,}75$
	Metals with elongation at break $\varepsilon_R < 7$ %	$k_{MAT} = \min(0{,}062\ 5\ \varepsilon_R + 0{,}312\ 5; 0{,}75)$[d]
	Wood and FRP	$k_{MAT} = 0{,}33$

Table 3 *(continued)*

4 - Values of load case factor k_{LC},[e]				
		Type of load:	normal	exceptional
k_{LC}	Mast/rig	Metal	(1,11)	(1,33)
	Rig	Pure fibre	(1,30)	(1,56)
	Mast/rig	FRP or wood	(1,20)	(1,44)
	Step of mast/pillar, chainplate	Metal	1,10	1,32
	Step of mast/pillar, chainplate	FRP/Wood	1,05	1,26
	Strapped FRP chainplates	(UD straps only)[f]	0,35	0,42
	Connection of above to structure	Metal	0,92	1,10
	Connection of above to structure	FRP/wood (bolts, screws, etc.)	0,88	1,05
	Connection of above to structure	FRP co-cured or glued[f]	0,83	1,00
5 - Values of design category factor for rig k_{DCR}				
k_{DCR}	Craft of design categories A and B		1,00	
	Craft of design categories C and D		1,25	

[a] Generally the heat affected zone is considered within 50 mm from welds.

[b] For metals, $\tau = 0{,}58\ \sigma$ often rounded to 0,6 as in EN 1993.

[c] Bearing stress depends on material type and dimensions. Item 4 of Tables D.6 or D.7 gives recommended values. (See References [13] and [15]).

[d] The formula gives 0,75 for $\varepsilon_R \geq 7$ % (e.g. main building metals and ductile cast iron) and 0,375 for $\varepsilon_R < 7$ % for lamellar graphite cast iron, with linear interpolation in between.

[e] The design stresses correspond either to "normal" or "exceptional" cases in Table 7, the "exceptional" stresses are 120 % the "normal "stresses i.e. the safety factor is 83 % of normal stresses. The “normal” design loads for mast step/pillar or chainplates are 120 % of the ones for mast/rig, and the values of connection of mast step/chainplate to the structure is again 120 % of the mast step/chainplate i.e. 144 % of mast/rig loads. k_{LC} varies as the inverse of these ratios (see Table 4 for explanations).

[f] The values for the UD of strapped chainplate are low to take into account stress raisers during the UD path around the pin bushing, but this is not necessary for the co-curing/gluing of the whole chainplate, provided the correct glue allowable shear stress is valid, see D.6.

NOTE The design stresses in Table 3 and safety factors (S_{Fu} or S_{Fy}) in Table 4 and loads for rig and mast elements are between brackets, for information only, as they are not covered by this document. The safety factor at ultimate is stated (2,4) for metal rig but in practice it frequently varies between 2 and 3,5 for monohulls according to the practice of the builder/designer and the type of craft racing/cruising. For light multihulls if may go down to 1,5 for the ones that “lift a hull” as this situation is non-frequent (exceptional) except for sheer sports multihulls. In addition, the rig is frequently much stronger than stated to limit rig elongation for mast stability reasons, particularly for non-metal rigging system.

NOTE The lowering of k_{LC} (or increase of safety factor S_F) from rig load to mast step/chainplate, then their connection to structure ensures that the mast step/chainplate connection will be stronger that the mast compression/rig tension (i.e. the chainplate shall break after the rig), taking due consideration to the uncertainties of calculation of the connection effective stresses.

6.2 Design load vs safety factor

The applicable limit stresses in the first row of Table 3 are multiplied by several factors like k_{DCR}, design category factor, k_{MAT}, material factor, and k_{LC}, load case factor. As many users or regulations refer to safety factors, S_F, for comparison purposes Table 4 transforms the requirements of Tables 2 and 3 in terms of safety factors or equivalent. Taking R_y and R_u as respectively the yield and ultimate strength of a structural element, and F_{RIG} as the load in a rig element, it gives in the rows of Metal or FRP respectively the ratio R_y/F_{RIG}, or R_u/F_{RIG} with, special consideration for metal whether $\sigma_y > 0{,}5\ \sigma_u$ or $\sigma_y \leq 0{,}5\ \sigma_u$.

For simplicity, Table 4 only calculates in column 7 the safety factor at ultimate $S_{FU} = 1/(\sigma_d/\sigma_u)$, and in column 8 the ratio $S_{FU}/S_{FU\ RIG}$ for “normal “load cases, showing the progression of the safety factors from mast/rig to connection to the structure. For “exceptional” load cases, the safety factor is multiplied by 0,833 (i.e. divided by 1,2).

CAUTION — Table 4 shows the values for design categories A and B, with k_{DCR} = 1, for design categories C and D with k_{DCR} = 1,25, the safety factor is multiplied by 1/1,25 = 0,8 i.e. reduced by 20 %.

Table 4 — Values of the various safety factors computed from Table 3

1	2	3	4	5	6	7	8
					$\sigma_d = \sigma_{LIM} \times k_{MAT} \times k_{LC} \times k_{DCR} / \sigma_u$		
Load case description	σ_{LIM}/σ_u [a]	k_{MAT}	k_{DCR}	k_{LC} Normal	σ_d/σ_u	R_u rig /F rig $1/(\sigma_d/\sigma_u)$	$R_{U\ ELEM}$ /$R_{U\ RIG}$
Rig or mast load - Metal	0,50	0,75	1,0	1,11	0,42	(2,40)	(1,00)
Rig or mast load - Pure fibre rig	1,00	0,33	1,0	1,30	0,43	(2,33)	(0,97)
Mast load FRP - Mast	1,00	0,33	1,0	1,20	0,40	(2,53)	(1,05)
Chainplate/mast step - AISI 316	0,42	0,75	1,0	1,10	0,35	2,87	1,19
Chainplate/mast step - ALU 5086 H111	0,42	0,75	1,0	1,10	0,34	2,91	1,21
Chainplate - FRP	1,00	0,33	1,0	1,05	0,35	2,89	1,20
Strapped FRP chainplates (UD straps only)	1,00	0,33	1,0	0,35	0.08	8,66	3,6
Connection to structure metal	0,42	0,75	1,0	0,92	0,29	3,48	1,45
Connection to structure FRP/wood - direct stress	1,00	0,33	1,0	0,88	0,29	3,46	1,44
Connection to structure FRP co-cured /glued	1,00	0,33	1,0	0,83	0,27	3,65	1,52

[a] Examples of calculation of values in column 2: AISI 316 plate σ_{LIM}/σ_u = min (220;0,5×520)/520 = 0,5; aluminium 5086 H 111 welded or not σ_{LIM}/σ_u = min(100;0,5×240)/240 = 0,423 0.

7 Developed method — General assessments, design moment

7.1 General

7.1.1 General topics on rigging design

This document defines the required design loads on rig elements, but not their actual ultimate strength or strain (elongation). This is because shrouds and stays are frequently over dimensioned due to stiffness considerations to avoid mast buckling and limit the ‘fall-off’ of the mast to leeward. This is particularly true for non-metal rig. In contrary, this document defines design loads for the connection of the rig elements to their attachment or foundation (mast or pillar steps and rig attachment chainplates). The loads on multihull rig elements (loads on shroud and stays, mast compression, mainsheet pull) defined in this document are also useful to assess the global loads used in ISO 12215-7:2020.

The equilibrium between the various loads on the masts and their rigging (and therefore their attachments) is of paramount importance. The values considered in this document are the minimal ones corresponding to this balance, which needs a proper setting of the rig and complete "tuning", see 7.1.3. For these reasons, some professionals take larger safety factors than those in this document, both on the rig and mast dimensioning, but this extra margin is not considered here.

NOTE Reference [5] has a similar approach to this document on several points, but mainly for sailing monohulls larger than the scope of this document (L_H > 24 m) and with safety factors in line with Classification society rules, i.e.; usually larger than those in this document.

7.1.2 Sail configurations:

Subclause 7.2.7 defines the sail configurations to be checked and the corresponding design forces and moments (righting or heeling), and for craft where heeling moment governs (case b), the apparent wind speed V_{ACEK1} (knots) or V_{ACEM1} (m/s) in sail configuration S_{C1} at sail center of effort (CE). The designer/manufacturer shall state the principal sail configurations assessed and to be used according to wind speed and direction (upwind, downwind, etc.). The designer/manufacturer shall either choose them by experience/tests or use the default proposed values of Table 7. The apparent wind speed values given in this table are however considered as close to minimal values for multihulls in case b) corresponding to global loads from rig experienced on sailing multihulls.

The designer/manufacturer shall include in the owner's manual (Clause 13):

— a table of recommended sail configurations and trimming according to apparent wind speed, course, sea state, etc.

  — for monohulls, it may be a simplified document;

  — for multihulls or for stable craft, this table may have a similar format to the one required by ISO 12217-2:2015, see NOTE 1, with actions to prevent capsize in gusts mainly in m_{MO} condition. This document, dedicated to strength, only considers the largest loads, i.e. in m_{LDC} condition, but for prevention of capsize, the owner's manual shall also and mainly consider the minimum operating condition m_{MO} as it is the condition more prone to capsize. In that case, the formulas for the heeling moment M_{H1} and the corresponding apparent wind speed V_{A1} at sail CE shall be lowered to m_{MO} condition.

  NOTE 1 This document deals with all sail configurations upwind and downwind, as explained in Table 7, and in m_{LDC} condition. For multihulls, the main purpose of ISO 12217-2:2015 is to prevent capsize in minimum operating condition; it only quotes upwind sail configurations, and only requires to use a "table similar" to its Table F.1. The paragraph above does not require the use of Table F.1 of ISO 12217-2:2015, but, for simplicity, the two tables can be combined into a single table.

  NOTE 2 As the apparent wind speed is measured by an anemometer, usually located at mast top, but sometimes lower on a pole, NOTE 4 of Table 5 proposes a classical wind gradient formula to calculate the apparent wind speed at a height different from sail CE. As this method depends on sea roughness, air turbulence, etc., the choice of the anemometer apparent wind speed given in the owner's manual is left to the craft/rig manufacturer.

— any other recommendations, such as, where relevant:

  — sail configurations to be avoided, with explanations e.g.: mainsail with 3 reefs + full genoa, or genoa alone in strong winds;

  — not to navigate under engine power against a choppy or steep sea without mainsail and without longitudinal staying set, as it may induce dynamic motions that may be dangerous for the mast and rig due to pitching, slamming; etc.

7.1.3 Rigging loads and adjustment information to be provided

The design of a mast/rig is the result of a choice of dimensioning its elements and of their correct setting up. For that purpose, the mast/rig provider shall give:

1) the design load of each of the rig element provided: mast step/pillar, shrouds, stays, etc., the dimensions of their end fittings, specifying whether this fitting, including its pin, corresponds to the design load or to a larger load. This information shall be included as per Clause 14. The definition of these loads shall either be assessed according to this document or from another documented method.

2) the recommended method of setting up/tuning the mast and its rigging through a specific notice delivered with the spars and rigging for the persons in charge of the mast/rig adjustment. This notice shall either be included as per Clause 14 (information for mast setup/rig tuning) or in a specific chapter of the owner's manual. This notice shall include the minimum and maximum values of pre-stressing applied to the rigging to guarantee its correct setting.

The pre-stressing loads shall be given in terms of

— tensile forces to be applied to the standing rigging, and/or,

— shortening of the turnbuckles with respect to the state 0 ("slack of the rig" just transformed into "just under tension"). This allows an easy pre-setting by any person working on the rig without a suitable tensiometer. This will constitute a minimum value of pre-stressing to be induced on the standing rigging, as the deflection of the craft will reduce the stress, particularly on multihulls. Non-metal shrouds and stays will usually need a much greater length reduction/number of turns of the turnbuckles as the E modulus is usually smaller.

At the end of this initial check, it is recommended that the shortening lengths be included as per Clause 14 or Clause 13 by the agent or dealer delivering the craft to its owner/user to allow the rigging adjustment to be resumed correctly after dismasting (e.g. for maintenance) by any intervener empowered to do so.

In addition, the recommended routine periodical check program for survey and or tuning of the rig, as determined by the mast/rig manufacturer/provider shall be given.

NOTE The initial verification of the actual tensions induced by a shortening value is made at the first adjustment of a rigging by the mast manufacturer, in particular on any production-built craft and on all craft for which the measurement of tension is difficult without a specific device.

7.2 Design moment M_D: righting or heeling moment

7.2.1 General

For simplification, the calculations and formulas are given for a single mast configuration, but the same principle of assessing the loads on sails and rig may be used for a multiple mast arrangement.

For a single mast arrangement, the design moment M_D is the smaller of the design righting moment M_{RUP} (case a) and the design heeling moment M_{HUP} (case b). This design heeling or righting moment is the moment of the couple made by the two equal and parallel forces, the aerodynamic force F_{Ai} and the hydrodynamic force $F_{Hi} = F_{Ai}$ multiplied by their distance $h_{CETi} + h_{CLR}$,see Figures 1 to 3.

NOTE These cases have been ordered in that way because sailing monohulls are mainly in case a) and are still in greater number than sailing multihulls, usually case b).

The same alternative applies for the main mast of a ketch or yawl rig arrangement; whereas for mizzen mast, it is obvious that its loads need to be assessed according to its respective heeling moment as one cannot reasonably require the whole righting moment of the craft taken by the mizzen mast alone.

For schooner rig, the case is more delicate and shall be assessed according to the sails considered set at the same time, same where there are more than two masts. Subclause 7.2.7.1 defines the sail configurations to be used (as stated by the manufacturer/designer or as proposed in Table 7), these settings shall be included in the owner's manual as per Clause 13.

Wing masts have an area that is considered in this document as a non-reefable sail, see 7.4.

7.2.2 Principle of design

The design moment M_D defined in Table 5 corresponds to the "Design moment" when the craft sails upwind in "normal" conditions. It is the lesser of cases a) and b) below:

— **Case a), the righting moment when sailing upwind governs:** $M_D = M_{RUP}$. This is the case for most monohulls and for "sports" multihulls that may "lift a hull" according to this document: the craft begins to heel significantly before the full wind force and a corresponding heeling moment applies. In "normal" load cases (see Item 4 of Table 3 and Table 7), this design righting moment is the righting moment upwind M_{RUP}, whereas in "Exceptional" load cases or other sail configurations, it can be the maximum righting moment M_{RMAX}. (See Tables 6 and 7.)

— **Case b), the heeling moment when sailing upwind governs,** $M_{D} = M_{HUP,}$ i.e. the heeling moment when sailing upwind, produced by the resultant force on the sail plan due to the wind. It applies to craft where $M_{RUP} > M_{HUP}$: the righting moment upwind is greater than the heeling moment. This is usually the case for cruising multihulls and for some "form stable" monohulls and/or strongly under canvassed monohulls. This is also usually the case for mizzen masts on ketches or yawls that are not designed to support the whole power of the craft but only their share, according to its sail area. In "normal" load cases (see Item 4 of Table 3 and Table 7), this design moment is the heeling moment upwind M_{HUP} whereas in "Exceptional" load cases or other sail configurations, it can be M_{HDOWN}, M_{BROACH} or M_{RMAX}. (See Tables 6 and 7.)

Unless experience has clearly shown which is the lesser of the righting moment M_{RUP} or the heeling moment M_{HUP}, one shall calculate both to know which one is the lesser. This is particularly true for well canvassed multihulls that "lift a hull" or 'form stable'/under canvassed monohulls.

Table 5 — Formulas for the determination of upwind design moment M_{D} and forces

$M_{D} = \min(M_{RUP}; M_{HUP})$ **Design moment and sail forces**

The calculations of this Table shall be made at least in the sail configuration S_{C1} or in the sail configuration S_{Ci} of Table 7 inducing the highest moment

1 - Case a: $M_{RUP} = M_{R\,\phi UP} + M_{RCREW} < M_{HUP}$
Righting moment upwind governs — Usually monohulls, see Figure 3

M_{RUP} is the righting moment at heel angle ϕ_{UP} in m_{LDC} condition, including the maximum effect of asymmetric ballasting (water-ballast, canting keel, foils, etc.), with maximum crew number positioned at deck level height and on the centerline of the craft, in (Nm).

For monohulls, the heel angle ϕ_{UP} is taken as 30°, and the righting moment at 30° heel is

$M_{RUP} = M_{R30} = 9{,}81 \times G_{Z30} \times m_{LDC} + M_{R\,CREW}$ (Nm), see Figure 3 e), where

— G_{Z30} (m) is the righting lever at 30° heel, and

— $M_{R\,CREW} = 75 \times 9{,}81 \times n_{PH} \times \cos\phi_{UP} \times 0{,}5\,B_{H}$ is the additional righting moment from hiking crew, where

— n_{PH} = number of persons hiking at 75 kg/person in the design category. In the absence of a specific value given by the manufacturer, n_{PH} shall be taken as 60 % of the total crew limit C_{L} declared in the higher design category. Other people within crew limit staying on the centerline and at deck level.

For multihulls, see Figures 3 f) and g), the heel angle $\phi_{UP} = \phi_{LIM}$, the angle where the canoe body of the windward hull for catamaran or central hull for trimarans just "takes off" of the heeled flotation, the righting moment is

$M_{RUP} = M_{R\phi LIM} = 9{,}81 \times G_{Z\phi LIM} \times m_{LDC} + M_{R\,CREW}$ (Nm), where

— $G_{Z\phi LIM} = (0{,}5\,B_{CB} \cos\phi_{LIM} - V_{CG} \sin\Phi_{LIM})$, where

— ϕ_{LIM} may be approximated by $\phi_{LIM} = \text{atan}(k_{\phi} \times Tc/B_{CB})$ with $k_{\phi} = 1{,}7$ for catamarans and $k_{\phi} = 4$ for trimarans and

— V_{CG} is the height of the center of gravity above the bottom of canoe body T_{C}, which may be taken conservatively at the height of sheerline at mid L_{WL} where not known by a sketch of weight; and

— $M_{R\,CREW}$ is as defined for monohulls.

NOTE 1 $M_{R\phi LIM}$ is equal to M_{RMAX} where the windward hull or central hull has no buoyant appendage, and close to it in the opposite case.

Design upwind heel angle ϕ_{UP}, righting moment, wind speed and aerodynamic forces in case a)
Unless specifically documented and without using asymmetric ballasting, the default values are

Craft type	Monohull	Multihull
ϕ_{UP} (degrees)	30°	$\phi_{UP} = \phi_{LIM} = \text{atan}(k_{\phi} \times Tc/B_{CB})$ with $k_{\phi} = 1{,}7$ for catamarans and 4 for trimarans
M_{RUP} (Nm)	$M_{R\phi\,UP} = M_{R\,30}$ derived from stability curve $+ M_{R\,CREW}$	$M_{R\phi\,UP} = 9{,}81 m_{LDC} \times (0{,}5\,B_{CB} \cos\phi_{LIM} - V_{CG} \sin\phi_{LIM}) + M_{RCREW}$

Table 5 *(continued)*

V_{ACEK} apparent wind speed (knots) at h_{CET1W} (See NOTE 2)	$V_{ACEK1} = \sqrt{\dfrac{M_{RUP}}{0{,}158\ A_{T1}\ (h_{CET1W} + h_{CLR})}}$ wind speed in knots at 30° heel	$V_{ACEK1} = \sqrt{\dfrac{M_{R\phi\ UP}}{0{,}190\ A_{T1}\ (h_{CET1W} + h_{CLR})}}$ wind speed in knots at ϕ_{UP1}
V_{ACEM} apparent wind speed (m/s) at h_{CET1W} (See NOTE 2)	$V_{ACEM1} = \sqrt{\dfrac{M_{RUP}}{0{,}597\ A_{T1}\ (h_{CET1W} + h_{CLR})}}$ wind speed in m/s at 30° heel	$V_{ACEM1} = \sqrt{\dfrac{M_{R\phi\ UP}}{0{,}720\ A_{T1}\ (h_{CET1W} + h_{CLR})}}$ wind speed in m/s at ϕ_{UP1}
Aerodynamic force (N) for total sail plan perpendicular to sail plan at sail CE	$F_{A30T1} = 0{,}158 \times A_T \times V_{ACEK1}{}^2$ with V (knots) $F_{A30T1} = 0{,}597 \times A_T \times V_{ACEM1}{}^2$ with V (m/s)	$F_{AT1} = 0{,}190 \times A_T \times V_{ACEK1}{}^2$ with V (knots) $F_{AT1} = 0{,}720 \times A_T \times V_{ACEM1}{}^2$ with V (m/s)

2- Case b $M_{RUP} > M_{HUP} = \max(M_{Hi})$ with i = 1 to 5 , see Table 7

The heeling moment upwind governs — Usually multihulls, see Figure 3

This applies to craft that do not heel significantly i.e. $\phi_{UP1} \leq 20°$

The input is the apparent wind speed at height h_{CETW1}, V_{ACEM1} (m/s), or V_{ACEK1} (knots), defined in Clause 13 and the respective heights of center of sail area h_{CET1W} and center of hydrodynamic resistance h_{CLR} defined in Table 8 and Figures 1 and 2. The forces perpendicular to each sail can be derived according to its area. The corresponding rig loads can then be derived from Clause 8.

$A_{Ti} = A_{Mi} + A_{Fi} + A_{WM}$	m^2	Total sail area (mainsail + foresail + wing mast) in sail configuration S_{C1}, see Table 7
$F_{AT1b} = 0{,}720 \times A_{T1} \times V_{ACEM1}{}^2$ $F_{AT1b} = 0{,}190 \times A_{T1} \times V_{ACEK1}{}^2$	N	Equal aerodynamic forces at C_E sails and hydrodynamic force at C_{LR} with wind speed V_{ACEM1} in (m/s) or V_{ACEK1} in (knots)
$M_{HUP1} = F_{AT1b} \times (h_{CET1W} + h_{CLR}) + M_{CREW}$	Nm	Heeling moment
$\Phi_H = \Phi_{LIM} \times M_{H1}/M_{RUP1}$	Degree	Heel angle
where		

3- Dimensions in both cases a) and b)

replace 1 by i for other sail configurations than S_{C1}.

A_{M1}, A_{F1}, $A_{WM,}$ and A_{M1} (m^2)	are respectively the full mainsail, full upwind foresail, wing mast and total sail area in sail configuration S_{C1};
V_{MSA1} (m/s) or V_{KNA1} (knots)	is the apparent wind speed for S_{C1} defined below and in 7.1.2 and/or Table 7 for sail configuration $S_{C1,}$ see Figure 3;
h_{CETW1} (m)	is the height of the application point of the total sail force above W_L, calculated at the height of the center of surface of all sails in sail configuration S_{C1}, plus wing mast, where relevant (see Figures 1 or 2) ;
h_{CLR} (m)	is the height of the center of underwater lateral resistance force below W_L, taken at mid-draft unless otherwise documented.

Table 5 *(continued)*

NOTE 2 For index i = 2 to 5, Table 7 considers the same heeling moment as in sail configuration S_{C1}: $M_{Hi} = M_{Hd} = M_{H1}$, which means, for S_{C2} to S_{C5} a greater force F_{Ti}, (but lower center of effort), a greater wind speed and a greater load on the sails and the low working rig elements.
NOTE 3 For an upright craft the wind force is $F_A = C_N \times 1/2 \times \rho \times A \times V_{MS}^2$ (N) where C_N = 1,2 is the side force coefficient (close to lift coefficient), ρ = 1,2 kg/m^3 is the density of air at 20 °C, A is the sail area in (m^2), and V_{MS} is the wind speed in (m/s), hence $F_A = 0{,}720 \times A \times V_{MS}^2$ (N) and if the wind speed is in knots the coefficient is $0{,}720 \times (1\,852/3\,600)^2 = 0{,}190$ and $F_A = 0{,}190 \times A \times V_{KN}^2$ (N). The side for coefficient is taken conservatively at 1,2 for all sails: foresails, mainsails and spinnakers, whereas Reference [5] uses lower and different values for each type of sails.
For a craft heeled at ϕ degrees, the horizontal force is $F_A = 0{,}720 \times (\cos \Phi)^{1,3} \times A \times V_{MS}^2$ (N) and for ϕ = 30° $F_{A30°} = 0{,}597 \times A \times V_{MS}^2$ (N) for wind speed in (m/s) and $F_{A30°} = 0{,}158 \times A \times V_{KN}^2$ (N) for wind speed in (knots). The heeled coefficient $(\cos 30°)^{1,3}$, with a power of 1,3, accounts for experimental aspects (velocity gradient, effective angle theory, etc., see Reference [17], and is used in ISO 12217-2:2015.)
NOTE 4 The wind heeling moment $M_H\ \phi_{UP1} = 0{,}720 \times (\cos \phi_{UP1})^{1,3} \times A_{T1} \times V_{MS}^2 \times (h_{CETW1} + h_{CLR})$ is multiplied by $(\cos \phi_{UP1})^{1,3}$, which corresponds to a reduction of lift with heel. To simplify and be conservative the cosine is neglected for multihulls for force and heeling moment because $(\cos \phi_{UP1})^{1,3}$ is 0,92 for ϕ_{UP1} = 20° and 0,98 for ϕ_{UP1} = 10°.
NOTE 5 The formula generally agreed for wind speed gradient is $V_{R2}/V_{R1} = \ln(h_2/Z_0)/\ln(h_1/Z_0)$ where V_{R2} and V_{R1} are the real wind speed at heights h_2 and h_1, and where z_0 is the ground rugosity (taken 0,000 2 for sea), and ln is the “natural” logarithm (Napierian).This formula may be used to derive the variation of true wind speed between CE of sails and anemometer position, or, with a small error, for the variation of apparent wind speed.
CAUTION — The wind speed V_{A1} is the design apparent wind speed, i.e. the actual apparent wind speed when the sail plan begins to be reduced. This wind speed is the one exerted at sail CE, which is smaller than the speed measured with an anemometer at mast top (see NOTE 5). Wind gusts can multiply this wind speed by 1,4 and therefore double the wind force.

7.2.3 Topics on multihulls/form stable sailing craft corresponding to case b) i.e. with $M_{H1} < M_{R\ UP1}$

In case b), the heeling moment is lower than the righting moment, sometimes down to $M_{H1} < 0{,}5\ M_{R\ UP1}$ particularly for large yachts. This means that the mast and rig can be damaged or break under severe gusts where the craft is over-canvassed. Devices limiting the heeling moment e.g. "fuse" or devices limiting loads in the mainsail sheet, overload alarm on sheets/shrouds, electric winches, or rams are recommended for that purpose.

When the wind - real and apparent - increases, the sail setting (sail reduction by reefing/rolling, incidence of the sails against apparent wind, pull on the sheets) is adjusted and/or reefed/reduced. This document considers that the sail area/setting, and sheet trimming, are adjusted for each sail reduction to reach M_{HD1}, the heeling moment at which the sail area is first reduced upwind (S_{C1} in Table 7). Some designers consider that the design heeling moment increases when the sail area is reduced, and they may use their own values. For dimensions, areas, etc. Table 8 shall be used unless specific values are available and documented.

CAUTION — When using different values than in Table 7, it is the responsibility of the builder/designer to define the apparent wind speed for these limits, whether leading to a heeling moment greater or smaller than the default proposed value (see 7.1.2), according to the way the craft is designed to be used, and to give in the owner's manual information about the sails to be set and how they should be trimmed, see Clause 13.

NOTE To simplify the calculations, the formulas of this document do not take into account the windage of hull, rig and superstructure, unlike in the method proposed in Annex G of ISO 12217-2:2015. This stability standard requires to supply information concerning maximum apparent wind speed to be given in the owner's manual according either to tests or to calculations, both in minimum operating m_{MO} condition and, voluntarily, in maximum load condition m_{LDC}. The apparent wind speeds used in this document have the same purpose as the ones given in ISO 12217-2:2015, but are mainly connected to mast/rig strength issues in m_{LDC} condition, so the results may differ.

7.2.4 Downwind longitudinal force F_{ADOWN} and nose trimming moment M_{HDOWN}, running under spinnaker alone — "Normal" (S_{c6}) or "exceptional" (S_{c8})

The longitudinal force F_{ADOWN} and corresponding nose-trimming moment M_{HDOWN}, exerted when running downwind under spinnaker alone at mast top or hounds, are defined in Table 6, the worst case being retained. The apparent wind speed V_{A6} is defined in Table 7. This force needs not be taken greater than the force corresponding to a nose trim angle of 10°.

7.2.5 Maximum righting moment M_{RMAX}, exceptional case, reaching under spinnaker

M_{RMAX}, which may be approximated by $M_{R\phi LIM}$ for multihulls, is the maximum righting moment in m_{LDC} condition calculated from the stability curve or measured. This case is exceptional as it only happens in some severe gust conditions in upwind sailing, or under lateral broaching under spinnaker. Dynamic and fatigue loadings are not considered to be relevant in this load case.

7.2.6 Heeling force $F_{ABROACH}$ and heeling moment $M_{HBROACH}$ while broaching under spinnaker, exceptional case

$F_{ABROACH}$ and $M_{HBROACH}$, defined in Table 6, are respectively the transverse force and corresponding heeling moment induced by the rig in S_{C9} to consider the rather rare case where the craft broaches under spinnaker, i.e. the craft gets out of balance and is heeled significantly. As for the upwind moment, it shall be compared to M_{RMAX}, the smaller value being retained.

Table 6 — Formulas for downwind design moments and forces

1 - Downwind longitudinal force and trimming moment (see Table 7)
$F_{ADOWN} = 0{,}720 \times A_6 \times V_{MSA6}^2$ (N) $= 0{,}190 \times A_6 \times V_{KNA6}^2$ (N) is the longitudinal force exerted under spinnaker, in sail configuration S_{c6} with the corresponding apparent wind speed expressed respectively in (m/s) or (knots), and $M_{HDOWN} = F_{ADOWN} \times h_{CET6W}$ (Nm) is the design heeling moment for "Normal" sail configuration S_{c6}. A_6 and h_{CET6W} being respectively the sail area and height of sails center of effort above W_L in sail configuration S_{c6}, see Table 7 and Figures 1 and 2.
2 - Heeling force and moment while broaching under spinnaker (see Table 7)
$F_{ABROACH} = 0{,}720 \times A_9 \times V_{MSA9}^2$ (N) $= 0{,}190 \times A_9 \times V_{KNA9}^2$ (N)transverse force exerted when broaching under spinnaker in sail configuration S_{c9} with the corresponding apparent wind speed expressed in (m/s) or (knots), and $M_{HBROACH} = F_{ABROACH} \times (h_{CET9W} + h_{CLR})$ (Nm) is the heeling moment for "Exceptional" sail configuration S_{c9}.
NOTE In M_{MDOWN}, the lever of the sail force is considered above W_L and not C_{LR}, as it is considered that the appendages do not play a significant part in this load case.

7.2.7 Minimum sail configuration and righting/heeling moment to be analyzed

7.2.7.1 General

The main relevant sail configurations with corresponding design heeling/righting moments and corresponding wind speed shall be analyzed. See 7.1.2 for more information.

7.2.7.2 Default proposed values

Table 7 proposes default values for sail configurations to be analyzed and the corresponding wind speed. This table is applicable to craft whether M_{HUP} or M_{RUP} govern. For Normal/Exceptional sail configurations, the factor k_{LC} shall correspond to the relevant value of Table 3.

Table 7 — Sail configurations and corresponding design heeling moment in m_{LDC} condition

S_C	Sail configuration	Design heeling/righting moment (Nm)	Default apparent wind speed value at CE of sails V_{ACEKi} or V_{ACEMi} [c] (knots) or (m/s)
1 - Sail configuration for "normal" values of k_{LC} of Table 3., according to load case			
1	Full mainsail + full foresail (Genoa or Solent as relevant)	Case a $M_{D1} = M_{RUP1}$	NOTE In case a, the apparent wind speed is informative as M_{RUP1} governs $V_{ACEK1a} = \sqrt{\dfrac{M_{RUP1}}{0,158\ A_{T1}\ (h_{CET1W} + h_{CLR})}}$ (knots) $V_{ACEM1a} = 0,514\ V_{ACEK1a}$ (m/s)
		Case b $M_{D1} = M_{HUP1}$	$V_{ACEK1b} = 22 + 1,9 L_{WL}^{0,5}$ (knots) $V_{ACEM1b} = 0,514\ V_{ACEK1b}$ (m/s)
2	Full mainsail + solent jib i.e. 100 % fore triangle	Case a $M_{Di} \geq M_{RUP1}$ Case b $M_{Di} \geq M_{HUP1}$	V_{Aia} calculated to induce at least M_{RUP1} V_{Aib} calculated to induce at least M_{HUP1}
3	Mainsail 1 reef (default 83 % P) + solent jib or 100 % fore triangle whichever is lower		
4	Mainsail fully reefed to 50 % P[a] + foresail reduced to 25 % of fore triangle[b]		
5	Mainsail fully reefed to 50 % P[a] alone		
6	General running case with spinnaker at mast top or hounds where relevant, plus full mainsail. Worst case chosen. It also includes the case where there is no fixed/running backstay	M_{HDOWN}	$V_{ACEK6b} = 25 - 1,7 L_{WL}^{0,5}$ (knots) $V_{ACEM\ 6b} = 0,514\ V_{ACEK\ 6b}$ (m/s)
7	Any other relevant sail configuration, for specific rig type	According to case	According to case
2 - Sail configuration for "exceptional" values of k_{LC} in Table 3 according to load case			
8	Same as S_{c6} gybing before tightening running backstay or removable backstay	M_{HDOWN}	$V_{ACEK\ 8b} = 25 - 1,7\ L_{WL}^{0,5}$ (knots) $V_{ACEM\ 8b} = 0,514\ V_{ACEK\ 8b}$ (m/s)
9	Broaching under full mainsail + spinnaker (head or mast top, where relevant) at 90° from apparent wind	Min (M_{RMAX}; $M_{HBROACH}$)	$V_{ACEK\ 9b} = 18 + 1,7\ L_{WL}^{0,5}$ (knots) $V_{ACEM\ 9b} = 0,514\ V_{KNSA9b}$ (m/s)
10	Any other relevant sail configuration, for specific rig type	According to case	According to case

[a] Mainsail reduced to 50 % means luff 0,707 P (and tack close to 0,707 E according to sail shape).

[b] Foresail reduced to 25 % of fore triangle depends from the type of reefing (furling /slab) or setting a smaller jib.

[c] See NOTE 5 in Table 5 for corresponding apparent wind speed at anemometer height.

CAUTION — The wind speed V_{A1} is the design apparent wind speed. The true wind speed when the sail plan begins to be reduced is smaller when sailing upwind (see CAUTION at the bottom of Table 5).

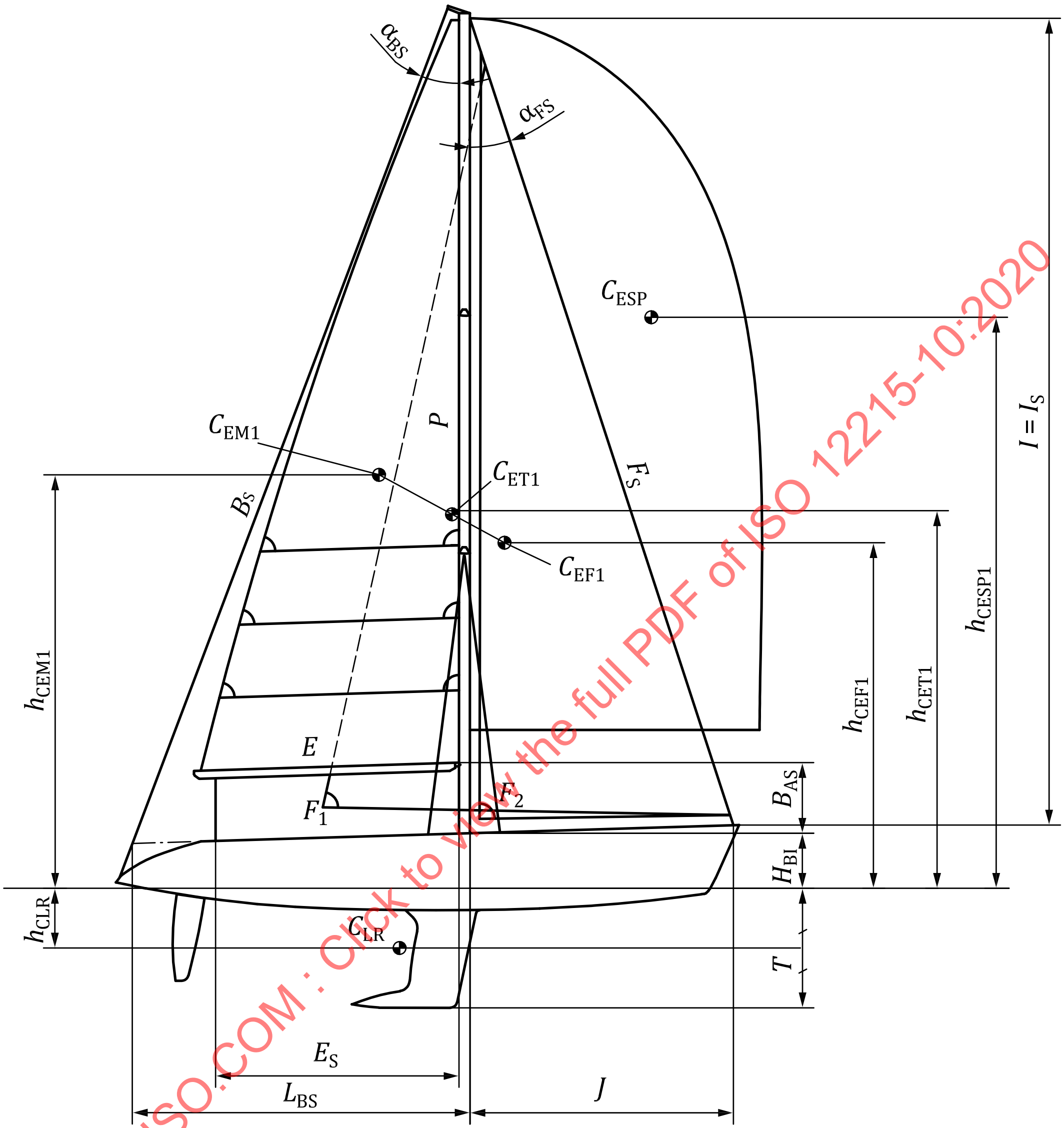
7.3 Rig dimensions, and default values for areas, forces and points of application

Table 8, Figure 1 (monohulls) and Figure 2 (multihulls) give the rig dimensions and default values for areas, forces and points of application of most frequent rig arrangements. These "default" values shall be used unless specific documented values are available. For other rig configurations, the same logic shall be applied to calculate areas and their center of area.

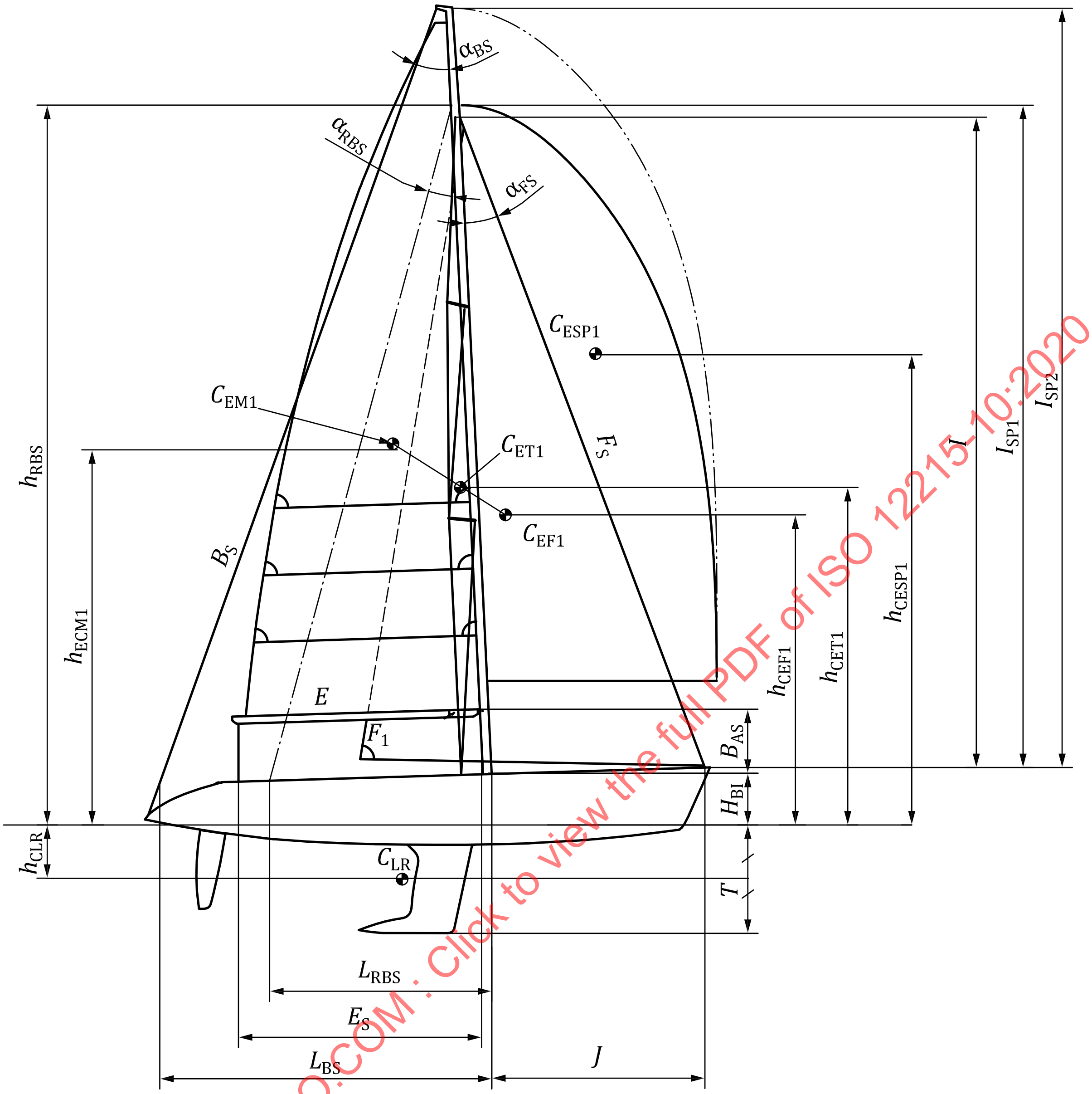
Table 8 — Rig dimensions and default values for areas, and points of application

Name	Definition[a]	Default value
A_{F1}	Area of max foresail in sail configuration $S_{C1.}$ With L_P between 0,9 for solent and 1,3 to 1,5 for genoa	$A_{F1} = 0,85\ L_P \times J \times (I^2 + J^2)^{0,5}$
A_{F2}	Area of solent or 100 % foretriangle whichever is smaller	$A_{F2} = 0,5\ I{\times}J$ or A_{Solent}
A_{Mi}	Area of mainsail in S_{ci} with $P_1 = P$ for full mainsail	$A_{Mi} = 0,5\ P_i \times E_i \times k_{ROACH}$
A_{SP1}	Area of symmetric spinnaker 1 (hounds)	$A_{SP1} = 1,56\ I_{SP1} \times J$
A_{SP2}	Area of symmetric spinnaker 2 (mast top)	$A_{SPI2} = 1,56\ I_{SP2} \times J$
A_{WM}	Area of wing mast, where W_{WM} is the wing mast mean chord	$A_{WM} = (P{+}B_{AS}){\times}W_{wm}$
A_{T1}	Total area in sail configuration S_{ci}	$A_{Ti} = A_{Mi} + A_{Fi} + A_{WM}$
B_{AS}	Height of boom above H_{BI}	B_{AS}
E	Length of mainsail luff along the boom	E
E_s	Horizontal distance of the mainsheet pull aft of front of E	E_s
F_{Ai}	Aerodynamic force in sail configuration S_{ci}	$F_A = 0,720 \times A \times V_{MS}^2$ (N) $F_A = 0,190 \times A \times V_{KN}^2$ (N) where V_{MS} and V_{KN} is the apparent wind speed in (m/s) and (knots)
h_{CEMi}	Height of center of mainsail area above W$_L$ in S_{Ci} configuration	$h_{CEMi} = P_i \times k_{HM} + H_{BI} + B_{AS}$
h_{CEFi}	Height of center of foresail area above W$_L$ (see Table 7, for k_{HF}) in S_{Ci}	$h_{CEFi} = k_{HF} \times I + H_{BI}$
h_{CETi}	Height of center of total sail plan above W$_L$ in S_{Ci} configuration	$h_{CETi} = (A_{Fi} \times h_{CEFi} + A_{Mi} \times h_{CEMi} + A_{WM} \times h_{CEWM})/A_{Ti}$
h_{CEWM}	Height of center of wing mast above W$_L$ in S_{Ci} configuration	$h_{CEWM} = k_{HWM} \times (P + B_{AS})$
h_{CLR}	Default height of center of lateral resistance below W$_L$ unless otherwise documented	$h_{CLR} = 0,5\ T$
H_{BI}	Height of hull/deck connection above W$_L$ at front of mast section in m_{LDC} condition	H_{BI}
I	Height above H_{BI} of hounds (intersection between mast and forestay)	I
I_{SP1}	Height above H_{BI} of spinnaker hoist at hounds	$I_{SP1} \approx I$
I_{SP2}	Height above H_{BI} of spinnaker hoist at top of fractional mast	$P + B_{AS}$
J	Longitudinal distance between mast front and intersection between main forestay and deck	J
k_{DSR}	Dynamic load factor, see Table 10, for definition	$k_{DSR} = \max\ (3,086 \times L_{WL}{}^2/m_{LDC}{}^{0,66};1)$
k_{HWM}	Ratio between h of center of area of wing masts/total height	$k_{HWM} = [h_{CEWM}/(P + B_{AS})] \approx 0,5$
k_{ROACH}	Ratio between projected mainsail area and $0,5 \times P \times E$, varies between 1 for triangular mainsail up to 1,5 + for modern gaff rig.	$k_{ROACH} = A_M/(0,5 \times P \times E)$
L_{ASH}	Horizontal aft foot of shroud	L_{ASH}
L_{BS}	Horizontal aft foot of backstay aft of front of mast at H_{BI} level	L_{BS}
L_{RBS}	Horizontal aft foot of running backstay at H_{BI} level aft of front of mast	L_{RBS}
L_P	Distance of sheeting point of foresail perpendicular to forestay	L_P
P	Height of top of mainsail above boom (P_1 for full mainsail)	P
Pi	Height of top of mainsail above boom in sail configuration Sci	Pi
α_{BS}	Aft angle of backstay connected to mast at top of I level	$\alpha_{BS} = [L_{BS}/(P + B_{AS})]$
α_{BRB}	Aft angle of running backstay connected to mast at top of I level	$\alpha_{RBS} = [L_{RBS}/(P + B_{AS})]$
α_{FS}	Angle of forestay against vertical	$\alpha_{FS} = [J/(I + H_{BI})]$

[a] Index i means sail configuration S_{ci}.



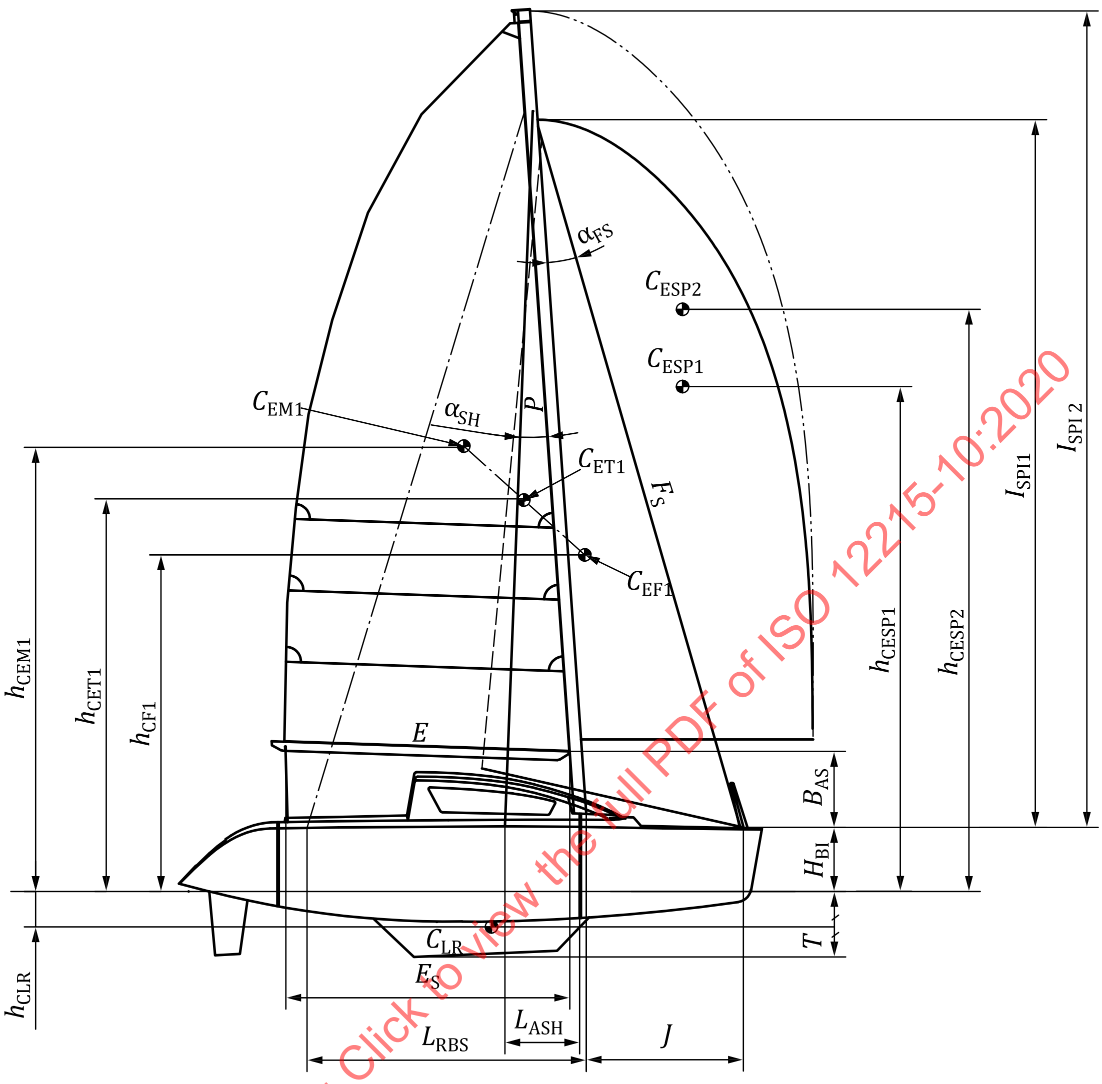
a) Fore and aft lower shrouds and backstay



b) Fractional rig, with aft angled spreaders, fixed and running backstays

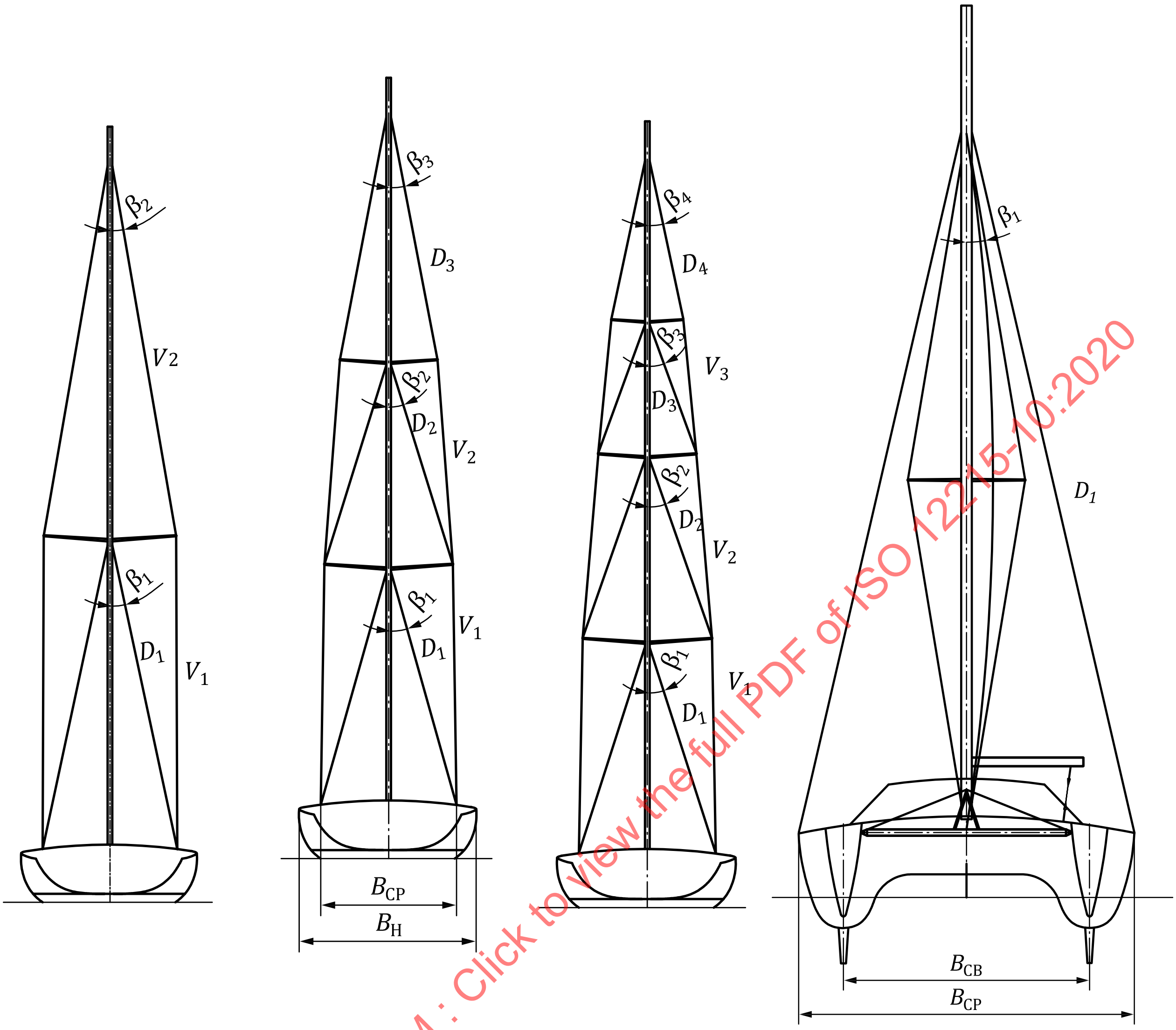
All values defined in Table 8.

Figure 1 — Typical longitudinal rig (stays) arrangements for monohulls

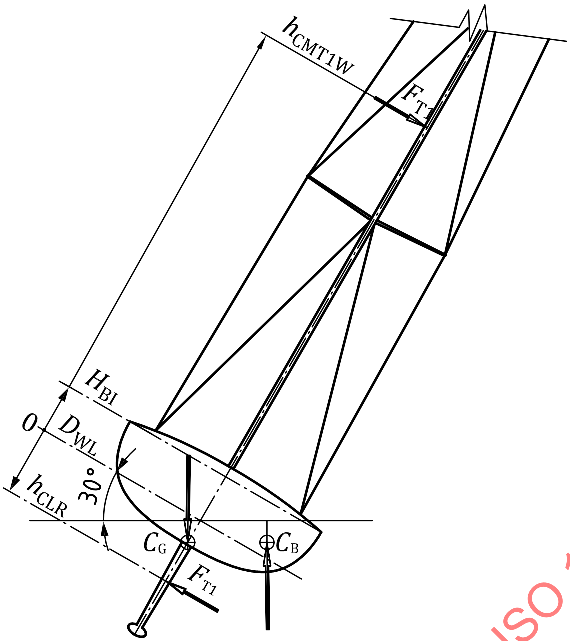


All values defined in Table 8.

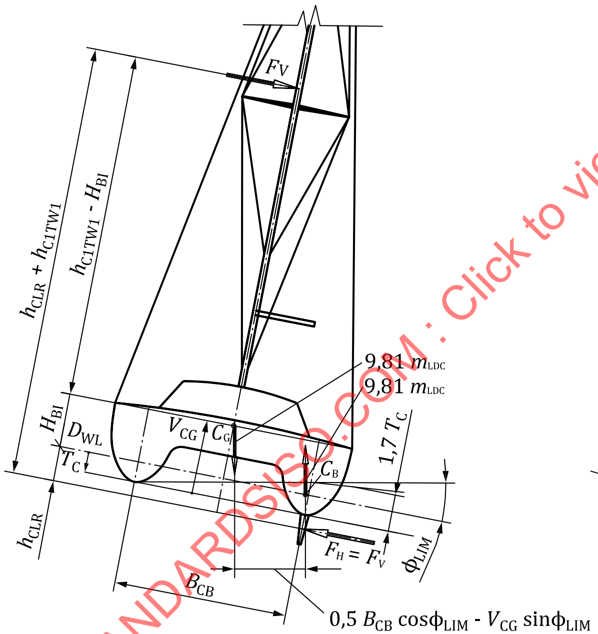
Figure 2 — Typical longitudinal rig (stays) arrangements for multihulls



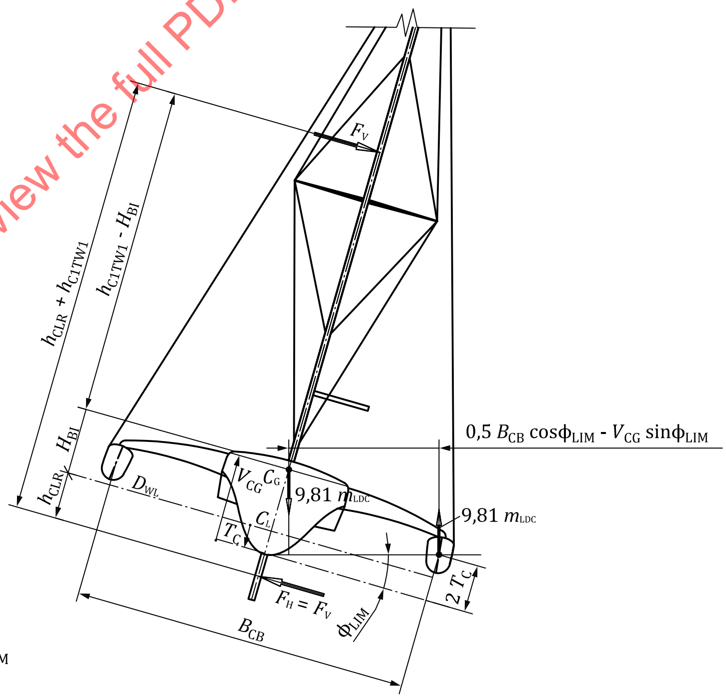
a) Monohull 1 set of spreaders **b) Monohull 2 sets of spreaders** **c) Monohull 3 sets of spreaders** **d) Catamaran**



e) Heeled monohull



f) Heeled catamaran



g) Heeled trimaran

Figure 3 — Typical transversal rig (shrouds) arrangements

7.4 Wing masts

Unless fitted with areas reduction devices, wing masts shall be considered with a constant area added to mainsail and foresail in all sail configurations. Unless otherwise documented, its center of effort is at its mid height.

7.5 Resultant forces in sails

The resultant of aerodynamic forces on sails is located slightly higher than the center of area of the sail shown in Figures 1 to 2. Table 9 gives default values to be used, but these data are "basic" and conservative, and specific documented values may be used.

NOTE Software analyzing stresses in sails, based on fluid dynamics: aerodynamic/mechanical behavior of sails materials, etc. are being developed at the date of publication of this document, and the trimming of sails has a great influence on the results. This lack of "universally recognized" data is particularly true for mainsails transverse loads, where the traditional triangular with small roach pattern is being more and more replaced by big roach or modern gaffed mainsails. The default values proposed in Table 9 are still pending a wider validation, and documented values may also be used. Same for the default proposed distribution of transverse loads from mainsail on the mast, according to roach factor k_{ROACH} and from foresails to hull and rig are given in Table 9.

Table 9 — Default transverse forces on the sails

<table>
<tr><th colspan="8">1 - Vertical position of the center of effort in foresails</th></tr>
<tr><td>Upwind & reaching foresails</td><td colspan="7">$k_{HF} = h_{CEFi}/I_i = 0,39$ where I_i is the actual hoist height</td></tr>
<tr><td>Spinnakers</td><td colspan="7">$k_{HSPI} = h_{CESPi}/I_{SPIi} = 0,45$ for asymmetric spinnaker and 0,59 for symmetric spinnaker</td></tr>
<tr><th colspan="8">2 - Distribution of forces in foresails</th></tr>
<tr><td>Proportion of transverse force</td><td colspan="4">Upwind or reaching foresails and asymmetric spinnakers</td><td colspan="3">Symmetric spinnaker</td></tr>
<tr><td>Head</td><td colspan="4">0,43</td><td colspan="3">0,40</td></tr>
<tr><td>Tack</td><td colspan="4">0,29</td><td colspan="3">0,30</td></tr>
<tr><td>Clew</td><td colspan="4">0,29</td><td colspan="3">0,30</td></tr>
<tr><th colspan="8">3 - Vertical position of the center of effort in the mainsail</th></tr>
<tr><td>Ratio between h of center of effort CE of mainsail and P_i with $k_{HMi} = h_{CEMi}/P_i$</td><td colspan="7">$k_{HM} = 0,17 \times k_{ROACH} + 0,19$</td></tr>
<tr><td rowspan="2">Pre-computed values of k_{HM} for k_{ROACH}</td><td>k_{ROACH}</td><td>1,0</td><td>1,1</td><td>1,2</td><td>1,3</td><td>1,4</td><td>1,5</td></tr>
<tr><td>k_{HM}</td><td>0,36</td><td>0,38</td><td>0,39</td><td>0,41</td><td>0,43</td><td>0,45</td></tr>
<tr><th colspan="8">4- Distribution of forces from mainsail to the mast</th></tr>
<tr><td colspan="8">Where the mainsail is connected to the mast/structure by only 3 points, like in trysails or luff furling mainsails, the same distribution as an upwind foresail shall be used.

Where the mainsail is connected to the mast by cars or rope luff, the distribution of the forces from mainsail to the mast is, as explained in 7.5, not fully validated and research is still ongoing. Documented values may be used.

To determine the loads on transverse rig by one of the calculation methods explained in Clause 11, the knowledge of the transverse load at all nodes of the mast/rig is needed. The sum of the forces from the mainsail shall be equal to the aerodynamic transverse force and, same where possible, for moments about tack. This method shall be applied, from full mainsail to a reefed down to 0,5 P, as required in Table 7. As the rig configuration may be mast top or fractional, this entails many load distributions, in addition to the large variation of roach. Annex E shows an example of such a calculation.</td></tr>
</table>

Table 9 *(continued)*

5 - Possible transverse mainsail load distribution factor[a]	
Main headboard	0,3 to 0,7 F_M transverse on mainsail distributed along the top 25 % of the tack
Spreader levels	Rest of F_M linearly distributed as follows: Regular load variation between headboard and tack; based on: — either mainsail chord at each spreader level or — mainsail transverse force according to aerodynamic forces. Sum of forces = transverse force of mainsail, but F_M moments need not be respected
Tack	0 times F_M transverse main
Clew[b]	0,25 F_M transverse main but not considered in this document
[a] All values to be changed if other documented values are available. [b] Not applied on mast, but the total to be 100 % of mainsail transverse force F_M.	
NOTE This distribution is used to ensure conservative loads values on the rig.	

8 Loads in rigging elements — Developed method

8.1 General

The loads in stays, shrouds, and all rigging elements, except for masts, shall be assessed by multiplying the forces determined in Tables 5 and 6 by k_{DSR}, where > 1. The main core of this document deals exclusively with the loads developed/exerted while the craft is sailing, and does not consider the possible external loads that may arise when a rig element is caught by an exterior element, e.g. other craft, quay, etc.

NOTE As the safety factor is kept minimal, the loads on the rig, and therefore on the structure, need to be as close as practical to the observed maximal. Therefore, the loads are multiplied by a dynamic factor k_{DSR} close to the one used in ISO 12215-7:2020 which is connected to the length displacement ratio of the craft. Lighter craft have been reported to be subject to greater dynamic effects due both to wind gusts and to waves.

8.2 Force in forestay, inner forestay, mainsail leech and on halyards

8.2.1 General

The load on forestay, and to a lower extent, on inner forestay, shall be assessed using the two following complementary methods, the greater load value of these two methods shall be used, including for the determination of mast compression due to longitudinal staying:

a) assessing the load connected with expected headstay sag factor k_{SAGF} defined in item 3 of Table 10. For yachts used in sports/racing, where the crew requires a stiff headstay for good upwind performance, which usually goes with tight mainsail, backstay and eventual runners, k_{SAGF} is towards the smallest values of item 3 of Table 10. For cruising yachts k_{SAGF} is, on the contrary, towards the greatest values of $k_{SAG,}$ (0,02 for monohulls and 0,03 for multihulls being frequently used); and,

b) checking the load in stays needed to balance the longitudinal component forces developed by aft set shrouds, running backstays, mainsail leech/sheet, etc. using items 4 and 5 of Table 10.

NOTE 1 Multihulls, particularly catamarans, usually have higher k_{SAGF} values than monohulls, due to difficulties to achieve a stiff platform, and because they do not need to point as hard.

NOTE 2 The scantlings of forestay and, to a lesser extent, inner forestay are, in craft building and mast manufacturing practice, frequently determined by practical reasons (wear, chafe, whiplash, etc.) rather than required by this document. As quoted in References [5] to [8], the forestay is often chosen "with the same diameter as the largest standing rigging wire element in the craft", even if it leads to overbuilding. This could also lead to overbuilding the chainplate and its connection, even if this is not required by this document, therefore Clause 14 requires the design loads to be given by the rig manufacturer.

8.2.2 Force in forestay, inner forestay, mainsail leech and on halyards connected with sag

As for any wire subject to a distributed pressure, the tensile force in the forestay F_{FS} is proportional to its transversal force F_{FS1} in sail configuration S_{C1} and to its sag. See Items 1 and 2 of Table 10.

For the forestay, the factor k_{SAGF} is the relative forestay lateral sag (i.e. the lateral deflection divided by forestay length) which shall either be taken from the default values of Table 10 or derived from experience from manufacturer's experience for the type and size of craft.

For mainsail leech, the same logic applies as its leech tensile force depends on k_{SAGM}, its sag factor, defined the last column of item 2 of Table 10. A sail with a large roach needs a large leech and mainsheet tension to maintain its shape.

For the mainsail sheet, the force depends from the position of the mainsheet E_S aft of mast divided (see Figure 1) by the mainsail foot E, including with reefed or rolled main. Where $E_S/E < 1$, the vertical component of its reaction at tack, if fitted, shall be added to the mast compression.

For the mainsail halyard, the force is the same as the vertical component of the leech tension. The halyard may add compression in the mast, according to its configuration: single or purchased masthead blocked, hooked, etc. According to the way the halyard is connected to the structure, it can also add some compression in the mast step/pillar.

For the jib halyard, the force on the mast depends on the way the sail is connected to it (it is doubled, due to the block forces where the foresail is not connected to the mast by a hook). Similar considerations as for mainsail halyard. This document considers the foresail halyard tensile force is ≤25 % of the tension in its stay.

8.2.3 Force in forestay to balance the longitudinal component of forces from aft set shrouds, fixed/running backstays, mainsail leech

This method balances the moments around the mast bottom from the longitudinal components of the forestay on one side and the aft shrouds, mainsail leech and, where relevant, fixed and running backstay on the other. This method is an alternative solution to the k_{SAG} method, and allows determining the tensile force in the forestay, hence its sag, from the tensile force in the mainsail sheet and in the fixed and/or running backstays. See item 4 of Table 10.

8.3 Force in backstay, running backstays, or equivalent

8.3.1 General

Apart from the "exceptional" sail configuration S_{C8}, or "normal "sail configuration S_{C6}, the mast of monohulls is generally held aft by fixed and/or running backstays. The purposes of these backstays are mainly:

— upwind, to stabilize the mast longitudinally and contribute to achieve the forestay sag defined above, the other contribution being the mainsail via its sheet, or aft set top V/D shrouds, see Figure 1;

— downwind, to mainly contribute to prevent the mast from falling forward under mainsail and spinnaker force F_{DOWN}.

The fixed and/or running backstay shall therefore be checked against its load for the two above uses, i.e.; respectively

— F_{BS1} or F_{BS2} for fixed backstay, the greater value being retained, or

— F_{RBS1} or F_{RBS1} for running backstays, the greater value being retained.

Table 7 summarizes the more common arrangements, see Figure 1, and Table 8 for the dimensions and variables. As F_{DOWN} and F_{F1} correspond to "normal" load cases, the value of k_{LC} in Table 3 shall be taken accordingly to assess the strength of the chainplate or its foundation. Where truss analysis methods are used, the proper values of the loads in the backstays corresponding to the relevant sail configuration may be used instead of the values of item 5 of Table 10.

8.3.2 Fractional rig with fixed backstay, no running backstay and aft angled spreaders

On fractional rigs with fixed backstay and no running backstay and aft angled spreaders:

— Upwind, the forestay balance is mainly achieved by aft set V/D shrouds (see Figure 1 b). The tensile force in these shrouds is, in addition to the one coming from their action as transverse rigging elements, the one coming from their action as longitudinal staying elements. The contribution of the fixed backstay to forestay balance depends on the ratio $I/(P + B_{AS})$ and on the mast stiffness above I. The contribution of the mainsail sheet to the headstay balance may be applied.

— Full downwind, the force and moments F_{DOWN} and M_{HDOWN} under spinnaker and mainsail are also shared between aft set top shroud V and fixed backstay. For mast top spinnakers, it depends on the ratio $I_{SP2}/(P + B_{AS})$ and whether the mast and its rig (e.g. jumper struts) can support the bending moment and compression taken by the fixed backstay.

NOTE The sweptback angle of spreaders in the horizontal plane is usually at least 18° in order to have the aft angle of the top shroud. Seen on a longitudinal plan, the angle is generally at least 5° to ensure a correct tension of the forestay.

8.3.3 Case of rigs without fixed nor running backstay

On fractional rigs without fixed nor running backstay and aft angled spreaders and shrouds, the relevant loads of Table 6 and Table 7 shall be supported according to the sail configuration, and particularly when running under spinnaker. In all sail configurations, the contribution of the mainsail leech or sheet tension to support the headstay load shall not be considered. This configuration entails that the forestay sag is usually higher in the range of item 3 of Table 10.

This configuration is the most common on cruising catamarans, as there is generally no possibility of fixed backstay, but with large aft angle and foot of shrouds. For monohulls, this configuration is mainly found on craft less than 10 m and design category B and C, as it is difficult to have enough aft foot, L_{ASH} to support efficiently the mast (see Table 8 and Figures 1 and 2):

— Upwind, the forestay balance is mainly achieved by aft set V/D shrouds (see Figure 1 b). The tensile force in these shrouds is, in addition to the one coming from their action as transverse rigging elements, the one coming from their action as longitudinal staying elements. The contribution of the mainsail sheet to the headstay balance may be applied.

— Full downwind, the force and moment F_{DOWN} and M_{HDOWN} under spinnaker defined in Table 6 are considered as only supported by the two aft set shrouds working together, i.e. no contribution from mainsail sheet/leech.

— Reaching and broaching, the force and moment F_{BROACH} and $M_{HBROACH}$ under spinnaker defined in Table 6 are considered to be unequally shared by the port and starboard shrouds. Long term experience is lacking, but a proportion of 60 % taken by the windward shroud, 30 % taken by the leeward shroud, and 10 % by the mainsail leech/sheet may be considered.

Table 10 — Factors and forces on the forestay and backstays

1 – Dynamic sail and rig load factor k_{DSR}

$$k_{DSR} = \max\left(3{,}086 \times L_{WL}^{2}/m_{LDC}^{0,66};1\right)$$

This factor considers dynamic overloading of some rig elements when a "light displacement" craft moves in the seaway, the lighter the craft for its size the greater is its dynamic behavior, see calculation examples below.

k_{DSR}	L_{WL} (m)	6	8	10	12	14	16	18	20	22	24
1,00	m_{LDC} (kg)	1 258	3 007	5 913	10 274	16 392	24 567	35 105	48 309	64 485	83 940
1,50		680	1 627	3 199	5 558	8 868	13 291	18 992	26 135	34 886	45 411
2,00		440	1 052	2 069	3 595	5 735	8 595	12 282	16 901	22 561	29 367

2 - Design force in the forestay or mainsail leech

Design force in the forestay for sail configuration S_{C1}	Design force in mainsail leech for sail configuration S_{C1}
$F_{FS1} = k_{DSR}\dfrac{F_{F1}}{8\times k_{SAGF}}$ see values of k_{SAGF} in item 3	$F_{ML1} = k_{DSR}\dfrac{F_{M1}}{8\times k_{SAGM}}$ see values of k_{SAGM} in item 3
where F_{F1} is the transverse force on fore sail in S_{C1}	where F_{M1} is the transverse force on mainsail in S_{C1}

3 - Values of k_{SAG} factors

k_{SAGF} on forestay[a]			k_{SAGIF} on inner forestay with sails on	k_{SAGM} on mainsail leech
Monohull	Trimaran	Catamaran		
0,007 to 0,04	0,01 to 0,04	0,015 to 0,04	$k_{SAGIF} = 2 \times k_{SAGF}$	$k_{SAGM} = \min(0{,}012\ 5\ k_{ROACH} + 0{,}062\ 5)$
Default value for cruising craft 0,02				

4 - Force on forestay to balance the longitudinal component of forces

$$F_{FS2} = \frac{\left[F_{ML1}\times\sin\left(\operatorname{atan}\frac{P}{E}\right)\times\left(P+B_{AS}\right)\right]+\left(F_{RBS}\times\sin\alpha_{RBS}\times I\right)+\left[F_{BS}\times\sin\alpha_{BS}\times\left(P+B_{AS}\right)\right]}{I_{FS}\times\sin\alpha_{FS}}$$

The formula shows the balance of the longitudinal component of the mainsheet leech, fixed and running back-stay by the forestay as in Figure 1 b) and should be adapted to other sail configurations.

5 - Design forces on, backstay and/or running backstay

Rig arrangement	**Function**	**Fixed backstay (BS)**	**Running backstay (RBS)**
Masthead rig	Forestay balance, particularly when sailing upwind	$F_{BS1} = F_{F1}\dfrac{\sin\alpha_{FS}}{\sin\alpha_{BS}}$	Where there is no fixed backstay depends of height of running backstay/I
	Support of downwind force spinnaker + mainsail	$F_{BS2} = \dfrac{F_{DOWN}}{\sin\alpha_{BS}}\times\dfrac{h_{CETW6}}{I}$	Where there is no fixed backstay depends of height of running backstay/I
Fractional rig	Forestay balance	The bending stress on mast at top of forestay level induced by backstay ≤ σ_d	$F_{RBS1} = F_{F1}\dfrac{\sin\alpha_{FS}}{\sin\alpha_{RBS}}$
	Downwind force spinnaker + mainsail	$F_{BS2} = \dfrac{F_{DOWN}}{\sin\alpha_{BS}}\times\dfrac{h_{CETW6}}{h_{BS}}$ [b, d]	$F_{RBBS2} = \dfrac{F_{DOWN}}{\sin\alpha_{BS}}\times\dfrac{h_{CETW6}}{h_{RBS}}$ [c]

NOTE 1 On fractional rig where $I/(P + B_{AS}) > 0{,}8$, the mast may be only held by the (adjustable) fixed backstay, often with contribution of aft set shrouds and eventual extra running backstay to help tightening the forestay. On fractional rig where $I/(P + B_{AS}) < 0{,}8$, the mast is mainly held by running backstays plus an additional adjustable fixed backstay, which shall be tightened so that the bending stress induced at the topmast foot ≤ σ_d.

Table 10 *(continued)*

F_{Fi} and F_{Mi} are respectively the forces of foresail and mainsail in sail configuration S_{Ci};
h_{CETW6} is the height of total center of effort C_{ET} of rig forces F_{DOWN1} and F_{DOWN2} above W_L for sail configuration S_{c6} with either spinnaker S_{PI1} at of top of I_{SPI1}, or S_{PI2}, at I_{SPI2} i.e. top of mast;
h_{BS}, and h_{RBS} are respectively the height of top of fixed backstay and running backstays above W_L;
α_{FS}, α_{BS}, and α_{RB}, are respectively the angles forestay, fixed backstay and running backstays with the vertical.
[a] The smaller k_{SAG} values correspond to racing/sports craft with tightening devices, the upper value corresponds to cruising craft. Documented values may be used. The factor 8 in the formula of forestay tension is the ratio between sag and tensile force in a cable.
[b] Fractional rig with a masthead spinnaker I_{SP2}, with F_{DOWN2}, and h_{CETW6}. This supposes that the mast and its rig (e.g. jumper struts) can support the longitudinal or lateral bending moment and compression.
[c] Fractional rig with a top of spinnaker at hounds I_{SP1}, with F_{DOWN1}, and h_{CETW6}.
[d] Fractional rig with a top of I_{SP1} of spinnaker, with F_{DOWN1}, and h_{CETW6} and no running backstay. The load is considered only supported by the fixed backstay. This considers that the mast and its rig (e.g. jumper struts) can support the longitudinal or lateral bending moment and compression. In practice a significant part of the load is taken by aft set spreaders and rig.
NOTE 2 The value of k_{DSR} is connected to the fact that when running on a sailboat in rough sea or on a craft with a "dynamic behavior" the longitudinal accelerations induce overloads in forestays and decelerations induce overloads in aft stays, the mast compression being unchanged.

8.4 Compression in the mast step/pillar

8.4.1 General

The design of mast and rigging is usually based, in addition to have a tight forestay for good upwind performance, to the will to limit as much as possible slack on transverse rigging elements when sailing. This comes from two reasons:

— tight transverse rigging in all sail configurations will “support” correctly the mast, and provide greater buckling resistance, see NOTE 2 in 8.4.2;

— non-flapping rig will limit fatigue stress both on rig and their end fittings.

This is usually made by pre-stressing the mast, through tightening the rig with turnbuckles or mast jack/rams, and 7.1.3 requires the mast designer/provider to detail the method of setting up the mast to obtain the required pre-stress loads.

8.4.2 Initial mast compression due to pre-stressing

The pre-stressing performed first in the harbour, then while sailing, is fully superseded in loaded shrouds and partly in the non-loaded shrouds when heeling and broaching and under other mast compression forces coming from mainsheet, halyards and stays defined previously. This is usually checked, amongst other calculations, by ensuring that the leeward rig (for a monohull) is not slack (i.e. working in compression for a software) in the various sail configurations, see NOTE 2.

NOTE 1 Compression on mast step due to pre-stressing is usually more important on monohulls than on multihulls for which the mast usually has a “self-supported” diamond rig [see Figures 3 d), f) and g)] that is set-up on land before installing the mast. The values of pre-stressing loads also depend on the purpose of the craft. Racing monohulls have this pre-stressing helped by a hydraulic mast jack whereas small and medium size cruising monohulls have this tightening made by hand on the lee shrouds after tacking.

NOTE 2 On “traditional” monohull rigging where transverse and longitudinal staying were not interfering, this set-up was generally only made on transverse rigging, adjusting the fore and aft staying “on demand” by tightening the fixed and/or running backstay. On modern rigging with aft set spreaders and shrouds, the transverse and longitudinal supports of the mast are coupled, and this coupling varies with the sail configuration of Table 7, requiring the pre-setting to be “balanced” to fit as much as possible all cases, a difficult task. This task is now helped by dedicated FEM software.

8.4.3 Mast compression due to heeling or broaching

The heeling moment is the couple made by the equal forces aerodynamic F_{Ai} and hydrodynamic F_{Hi}. This heeling moment is only a part of the righting moment as it is the one made by the force F_{AI} only multiplied by the height of this force above chainplates level.

8.4.4 Design compression in the mast step/pillar

The design mast compression in the mast step/pillar of a single mast F_{DMC} is the sum of the compression due to heel plus, where relevant, loads from halyards, adjusted according to the presence or absence of hooks, loads from blocks, foresail vertical component plus mainsheet pull, added to the remains of the initial pre-stress due to transverse and longitudinal rig pre-stress. This work needs experience and practice. It is wise to compare this result with "Established practice" values given in Annex C.

8.4.5 Detail topics on mast step/pillar

The calculation of the pillar, either by simplified or developed methods, considers that the pillar is loaded axially with limited bending moment at its top, which is not always true in practice. Unless made through a sphere like on a rotating mast, the introduction of the mast compression load on a deck stepped mast is made through a mast plug plus mast base, the plug being sometimes curved to transmit a lateral bending moment improving the mast lateral stability but allowing some longitudinal mast bending. Where the matching between the mast foot and the socket is not correct, this may cause non-axial compression and/or longitudinal bending moment on the deck and pillar, that are usually not considered in calculation and need special consideration.

This document does not give specific requirements on the dimensions of top and bottom plates of the pillar and eventual brackets, and their scantlings shall be established through sound engineering and experience. Mast manufacturers recommendations on this subject shall be followed. Local weakening of the pillar tube, e.g. bores to pass electric cables into the mast shall also be considered/reinforced.

8.5 Final design load on rig elements

The knowledge of:

— the design stresses and load cases defined in Table 3;

— the relevant design moments M_{D}, M_{HMAX}, M_{HDOWN}, M_{HBROACH}, defined in Table 5;

— the corresponding sail configurations, defined in Table 7;

— the distribution of forces from the mainsail to the mast and its rigging, defined in Tables 9 and 10, and;

— the loads in staying elements, defined in Table 10;

is normally sufficient to define the loads, using any strength of material method or software, in all the elements of mast(s) and rig, and particularly:

— the design loads and stresses in the mast or rig element, without forgetting to multiply the rig loads (but not mast compression) by k_{DSR} as defined in Table 10;

— the design loads and stresses in mast steps/pillars or rig attachments, i.e. chainplates;

— the design loads and stresses in the connection between mast step or pillar step or rig attachment and the structure.

These stresses shall be determined for all the relevant righting/heeling moments associated with their corresponding sail configuration and shall be taken as the worst case of all possible combination, see Clause 11.

Annex B gives information on metal and bolts and Table B.1 gives information on breaking loads of some metal rig elements.

Annex C gives "established practice" methods and examples of mast step and pillar and supporting floor calculation.

Annex D gives "established practice" methods and examples of chainplate (metal, FRP connection, strapped FRP chainplate) calculation.

For information only, Tables E.1 and E.2 show examples of tabular calculation of rig loads according to Clauses 7 and 8, and Clause E.2 and Table E.3 show an example of a simplified calculation of transverse loads on a monohull rig.

9 Structural components to be assessed — Simplified or developed method

9.1 General

The following items shall be considered when assessing or designing structural components which are intended to support the loads and transmit them:

a) mast steps, pillars, mast bulkheads, beams, and their connection to the structure, see 9.1.

b) chainplates and their connection to the structure, see 9.2.

This assessment shall be made using:

— either a simplified method using the "established practice" methods defined in Table 2 and Clause 10; or,

— a developed method using one or several calculation methods defined in Table 2 and Clause 11.

Figures 1 to 3 show typical rig arrangements for monohulls and multihulls.

9.2 Mast steps and mast pillars and their connection to the craft's structure

Once the mast compression is determined using the simplified or a developed method as specified in Clause 5, the mast step/pillar and their connection to the structure shall be checked not to exceed the design stress given in Table 3 under the action of the mast compression force. The force may be applied as a point load or a patch pressure corresponding to the mast footprint. Conventional beam theory is not generally suitable for 'short-span' mast step. See Clause 11 when using the developed method. Clauses C.4 to C.5 can be useful for that purpose.

9.3 Chainplates and their connections to the craft's structure

Once the load in each rig element is determined, using the simplified method or developed method as specified in Clause 5, the chainplates and their connections with the structure shall be checked not to exceed the design stress given in Table 3 under the action of each rig element.

Where the strength of the rig element is greater than its design strength, usually for stiffness or other practical reasons, the boatbuilder has the choice to:

— either dimension the chainplate and its connection to the structure to correspond to the (oversized) rig element;

— or require the rig manufacturer to provide a rig end fitting (eye, pin, toggle, etc.) with a pin according to the design load and build the chainplate and its connection with the structure according to this document. In which case, in the event of an unexpected overload (e.g. dismasting, hooking another craft or a fixed object) the pin will act as a “fuse” and will not tear out the chainplate.

Where several standing rig elements are fitted on the same chainplate, the total load on the chainplate corresponding to the various sail configurations S_{Ci} and corresponding design loads and stresses shall be used to check its attachment with the hull structure, using the worst case of their load combination.

Where the rig is extended by a tie rod below the deck, this rod shall be considered as part of the chainplate, fitted at the bottom of this tie rod.

The design details of 9.4 shall also be followed.

CAUTION — Chainplates are normally only designed as attachment of rig elements. Chainplates may also be used to lift the craft, but only if they have been assessed for this purpose. In that case this shall be documented in the owner's manual, see Clause 13, and this case is not considered in this document (see NOTE).

NOTE Regulations on lifting devices usually require much greater safety factors than this document.

9.4 Design details of chainplates and their connection to the structure

9.4.1 General

In general, the structural arrangement of the chainplates and their fittings shall be such that the rig loads are transmitted in line with the rig at its ends, without creating parasitic bending moments, e.g. using toggles, self-aligning cup or ball, barrel pins, etc. Non-aligned loads or bending moments create long term fatigue stresses that shall be avoided, whether the rig element is tight or slack. This is particularly critical on forestays that sags transversally and longitudinally when the foresail is under wind pressure. Both ends of a forestay wire or rod end fitting shall therefore not be used without a proper arrangement (e.g. a toggle) allowing free lateral sag, unless their free rotation range is checked to be adequate. In that context forestay chainplates along the craft or hull axis need special consideration, e.g. "barrel toggles" to avoid bending stresses and fatigue, a transverse chainplate aligned with the headstay direction is a better arrangement. The possibility of 5° angle of the toggle or end fitting in any direction at its connection with the chainplate is a general "Established practice".

Unless specifically engineered, rig elements should not be connected to any deck or near horizontal elements only and shall be connected to a vertical or near vertical element able to take the load and transmit it to the structure.

Typical rig end connections are:

— rig end fitting connected to a vertical bulkhead or bracket;

— rig end fitting connected to an aligned internal tie rod which is the connected to the structure;

— rig end fitting directly connected to a near vertical part of the shell (hull side, stem, transom, etc.).

When the near vertical element is not in line with the rig element, the near horizontal structure (e.g. deck) shall be able to support the horizontal load component of the connection.

Where stainless steel tie rods are used, their mechanical properties and design strength shall be precisely known, as they can differ substantially from one material to another (e.g. rod rigging, wire, threaded rod, etc.).

9.4.2 Strapped FRP chainplates

Strapped chainplates, see Figures D.8, first appeared on racing craft, but are now getting more and more popular on cruising craft, particularly the ones with carbon FRP hulls.

Under nominal load:

— the chainplate components (bushing/tube, wrapping and foundation) shall withstand the design load without exceeding the design stress;

— the contact area connecting the laminated chainplate on the structure shell, bulkhead or web shall be such that the ultimate shear stresses in the contact surface between the plies and the structure or in the glue joint are not exceeded before achieving the design load;

- some allowance for the misalignment of fibers in wholly or largely UD layups (see NOTE) shall be included in checking material properties. In the absence of better data, a misalignment of 5 degrees shall be assumed;
- for connection straps consisting of fan arranged UD's (with possible intermediate DB+, BDx, Qx layers, see Note), the contact area should make allowance for misalignments;
- for analysis of complex laminates, designers may use either linear (maximum stress or strain) or quadratic (Tsai-Wu) criteria, and the design stress/safety factor shall be as required by the last row of Table 4, i.e. using primary or secondary bond design shear stress as required. Data given in Annexes C or H of ISO 12215-5:2019 can be useful.

Clause D.6 gives "Established practice" for metal or strapped FRP chainplates and worked examples.

NOTE The definition of acronyms for plies UD (unidirectionnal) BD+(bidirectionnal 0/90°) DBx (double bias ±45°) or Qx (quadriaxial) are explained in ISO 12215-5:2019, particularly its Annex C).

10 Application of the simplified method

Annex C gives "Established practice" methods of mast step and pillar and supporting floor calculation, with worked examples.

Annex D gives "Established practice" methods for chainplate (metal, connection with FRP or Plywood, strapped FRP chainplate) calculation, with worked examples.

11 Application of the developed method

11.1 General

The rigging structure shall be assessed using any appropriate method, e.g. graphical or computed truss calculation, general or dedicated software, FEM. These methods shall be properly applied by a person competent and trained to their usage.

In order not to stifle innovation, this document is written in terms of defined load cases and associated stress factors/factors of safety. The design stress assessment is left to the discretion of the designer, subject to the criteria listed in Clause 6 and Table 3.

This document recognizes that many structural components within its scope are best analyzed using 3-D numerical procedures (e.g. FEM and /or dedicated software).

Annex E also shows an example of an established practice to roughly determine the transverse rig load calculation on a sailing monohull. This method is derived from the one explained in Reference [7] adapted to the method described in this document, but one shall be aware of its shortcoming due to its simplicity, knowing that modern rigs combine transverse and longitudinal staying through sweptback spreaders.

11.2 General guidance for assessment by 3-D numerical procedures

11.2.1 General

The term '3-D numerical procedures' is intended to indicate any structural assessment method which is not limited to simple geometries. In most cases the term corresponds to finite element method analysis (FEM).

11.2.2 Material properties

Irrespective of the numerical method, the mechanical properties used should be according to Annex B for metals and bolts and the relevant Annexes of ISO 12215-5:2019 (Annex C for composite, Annex F for wood/plywood).

11.2.3 Boundary assumptions

No explicit boundary assumptions are specified within this document. The analyst shall ensure that St Venant's principle is complied with, i.e. the critical area to be analyzed shall be located well away from the model boundaries.

11.2.4 Load application

Wherever possible, loads should be applied as distributed loads. Where forces or moments are applied as concentrated nodal loads, these shall be located well away from the critical area to be analyzed.

11.2.5 Model idealization

Models may be of beam-element, plate or brick type. Where beam-elements are adopted, effective plate dimensions may be obtained from ISO 12215-5:2019 or from published effective breadth formulas. Closed sections having significant torsional stiffness should have this parameter calculated using accepted methods, e.g. Bredt-Batho theory.

When using plate-based model's, sufficient elements shall be used at connections to replicate local bending effects.

Unless a non-linear analysis is used, analysts should take care to ensure that buckling modes of failure are precluded. This can normally be accounted for by respecting the allowable slenderness ratios for beams and flanges as outlined in ISO 12215-5:2019. Non-linear analysis can be required for obtaining accurate load distributions in mast-rigging frameworks. Non-linear analysis is also required for bolted structures using contact algorithms.

It is considered prudent design practice to compare scantlings derived from the "developed" methods with those derived from the "simplified" methods and a technical explanation should be provided in cases where the former gives significantly lower scantlings than the latter.

11.3 Assessment by 'strength of materials' based methods

The methods outlined in Annexes C and D contain a series of standard beam/plate theory-based methods and other simplified procedures. Many of these derive from "established practice", which gives normally conservative results. The methods work well for one and two-dimensional structures of isotropic material construction.

12 Application of this document

Annex A helps checking a proper application of this document.

13 Information in the owner's manual

The owner's manual shall include at least the following information:

1) The following statement or similar: "The rig of this craft has been set-up and tuned according to the recommendations of the mast/rig manufacturer. Do not change its setting without consulting the builder's instructions and/or his/her agreement. Where the mast has been taken off, have the mast being re-installed by a professional following the setting-up instructions given by the mast manufacturer".

2) The information required in 7.1.2: i.e. the recommended sail configurations and trimming according to prevailing wind, course, sea state, etc. and, where relevant, sail configurations and usages to be avoided, with corresponding explanations.

EXAMPLES

— Information not to change anything on the rig or sails shape or material (e.g; triangular mainsail to gaff, change between Dacron to membrane sail material) without the manufacturer's agreement.

— Do not motor the craft without the mainsail set and mast supporting devices (e.g. runners) in choppy conditions, as the movement of the craft in the sea may induce loads in the mast due to its inertia.

3) Where heeling moment M_H has been used instead of righting moment M_R (this is generally the case for cruising multihulls, and may be the case for multiple mast rig, see 7.2.1.), include the following information according to the contents of 7.2.3 (devices limiting heeling loads), Table 7, etc. or wherever relevant:

   — the rig of this craft is designed to only support a part of its maximum heeling moment, do not modify the rig setup made by the boat builder or its representative, where relevant, only use the hydraulic rams, including mast jack as recommended.

   — follow the apparent wind speeds recommended at anemometer position (e.g. mast top) for reefing/sail reduction scheme affixed close to the main steering position. Do not take off or alter this instruction sheet.

   — any information that may be relevant.

EXAMPLE "Where installed, do not impair the devices limiting the heeling moment from the rig such as "fuses" on sheets, rams, electric winches, alarms warning overload on standing/running rig elements, this may overload the rigging and break/damage the mast."

Where relevant, the owner's manual shall inform, the user whether the craft may or may not be lifted by the chainplates (albeit generally with a safety factor much lower than in lifting standards) or specific strong points, the loading conditions, and the recommended lifting procedure(s).

14 Information to the boat builder

The mast/rig manufacturer, provider or designer shall provide a written or electronic file containing the following information that may be a specific part of the owner's manual, and shall give the following information:

1) the design load of each of the rig elements provided (shrouds, stays, mast step, etc.), the dimensions of their end fittings, specifying whether this fitting, including its pin, corresponds to the design load or a greater load.

2) the information for a proper rig setup/tuning as specified in 7.1.3.

Annex A
(informative)

Application sheet of ISO 12215-10

Element	Description	Tick valid cell
Type of sailing craft	Monohull	
	Multihull catamaran	
	Multihull trimaran	
Building material	Steel	
	Aluminium	
	Wood	
	FRP	

Craft main data (Table 1)	Symbol	Unit	Value
Length of hull	L_H	m	
Length waterline in maximum loaded condition	L_{WL}	m	
Beam of hull	B_H	m	
Beam waterline in maximum loaded condition	B_{WL}	m	
Beam between chainplates	B_{CP}	m	
Maximum loaded condition mass	m_{LDC}	kg	
Maximum draught of canoe body	T_C	m	
Design category factor for rig (1 A and B/1,25 C and D)	k_{DCR}	1	

Assessment of rig loads- Used method (Table 2)		Tick valid cell
Simplified method Use of Annex C "Established method"	Mast step/pillar: use of rig manufacturer/provider load	
	Mast step/pillar: use of Table C.1 "basic" method	
	Mast step/pillar: use of Table C.2 "enhanced" method	
	Mast step on plywood bulkhead: use of Table C.3	
	Mast pillar calculation: use of Table C.4	
	Simplified floor calculation: use of Table C.5	
	Metallic chainplate from rig load using Tables D.4 to D.6.	
	Metallic chainplate from rig strength using Tables D.4 to D.6	
	FRP strapped chainplate Clause D.6 and Table D.9	

Developed method	Application of the following rows

Determination of M_D = min ($M_{R\phi UP1}$; M_{HUP1}) (Table 2)			**Value**
Design heel angle ϕ_{UP} = 30° monohull $\phi_{UP} = \phi_{LIM}$ multihull	ϕ_{UP}	degree	
Righting moment from hiking crew	$M_{R\ CREW}$	Nm	
Total righting moment	$M_{R\phi UP1}$	Nm	
Proposed apparent wind speed at sail CE proposed in Table 7	V_{ACEK1P}	knots	
Effective apparent wind speed at sail CE used for calculation	V_{ACEK1E}	knots	
Total sail area in sail configuration S_{C1} $A_{T1i} = A_{M1} + A_{F1} + A_{WM}$	A_{T1}	m^2	
Distance between aero/hydro forces	$h_{CET1W} + h_{CLR}$	m	
Aerodynamic/hydrodynamic forces in case b	F_{AT1b}	N	
Heeling moment in case b $M_{H1} = F_{AT1b} \times (h_{CET1W} + h_{CLR})$	M_{HUP1}	Nm	
$M_{RUP1} \leq M_{HUP1}$ case a or $M_{RUP1} > M_{HUP1}$ case b	Case a or b	1	
Final design moment M_D = min (M_{RUP}; M_{HUP})	$\boldsymbol{M_D}$	**Nm**	
Final design aerodynamic force in S_{C1}	F_{AT1}	N	
Rig load determination using the developed method (Table 2)			**Tick valid cell**
Mast step/rig loads from rig manufacturer/provider (7.1.3)			
Mast step/rig loads determined by Clauses 8 to 11			
Mast step floor or support/chainplate scantlings using Annexes C and D			
Mast step/chainplate floor or support scantlings using Clauses 8 to 11			
Information required to be provided			
Clause 13	Information required to be included in the owner's manual		
Clause 14	Information required to be provided to the boat builder		

Annex B
(informative)

Information on metals and bolts

B.1 Typical metal properties

B.1.1 General information

Table B.1 gives the mechanical properties of the most frequently used metals in rigging and chainplates which can be used for the cited state as default values, unless derived from tests, except the ones for precipitation hardened stainless steel. For precipitation hardened stainless steel, e.g. F16 PH, the values given are indicative, and specific data shall be taken from a certificate obtained from the steel manufacturer or supplier. If derived from tests, the values of σ_u and σ_y used in Table 3 and the rest of this document shall be 90 % of the mean relevant tested value or the mean value minus two standard deviations whichever is the lesser.

The yield stress and ultimate strength can vary a lot after being machined or formed, and this is particularly true for AISI 304 or 316, it is therefore wise to make tests to optimize the design.

Equivalence between several standard denominations for stainless steel is given in Table B.2.

CAUTION — The mechanical properties of bolts (SS or steel) shall not be taken from Table B.1, but from Table B.4 for stainless steel and Table B.5 for allied steel screws.

The Tables of this Clause usually only give the tensile stresses, for all metals; the shear stresses may be taken as $\tau = 0{,}58\ \sigma$.

B.1.2 Corrosion

Non-stainless steels are subject to rust and need protection coatings in marine environment e.g. galvanization, painting.

AISI 316 (A4 screws) is recommended where located below waterline, particularly 316 L, whereas AISI 304 (A 2 screws) is only recommended above waterline.

AISI 630 (17-4 PH or equivalent) are subject to crevice corrosion in environment without oxygen like stagnant water.

Galvanic corrosion is an issue for all metals, and when there is direct contact between metals having different galvanic potential below waterline or in marine environment. This is normally not the case between two different stainless steels.

Contact between stainless steel and aluminium below waterline shall be avoided, by using, for example, nonconductive bushing and washers. Contact between stainless steel pins and aluminium alloy chainplates is acceptable above waterline, but the use of a tight fit stainless steel bushing reduces wear and corrosion and is recommended. However, as non-metallic bushings or washers have lower bearing strength than the mating metals, the connection needs special consideration in that sense, and the use of the method explained in Clause D.7 or equivalent is required.

B.1.3 High strength stainless steels

There are many high strength stainless steels available in the market, which are frequently used by rig manufacturers or for performance/racing crafts chainplates, fittings, or connections. Even if they correspond to some standard, they are often known by brand names. Their mechanical properties vary significantly with heat treatments, cold forming, etc. and except Nitronic 50 cited in Table D.1, they are not cited in the following tables. Their mechanical properties shall be obtained from their manufacturer or provider.

B.1.4 Calculation of the strength of a bolt or a screw

Where several bolts or screws are used, their holding strength in shear may be problematic if there is a clearance between the bolts and the bore as the transmission of force in shear in all the bolts only happens where some yield or plasticity has occurred. When bolting metal chainplates to metal structure, it is therefore preferable either to use the chainplate as a template to bore the hones in the metal structure with no or minimal play to ensure that all the bolts work together in shear, or rely only on friction coefficient to transfer the load. When bolting a metal chainplate to material with smaller elastic modulus, as plywood of FRP, the problem is less acute, and the "established practice" method explained in D.4 may be used.

Table B.1 — Values of σ_{LIM}, τ_{LIM}, σ_{LIMb}, σ_{LIMw} for some typical metals used in rigs

Material	Chemical composition	σ_u [a]	σ_y [a]	σ_{uw}	σ_{yw}	σ_{LIM} [a]	σ_{LIM} [b] HAZ	ε break app
		N/mm²						%
Stainless steels [c]								
AISI 304 – EN 1.4301, EN 1.4307	X5 Cr Ni 18.9	520	210	520	210	210	210	45
AISI 316, 316 L- EN 1.4401	X5 Cr Ni Mo 17.2.2	520	220	520	220	220	220	40
AISI 329 not cold worked	X3Cr Ni Mo N 27-5-2	650	500	650	500	325	325	15
AISI F51, DX45, 2205, Uranus [c]	X2 Cr Ni No N 22.5.3	620	450	620	450	310	310	40
Aluminium alloys series 5000								
5086 0/H111	Al,Mg,4	240	100	240	100	100	100	16
5086 H32	Al,Mg,5	275	185	240	100	138	100	10
5083 0/H111	Al,Mg,4,5 Mn 07	275	125	270	125	125	125	15
5083 H32	Al,Mg,4,5 Mn 07	305	215	270	125	153	125	9
5059 Alustar 0/H111	Al, Mg, 5-6	330	160	300	160	160	150	24
5059 Alustar H32	Al, Mg, 5-6	370	270	300	160	185	150	10
Aluminium alloys series 6000								
6005 A T6	Al, Si ,Mg (A)	260	215	165	115	130	83	8
6061 T6	Al, Mg1,Si,Cu	260	240	165	115	130	83	10
6082 T6	Al, Mg1,Si,Mn	310	260	170	115	155	85	10
Titanium alloys								
UTA 6V		900	820			450		10
Copper alloys								
Bronze-manganese		510	245			245		>7
Bronze-Ni-Al		740	390			370		>7
Monel 400		550	350			275		>7
Monel 500		960	690			480		>7

[a] Non-welded or out of welding heat affected zone (HAZ).

[b] In way of heat affected zone.

[c] Mechanical properties taken from EN 10088-2:2014 and Reference [11].

Table B.2 — Equivalence between stainless steel standard denominations

Stainless steel AISI common name/brand	Chemical composition	AISI	EN 10088-3	ISO 16143-2
AISI 304, 304L	Cr Ni 18.9	304 L	1,4307	1
AISI 316, 316L	Cr Ni Mo 17.12	316 L	1.4404-1.4432	21-22
AISI 329	Cr Ni Mo N 27-5-2	329	1,4460	55
17-4 PH, F16 PH	Cr Ni Cu Nb 16.4	630	1,4545, 1,45nn	101
AISI F 51, DX45, Uranus 2205	Cr Ni Mo 22.5.3	UNS 31803	1,4462, 1,44nn	52

NOTE AISI terminology is widely used worldwide, particularly in the USA. EN 10088-3 is widely used in the EU, ISO 16143-2, even if easier to understand, is not yet widely used at the time of publication.

B.2 Mechanical properties of typical bolts

B.2.1 General information

Bolts may be made from any suitable metal, like carbon steel and stainless steel, or non-ferrous metals such as Monel 400, etc. Stainless steel and carbon steel bolts are considered in this clause, because they are the most popular material on small craft even if the latter are less used as they need painting/coating.

Bolts or machined threaded rods shall not be made from high tensile or precipitation hardened stainless steel (17-4 PH, F16-PH, etc.), unless their mechanical properties are validated by comparative tests with stainless steel bolts according to ISO 3506-1:2020.

When using a machined threaded rod or a bolt, the user shall have a written proof of the mechanical properties and should ensure these properties meet or exceed the ones of screws according to ISO 3506-1:2020.

Bolt choice information and suggested tightening torque are given in B.2.2 and B.2.3.

B.2.2 Stainless steel screws and bolts according to ISO 3506-1:2020

Stainless steel screws and bolts are classed by ISO 3506-1:2020 into four main categories, see Table B.3.

Table B.3 — Classification of stainless steel screws according to ISO 3506-1:2020

Material	AISI	Texture
A1	303	Austenitic
A2	304	Austenitic
A4	316	Austenitic
C1 to C4	400 serials	Martensitic
If the steel has a low carbon content, the letter L is added after the ISO material.		

Table B.4 — Mechanical properties of stainless steel screws according to ISO 3506-1:2020

		Stainless steel screws according to ISO 3506-1:2020		
		Property class		
		50	70	80
σ_u	N/mm^2	500	700	800
σ_y	N/mm^2	210	450	600
σ_{LIM}	N/mm^2	210	350	400

Class 50 is usually made by machining a thread from a solid rod. This is usually how threaded rods are made.

Classes 70 and 80 are made by a combination of stamping and cold stretching/rolled threads, this is the most common method for screws and bolts.

The quality of SS bolts is usually stamped on their head with the identification of the manufacturer with 3 letters, with the material and class quality underneath.

For example, A4 L – 80 means Material A4 with low carbon and Class 80.

B.2.3 Steel bolts according to ISO 898-1

Steels (plain or galvanized) are classed by ISO 898-1:1999 into several classes. The first digit multiplied by 100 gives the ultimate strength σ_u (N/mm^2). The yield strength σ_y is obtained by multiplying the first digit by 10 times the second digit.

Table B.5 — Mechanical properties of steel screws according to ISO 898-1

		Classes according to ISO 898-1						
		4.8	5.6	5.8	6.8	8.8	10.9	12.9
σ_u	N/mm2	400	500	500	600	800	1 000	1 200
σ_y	N/mm2	320	300	400	480	640	900	1 080
σ_{LIM}	N/mm2	200	250	250	300	400	500	600

B.2.4 Recommended bolt tightening torque

Table B.6 gives examples of preload and tightening torque for M bolts with friction washers applying the method explained in ISO 12215-9:2012 that may be consulted for further details.

Table B.6 — Examples of values of preload P_r (kN) and tightening torque T_o (Nm) for M bolts according to ISO 12215-9:2012, valid with a friction washer

Nominal diametre (mm) — Normal pitch											
		M bolt		**M6**		**M8**		**M10**		**M12**	
		d	mm	6		8		10		12	
		p	mm	1,00		1,25		1,50		1,75	
		d_3 neck	mm	4,8		6,5		8,2		9,9	
		S neck	mm^2	17,9		32,8		52,3		76,2	
		σ/σ_y=	1,00	**0,70**		**0,70**		**0,70**		**0,70**	
Stainless steel bolts				**Preload Pr in (kN) and torque T in (Nm) method with k_{nut} factor**							
Material	σ_y	State	K_{nut}	Pr	T	Pr	T	Pr	T	PrF	T
SS 50	210	No Grease	**0,22**	2,6	3,5	4,8	8,5	7,7	16,9	11,2	29,6
SS 50	210	Greased	**0,15**	2,6	2,4	4,8	5,8	7,7	11,5	11,2	20,2
SS 70	450	No Grease	**0,22**	5,6	7,4	10,3	18,2	16,5	36,2	24,0	63,4
SS 70	450	Greased	**0,15**	5,6	5,1	10,3	12,4	16,5	24,7	24,0	43,2
SS 80	600	No Grease	**0,22**	7,5	9,9	13,8	24,3	22,0	48,3	32,0	84,5
SS 80	600	Greased	**0,15**	7,5	6,8	13,8	16,6	22,0	32,9	32,0	57,6

NOTE Annex B of ISO 12215-9:2012 gives detailed information on bolts, their pre-stressing, tightening, etc. Table B.6 is an excerpt of this information.

Annex C
(normative)

Simplified "established practice" for mast step/pillar assessment

C.1 Status of this Annex

This Annex shall be used when the "simplified method" of Clause 5 is chosen. For mast step/pillar, this Annex proposes the use of two "established practice" methods to determine mast step/pillar design loads:

— applying the "basic" method defined in Clause C.2, or

— applying the "enhanced" method defined in Clause C.3.

Once the mast/step compression is defined, Clause C.4 gives an "established practice " method to calculate a mast step/pillar, and Clause C.5 gives an "established practice" method for floor/support calculation.

C.2 Calculation using the "simplified method" for single mast or a two-masted rig

As explained in 8.4 the calculation of the mast compression on its step or pillar is complex and, on modern aft-angled spreader rigs, it depends on pre-stressing.

Table C.1 gives the calculation method for single mast or two-masted configurations.

Clause 14 requires the mast manufacturer/designer to provide the mast compression, but, in the absence of such information, Table C.1 can be used. Detail topics of 8.4.5 for mast step/pillar also apply.

Table C.1 — Simplified method — Mast step/pillar design compression force

1- Calculation for single mast — Simplified method		
Monohulls		**Multihulls**
$F_{DMC} = 2{,}4\ M_{R30} \times k_{DSR}^{0,5}/(0{,}5\ B_{CP})^{0,9}$ (N) May be conservatively approached by $F_{DMC} = 10\ m_{LDC}$ (N) where $k_{DSR} = 1$		$F_{DMC} = 1{,}1\ M_{HUP}/(0{,}5\ B_{CP})^{095}$ (N) May be conservatively approached by $F_{DMC} = 10\ m_{LDC}$ (N)
where		
M_{R30}	Nm	is the design righting moment for monohulls at 30° heel as defined in item 1 of Table 5;
M_{HUP}	Nm	is the design heeling moment for multihulls, as defined in item 2 of Table 5;
k_{DSR}	1	is the dynamic sail and rig load factor defined in item 1 of Table 10;
B_{CP}	m	is the beam between chainplates defined in Table 1 (average value with several shroud beams).
2- Calculation for a two-masted rig — Conservative approach simplified method		
$F_{DMCi} = k_{MMCi} \times 10 \times m_{LDC}$ (N) final design mast compression for mast i		
where		
i	1	index i = 1 or 2 for a two-masted configuration;
$k_{MMCi} = A_{TMi}/(A_{TM1} + A_{TM2})$	1	is the compression factor for mast i for a two-masted configuration;
A_{TMi}	m^2	is the total sail area as defined in item 3 of Table 5 for each mast i.

C.3 Calculation using the "enhanced "method for single mast rig

Table C.2 — Enhanced method — Mast step/pillar design compression force

Calculation for single mast — "Enhanced" method	
1-Monohulls	
1.	Determine M_{R30}, the righting moment at 30° heel, from item 1 of Table 5.
2.	Determine the ratio heeling, moment on rig/righting moment: $(h_{CT1W\text{-}HBI})/(h_{CT1W} + h_{CLR})$.
3.	Calculate $F_{DM\ HEEL} = (M_{R30}/0{,}5\ B_{CP}) \times (h_{CT1W\text{-}HBI})/(h_{CT1W} + h_{CLR})$, the mast compression due to heel.
4.	Calculate F_{FS}, the tension in the forestay, and its resulting compression force in the mast (Tables 8 to 10).
5.	Calculate the tension in the mainsail leech and its resulting compression force in the mast (Tables 8 to 10).
6.	Calculate the force on fixed/running backstay(s) and the resulting compression force in the mast (Tables 8 to 10).
7.	Add the 3 forces in 2 to 4 above.
8.	Find the final mast compression force, F_{DMC}, by multiplying the sum of these forces by $1{,}8\ k_{DSR}{}^{0{,}5}$.
9.	Check the result by comparing with the value find using the simplified method, they should not differ by more than 30 %.
2- Multihulls	
Same method as for monohulls, with the following exceptions:	
—	Replace M_{R30} by M_{HUP}.
—	Check if a fixed/running backstay is used, generally it will not.
—	Replace the multiplying factor $1{,}8\ k_{DSR}{}^{0{,}5}$ by 1.

Tables E.1 and E.2 give examples of such calculations, respectively for a monohull and a multihull.

C.4 Mast step/pillar calculation

C.4.1 Design load / stress on mast step or pillar

The mast step or pillar structure shall be able to support F_{DMC} or F_{DMCi}, as defined in Table C.1 or Table C.2 without surpassing the design stress defined in Table 3, considering the "normal" load case.

C.4.2 Deck stepped masts

C.4.2.1 General

F_{DMC} or F_{DMCi}, shall be transmitted to the bottom structure using a transverse bulkhead, a pillar, or any adequate structural element. Where the bulkhead cannot be located within 50 % of the mast chord from the centerline of the mast, a pillar directly under the mast is required.

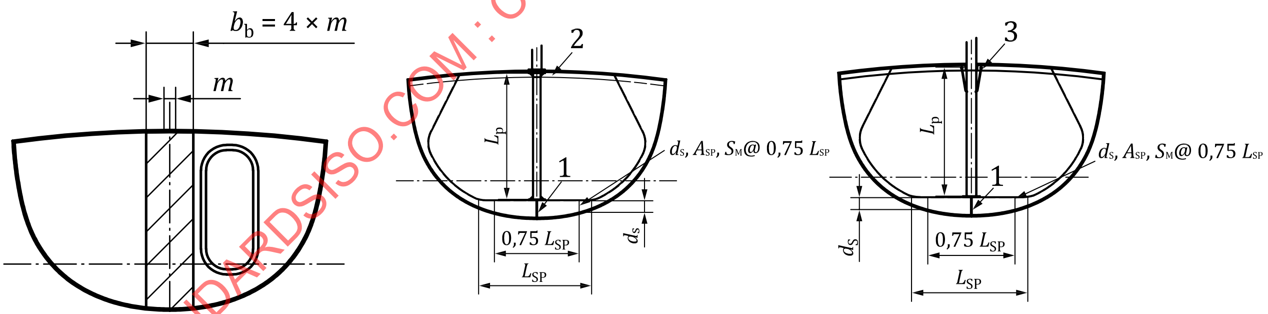
C.4.2.2 Unstiffened plywood or sandwich bulkheads

The mast bulkhead is presumed to offer effective support over a width $b_b = 4 \times m$, where m is the transverse dimension of the mast, see Figure C.1 a); Table C.3 shall be used for that purpose.

Table C.3 — Deck stepped mast on plywood sandwich bulkhead

$t_b = 0{,}82 \times [(F_{DMC} \times b_b)/E]^{0{,}33}$ (mm)			minimum required mast bulkhead thickness in way of mast
where			
F_{DMC} or F_{DMCi}	N		is the compression on mast step/pillar as calculated by Table C.1 or Table C.2;
b_b	mm		is the width of the cored or plywood bulkhead = 4 × mast width;
E	N/mm^2		is the elastic modulus of bulkhead, for plywood, use the plywood on edge values of ISO 12215-5:2019.
WORKED EXAMPLE FOR MONOHULL DECK STEPPED MAST ON PLYWOOD BULKHEAD			
1- DATA			
m_{LDC}	kg	7 200	Loaded displacement (monohull with $L_{WL} \approx 9{,}75$ m with $m_{LDC}/L_{WL}{}^{2{,}4} = 30{,}5$)
m	mm	150	Mast width
E	N/mm^2	4 720	Elastic modulus of the plywood or cored bulkhead- Plywood 550 kg/m^3 9 plies
2- CALCULATION			
F_{DMC}	N	72 000	Mast compression by approached simplified method F_{DMC} = 10 × 7 200 = 72 000 N
b_b	mm	600	150 × 4 = 600
t_b	mm	16,6	$t_b = 0{,}82 \times [(F_{DMC} \times b_b)/E]^{0{,}33}$ use closest available value 18 to 20 mm
NOTE Buckling stress of a 'long' simply supported panel is $3{,}62\,E\,(t_b/b_b)^2$. The applied stress is $F_{MT}/(b_b \times t_b)$. A safety factor of 2 against buckling is required, hence $3{,}62\,E\,(t_b/b_b)^2 = 2 \times F_7/(b_b \times t_b)$ and $t_b = (2/3{,}62 \times F_7 \times b_b/E)^{1/3}$ Or, $t_b = 0{,}82\,(F_7 \times b_b/E))^{1/3}$			

For sandwich bulkheads, in the area with a width b_b, below the deck step, the second moment of area of the bulkhead (see A.13 of ISO 12215-5:2019) shall not be less than $t_b{}^3/12$ per meter width. It should be noted that this equivalence assumes that the core has a high shear modulus. If this is not the case, the buckling strength should be corrected for the effective of bending/shear stiffness ratio. In addition, checks should be made on compressive strength and local face buckling. A factor of safety of at least 2 is required for each mode of failure.



a) Deck stepped on a bulkhead **b) Deck stepped with a pillar** **c) Keel stepped**

Key

1 bracket to stabilize and introduce the pillar load in the floor by shear

2 beam not meant to take vertical loads but stiffening the deck for transversal loads

3 device (tie rods) to prevent vertical deck movement under transversal and halyard blocks vertical load

Figure C.1 — Sketch of different mast step arrangements

C.4.2.3 Mast pillar calculation

Table C.4 shows the method of calculating a mast pillar, see Figure C.1 b).

Table C.4 — Mast pillar calculation

$A_p = F_{DMC}/(100\ \sigma_p)$ where	cm^2	minimal required cross section of the mast pillar,
$\sigma_p = \dfrac{\sigma_{dc}}{1 + k_p \left(\dfrac{L_{BP}}{r}\right)^2}$	N/mm^2	is the design compressive stress of the mast pillar (Rankine formula);
σ_{dc}	N/mm^2	is the design compressive stress taken from Table 3 (mast step/pillar, "normal");
L_P	m	is the actual distance between pillar support points, normally the vertical distance between top of the mast step and the underside of the deck or deck beam in way of the mast;
L_{BP}	m	is the buckling length of the pillar. Use L_{BP} = 0,7 L_P if fully fixed i.e. connected with plate and brackets instead of 0,5 in theory to consider linearity defects of the pillar
k_p		is the pillar strength factor, k_p = 1,2 for steel (mild or stainless) and k_p = 1,9 for aluminium alloys, see NOTE;
$r = \sqrt{\dfrac{I_{min}}{A_A}}$	cm	is the radius of gyration of the pillar, where I_{min} (cm^4) is the least second moment of area of the pillar cross section, and A_A (cm^2) is the actual cross-sectional area of the pillar.

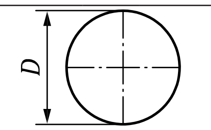
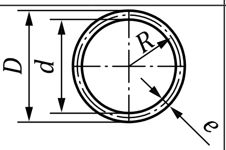
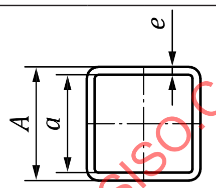
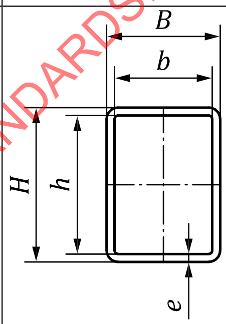
Section	Figure	Area, S	I_{max}	I_{min}	Radius of gyration, r	Approached value for r
Solid circle		$\pi D^2/4$	$\pi D^4/64$		$[\pi D^4/(64S)]^{0,5}$	r = 0,25D
Hollow circle		$\pi(D^2\text{-}d^2)/4$	$\pi(D^4\text{-}d^4)/64$		$[\pi(D^4\text{-}d^4)/(64\ S)]^{0,5}$	$0,26(t_p/D)^2$ - $0,36t_p$ + 0,354
Hollow square		$(A^2\text{-}a^2)$	$(A^4\text{-}a^4)/12$		$[(A^4\text{-}a^4)/(12S)]^{0,5}$	$0,3(t_p/A)^2$ - $0,418t_p$ + 0,408
Hollow rectangle		$BH\text{-}bh$	$(BH^3\text{-}bh^3)/12$	$(HB^3\text{-}hb^3)/12$	$(I_{min}/S)^{0,5}$	
Transversal force to maintain the mast foot on deck: 0,5 to 0,8 F_{MH}.						
NOTE $k_p = \dfrac{\sigma_y}{\pi^2 \times E \times 0{,}01^2}$, where σ_Y is the yield strength of the pillar material.						

Table C.4 *(continued)*

WORKED EXAMPLE OF MAST PILLAR ASSESSMENT			
1-DATA			
Variable	Detail	Unit	Value
m_{LDC}	Loaded displacement	kg	7 200
$F_{DMC} = 10 \times m_{LDC}$	Design mast step compression force, monohull, Table C.1	N	72 000
Material	Pillar material		AISI 316
E	Elastic modulus of pillar	N/mm^2	190 000
σ_u	Ultimate stress	N/mm^2	520
σ_y	Yield stress	N/mm^2	220
σ_{LIM}	Limit stress, Table 3 item 2	N/mm^2	220
k_{MAT}	Material factor, Table 3 item 3	1	0,75
k_{LC} (pillar)	Load case factor for pillar, Table 3 item 4	1	1,10
k_{DCR}	Design category factor for rig, Table 3 item 5	1	1,00
L_P	Actual length of pillar	m	2,00
k_{LE}	Euler length factor FF (Clamped) = 0,7; SS(pinned) = 1	1	0,70
L_{MP}	$L_{MP} = L_P \times k_{LE}$	m	1,40
D	Tube external diameter	mm	88,9
e	Tube wall thickness	mm	3,05
2-RESULTS			
e/D	Ratio e/D	1	0,034
$d = D\text{-}2e$	Tube inner diameter	mm	82,80
R_{mid}	Middle radius, $R_{mid} = (D + d)/2$	mm	85,85
I_{min}	Actual $I_{min} = \pi (D^4\text{-}d^4)/64 \times 10^{-4}$	cm^4	75,9
A_{PA}	Actual pillar section area $A_{PA} = \pi (D^2\text{-}d^2)/4 /100$	cm^2	8,23
r	Radius of gyration $r = (I\ \text{min}/_A\text{p})^{0,5}$	cm	3,04
σ_d	Design stress of pillar material, Table 3 item 1, $\sigma_d = \sigma_{LIM} \times k_{MAT} \times k_{LC} \times k_{DCR}$	N/mm^2	182
σ_a	Actual compressive stress $\sigma_a = F_{DMC}/(100A_A)$	N/mm^2	88
σ_{cBR}	Rankine buckling stress $\sigma_{cBR} = \sigma_{dc}/(1 + k_p(L_{MP}/r)^2$	N/mm^2	145
C_F Rankine	Buckling Compliance factor Rankine	1	1,65
σ_{cLB}	Checking local buckling $\sigma_{cLB} = \sigma_{dc}/[1 + (3R_{mid}/e) \times (\sigma_{dc}/E)]$ [a]	N/mm^2	168

[a] Ref [16] gives a formula defining the local buckling stress not to be exceeded; in this example the local buckling stress $\sigma_{cLB} > \sigma_a$ but it can be governing for thin walled tubes.

On sandwich decks, the core shall be strong enough to support bolts compression loads and bolt bearing loads from lateral forces (plywood core, high density core, single skin, etc.).

As there are some transversal loads at the mast foot (lateral wind and rig forces), it is a current practice to stiffen the deck at this level (beam, stiffer deck sandwich, etc.).

C.4.2.4 Mast bulkheads with a well-bracketed vertical stiffener in way of the mast

The stiffener may be analysed as a mast pillar, but the attached bulkhead plating can be included in I_{min} (see ISO 12215-5:2019).

C.4.3 Keel stepped mast, see Figure C.1 b)

In the case of keel stepped mast or where the mast pillar is effectively supporting the mast alone, the mast or pillar shall be supported by a step. The mast step shall be able to support the resulting bending load and transfer the shear load to the supporting bottom structure.

It is a current practice to have a device preventing the deck from moving vertically under transversal compression loads and halyard blocks, e.g. tie rods on mast foot or mast walls, on bulkhead, etc. see key item 3 of Figure C.1 b).

The cut-out in the deck shall have a collar, usually metallic, with rubber or wood spacing material giving suitable horizontal support to the mast. In way of the collar, the deck shall be able to support the horizontal loads from the collar, e.g. metal collar, single skin, plywood core, high density core, etc.

C.4.4 Analysis by finite element method

The design load may be applied as a patch load over an area equivalent to the mast footprint. In developing the model, the requirements of Clause 11 shall be met.

C.5 Simplified mast step/pillar floor/support scantling method

See Table C.5.

Table C.5 — Simplified mast step/pillar floor/support scantlings method

$M_{MS} = k_{MSB} \times F_{DMC} \times L_{SP}/4$	Nm	Short span design bending moment in the mast step/pillar floor considered simply supported (see NOTE)
$F_{SMS} = k_{MSS} \times k_S \times F_{DMC} \times L_{SP}/2$	Nm	Short span design shear force in the mast step/pillar floor considered simply supported (see NOTE)
where		
F_{DMC}	N	is the design compression from mast step/pillar bottom defined in Table C.1;
L_{SP}	m	is the span between support points for the mast step/pillar floor;
$k_{MSB} = 4{,}5 \times d_s/L_{SP}$	1	is the floor mast step factor in bending, not be taken less than 1;
$k_{MSS} = 3{,}65 \times (d_s/L_{SP})^{0{,}7}$	1	is the floor mast step factor in shear, not be taken less than 1;
d_S	m	is the depth of the mast step floor.
$\sigma_{MAX} = M_{MS}/SM_{min} \leq \sigma_d$	N/mm^2	Maximum bending stress in the mast step floor
$\tau_{MAX} = k_S \times F_{SMS}/(100\,A_{SH}) \leq \tau_d$	N/mm^2	Maximum shear stress in the mast step
where		
SM_{min}	cm^3	is the minimum section modulus of the mast step floor;
A_{SH}	cm^2	is the floor shear area;
k_S	1	is the floor shear factor.
For mast-step/pillar floors consisting of a rectangular block (e.g. as commonly found on wooden craft), A_{SH} is the actual cross-sectional area and $k_S = 1{,}5$. For mast- step/pillar floors which consist of a web and flanges, A_{SH} is the web area and $k_S = 1$. σ_d and τ_d are defined in Table 3. Where the height of the floor web is variable, the values of d_S, SM and A_{SP} shall be taken at 75 % of the span L_{SP}, see Figure C.1 b) and c). Where possible, step/pillar floors should be supported by brackets which stabilize the floor against torsional buckling, and transmit load by shear. NOTE k_{MSB} and k_{MSS} are approximate correction factors intended to make standard beam theory more applicable to short-beams of the type found on boat mast steps. Generally, standard beam theory requires that the depth be less than about 15-20 % of the span. From formulas for k_{MSB} and k_{MSS}, the factors are equal to 1,0 at depth/span ratios of 22 % and 16 % respectively.		

C.5.1 Worked examples for mast step calculations

Table C.6 — Worked examples for step/pillar floor calculation

Worked example Floor for mast step for a design category A craft				
DATA				
F_{DMC} = 72 000 N	L_{SP} = 0,9 m	d_s = 0,25 m	k_{DCR} = 1	k_S = 1,0
PRELIMINARY CALCULATION				
$k_{MSB} = 4{,}5 \times d_s/L_{SP} = 4{,}5 \times 0{,}25/0{,}9 = 1{,}25$ $k_{MSS} = 3{,}65 \times (d_s/L_{SP})^{0{,}7} = 4{,}5 \times (0{,}25/0{,}9)^{0{,}7} = 1{,}49$ $M_{MS} = k_{MSB} \times F_{DMC} \times L_{SP}/4 = 1{,}25 \times 0{,}25 \times 72\,000 \times 0{,}9 = 20\,250$ (Nm), bending moment $F_{SMS} = k_{MSS} \times k_S \times F_{DMC} \times L_{SP}/2\ _S$= 1,49 × 1,0 × 72 000 / 2 = 53 600 (N), shear force Table 3 gives k_{LC} = 1,05 for step of mast/pillar in wood/FRP, and k_{LC} = 0,88 for its connection to the structure.				
Worked example 1: Floor made with an oak wooden block 250 × 250 × 15 mm thick, hollow box configuration				
For oak, Table E.1 of ISO 12215-5:2019 gives $\sigma_{LIM} = \sigma_{Uf\,//}$ = 77 N/mm² and τ_{LIM} = 11 N/mm² k_{MAT} = 0,33. $\sigma_d = \sigma_{LIM} \times k_{MAT} \times k_{LC} \times k_{DCR} = 77 \times 0{,}33 \times 1{,}05 \times 1 = 26{,}7$ N/mm². $\tau_d = \tau_{LIM} \times k_{MAT} \times k_{LC} \times k_{DCR} = 11 \times 0{,}33 \times 1{,}05 \times 1 = 3{,}8$ N/mm². $SM_{min} = (25^4 - 22^4) / (12 \times 12{,}5) = 1\,042$ cm³.m actual *SM* of the mast step/floor. $A_S = 2 \times 25 \times 1{,}5 = 75$ cm² = 7 500 mm². $\sigma_{max} = M_{MS} / SM_{min} = 20\,250 / 1\,042 = 19{,}4$ N/mm² < 26,7 mast step complies on bending strength C_F = 1,37. $\tau_{max} = F_{SMS} /(100A_{SH}) \leq \tau_{max} = 53\,600 / 7\,500 = 7{,}1$ N/mm² > 3,8 mast step does not comply on shear strength. The compliance factor is C_F = 3,8/7,1 = 0,53. To comply, the 15 mm webs shall be thicker, t_s = 15/0,53 = 28 mm. The flanges and webs of the mast step block are considered glued with epoxy, and the whole block glued on its full bottom to the craft's inner side of bottom plating 250 mm wide. As explained in ISO 12215-6:2008, the shear flow is $q = F_{SMS}/1\,000\ d_s = 53\,600/250 = 214$ N/mm. If the epoxy glue has a design shear stress of about 5 N/mm², the shear stress in the glue joint will be $\tau_{max} = q/250 = 214/250 = 0{,}8 \leq 5$; complies.				
NOTE Attached plating contribution is ignored in this example, as planking grain is assumed to run perpendicular to the mast step axis. See Annex G or H of ISO 12215-5:2019 for more in-depth method for analyzing wood beams with effective plating.				
Worked example 2: Same floor made from a top hat.				
Top hat corresponding to "tall top hats" in Table G.3 of ISO 12215-5:2019. Material CSM GRP ψ = 30 %. The top flange of the top hat is loaded in compression and is probably weaker than the bottom flange (attached plating) in tension. Considering Table G.3 of ISO 12215-5:2019 extrapolated to 250 mm height (or using Annex H) with 250 × 250 × 250 with, t_p = 10 mm, then SM_{min} = 557 cm³ and a shear area (A_w) = 50 cm² = 5 000 mm² are found. With the same dimensions, the bending moment and shear forces are the same. $\sigma_{LIM} = \sigma_{UC\,//}$ = 125 N/mm² (Table C.9 of ISO 12215-5:2019), multiplied by $k_{BB} = k_{AB}$ = 0,95 and $\sigma_d = 141 \times 0{,}33 \times 1{,}05 \times 1 = 44$ N/mm². $\tau_{LIM} = \tau_U$ = 53 N/mm² and $\tau_d = 53 \times 0{,}33 \times 1{,}05 \times 1 = 18{,}4$ N/mm². With M_{MS} = 20 250 N.m and SM_{min} = 557 cm³, $\sigma_a = 20\,250/557 = 36{,}4 < \sigma_d = 44$ m/mm² compliance factor C_F = 1,21. For shear stress check, the shear flow is the same q = 214 N/mm. With a design shear stress in the flanges laminated to the hull plating τ_d = 3 N/mm² (see ISO 12215-6:2008), the width of the gluing area shall be greater than 214/3 = 71 mm which means 36 mm each side, smaller than the usual 50 to 75 mm.				

Annex D
(normative)

Simplified "established practice" for the assessment of chainplatesand their connection

D.1 Status of this Annex

This Annex shall be used when the "simplified method" of Clause 5 is chosen.

D.2 Loads

D.2.1 General

This Annex is mainly dedicated on chainplates connected to the metal rig quoted in Table D.1 and, to simplify, are based on column 8 of Table 4, i.e.:

— at the connection rig element/chainplate, the ultimate strength of the chainplate is 120 % of the strength of the metal rig element it supports;

— at the connection chainplate/structure, the ultimate strength of the connection is 144 % of the strength of the metal rig element it supports.

This supposes that the rig is correctly sized, i.e. R_u = 240 % of the design load. If this is not the case, columns 2 and 3 of Tables D.4 or D.5 or R_u wire strength of Table D.2 shall be corrected to be 240 % of the design load.

Non-metal rigs are not formally quoted in this document. As their elastic modulus is smaller than metal rig and their ultimate strain larger, and therefore to provide the same support as a metal rig they need a larger section which means a much larger ultimate load than for metal rig elements. They shall therefore be treated as in the previous paragraph replacing R_u wire of Tables D.2, D.4 and D.5 by 240 % of the design load.

D.2.2 Rig breaking load — Metal rig

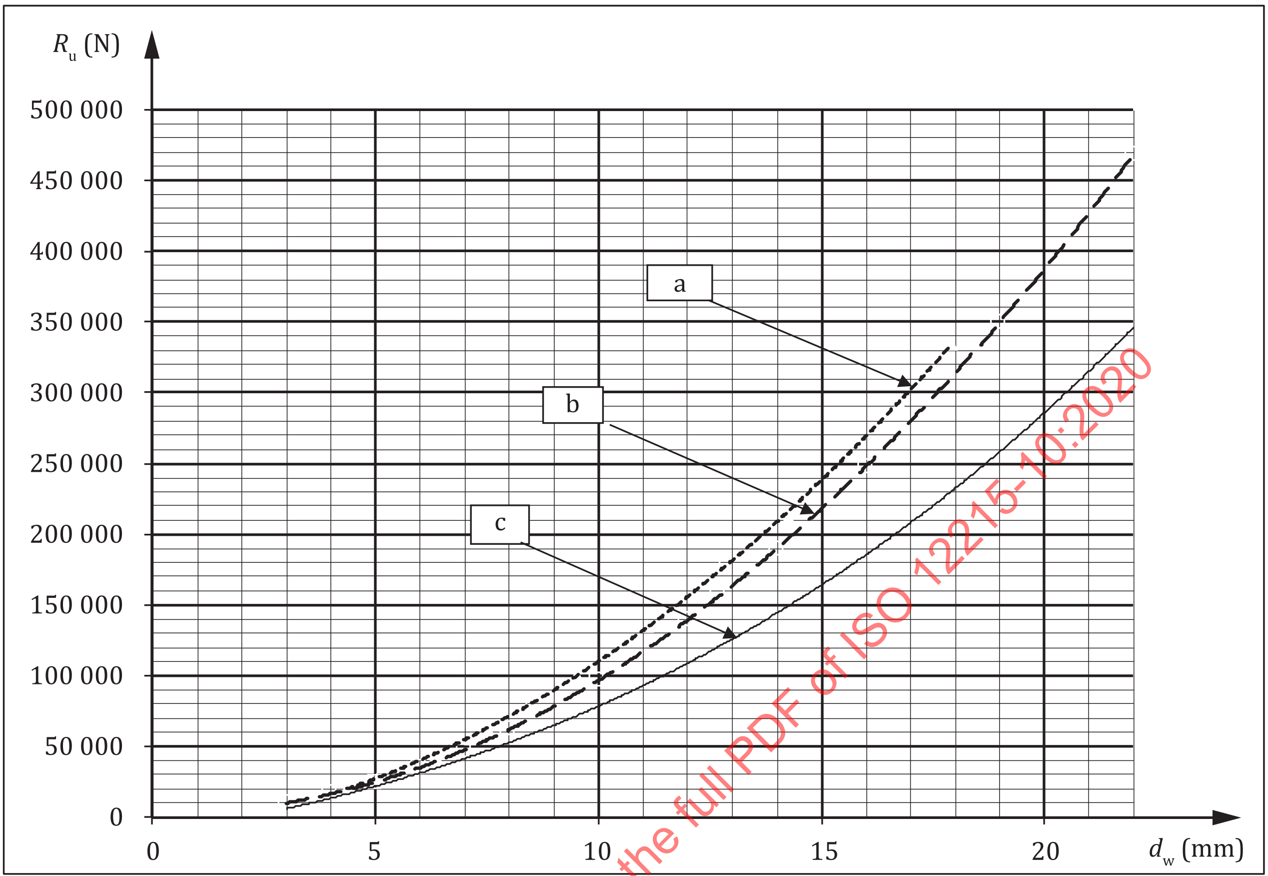
The ultimate strength of the rig element, R_u rig, shall be taken from the manufacturers' specified breaking load data for the appropriate rigging size and type.

Manufacturers have different practices for specifying breaking loads, being often minimum values in Europe while American practice is to use nominal breaking loads subject to 2,5 % underload tolerance. This should be checked with the manufacturer.

The values of Table D.1 and Figure D.1 are approximate averaged values; where available, the data given by the rig provider shall be used. The strength of an AISI 304 wire is 87 % of the same wire in AISI 316.

Table D.1 — Default values of some metal rig elements

	1x19 AISI 316			**Dyform**			**Nitronic 50 Rod**				
d_w	σ_u average	Section	R_u	σ_u average	Section	R_u	dash	d_w	Section	σ_u average	R_u
mm	N/mm^2	mm^2	N	N/mm^2	mm^2	N	#	mm	mm^2	N/mm^2	N
3,0	1 390	5,4	**7 500**	1 530	6,4	**9 730**					
4,0	1 390	9,6	**13 300**	1 530	11,3	**17 300**	# 4	4,37	15,0	1 390	**20 850**
5,0	1 390	14,9	**20 700**	1 370	17,7	**24 210**	# 6	5,03	19,9	1 410	**28 020**
							#8	5,72	25,7	1 400	**35 980**
6,0	1 390	21,5	**29 900**	1 370	25,4	**34 860**					
							#10	6,35	31,7	1 410	**44 650**
7,0	1 390	29,2	**40 700**	1 370	34,6	**47 450**	#12	7,14	40,0	1 410	**56 460**
							#15	7,52	44,4	1 410	**62 620**
8,0	1 390	38,2	**53 100**	1 370	45,2	**61 980**	#17	8,38	55,2	1 410	**77 770**
							#22	9,53	71,3	1 410	**100 580**
10,0	1 300	59,7	**77 600**	1 370	70,7	**96 840**					
							#30	11,10	96,8	1 400	**135 480**
12,0	1 300	86,0	**111 700**	1 370	101,8	**139 450**					
12,7	1 300	96,3	**125 200**	1 370	114,0	**156 190**	# 40	12,70	126,7	1 400	**177 350**
14,0	1 200	117,0	**140 400**	1 370	138,5	**189 810**					
							#48	14,27	159,9	1 330	**212 710**
16,0	1 200	152,8	**183 400**	1 370	181,0	**247 910**					
							# 60	16,76	220,6	1 330	**293 420**
							# 76	17,90	251,6	1 330	**334 690**
19,0	1 200	215,5	**258 600**	1 370	255,2	**349 590**					
22,0	1 200	288,9	**346 700**	1 370	342,1	**468 700**					
	Section = 0,76πd^2/4			**Section = 0,9πd^2/4**			**Section = πd^2/4**				
σ_y/σ_u	≈0,85			≈0,85			≈0,85				
E (N/mm^2)	150 000			170 000			200 000				



a Nitronic 50 Rod. b Dyform. c 1 × 19.

Figure D.1 — Graph for values of Table D.1

A tie rod passing through the deck or connected to a deck level with a chainplate/connection aligned with the rig/shroud may be considered as a prolongation of the rig, i.e. the chainplate to consider is the one at its lower end and connected to the structure. This is only valid provided the connection at deck level does not affect significantly the deck and its structure, i.e. if the deck and eventual beam are not stiff enough to absorb any near vertical significant load.

NOTE The choice of the rig diameter is frequently governed by its stiffness to ensure that the mast is sufficiently supported to prevent its buckling under compression. This entails that load in the rig element is usually between 30 % and 40 % of its breaking strength R_u. Even if this document (see 8.1) excludes the case where the rig can catch objects while sailing (including another craft's mast), to ensure that the rig will fail before its attachment, it is a common practice to have the chainplate strength at least 120 % of the rig strength.

D.2.3 Loads in way of chainplate foundation

$F_{CPLT} = \sum_1^n F_U$ (N), is the load in way of a chainplate and its foundation, for all Table D.1 rig elements which are connected to the same chainplate. If the rig elements have different angles, this sum shall be made vectorially, i.e. by composition of the forces in all rig elements connected to the chainplate working simultaneously.

NOTE The term “working simultaneously” means that the final load on the chainplate cannot be the sum of the maximum load in each rig element but the greater load in the chainplate according to the worst load case, e.g. the loads in diagonal D1 and vertical V1 vary from S_{C1} to S_{C5}.

D.3 "Established practice" method for dimensioning a metallic lug

Table D.2 is based on the experimental method presented in D.7 and is similar to References [9] and [10]. It allows a chainplate with balanced resistance between shear/bearing resistance and tensile/net section.

Table D.2 — Proportion between the values for a stainless steel or aluminium chainplate

Material	e_2/D	w_2/D	t_2
SS AISI 304 & 316	1,6	2,963	$\dfrac{C_F \times 1{,}2 R_{\text{u wire}}}{1{,}425 \times \sigma_u \times D}$
Aluminium 5086 H 111	2,0	3,366	$\dfrac{C_F \times 1{,}2 R_{\text{u wire}}}{1{,}7 \times \sigma_u \times D}$

CAUTION — The formulas are only applicable when the pin is loaded in double shear as shown in Figure D.2.

Where, see also Figure D.2:

D	mm	is the bore for the rig pin, usually not greater than 1,05 Dpin;
e_2	mm	is the height of the chainplate above the axis;
t_2	mm	is the thickness of the chainplate;
w_2	mm	is the width of the chainplate;
$R_{\text{u wire}}$	N	is the ultimate strength of the wire as given by the rig manufacturer or by Table D.1;
σ_u	N/mm^2	is the ultimate stress of the chainplate material given below or according to the material provider;
C_F		is the compliance factor against the requirement to have the chainplate 120 % R_u wire.

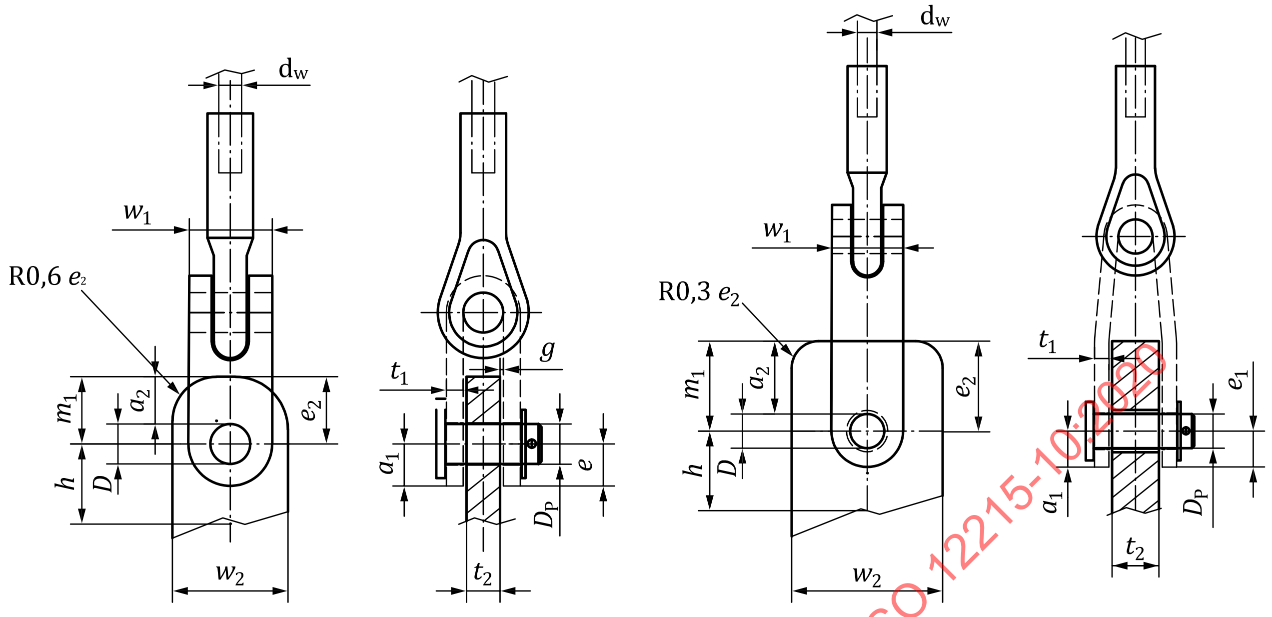
This simplified method is mainly applicable for 1 × 19 or 1 × 36 SS wire up to 16 mm diameter. For higher diameter or other material like Rod, the rig manufacturer shall be contacted to have the manufacturer's ultimate strength.

Table D.3 gives the mechanical properties of metals taken from Table B.1.

Tables D.4 and D.5 correspond to the "established" practice used or recommended by many mast/rig manufacturers. Its dimensions are slightly different from the one recommended by Table D.2: the compliance factor shown in the two last columns of Tables D.4 and D.5 are higher.

Table D.3 — Mechanical properties used in Tables D.3 and D.4

Stainless steel chainplate material					
AISI reference	**EN 10088 reference**	σ_y N/mm^2	σ_u N/mm^2	E N/mm^2	ε_u %
316	1,44	220	520	200 000	40
5086 H111 aluminium					
AISI reference		σ_y N/mm^2	σ_u N/mm^2	E N/mm^2	ε_u %
5086 H111 (annealed)		100	240	27 000	13



a) Stainless steel chainplate/toggle

b) Aluminium alloy chainplate/toggle

Figure D.2 — Metal chainplate dimensions in Tables D.4 and D.5

Table D.4 — Typical dimension of AISI 304 & 316 SS steel chainplates for 1x19 AISI 304 wire

1	2	3	4	5	6		7	8		9	
d SS wire	R_u wire AISI 316	1,2 R_u	D_p[a] pin	D[b] bore	t_2[c] thickness min	max	w_2[d] plate width	e_2 height above axis min	max[c]	$C_F = R_u$ plate[e] /1,2 R_u rig	
t	N	N	mm	mm	mm	mm	mm	mm	mm	Bearing or shear	Net section tensile
4	13 300	15 960	6,5	7,0	5,0	6	23	13	15	1,83	1,88
5	20 700	24 840	8,0	8,5	6,5	7,5	29	16	19	1,88	2,00
6	29 900	35 880	9,5	10,5	8,0	9	29	16	19	1,67	1,57
7	40 700	48 840	11,0	12,0	9,5	10	34	20	23	1,79	1,62
8	53 100	63 720	12,0	13,0	11	12,5	34	20	23	1,61	1,39
10	77 600	93 120	16,0	17,0	15	16	42	22	27	1,62	1,55
12	111 740	134 090	19,0	20,5	16	18	55	32	36	1,78	1,57
12,7	125 160	150 190	19,0	20,5	16	18	55	32	36	1,59	1,40
14	140 390	168 470	22,0	23,5	17	20	64	36	41	1,69	1,56
16	183 370	220 040	25,5	27,5	21	24	73	40	49	1,78	1,66
19	258 580	310 300	32,0	34,0	24	28	91	52	61	1,88	1,68

All dimensions according to Table D.2 and Figure D.2.

[a] ±0,2 mm for $D_p \leq 10$; ± 0,3 mm for $D_p > 10$.

[b] 1,05 D_p ± 0,3 mm.

[c] Maximal value to allow rigging screw and toggle to fit and allow the rig and its attachment to articulate with rig movement.

[d] Where two shrouds are connected to the same plate w_2 may be used as the distance between the axis of the bores.

[e] See Table D.10.

The calculations have been made for AISI 316, but as the mechanical properties of this grade are marginally greater than the ones of AISI 304, Table D.4 may be used for both metals.

Dimensions not in the Table: clearance above deck h = 1,2 e_2 and radius at top of chainplate R = 0,6 e_2.

CAUTION — For simplicity, Tables D.4 and D.5 are based on R_u wire, which is supposed to be 2,4 F_d, the design load in the wire (see Table 4), with compliance factors against rupture R_u plate/1,2 R_u rig between 1,4 and 2,3. A thorough application of this document using the developed method of Clause 6 requiring the application of the design stress and not the ultimate stress would entail $C_{Fu} = \sigma_u/\sigma_d$ that are 20 % lower than displayed in the two last columns of Table 4. Playing with the figures of Table D.4 should not end with values in the two last columns below 1,2.

D.3.1 Typical dimensions of aluminium chainplates

Table D.5 gives typical lug dimensions for 5086 alloy lugs for 1 × 19 wire in a similar way as for Table D.4.

As pin movement wears and tends to ovalize the aluminium bore, the addition of a press fitted stainless steel bushing in pin bore is highly recommended for pin diameters greater than 10 mm. Table D.5 has been calculated similarly to Table D.4, using D_o in place of D where appropriate. The stainless-steel bushing is inserted with a press or equivalent (adjustment H7p6), that will entail sufficient watertightness between bushing and chainplate to reduce SS/aluminium galvanic corrosion.

Table D.5 — Typical dimension and calculation of aluminium alloy chainplates for 1 × 19 wire

1	2	3	4	5	6	7	8	9	10	11	
d SS wire	R_u wire AISI 316	1,2 R_u	D_p[a] pin	D_i[b] bush	Bush thick	D_o bush	t_2 plate thick	w_2[c] plate width	e_2 height above axis	$C_F = R_U$ plate[d] /1,2 R_u rig	
t	N	N	mm	mm	mm	mm	mm	mm	mm	Bearing or shear	Net sect tensile
4	12 800	15 960	6,5	7,0	0	7,0	10	24	14	1,79	1,84
5	20 000	24 840	8,0	8,5	0	8,5	14	29	17	1,95	1,99
6	28 790	35 880	9,5	10,5	2	14,5	14	49	29	2,31	2,32
7	35 540	48 840	11,0	12,0	2	16,0	14	54	32	1,87	1,88
8	46 420	63 720	12,0	13,0	2	17,0	18	58	34	1,96	2,00
10	72 520	93 120	16,0	17,0	2	21,0	25	70	42	2,30	2,27
12	104 430	134 090	19,0	20,5	2	24,5	32	84	50	2,42	2,45
12,7	116 970	150 190	19,0	20,5	2	26,5	32	90	54	2,34	2,33
14	142 150	168 470	22,0	23,5	3	29,5	32	100	60	2,31	2,31
16	185 660	220 040	25,2	27,5	3	35,5	35	120	70	2,28	2,32
19	230 570	310 300	32,0	34,0	4	42,0	36	140	84	1,99	1,96

All dimensions according to Table D.2 and Figure D.2.

[a] ±0,2 mm for $D_p \leq 10$; ±0,3 mm for $D_p > 10$.

[b] 1,05 D_p ± 0,3 mm.

[c] Where two shrouds are connected to the same plate w_2 may be used as the distance between the axis of the bores.

[d] See Table D.10.

Dimensions not in Table D.5: Clearance above deck, h = 1,2 e; and radius at top of chainplate, R = 0,3 e_2.

D.3.2 Dimensions and bending or shear stress of the pin

The strength of the pin itself is generally not the choice of the boat builder or designer as it is generally provided by the rig manufacturer. Pin double shear strength is straightforward, but the pin bending analysis is more complex, and depends of course of the gap between chainplate and toggle. The analyses explained in References [9] and [10] summed up in Clause D.7 may be used, but practical experience of the rig manufacturer is determinant.

Some references advocate that the bore shall not be greater than 105 % of the pin diameter to avoid fatigue issues on the pin, but this is difficult to achieve in practice, as a too small clearance can lead to seizing of the pin in the bore due to salt/dust, a situation to be avoided in any case.

D.3.3 Metal lugs with additional thickness in way of pin

To gain weight, some builders/designers sometimes use thinner chainplate lugs than required by Table D.4 away from the pin area, and provide a greater thickness (or weld a washer) in way of pin to have at least the chainplate thickness and width of Table D.4. In that case, one shall check that the compliance factor on tensile stress is at least the one in the last column of Table D.4 using the method explained in Clause D.7 and Table D.10.

D.3.4 U bolt type chainplates

D.3.4.1 General

U bolt type chainplates are frequently used for standing rigging or for attachment points of running rigging. Figure D.3 shows 3 typical types of U bolt chainplates.

CAUTION — It is of paramount importance that the pull, whether vertical or horizontal, against the deck/hull general plane be made within the vertical plan of the U bolt. A pull in a direction outside of this plan shall be avoided as it induces bending loads and is correlated to fatigue loads. Figures D.3 and D.4 shows the recommended load direction, V or H, and the load direction(s) to be avoided.

D.3.4.2 Strength assessment

D.3.4.2.1 Vertical pull

The most frequent use of U-bolt chainplates is when the load is vertical or near vertical (arrow V in Figures D.3 and D.4).

The strength of U-bolt chainplates depends significantly on their material, shape, fabrication, installation, shape of rig end fitting attached, etc. and on the way the load is transferred from the rig to the structure. When loaded close to the limit, and according to the various parameters above, the U bolt deflects, then the load is not any more evenly shared by the rods and threads, there are stress concentrations, etc.

Therefore, the stress assessment for the vertical load shall be:

— if a specific U-bolt chainplate has been tested up to ultimate, the value to be taken is 90 % of the mean ultimate strength or the mean value minus two standard deviations, whichever is the lesser;

— if a specific U-bolt type has not been previously tested, it is necessary to take a safety margin, as explained above, and the ultimate strength of the U-bolt chainplate shall be taken as 85 % of the theoretical ultimate stress of the sum of the strength of all loaded bolts, calculated at thread necks.

D.3.4.2.2 Horizontal pull

Some U-bolts are used with a horizontal or near horizontal pull [arrow H in Figure D.3 a)], e.g. pull of backstay load where the U-bolt chainplate is bolted on the transom. In that case, the stress assessment is even more specific, as the plate connecting the two sides of the U distributes the load between them which shall be strong enough. Also, the U rods are loaded in shear.

The strength assessment for a horizontal load shall use the same procedure as for the vertical pull.

D.3.4.3 Detailed recommendations

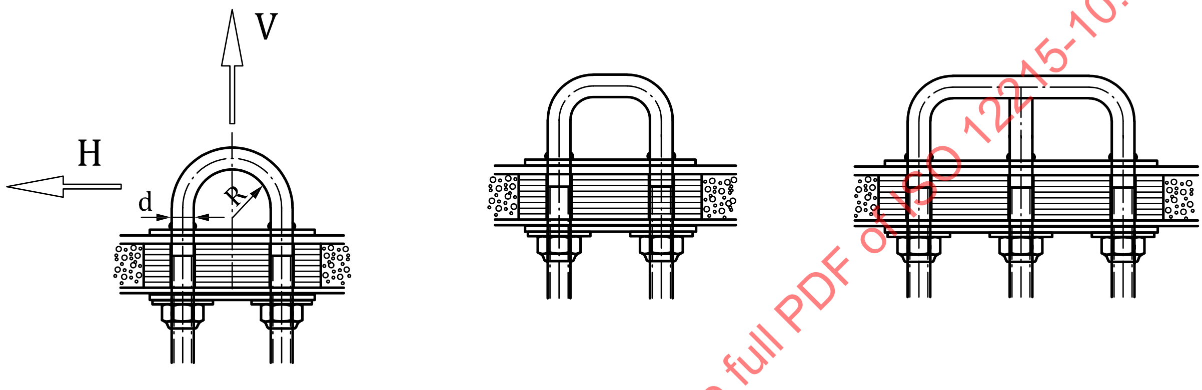
The following should be undertaken.

— Ensure that the sandwich deck core material is stiff enough to support the bolting compression/shear load, or replace by wood/plywood, reinforced resin, high density core, etc.

— Bore the deck or hull at exactly the same spacing, using the top plate as a template. Unless the chainplate has a watertightness device, finish the top of the boring with a chamfer to allow forming a watertight "O ring gasket" with the jointing compound.

— Do not overstress the bolts (to be recommended by the manufacturer) otherwise see Table B.5.

— Ensure that the load is distributed.



a) Half circle b) U-shape c) Double U-shape

Key

V vertical or near vertical pull

H horizontal or near horizontal pull

Figure D.3 — Sketch of various types of U-bolt chainplates

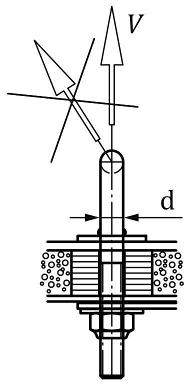


Figure D.4 — U-bolt-recommended direction of load

D.4 "Established practice" for bolted chainplate connections to the structure

D.4.1 Chainplates or plates connected to the structure by bolts

Flat plates bolted to a bulkhead or side shell/transom constitute the most traditional type of connection. They are commonly used for shroud and backstay attachment.

The plate is usually bolted on one side of the structure element, and the bolts are therefore loaded in single shear. This asymmetry also entails that the bolts work both in bearing and bending in the bulkhead or structure.

Table D.6 shows the logic to follow, the "final" load of the chainplate is the one corresponding to the lowest load given by this table for bolts or group of bolts.

NOTE There are not many published works on this type of connection in the nautical field, and the logic of EN 1995-1 (Eurocode) has been used, with lower safety factors than in house building practice. Aircraft literature also has its recommended practice, usually more sophisticated than in EN 1995.

Table D.6 — Strength of bolted connections with the structure

Definition	Unit	Formula/specifications
1 - Strength per bolt in shear — Single shear (×2 if double shear)		
Not considering friction (see below), this is the greatest load that a bolt can transmit per shear plane.		
Simplified method	N	$R_{ubs} = 0{,}6 \times A \times \sigma_{ub}$, ultimate force of bolt in shear,
Developed method	N	$F_{dbs} = 0{,}6 \times A \times \sigma_{db}$, design force of bolt in shear,
where		
$A_e = \pi/4 \times d_b^2$	mm^2	is the bolt shear area, where the shear plane passes through the plain section;
$A_s = \pi/4 \times (d_b - 0{,}938\ p)^2$	mm^2	is the bolt shear area, where the shear plane passes through the threaded section;
p	mm	is the thread pitch (mm).
See Table D.7 for pre-calculated values of R_{ubs}.		
2 - Force per bolt in bearing in a plate/chainplate		
Simplified method	N	$R_{ubp} = d_b \times t_b \times \sigma_{ubp}$, ultimate force of (chain)plate in bearing,
Developed method	N	$F_{dbp} = d_b \times t_b \times \sigma_{dbp}$, design force of (chain)plate in bearing.
See Item 4 for values of σ_{ub} and bolt minimum spacing.		
3 - Force per bolt in bearing in a bulkhead or structure		
Simplified method	N	$R_{ubbk} = d_b \times \Sigma t_{bki} \times \sigma_{ubp}$
Developed method	N	$F_{dbbk} = d_b \times \Sigma t_{bki} \times \sigma_{dbp}$
Where - see Figure in item 4, where i is each layer of material, where the bulkhead or structure is made of several different materials. See Item 4 for values of σ_{ub} and bolt minimum spacing.		

4 - Bearing ultimate stresses and minimal hole spacing according to material (see sketch)

Material	Ultimate bearing stress[a], σ_{ub} N/mm^2	e_1/d_b min	p_1/d_b min	e_2/d_b min	p_2/d_b min
Steel	$1{,}5\ \sigma_u$	2	3	1,5	3
Balanced or isotropic laminate	$1{,}5\ \sigma_{uc}$	3	3	2	3
Wood along grain	$0{,}082\ \rho \times (1{,}0{,}01\ d_b)$	5	4	2	3
Plywood	$0{,}11\ \rho \times (1{,}0{,}01\ d_b)$	5	4	2	3

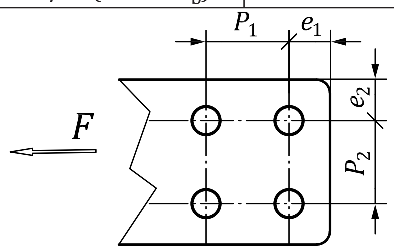


Table D.6 *(continued)*

where
d_b mm is the nominal bolt diameter;
t_p mm is the thickness of the plate/chainplate (directly loaded plate, not including backing plate);
t_{bk} mm is the effective thickness of the bulkhead index *i* if several elements;
σ_{ub} N/mm² is the ultimate bearing stress of the structure on which the plate is bolted;
σ_{db} N/mm² is the design bearing stress of the structure on which the plate is bolted.
[a] For metal or isotropic materials, the values of $\sigma_{ub}/\sigma_u = k_b$ of Figure D.9 a) where values >1,5 may be used; the values for wood and plywood are derived from EN 1995-1-1:2004.

Table D.7 — Dimensions and properties quoted in Table D.6

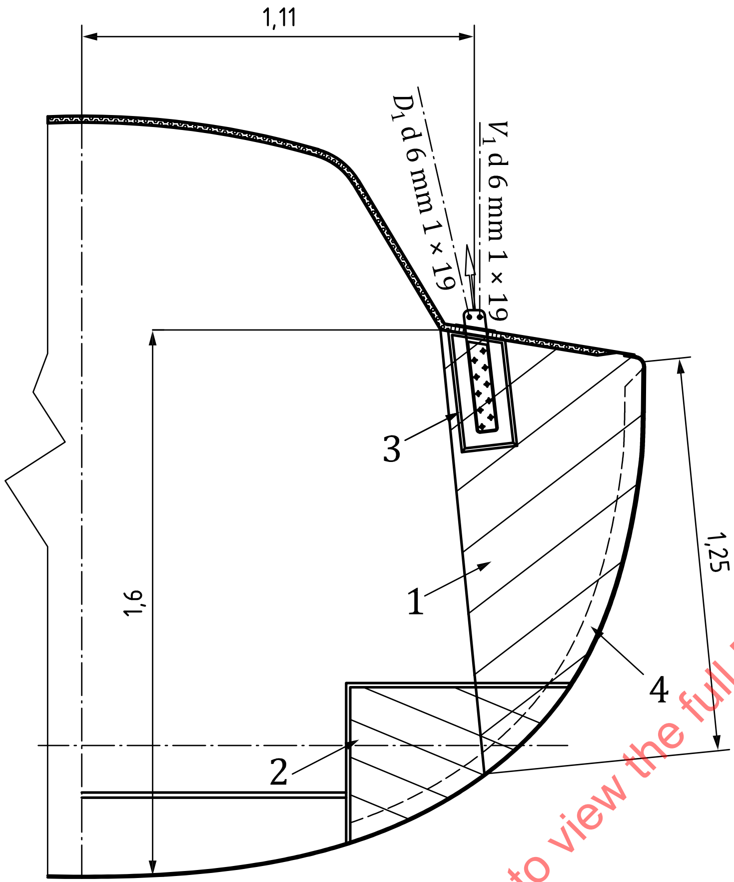
Ultimate strength of bolts					**R_u single shear** shear plane trough unthreaded section			**R_u single shear** shear plane trough threaded section[a]		
Type of stainless-steel bolt					A4.50	A4.70	A4.80	A4.50	A4.70	A4.80
Bolt tensile stress, σ_u (N/mm²)					500	700	800	500	700	800
d_b	d_0 hole	*P* pitch	*A* Area of unthreaded section	A_s Area of threaded section	Ultimate strength of bolts in simple shear R_{ubs}					
mm	mm	mm	mm²	mm²	N			N		
6	6,5	1,00	28,3	20,1	8 482	11 875	13 572	6 037	8 452	9 660
8	9	1,25	50,3	36,6	15 080	21 112	24 127	10 983	15 377	17 573
10	11	1,50	78,5	58,0	23 562	32 987	37 699	17 398	24 357	27 837
12	13	1,75	113,1	84,3	33 929	47 501	54 287	25 282	35 394	40 451
16	18	2,00	201,1	156,7	60 319	84 446	96 510	47 003	65 804	75 205

[a] Not recommended as the effect of the threads on bearing material entails damages and secondary/other stresses.

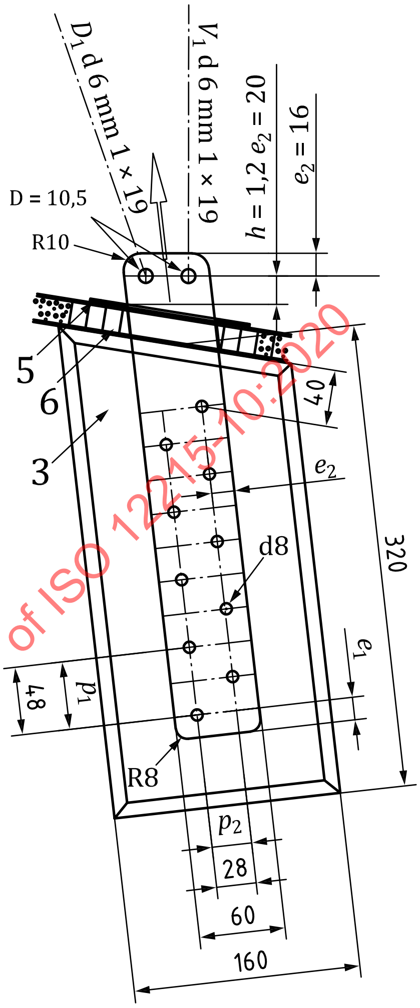
D.4.2 Worked example of a chainplate bolted to a bulkhead

The following is an example of the calculation of a connection of a bolted chainplate to a bulkhead. See Figure D.5.

Dimensions in metres [Figure a)] and in millimetres [Figure b)]



a) General dimensions



b) Chainplate details

Key

1 chainplate bulkhead (GRP sandwich or plywood)
2 eventual partial bulkhead in way of chainplate bulkhead
3 glued plywood reinforcing plate (plywood bulkhead)
4 bulkhead tabbing or gluing
5 deck plate for watertightness
6 sandwich replaced by wood insert if bolted deck plates

Figure D.5 — Sketch of chainplate section

Table D.8 — Example of bolted chainplate calculation

	Designation	Definition	Name	Unit	Value
	1-DATA				
1	R_u V1 d6	1 × 19 AISI 316 from Table D.1	R_u V1	N	29 990
2	R_u D1 d6	1 × 19 Aisi 316 from Table D.1	R_u D1	N	29 990
3	F_u conn to structure FRP/rig strength	Column 8 of Table 4	S_F R_u conn	1	1,44
4	Chainplate material	AISI 316			
5	Width of chainplate	2 × 30 mm as per Table D.4	W_p	mm	60
6	Thickness of chainplate	8 mm as min of Table D.4	t_p	mm	8
7	σ_u chainplate	From Table B.1	$\sigma_{u\ chplate}$	N/mm^2	520

Table D.8 *(continued)*

8	*d* connecting bolts	8 mm M8 Bolts A 4 70	d_b	mm	8
9	σ_u ultimate tensile strength in bolt	σ_u bolts A4 70 Table B.4	$\sigma_{u\ bolts}$	N/mm^2	700
10	Actual number of bolts		N_{ba}	1	10
11	e_2/d = bolt spacing/d	$e_2/d = 48/8$	a_2/d	1	6,00
12	σ_{ut} bulkhead/plating QX GRP $\psi = 0,4$ $\sigma_{ut} = 119$ N/mm^2	Annex C ISO 12215-5:2019 $k_{BB} = 0,95$ $k_{AM} = 0,9$	$\sigma_{ut\ bulkh}$	N/mm^2	102
13	**2- RESULTS OF CALCULATION**				
14	Total R_u rig	Σ ($R_{uV1} + R_{uV2}$) ignoring angles		N	59 980
15	Req F_u connect chainplate /structure	Sum R_u rig × S_F connection to structure		N	86 371
16	$k_{ubp} = \sigma_{ubp}/\sigma_{up}$	Table D.10 ≤ 2 of Figure D.9 a) for bolt spacing	$k_{ubp} = \sigma_{ubp}/\sigma_{up}$	1	2,00
17	Ultimate shear stress in bolt	τ_u bolt = 0,58 σ_u bolt	τ_u bolt	N/mm^2	406
18	Fu /bolt (shear plane out of thread)	$F_{\tau u} = \pi/4 \times d_b^2 \times \tau_{u\ bolt}$	$F_{\tau u}$	N	20 408
19	Ultimate bearing stress of the plate	$\sigma_{ub} = \min(\sigma_{ubp} = k_{ubp} \times \sigma_{up}$; $\sigma_{ubb} = k_{ubb} \times \sigma_{ub})$	σ_{ub}	N	1 040
20	Bearing force/bolt in plate	$d_b \times t_p \times \sigma_{ub}$	F_{bp}	N	66 560
21	Min nb bolts (if bolt shear only)	n_1=	n_1	1	4,23
22	Min nb bolts (if bolt bearing in chainpl)		n_2	1	0,77
23	Req R_u conn force to structure	*F* connection	F_{RCP}	N	86 371
24	**2.1 CALCULATION FOR 500 KG/M^3 PLYWOOD BULKHEAD 12 MM WITH 10 M8 BOLTS A2 70**				
25	Plywood density		ρ_b	kg/m^3	500
26	Bearing strength in plywood	$\sigma_{ubb} = 0,11 \times (1\text{-}0,01d) \times \rho$ Eurocode	σ_{ubb}	N/mm^2	50,60
27	Initial plywood thickness (Table A.13 ISO 12215-5:2019)	From Table A.13, $t_b = 7$ $D_b = 7 \times 1,6 = 12,6$	t_{b1}	mm	12,00
28	Bearing force/bolt in bulkhead	$F_{b1} = d_b \times t_{b1} \times \sigma_{ubb}$	F_{b1}	N	4 858
29	Bearing force without extra plate	$F_{bT} = F_{b1} \times N_{ba}$	F_{bT}	N	48 576
30	Nb of bolts required in bearing for t_{b1}	$n_{bb} = F_u C_P / F_{b1}$	n_{b1}	1	17,8
31	Req total local plywood thickness (no friction)		t_{bkr}	mm	21,3
32	Extra plate	320 × 160 × 12	t_{bka}	mm	24,0
33	*F* extra plate to bulkhead	$F = F_{RCP} (t_{b2} - t_{b1})/t_{b2}$		N	37 795
34	Req plate area τ_d bond = 3 N/mm^2	Table B.1 of ISO 12215-6	*A* plate req	mm^2	12 598
35	Actual area of the extra plate	320 × 160 × 12	*A* plate act	mm^2	51 200
36	Compliance factor on gluing		C_F glue	1	4,1
37	**Strength calculation for plywood bulkhead with friction coefficient**				
38	Friction coefficient		k_f	1	0,40
39	Tensile stress on a A2-70 bolt at 0,7 σ_y	$\sigma_{cb} = 0,7 \times 450$	s_{cb}	N/mm^2	315
40	Core area of screw M8 pitch 1,5 mm	$A_S = \pi/4\ (d\text{-}0,938p)^2$	A_s	mm^2	34,14
41	Compressive force/M8 bolt at 0,7 σ_y	$\sigma_{cb} \times A_S$	F_c	N	10 754
42	Friction force of 10 bolts	$F_F = F_C \times k_f \times N_{ba}$	F_{FC}	N	43 016
43	Bearing force without extra plate + friction force	$F_{bT} + F_c$	$F_{bT} + F_c$	N	91 592

Table D.8 *(continued)*

44	**2.2-CALCULATION FOR A SANDWICH BULKHEAD**				
45	Balsa core (reinforced by plywood in way of chainplate) with 1 Rovimat R 800 M300/Polyester each side at ψ = 0,319				
46	Local Reinforced by 1,0 kg Qx ψ = 0,5 t/w = 1,225 each side 150 × 200 initial wide under chainplate/backing plate				
47	Thickness Rovimat 800 × 300 with t/w = 1,58 for ψ = 0,411 (Table C.11 ISO 12215-5:2019)		$t\ R_m$	mm	3,16
48	σ_{uc} Rovimat 800/300	σ_{ucRM}	σ_{ucRM}	N/mm^2	163
49	σ_{ub} Rovimat 800/300	σ_{ubRM}	σ_{ubRM}	N/mm^2	245
50	Thickness Qx with t/w = 1,225 at ψ = 50 %		t Qx	mm	2,45
51	σ_{uc} Qx	Annex C of ISO 12215-5:2019	σ_{ucBD}	N/mm^2	144
52	σ_{ub} Qx	σ_{ubBD}	σ_{ubBD}	N/mm^2	216
53	Bearing force/bolt in bulkhead	$F_b = d_b \times (t_{bk1} \times \sigma_{ubp1} + t_{bk2} \times \sigma_{ubp2})$	F_{bbk2}	N	10 415
54	Bearing force for 10 bolts		$10\ F_{bbk2}$	N	104 146
55	**2.3-CONNECTION TO THE STRUCTURE BY QUADRIAXIAL LAMINATED ANGLES**				
56	Safety factor for laminated chainplate	Table 4	S_{FU}	*	1,44
57	Shear force to transmit to the structure	F connection = Total R_u chainplate × S_F	F_{rCP}	N	86 371
58	Length of connection // to force	From Figure D.5 a)	L_{conn}	mm	1 250
59	Shear flow each side	Force / L conn/2	q	N/mm	41
60	τu angles Annex C ISO 12215-5:2019 ψ = 0,4	with k_{BB} = 0,95 and k_{AM} = 0,95	τ_{uQx}	N/mm^2	57
61	t/w Qx angles ψ = 0,4		t/w	1	1,63
62	Required thickness of angles	t req angles Qx = q/τ_{uQx}	t_{angRM}	mm	0,72
63	w (mass) of dry Qx	$w = t$ angle/(t/w)	w angle	kg/m^2	0,44
64	τ_d bond polyester	Table H.5 of ISO 12215-5:2019	τ_{dbond}	N/mm^2	3
65	Shear flow each side	Force/L_{conn}/2	q	N/mm	41
66	Width of angles	Width = q/τ_d bond	W_{sb}	mm	14

Comments to Table D.8:

The required ultimate strength of the connection chainplate/bulkhead is 86 300 N. The proposed 10 M8 bolts in a 12 mm plywood bulkhead 500 kg/m^3 only allows 48 600 N. If one does not consider friction, the solution is either to use 20 bolts in the 12 mm or to add a reinforcing plywood plate 320 × 160 × 12, this doubles the bearing force at 97 200 N > 86 300. One shall note that plywood, with its alternate layers is much stronger than plain wood.

However, many builder/designers consider the friction load, with a friction coefficient up to 0,5 in plywood that allows the load to be transferred to the structure without any additional plate.

The same logic is applied when bolting a chainplate in FRP sandwich.

The lower part of Table D.8 calculates the load transferred by laminated Qx angles, which only requires 0,44 kg/m^2 Qx, but it would be wise to have 2 angles of 300 g/m^2 with a total 20 + 20 gluing/laminated width each side, as the bulkhead is not only loaded by chainplate and is also loaded as a frame.

D.4.3 Welding of chainplates

Welding a chainplate of a metal craft shall be made following first the general requirements of Clause 10, ISO 12215-6:2008 gives some details on welding, and ISO 12215-9:2012 also gives "established practice" methods, particularly its Annex F for fatigue issues. This is particularly true for aluminium as its welding can bring stress raisers.

For arrangements of the type shown in Figure D.6, where the lug does not extend below the deck, the breaking loads may be estimated as follows.

Weld attaching the lug to the base plate: $F_{\text{ultimate}} = l_w \times a \times 0{,}57 \times \sigma_{ut}$

Base plate securing bolts: $F_{\text{ultimate}} = N_b \times a \times 0{,}57 \times d_b^2 \times \sigma_{ut}$

NOTE 0,57 = π/4 × 0,85^2.

where

l_w	mm	is the total length of the fillet (on both sides if double);
a	mm	is the throat size;
σ_{ut}	N/mm^2	is the ultimate tensile strength of weld or bolt material.

The weld strength formula is also suitable for the case of a plate welded to a metal bulkhead or side shell/transom.

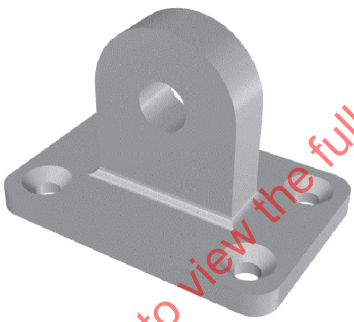


Figure D.6 — Typical lug to base plate assembly

D.4.4 Complex chainplates

In addition to strap-style chainplates, other types are commonly seen which are more complicated to analyse. Angle bracket with tie bar is one example. The most common 'complex' is the stem head fitting with roller and stem tang, see Figure D.7.

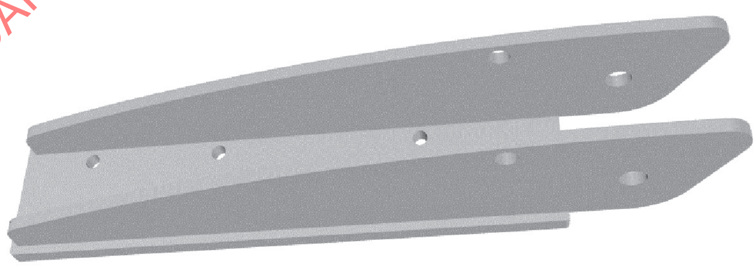


Figure D.7 — Typical stem head fitting

This cannot be analysed by simple formulas with any certainty. The lug part may be analysed using Clause D.2, but the holding down bolts, bending and shear stresses in way of the roller and the stress in the stem tang require either a numerical method able to cope with the structural redundancy or some indication of the load distribution between the components.

A pragmatic approach would be to make an estimate of the load sharing based on the relative sizes of the components and then treat these in isolation, e.g. stem tang under tension as per Clause D.2, tripping about the aft most bolts for bolt stressing and simple bending of the 'cantilevered' roller bracket.

D.5 Method limitations

The simplified methods presented in this Annex are intended to be used in support of practical experience and do not pretend to be able to predict actual stress distributions. Simple methods of analysis neglect load eccentricity. Poor alignment renders the foregoing methods liable to greatly overestimate the strength of the connection. It is also assumed that the bolts are evenly loaded although this is often not the case, with some bolts remote from the load point being largely ineffective. It is true that friction may make a significant contribution to the load capacity of the chainplate, although this may decrease with time unless bolts are regularly tightened. The effect of the backing plate/friction has been implicitly allowed for in the assumption of uniform loading of bolts and in calculating the bearing strength, see Clause D.2.

D.6 "Established practice" strapped composite chainplates and their connection to the structure

D.6.1 General overview

It is more and more frequent in performance sailing craft to have composite chainplates wrapped around a rig pin tube/bushing and laminated or glued directly to the hull, bulkhead or transom. It is common to use layup consisting of mainly unidirectional fibres, which are glued or laminated over a substantial area with, where relevant, additional double bias (DBx) plies to spread the load by shear on a larger area. Simple formulas offer limited scope for analysis, and it is strongly recommended to make tensile tests on a representative sample.

This clause gives recommended "established practice". The safety factors against rig strength are larger than for metal chainplates (see Tables 3 and 4) for UD straps as there is a stress concentration in the straps in their path around the pin bushing. For the connection between the straps and the craft structure, the safety factor/design strength is similar as for metal chainplates i.e.1,5 times the rig strength for metal rig, with however two main issues:

— the knowledge of the "actual" strength of the glued or co-cured joint;

— the fact that on a glued connection the stresses are not even in the whole gluing area but concentrate at the beginning and the end of the glued connection along the load axis.

This explains that the final actual gluing area divided by the design loads corresponds to a seemingly conservative shear stress.

The method described in this clause corresponds to the method applied by several designers/manufacturers, but other methods are possible provided they respect the design loads of Table 3 and follow sound engineering.

NOTE Strapped chainplates constitute a rather new subject. The practice of various designers/builders differ, so that the practice is not yet fully established. This is particularly true on the amount of BDx in relation to UDs.

D.6.1.1 General

Strapped chainplates are made of mainly UD straps made of glass or carbon composites laminated around the bushings holding the pin(s). The pins are usually "barrel" pins acting as a knuckle to allow the required swivelling in the 3 directions. Unless specific design, the barrel axis is perpendicular to the rig element load axis. The barrels are ended with flanges at each end to ensure that the UD straps do not slip sideways.

Strapped chainplates can be simple or multiple, i.e. made to hold several rig elements.

Strapped chainplates may be applied on single skin or sandwich plating/bulkhead and laminated or glued on both sides or only on one side. When chainplates are laminated on the inside, which allows a better aspect on the outside plating, one has to add a wedge allowing the plies to join without a significant peeling effect.

The lamination of the plies around the bushing requires some skills. Several sources recommend a dry or wet-preg of the plies without infusion as the vacuum bag tends to make wrinkles that in their turn make wrinkles in the UD straps, to be avoided in any case. It is also a usual practice of some manufacturers to insert the UD plies in a DBx "sock" that holds them together and helps transferring the load to the structure.

A composite block is inserted between the deck and bushing. In case of straps on one side only, it is recommend to position the straps on a jig having the shape of the hull, plus a high density foam wedge as shown in Figure D.8 b), then to connect it by gluing with epoxy structural adhesive where cured, or co-curing where uncured with a vacuum bag secondary bonding. If glued, vacuum bagging is recommended, having holes in the strap laminate to be glued to allow air escaping.

Positioning a stiffener or bulkhead in way of the chainplate allows both a stiff hull in that area and an efficient load feeding into the structure by shear flow.

There are usually two main types of strapped chainplates: either straps parallel to rig axis (see D.6.1.2) or straps distributed as a fan (see D.6.1.3).

Additional DBx plies (double bias) are added before and after gluing the straps, the purpose being to "feed" the UD load outside its area into the surrounding laminate, and to ensure the shear stress in the inside /outside plating is within design shear stress. The amount of DBx follows usually a ratio of 1 g of DBx for 5 g to 8 g of UD, it needs to be increased if the available plating height is limited (window, accommodation, etc.) and needs in that case a specific assessment outside of the scope of this Annex.

D.6.1.2 Straps parallel to the rig load axis, see **Figure D.8** a) to c)

Two multi-layer composite (glass or carbon) straps, each one with a width B_s, are laminated around the two bushings holding the pin.

These straps are mainly made of UD plies aligned with the rig load main direction, with a width W_t (total width of two bushings) with additional DBx ± 45° plies with the same material at a ratio defined in Table D.9.

The usual arrangements are either symmetric, i.e. attached on both sides of the structural element on which it is connected, or asymmetric, i.e. attached only on the inside or outside:

a) the straps are symmetrical around the – single skin or sandwich – hull plating or bulkhead. This usually needs local thinning of the core and fairing to have a good outside finish;

b) the straps are only connected one side of the structural element, laminated on a wedge. An inside connected chainplate allows a smoother finish of the outside hull but adds some traction perpendicular to the structural element that needs to be limited.

In Table D.9:

— The safety factor against ultimate S_{FU} in Table D.9 is 3,6 (row 26) for UD plies and 1,52 (row 37) for gluing connection as recommended in Tables 3 and 4. These are minimum values and additional safety margin is recommended.

— The ultimate stress values of τ_u of glue/co-cure is usually taken as 30 N/mm^2 for epoxy glue, 25 N/mm^2 for vinylester and 15 N/mm^2 for polyester.

— For definition of plies lap, an additional safety factor of 1,5 is used to consider stress concentration at the lap ends.

