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Small craft — Hull construction - Scantlings — Part 9: Sailing boats - Appendages and rig attachment

Petits navires — Construction de la coque - Echantillonnage — Partie 9: Bateaux à voiles- Appendices et points d'attache du gréement

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies

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International Standard ISO 12215 was prepared by Technical Committee ISO/TC 188, Small craft.

Beside this ninth part, ISO 12215 consists of

- Part 1: Materials - Thermosetting resins, glass fibre reinforcement, reference laminate
- Part 2: Materials - Core materials for sandwich construction, embedded materials
- Part 3: Materials - Steel, aluminium, wood, other materials
- Part 4: Workshop and manufacturing
- Part 5: Design pressures for monohulls, designs stresses, scantlings detrmination
- Part 6: Structural arrangements and details
- Part 7: Multihulls
- Part 8: Rudders

The development of ISO 12215 parts 1 to 9 owes a considerable debt to the energy and work of Mr Fritz HARTZ who was involved at the start of the project and was the convener of TC 188 WG 18 until his death on the 16th of November 2002. All the members of WG 18 and TC 188 wish to express their gratitude for his major contribution to the production of this International Standard

Introduction

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

Small craft — Hull construction - Scantlings — Part 9: Sailing boats - Appendages and rig attachment

1 Scope

This part of ISO 12215 applies to determination of the load and scantlings of sailing craft appendages and rig attachments on craft with a length of the hull (L_H) according to ISO 8666 of up to 24 m.

It applies to

— Appendages such as Ballast keels on sailing monohulls, Centreboards, etc

— Rig attachment such as chainplates, tie rods, mast pillars and mast step

This part of 12215 only covers the mot common arrangements, other arrangements are outside the scope of this part of ISO 12215, but if the loads and safety factors given in the present document may be used as a basis for engineering calculation.

In many cases this part of ISO 12215 shall be used in conjunction with Part 5 for pressure and scantlings determination, Part 6, for details and Parts 8 for rudders;

NOTE1 Scantlings derived from this International Standard are primarily intended to apply to recreational craft including charter vessels.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 12215. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO 12215are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 8666:— *Small craft — Principal data.*

ISO 12215-3:— *Small craft — Part 3: Materials — Steel, aluminium, wood, other materials.*

ISO 12217-2:— *Small craft —Stability and floatability –Assessment methods and categorisation – Part 2 sailing craft with a hull length greater than 6 m.*

3 Terms and definitions

For the purposes of this part of ISO 12215, the following terms and definitions apply.

3.1

design categories

sea and wind conditions for which a boat is assessed by this International Standard to be suitable, provided the craft is correctly handled in the sense of good seamanship and operated at a speed appropriate to the prevailing sea state.

3.1.1

design category A ("ocean")

category of boats considered suitable to operate in seas with significant wave heights above 4 m and wind speeds in excess of Beaufort Force 8, but excluding abnormal conditions, e.g. hurricanes.

3.1.2

design category B ("offshore")

category of boats considered suitable to operate in seas with significant wave heights up to 4 m and winds of Beaufort Force 8 or less

3.1.3

design category C ("inshore")

category of boats considered suitable to operate in seas with significant wave heights up to 2 m and a typical steady wind force of Beaufort Force 6 or less

3.1.4

design category D ("sheltered waters")

category of boats considered suitable to operate in waters with significant wave heights up to and including 0,30 m with occasional waves of 0,5 m height, for example from passing vessels, and a typical steady wind force of Beaufort 4 or less

3.2

loaded displacement mass m_{LDC}

mass of the craft, including all appendages, when in the fully loaded ready for use condition as defined in ISO 8666.”

3.3

sailing craft

boat for which the primary means of propulsion is by wind power, having a total profile area, As as defined in ISO 8666, expressed in m², of all sails that may be set at one time when sailing closed hauled of

$As > 0{,}07(m_{LDC})^{2/3}$

3.4

design category factor

f_w

factor lowering requirements according to design category, its values are according to Table 1

Table 1 — Values of design category factor

Design Category	A	B	C	D
Value of f_w	1	0,9	0,75	0,5

4 Symbols

Unless specifically otherwise defined, the symbols shown in Table 2 are used in this part of ISO 1215.

Table 2 — Symbols, coefficients, parameters

Symbol	Unit	Designation/Meaning of symbol	Reference/Article concerned
		Principal data	

5 Design criteria

5.1 Design stresses for metal

5.1.1 Basic design stresses

For the design tensile, compressive, and flexural loads shall be the smallest of

$$\sigma_d = 0{,}5\ \sigma_u \ \ or\ \ 0{,}9\ \sigma_y \text{ where relevant} \qquad \text{(N/mm}^2\text{)} \qquad (1)$$

and

$$\tau_d = \frac{\tau_u}{2} \qquad \text{(N/mm}^2\text{)} \qquad (2)$$

where

— σ_d is the design tensile, compressive, and flexural stress (N/mm²)

— σ_u is the ultimate tensile, compressive, and flexural stress (N/mm²)

— σ_y is the yield tensile , compressive, and flexural stress (N/mm²)

— τ_d is the design shear stress (N/mm²)

— τ_u is the design shear stress (N/mm²)

For metal, the design shear stress shall be taken as $\tau_d = 0{,}577\ \sigma_d$

The design bearing stress shall be taken as $\sigma_{bd} = 1{,}8\ \sigma_d$

NOTE To be consistent with parts 5 and 8 the design stresses of are high. To take this fact into account, the actual loads are raised by an adequate dynamic factor.

5.1.2 Design stresses for typical bolts or metals

Bolts may be made from the unsophisticated black steel to high quality Stainless steel, or non ferrous metals such as Monel 400, etc. Only Stainless steel or Carbon steel are considered in the present article, because they are the most popular material, but bolts and screws may be made of any material.

5.1.2.1 Stainless steel ISO bolts

Stainless steel is classed by ISO 3506 into four main categories , see Table 3

Table 3 — Mechanical properties of ISO SS screws according to ISO 3506-1979

ISO material	AISI	Texture
A1	303	Austenitic
A2	304	Austenitic
A4	316	Austenitic
C1 to C4	400 serial	Martensitic

If the steel has a low carbon content, the letter L is added after the ISO material

Table 4 — Mechanical properties of ISO SS screws according to ISO 3506-1979

		Property Class		
		50	70	80
σu	N/mm²	500	700	800
σd	N/mm²	250	350	400

Class 50 is usually made by machining a thread from a solid rod. This is how are made threaded rods. These screws are used for lowest quality screws.

Class 70 and 80 are made by a combination of stamping and cold stretching, this is the most used threads.

Quality SS bolts are usually stamped on their head with, on top the identification of the manufacturer wwith 3 letters, and below the ISO material and class quality.

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

5.1.2.2 Steel ISO bolts

Steel (plain or galvanized) are classed by ISO 898-1 into several classes. The fist digit multiplies by 100 gives the ultimate strength σ_u (N/mm².) The yield strength σ_y is obtained by multiplying the fist digit by 10 times the second digit.

Table 5 — Mechanical properties of ISO Steel screws

		ISO Class According to ISO 898-1-1988						
		4.8	5.6	5.8	6.8	8.8	10.9	12.9
σu	N/mm²	400	500	500	600	800	1 000	1 200
σy	N/mm²	320	300	400	480	640	900	1 080
σd	N/mm²	200	250	250	300	400	500	600

5.1.3 Combined design stresses

For metallic elements, equation (3) shall be fulfilled in any point of the stock:

$$\sqrt{\sigma^2+3\tau^2} \le \sigma_d \qquad (3)$$

5.2 Design stress for other metals

The mechanical properties of metals shall be according to ISO 12215-3.The values of Table 6 may also be used.

RL and GD This table needs correcting to reflect ‘as-welded’ properties and shall also include Temet 25 Duplex, Aquamet, etc

Table 6 — Values of σ_d and σ_d bearing for typical metals

Material	ISO or other	σd N/mm²	σd welded N/mm²	σd bearing N/mm²
Stainless Steels				
AISI 304		176	176	316
AISI 316, 316 L		176	176	316
17-4 PH, F16 PH	ASTM 630, Type a	500	NR	900
DX45, Uranus	4462	330		594
Mild Steel				
A42		210	210	378
Cast Iron for ballast keel				
EN-GJL -150	ISO 185/JL/150	75	75	135
Aluminium Alloys				
5083 H 111		113	113	203
6005 A T6 d=<50 mm		135	135	243
6005 A T6 d>50 mm		130	130	234
6061 T6		145	145	261
6082 T6		155	155	279
Titanium Alloys				
UTA 6V		450	NR	810
Copper Alloys				
Bronze-Manganese		221		397
Bronze-Ni-Al		351		632
Monel 400		275		495
Monel 500		480		864
Lead - Antimony Alloys				
Pure Lead		9		16
Lead with 1% Antimony		10		18
Lead 96 % with 4 % Antimony (Hard Lead)		40		72

5.3 Design stress for FRP or wood elements

For FRP or wood elements, equation (4) shall be fulfilled:

$$\left(\frac{\sigma}{\sigma_u}\right)^2+\left(\frac{\tau}{\tau_u}\right)^2 < 0{,}25 \qquad (4)$$

where

— σ_u is the appropriate ultimate normal strength for the component under consideration (N/mm²)

— τ_u is the minimum shear strength for the component under consideration (N/mm²)

6 Load on appendages

6.1 Gravity and dynamic loads on ballast keels.

6.1.1 Load due to heel (see figure 1)

$M_{qd} = 30\ f_w\ Q\ a$ is the ballast keel design bending moment at keel junction, (Nm) (5)

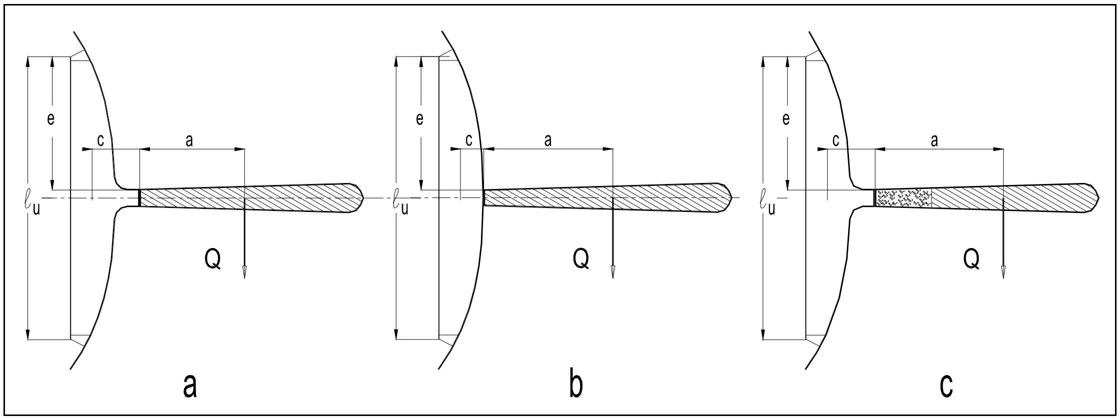
any element of the ballast keel, connection, and boat structure shall not to exceed its design stress under this load.

NOTE This bending moments includes a factor which reflects dynamic effects

where

— Q is the mass of ballast keel, (kg)

— a is the vertical distance from CG of keel to keel junction (m)



a: ballast bolted on a skeg b: ballast directly bolted on the hull c: bolted keel not fully ballasted

Figure 1 — Different types of bolted ballast keel

6.1.2 Maximum longitudinal allowable offset (see figure 2)

If the arrangement of the ballast CG is longitudinally distant of more than 0,2 L bolts from a vertical from the Centre of surface of the bolts, it is outside the scope of the present part of ISO 12215.

NOTE In this case, the corresponding longitudinal and vertical bending and torsional moments induced by the ballast weight shall also be considered.

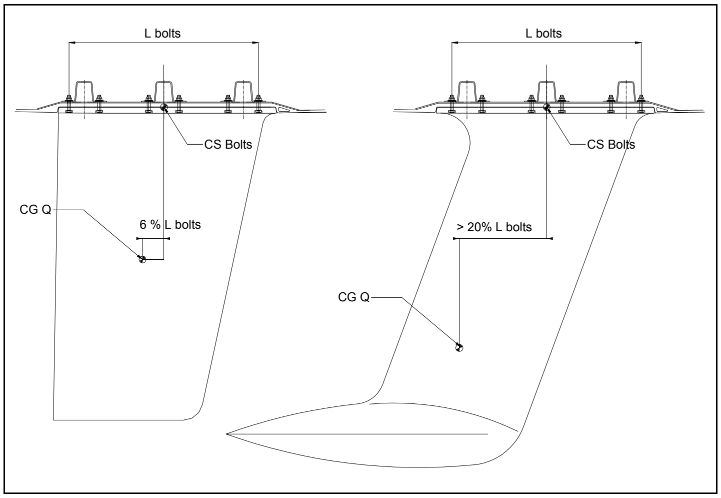


Figure 2 — Keel rake smaller or greater than 0,2 Lbolts

6.1.3 **Vertical load case** (see figure 3)

This case allows for the possibility that the keel could de subjected to a vertical force. Equation (6) presumes a low to moderate impact speed and is intended to cover cases of dry-docking or grounding.

considers a slow speed grounding or dry docking with moderate dynamic effect.

The boat structure and keel connection and stiffeners shall be able to withstand without exceeding design stresses a vertical force F_{qvd} exerted at the ballast keel CG

$$F_{qvd} = 15 f_w (m_{LDC} - Q) \quad \text{(N)} \quad (6)$$

where

— m_{LDC} is the fully loaded mass of the craft as defined in 3.2 (kg)

— other dimensions previously defined.

6.1.4 Longitudinal load case

This case allows for acknowledges the possibility that the keel could de subjected to a horizontal force. Equation (7) presumes a low to moderate impact speed and is intended to cover impact of submerged objects.

The boat structure and keel connection shall be able to withstand without exceeding design stresses a longitudinal force F_{qld} exerted at the ballast keel CG

$$F_{qld} = 2{,}4\ f_w (m_{LDC} - Q) \frac{L_H}{T} \quad \text{(N)} \quad (7)$$

where

— T is the maximum draft of the craft (m)

— other dimensions previously defined.

6.2 Design loads on non ballasted centreboards or daggerboards.

6.2.1 Design loads for any type of boards

For non ballasted boards, the loads and design stresses shall be assessed as for rudders in ISO 12215-8, but using upwind speed V_u instead of maximum speed.

$$Vu = 1{,}5 \cdot 1{,}45\ V^2 A\,\frac{h_r}{2} = 2{,}175\ V^2 A\,\frac{h_r}{2} \qquad \text{(knt)} \quad (8)$$

Where

- V is the maximum speed of the craft (knt)
- A is the outside area of the board (m²)
- h_r is the vertical span of the board when the boat is upright (m)

6.2.2 Design loads for boards fitted on capsize recoverable boats

For capsize recoverable boats according to 12217, the board shall be able to support without exceeding the design stress σ_d when the force F_{tb} at the tip of the board

$$F_{tb} = 10\ n 75 = 750\, n \qquad \text{(N)} \quad (9)$$

Where n is the minimal number of persons for recovering from capsize according to ISI 12217

7 Design strength of ballast keels

7.1 Ballast keel material design strength

See the relevant values in Table 6, or use specific data.

7.2 Resistance of ballast keels

7.2.1 General case

The design stress within the ballast keel material(s) shall not be exceeded in any point the design stress.

At the keel junction $\sigma = \dfrac{M_{qd}}{SM_q} \le \sigma_{dq}$ (N/mm²) (10)

Where

- $M_{qd} = 30\ f_w\ Q\ a$ is the ballast keel design bending moment at keel junction, (Nm) defined in eq (5)
- SM_q is the Section modulus of the ballast keel (cm3) (

If the level of keel junction is not the critical one, the same method shall be applied at this level, interpolationg the heel Moment.

7.2.2 Lead ballast

Lead or lead alloys have such low mechanical properties that thin and deep fins lead alloy ballasts usually need a steel framing and top flange to allow both sufficient bending strength and connection.

As screws of bolts have difficulties to fix in lead, the mechanical connection of lead ballast keel is usually made with threaded rods cast in the lead. Their lower part is either bent or connected to plats to ensure a correct anchoring of these threaded rods in the lead.

7.2.3 Case of solid NACA foil

For solid NACA foils

$$S = C_1 \ L_f \ b_f \qquad (\mathrm{m}^2) \quad (11)$$

$$SM = C_2 \ 10^6 \ b_f \frac{L_f^2}{6} \qquad (\mathrm{cm}^3) \quad (12)$$

where

— b_f is the maximal beam of the foil (m)

— L_f is the horizontal chord length of the foil (m)

— C1 and C2 are given in Table

Table 7 — Values of coefficient C_1 and C_2

Naca Profile	C1	C2
0012		
65a12	0,674	0,460

7.2.4 Hollow NACA foil

To be implemented, if needed.

8 Analysis of bolted ballast keels

8.1 Bolt material choice

8.1.1 Bolt material for chemical corrosion.

All copper bases alloys of Table 6 may be used. Monel is one of the best but expensive.

Brass shall not be used in any case as it loses its zinc in sea water environment. Alloy named "Admiralty brass" is in fact a Bronze that may be used.

A2 bolts not recommended if any risk of being under water

A4 bolts highly recommended, but might be subject to corrosion in non oxidizing atmosphere. Care shall be taken when used in wooden boats, where under de-oxidized water.

C1 to C4 (Martensitic stainless steels) may have very high mechanical properties, after heat treatment, but are prone to crevice corrosion under tension, they should therefore only be used with the utmost care and where there is very limited risk of corrosion.

8.1.2 Prevention of electrolytic corrosion

On aluminium boats, non Aluminium bolts shall be electrically insulated from the rest of the structure, for example by inserting insulation bushings and washers.

8.2 Bolt diameter determination

8.2.1 Case where the longitudinal bending moment is negligible

In the case where the longitudinal bending moment is neglected (Keel CG less than 20% of L bolts from bolts centre of surface, see 6.1.2), the bending moment at the keel junction is M_{qd} defined by equation (5).

For each bolt, the following inequation (8) shall be fulfilled :

$$\sigma_i = \frac{1270\ b_i\ M_{qd}}{\sum b_i^2 d_i^2} \leq \sigma_d \qquad \text{(N/mm²)} \quad (13)$$

where

— M_{qd} is the heeling moment defined in 6.1.1, equation (5) (Nm)

— d_i is the diameter of the neck (at the bottom of the thread)of the bolt considered (i= 1,2, etc) (mm)

— b_i is the distance between the hinge bearing line and each bolt axis on the opposite side from the ballast centreline. (mm)

— $\sum b_i^2\ d_i^2$ is the sum of the product of b_i and d_i squared for each bolt row. (mm^4)

The "hinge bearing line" is a fictitious line around which the ballast is considered to bear on the bottom of the hull or skeg. When the boat is upright, the bearing pressure is uniform and equal to the sum of the tensile pre-tension loads of the bolts divided by the bearing area. When the boat heels, the windward bearing pressure is relieved and the leeward pressure is increased to achieve a triangular pressure repartition summarised in Figure 3 a. Pressure is considered nil at hinge bearing line, and the tensile load on each bolts is proportional to its distance di from hinge line.

For foil shaped ballast, Naca profile or equivalent, the hinge line is located $0{,}425\, b_{q\max}$ leeward of keel axis

For ballast with a top flange, the hinge line is located $0{,}5\, b_f$ leeward of keel axis

Where $b_{q\max}$ is the maximum width of the keel at its bolting level, and b_f the flange width

The $0{,}425\, b_{q\max}$ value is considered as the mean of the effective bearing curve of the foil.(85% of mid width)

8.2.2 Bearing pressure topics

The maximum bearing pressure at the hinge line level is

$$p_{\max} = \frac{126\ f_w\ Q\ a}{L_q\ b_{q\max}^2} \leq 0{,}5\sigma_{bu} \text{ for keel without a top flange} \quad (\text{N/mm}^2) \quad (14)$$

$$p_{\max} = \frac{91\ f_w\ Q\ a}{L_f\ b_f^2} \leq 0{,}5\sigma_{bu} \text{ for keel with a top flange} \quad (\text{N/mm}^2) \quad (15)$$

NOTE Equation (5) comes from the equilibrium between pressure and bending moment: $\frac{L_q\ 0{,}85\,b_{q\max}\ p_{\max}}{2}\ 0{,}66\ 0{,}85\,b_{q\max} = 30\ fw\ Q\,a$

As the surfaces of respectively the top of the ballast keel and bottom of hull or skeg cannot perfectly match in practice, a intermediate layer jointing compound, usually made or reinforced resin, is usually placed in between. The design compressive strength of this material shall be greater that the maximal bearing pressure defined above.

For wooden boats, the wood crushing strength is often lower than the maximal bearing pressure. The wood shall therefore be reinforced by a saturation of pure and/or reinforced epoxy resin.

For lead keels, the ultimate compression of lead, even allowed with antimony, is very low, and care shall be taken to avoid that the bearing design pressure to be greater than the lead design compressive strength. Lead is often reinforce by a steel backbone and upper flange.

According to Annex E of ISO 12215-5 the crushing strength of wood is respectively 0,073 ρ and 0,070 ρ for softwoods and hardwoods, where ρ is the wood density (kg/m^3)

8.2.3 Bolt diameter rough evaluation

Before applying equation (13) a rough evaluation of the bolt diameter for a first iteration of formula (13), one can use formula (16) which is only fully valid if all the b_i and d_i are respectively the same.

$$d_i\ approx = \sqrt{\frac{1270.M_{qd}}{\sigma_d.\sum b_i}} \quad \text{approximate neck diameter of the bolts} \quad (\text{mm}) \quad (16)$$

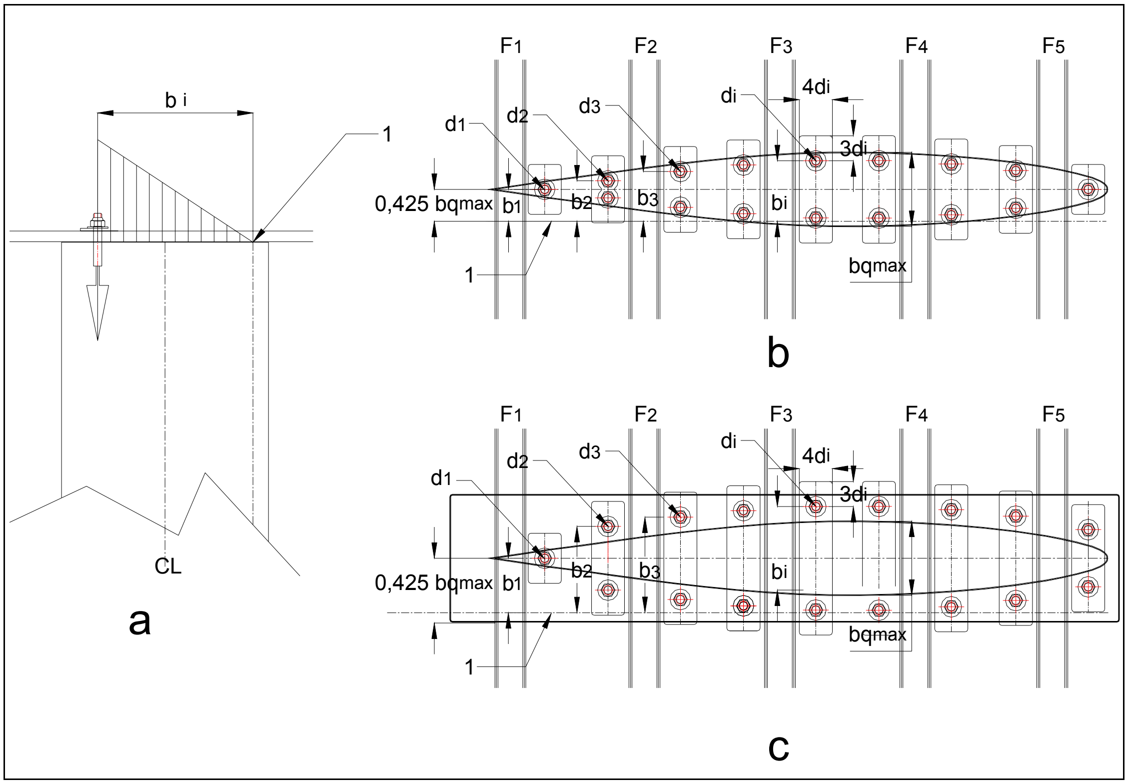


Figure a : Sketch of transverse load   Figure b: Keel directly bolted   Figure c: Keel with a top flange

Key:
1 Bearing line // to centreline at $0{,}425\ b_{q\ max}$ of b flange max

Figure 3 — Sketch of keel bolts

8.2.4 Validity of the calculations

The above calculation is only valid if all the bolts are stressed. This condition is considered met if :

— the bolts are less than 20di from the closest part of the floor.

— the bolts are fitted with counter plates and washers. This counter plate shall be at least 0,25 di thick, at least 3di wide, and 3di beamier each side than the bolts (see Figure 3).The counter plates can be made even stiffer if fitted with one or two flanges (L or U shaped)

— give requirements for ratio of cast iron flange protruding length to thickness according to strength : to be implemented at DIS stage

With these above conditions, the bolts are considered as fully stressed and the effort is fed to the floor by shear stress, either via laminated angles or welds.

If the bolts are farther from floors, the shell is normally not stiff enough to stress all the bolts, then keelsons able to transmit the bolt loads are needed, or only the bolts really working will be considered.

The above keelsons shall be able to transmit M and F according to the force of the bolts and their distance from the floor.

8.2.5 Bolt final evaluation

Equation (8) is only related to the neck diameter of the bolt, i.e the diameter at the bottom of the thread.

Table 3 gives the correspondence between this neck diameter and the nominal diameter according to thread type.

Where a bolt diameter is on table 3, and pitch is not known, normal pitch is to be assumed.

Where a bolt diameter is not on table 3,

- - if the pitch is known d neck = d-1,227 p
- - if the pitch is not known d neck =0,82 d

Table 8 — Values ISO M Screws

	Normal Pitch			Fine Pitch		
d nominal mm	p (pitch) mm	d neck ISO d_3 mm	S neck mm²	p (pitch) mm	d neck ISO d_3 mm	S neck mm²
12	1,75	9,85	76,2	1,5	10,16	81,1
14	*2,00*	*11,55*	*104,7*	*1,5*	*12,16*	*116,1*
16	2,00	13,55	144,1	1,5	14,16	157,5
18	*2,50*	*14,93*	*175,1*	*1,5*	*16,16*	*205,1*
20	2,50	16,93	225,2	1,5	18,16	259,0
22	*2,50*	*18,93*	*281,5*	*1,5*	*20,16*	*319,2*
24	3,00	20,32	324,3	1,5	22,16	385,7
27	*3,00*	*23,32*	*427,1*	*1,5*	*25,16*	*497,2*
30	3,50	25,71	519,0	2,0	27,55	596,0
33	*3,50*	*28,71*	*647,2*	*3,0*	*29,32*	*675,2*
36	4,00	31,09	759,3	3,0	32,32	820,4
39	*4,00*	*34,09*	*912,9*	*3,0*	*35,32*	*979,8*
42	4,50	36,48	1045,2	4,0	37,09	1080,6
45	*4,50*	*39,48*	*1224,1*	*4,0*	*40,09*	*1262,5*
48	5,00	41,87	1376,6	4,0	43,09	1458,5
52	*5,00*	*45,87*	*1652,2*	*4,0*	*47,09*	*1741,8*
56	5,50	49,25	1905,2	4,0	51,09	2050,3
60	*5,50*	*53,25*	*2227,3*	*4,0*	*55,09*	*2383,9*
64	6,00	56,64	2519,6	4,0	59,09	2742,6

8.2.6 Bolt screwing and pre-stressing

Screws and nuts shall be tightened to ensure pre-stressing.

Tightening torque is a function of many parameters such as screw and nut material, screw treatment, friction braking or washers and lubrication. The values of Table 8 are generally recommended values for normal screw pitch. They correspond to a friction coefficient of 0,125

Table 9 — Recommended tightening torque

Recommended tightening torque (Nm) according to Class and Nominal Diameter Normal Pitch							
Class	M 12	M 16	M 20	M 24	M 30	M 36	M 42
5.6	36	88	171	295	590	1 030	1 720
8.8	83	200	390	675	1 350	2 360	3 640
10.9	117	285	550	960	1 900	3 310	5 090
12.9	140	340	660	1 140	2 280	3 980	6 120

8.3 Laminate reinforcement in way of ballast keel

The laminate in way of a ballast keel shall be reinforced according to Part 6 of ISO 12215

To be implemented

8.4 Structural arrangement in way of ballast keel

In general, the ballast keel area of the hull shall be supported by floors, attached to longitudinal stiffeners or girders. Other arrangements connecting the floors together and effectively transferring the loads into the hull, are acceptable such as floors without girders that extend with a smooth transition to the shell, etc. (see Part 6 for arrangement examples)

8.4.1 Heeling load

The design Bending moment of the floors loaded by the ballast keel is:

$M_{qd} = 30 f_w Q(c+a)$ is the design bending moment of the floors loaded by the ballast keel (Nm) (10)

If there are n floors of equivalent stiffness, each floor has to resist a bending moment $\frac{M_{qd}}{n}$ (Nm) (11)

Floors made out of homogeneous materials need to have

$$SM = \frac{30 f_w \; Q \; (a+c) \; e}{\sigma_d \cdot \ell_u \cdot n}$$ (see Figure 1) (cm^3) (12)

where

— Q is the mass of ballast keel, (kg)

— a +c is the vertical distance from CG of keel to mid height of the floors, (m)

— ℓ_u is the width of the floor, (m)

— *e* is the horizontal distance from end of floor to outside edge of keel root, (m)

— σ_d is the design stress, (N/mm²)

— n = number of floors connected to the keel

9 Loads on sailing boats rig attachments

9.1 Scope

The scope of this section is a rough evaluation of the standing rig load to allow a basic dimensioning of the chainplates, mast steps, etc and their connection to the rest of the structure. It excludes the attachment points of running rigging, even if in many cases the mainsail sheet is an important element of the boat and mast equilibrium.

Loading cases are multiple (upwind with all sails up, upwind reefed, broaching under spinnaker alone, etc), but are more pertinent when designing and calculating the mast and rig. In the present document, the loads on rig attachments are considered mainly to be dependant from transversal stability, plus some addition loads due to longitudinal stability and pretensioning of longitudinal stays and rig.

9.2 Dimensioning heeling/righting moment

For sailing boats, the equilibrium between heeling and righting moment is used to evaluate the loads exerted on the rig.

9.2.1 Design heeling moment for sailing monohulls

$M_{HD} = f_w \left(3{,}3\ R_{M15} + R_{Mcrew}\right)$ is the design heeling moment (Nm) (13)

Where:

- R_{M15} = righting moment at 15° heel angle in the fully loaded condition according to ISO 12217, with max. crew positioned at sheerline height but on the centreline of the boat. (Nm)
- $R_{Mcrew} = 140\, n\, B_H$ is the additional righting added by hiking crew. This moment shall only be calculated if $75\ n \geq 0{,}05\ m_{LDC}$ (Nm)
  - n is the number of person in category C
  - B_H is the Beam of hull according to ISO 8666 (m)

9.2.2 Design heeling moment for sailing multihulls

For large sailing multihulls, the righting moment is so huge that it would not be realistic to assess the load on rig by equating heeling and righting moment. Therefore for multihulls, the design heeling moment is taken when the fist reef is taken, as calculated in ISO 12217-3, unless the boat is stated by its manufacturer to be designed to "fly a hull".

To be implemented

9.3 Calculation for single mast

9.3.1 Mast compression due to heeling moment

The total vertical (in the coordinate system of the boat) force on the shroud chainplates induced by the wind force is:

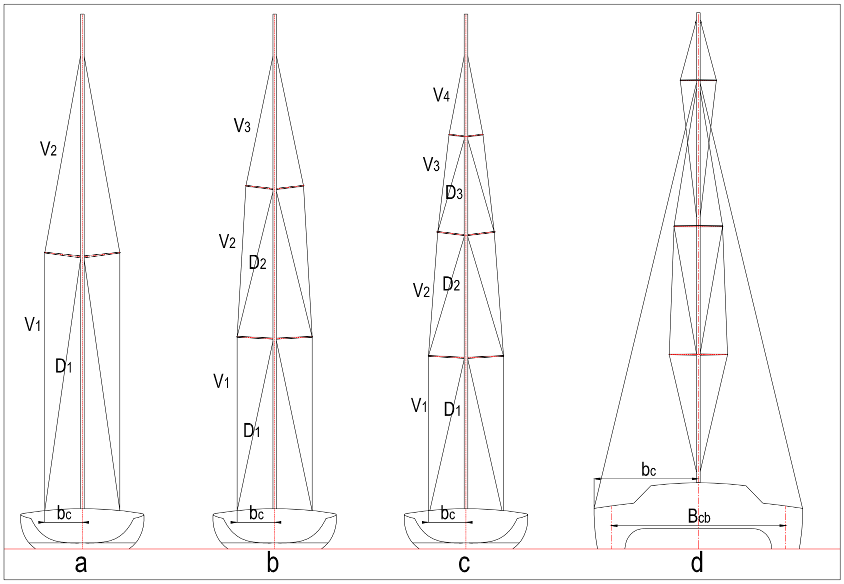
$F_v = \dfrac{M_{HD}}{b_c}$ is the vertical mast compression due to heel (N) (14)

— M_{HD} is the design heeling moment as defined in equation (13) (Nm)

— b_C horizontal distance from centreline of the boat to chainplate, (see figure 4) (m) (15)

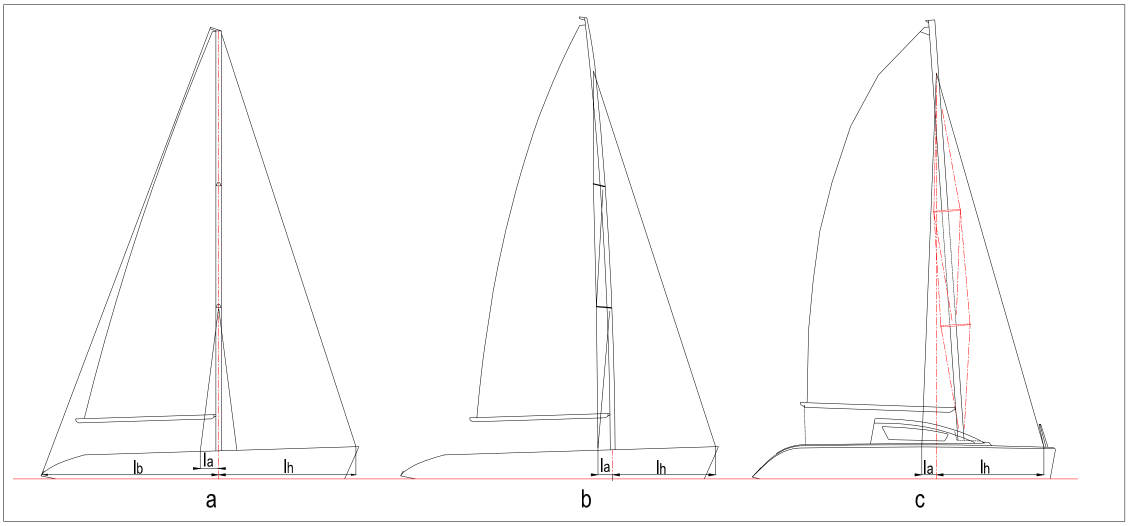
When chainplates at deck level are not at the same distance from centreline the average distance shall be used.

9.3.2 Design and ultimate loads on rid and rig attachment



a: One set of spreaders b: Two set of spreaders c: Three set of spreaders d: Typical multihull

Figure 4 — Typical transversal rig arrangements



a: Mast head rig with two sets of spreaders and fore and aft lowers b: Fractional rig with swept back spreaders d: Typical multihull rig

Figure 5 — Typical transversal rig arrangements

The respective design loads and ultimate loads shall be calculated as follows:

$F_{rd} = F_v \, k_{rd}$ is the design load for the rig element, where k_{rd} is given in Table 9 (N) (16)

$F_{ru} = F_v \, k_{ru}$ is the ultimate load for the rig element; where k_{ru} is given in Table 9 (N) (17)

$F_{cd} = F_v \, k_{cd}$ is the design load for the chainplate element, where k_{cd} is given in Table 9 (N) (18)

$F_{cu} = F_v \, k_{cu}$ is the ultimate load for the chainplate element; where k_{cu} is given in Table 9 (N) (19)

$F_{sd} = F_v \, k_{sd}$ is the design load for the chainplate/ structure connection, k_{sd} is given in Table 9 (N) (20)

$F_{su} = F_v \, k_{su}$ is the design load for the chainplate/ structure connection, k_{su} is given in Table 9 (N) (21)

Table 10 — Value of coefficients k_{id} and k_{iu}

	Ratio between load and design Load on the rig					
Transversal rig element and arrangement	**Load on rig**		**Load on chainplate**		**Load connection chainplate/Structure**	
Transversal	k_{rn}	k_{ru}	k_{cn}	k_{cu}	k_{sn}	k_{su}
	1,00	2,00	1,50	3,00	2,50	5,00
One set of spreader V1 transversal spreaders	0,45	0,90	0,68	1,35	1,13	2,25
One set of spreader V1 aft sweapt spreaders	0,55	1,10	0,83	1,65	1,38	2,75
One set of spreader D1 single	0,65	1,30	0,98	1,95	1,63	3,25
One set of spreader D1 double fore/aft	0,33	0,66	0,50	0,99	0,83	1,65
2 or 3 sets of spreader V1	0,55	1,10	0,83	1,65	1,38	2,75
2 or 3 sets of spreader V1 aft sweapt spreaders	0,65	1,30	0,98	1,95	1,63	3,25
2 or 3 sets of spreader D1 single	0,40	0,80	0,60	1,20	1,00	2,00
2 or 3 sets of spreader D1 double fore/aft	0,25	0,50	0,38	0,75	0,63	1,25
Longitudinal	k_{rn}	k_{ru}	k_{cn}	k_{cu}	k_{sn}	k_{su}
Headstay Masthead rig	0,45	0,90	0,68	1,35	1,13	2,25
Headstay Fractional rig	0,40	0,80	0,60	1,20	1,00	2,00
Headstay Masthead rig	0,45	0,90	0,68	1,35	1,13	2,25
Backstay Masthead rig	0,43 lb/lh	0,86 lb/lh	0,65 lb/lh	1,29 lb/lh	1,1 lb/lh	4,2 lb/lh
Mat step	k_{rn}	k_{ru}	k_{cn}	k_{cu}	k_{sn}	k_{su}
Headstay Masthead rig	1,85	3,70	2,78	5,55	4,63	9,25
Headstay Fractional rig	1,75	3,50	2,63	5,25	4,38	8,75

For aft swept spreaders, the formula may be a function of la/lh

9.3.3 Load on mast step

The total vertical load at the mast step (or the mast pillar if the mast is stepped on deck) is the sum of the loads induced by the transverse and the longitudinal rigging belonging to the mast in question.

$F_{md} = F_v\ k_{md}$ is the design load on the mast, where k_{md} is given in Table 9 (N) (22)

$F_{mu} = F_v\ k_{mu}$ is the ultimate load on the mast; where k_{mu} is given in Table 9 (N) (23)

$F_{msd} = F_v\ k_{msd}$ is the design load for the mast step, where k_{msd} is given in Table 9 (N) (24)

$F_{msu} = F_v\ k_{msu}$ is the ultimate load for the mast step; where k_{msu} is given in Table 9 (N) (25)

$F_{mssd} = F_v\ k_{mssd}$ is the design load for the maststep/structure connection, k_{mssd} is in Table 9 (N) (26)

$F_{mssu} = F_v\ k_{mssu}$ is the design load for the maststep/structure connection, k_{mssu} is in Table 9 (N) (27)

9.4 Distribution of heeling moment between several masts

For multiple mast rigs the maximum heeling moment of each mast is to be determined on basis of the *sail area moment,* SAM, of each mast:

$$SAM_i = \sum_{j=1}^{n} \left(A_j \cdot d_j\right) \qquad \text{(Nm)} \quad (12)$$

Where :

— A is the sail area of specific sail on specific mast (m²)

— d = is the vertical distance from centre or lateral resistance (CLR) to aerodynamic centre of effort (COE) for specific sail on specific mast. The CLR may be taken as the canoe body draft Tc and COE as the geometric centroid of the sail in the absence of more accurate data. (m)

— i = index for specific mast

— j = index for specific sail on specific mast

$r_i = \dfrac{SAM_i}{\sum_{i=1}^{n} SAM_i}$ is the ratio of each mast's sail area moment to the total moment (13)

This ratio shall be calculated for appropriate load cases which corresponding to normal use of the boat and mentioned in the owner's manual.

9.4.1 For a mast with a maximum fraction f between 0,67 and 1.00:

$$HM = 1{,}0 \cdot RM \qquad \text{(Nm)} \quad (14)$$

9.4.2 For a mast with a maximum fraction f between 0.30 and 0.67:

$$HM = 1{,}5 \cdot f \cdot RM \qquad \text{(Nm)} \quad (15)$$

10 Scantlings of chainplates

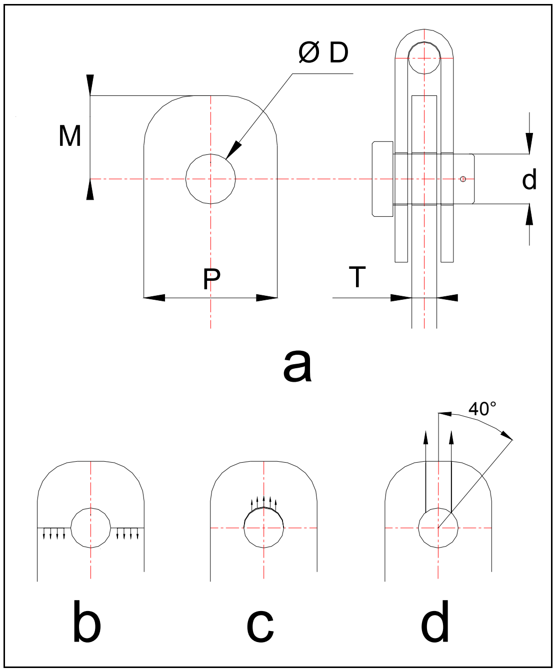
The design and ultimate loads given in and Table 10 shall be used to determine the scantlings of chainplates.

The load from the chainplates to the structure shall be essentially transferred via shear and bearing loads.

Annex A gives an example of Stainless steel and Aluminium chainplates calculations.

Annex A
(normative)

Example of calculation of a chainplate and its connection



a: General dimensions b :Tensile stresses c: Bearing stresses d: Shear stresses

Figure A 1 — Chainplate dimensions and loading layout

A.1 Formulas

$$SF_T = \frac{T(P-E)\,\sigma_d}{F_d} \geq 1{,}5$$ is the safety factor for tensile stress (see Figure A1 b) (A1)

$$SF_B = \frac{PD\,\sigma_b}{F_d} \geq 1{,}5$$ is the safety factor for bearing stress (see Figure A1 c) (A2)

$$SF_S = \frac{2(M-0{,}383\,D)\,\tau_d}{F_d} \geq 1{,}5$$ is the safety factor for shear (see Figure A1 d) (A3)

NOTE 0,383 =0,5 Cos 40. For aluminium D is the outer diameter of the bushing.

These formula may be applied at design or ultimate level.

The dimensions D,M,P,T are in mm, and are shown in Figure A1.

A.2 Pre-calculated values for typical chainplates

Tables A1 and A2 gives some typical chainplate dimensions respectively for AISI 304 /316 and 5083 Aluminium.

*Wire ultimate loads and diameter are there for comparative value, but shall not be take as granted as the actual wire properties vary from one manufacturer to another.

The approximation corresponds to rigid wire 1x19 for $d_w \leq 10$ mm and 1x37 above

$$R_u\ RIG = 1500\ 0{,}76\ \pi \frac{d_w^2}{4}\ \text{(N)} \text{ for } d_w < 5 \text{ mm and } R_u\ RIG = 1400\ 0{,}76\ \pi \frac{d_w^2}{4}\ \text{(N) for } d_w \geq 5 \text{ mm}$$

Wire diameter 9, 11, 13 and 15 are theoretical values as there is no metric wire this size on the marker.

For other types of wire, rod rigging, or fibre wires, the design load of the first column shall only be used.

The three last columns give the ratio between the Ultimate strength of the chainplate compared to the ultimate strength of the rig that shall be always > 1,5 for loading respectively in Tensile, Bearing and shear. (The comparison could have been made for design strength).

A.2.1 AISI 304 or 316 Stainless steel chainplates

Table A 1 — Typical Chainplate dimensions and Safety factors for AISI 304 or 316 Stainless steel

RIG			SS Chainplate dimensions				Ru Chainplate / Ru Rig >1,5		
Design load da N	Ultimate load da N	approx d SS wire* mm	D Pin mm	T thickness mm	P width mm	M mm	Tensile σ_u (N/mm²) 500	Bearing σ_b (N/mm²) 900	Shear τ_u (N/mm²) 289
410	810	3	6	3	15	10	1,67	2,00	1,65
720	1 430	4	8	4	20	13	1,68	2,01	1,60
1 120	2 240	5	8	5	22	15	1,56	1,61	1,54
1 510	3 010	6	10	6	25	18	1,50	1,79	1,63
2 050	4 090	7	12	7	30	20	1,54	1,85	1,52
2 680	5 350	8	12	8	35	24	1,72	1,61	1,67
3 390	*6 770*	*9*	*13*	*10*	*38*	*26*	*1,85*	*1,73*	*1,79*
4 180	8 360	10	14	10	40	28	1,56	1,51	1,56
5 060	*10 110*	*11*	*17*	*14*	*42*	*30*	*1,73*	*2,12*	*1,88*
6 020	12 030	12	18	14	46	32	1,63	1,89	1,69
7 060	*14 120*	*13*	*20*	*16*	*50*	*35*	*1,70*	*2,04*	*1,79*
8 190	16 380	14	22	16	55	40	1,61	1,93	1,78
9 400	*18 800*	*15*	*25*	*18*	*60*	*42*	*1,68*	*2,15*	*1,79*
10 700	21 390	16	25	18	65	42	1,68	1,89	1,57
15 090	30 170	19	27	20	75	50	1,59	1,61	1,52
20 230	40 450	22	33	25	85	55	1,61	1,84	1,51

A.3 Pre-calculated values for typical 5083 Aluminium

As the movements of the pin wears out the bore, it is highly recommended to fit a stainless steel bushing sleeve in the pin bore for pin diameter greater than 10 mm.

In that case, the calculations shall be made with the diameter as Di the diameter of the outer bore

Table A 2 — Typical Chainplate dimensions and Safety factors for 5083 Aluminium

Design	Ultimate	approx d	D	Di	Do	T	P	M	Tensile	Bearing	Shear
load	load	SS wire*	Pin	SS bushing		thickness	width		σ_u (N/mm^2)	σ_b (N/mm^2)	τ_u (N/mm^2)
da N	da N	mm	mm	mm	mm	mm	mm	mm	275	495	159
410	810	3	6	No bushing		6	15	10	3,06	2,20	1,81
720	1 430	4	8	No bushing		8	20	12	1,85	2,22	1,59
1 120	2 240	5	10	No bushing		10	23	15	1,60	2,21	1,58
1 510	3 010	6	12	12	14	12	26	18	1,53	2,37	1,70
2 050	4 090	7	14	14	16	14	30	20	1,51	2,37	1,59
2 680	5 350	8	14	14	16	16	35	24	1,73	2,07	1,77
3 390	*6 770*	*9*	*15*	*15*	*17*	*18*	*38*	*26*	*1,68*	*1,97*	*1,71*
4 180	8 360	10	16	16	21	20	40	28	1,58	1,89	1,66
5 060	*10 110*	*11*	*17*	*17*	*20*	*22*	*42*	*30*	*1,50*	*1,83*	*1,62*
6 020	12 030	12	18	18	21	24	46	32	1,54	1,78	1,59
7 060	*14 120*	*13*	*20*	*20*	*23*	*26*	*50*	*35*	*1,52*	*1,82*	*1,60*
8 190	16 380	14	22	22	25	28	55	38	1,55	1,86	1,60
9 400	*18 800*	*15*	*25*	*25*	*28*	*30*	*60*	*40*	*1,54*	*1,97*	*1,54*
10 700	21 390	16	25	25	25	32	65	42	1,65	1,85	1,54
15 090	30 170	19	27	27	30	38	72	48	1,56	1,68	1,51
20 230	40 450	22	33	33	36	42	88	60	1,57	1,70	1,56

A.4 Example of calculation of the junction between the chainplate and the structure.

A.4.1 Example of bolted junction.

To be implemented at CD stage

A.4.2 Example of welded junction

To be implemented at CD stage

A.4.3 Example of connection of a gusset with the hull

To be implemented at CD stage