INTERNATIONAL STANDARD

ISO 12215-5

Second edition
2019-05

Small craft — Hull construction and scantlings —

Part 5:
Design pressures for monohulls, design stresses, scantlings determination

Petits navires — Construction de coques et échantillonnage —

Partie 5: Pressions de conception pour monocoques, contraintes de conception, détermination de l'échantillonnage

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
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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 on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 188, *Small craft*.

This second edition cancels and replaces the first edition (ISO 12215-5:2008, including its amendment ISO 12215-5:2008/Amd 1:2014), which has been technically revised.

One of the main reasons to achieve this revision, after a decade implementing the first edition, was to allow other scantlings calculation methods than those given in the 2008 edition, noting the huge development of finite element analysis methods and software, and the trend already applied in ISO 12215-9 (keels and appendages) and ISO 12215-7 (multihulls).

Therefore, in this new edition, like in many other scantlings standards, the design pressure loads, and the design stresses are given in the main body of the standard and, where needed, the scantlings calculation methods are detailed in Annexes.

The main changes compared to the previous edition are as follows:

— clarification of the scope and of many definitions, dimensions, and assessment;

— definition of a theoretical hull/deck limit height Z_{SDT} in Table 3;

— renaming of n_{GC} into k_{DYN} in Table 7;

— lowering of the values of k_L in the aft part of the craft in Table 8;

— deletion of k_{AR} min, to better consider large panels, mainly sandwiches, in Table 9;

— improvement of the values of k_{SUP} in Table 10;

— modification of design pressures for motor and sailing craft in Tables 12 & 13;

— modification of design stresses introducing k_{BB} and k_{AM} factors in Tables 15 to 17;

— incorporation of requirements for work boats in Table 2, Clause 12 and Annex J;

— possibility to use a wider range of assessment methods detailed in Table 18;

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- move of the previous assessment method (now called "simplified") in Annex A;
- improvements/clarification of the simplified method (panel assessment, hard chined sections, frameless sections, simple and double curvature, attached plating, requirements for core, etc.);
- development of Annex C for the determination of mechanical properties of composites;
- reminder in A.14 of the requirements of ISO 12215-9 on reinforcement of the hull in way of ballast keel attachment;
- new Annex I only recommending minimum thickness for single skin and sandwich that are no longer mandatory;
- new Annex J defining different types of commercial craft and workboats and their requirements;
- new Annex K defining loads induced by outboard engines;
- new Annex L proposing an application sheet of this document to explain how it has been used;
- for clarity, this edition generally uses tables to present formulas and requirements.

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

NOTE The mechanical properties of ISO 12215-1 to -3 are largely superseded by the ones of this document.

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.

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Introduction

The reason underlying the preparation of this document is that standards and recommended practices for loads on the hull and the dimensioning of small craft differ considerably, thus limiting the general worldwide acceptability of craft scantlings. This document has been set towards the minimal requirements of the current practice.

The implementation of this document allows to achieve an overall structural strength that ensures the watertight and weathertight integrity of the craft. This document is intended to be a tool to determine the scantlings of a craft as per minimal requirements. It is not intended to be a structural design procedure.

It is also emphasized that this document should only be used to check the main structural features of a craft but should not be used as a scantlings guide. Users of this document should have practical and theoretical experience in strength of materials and engineering, even if calculation software are available. Many details can have a significant influence on the final stresses and strength of the structure, ISO 12215-6 shows "established practice".

The scantlings requirements aim at providing adequate local strength. Serviceability issues such as deflection under normal operating loads, global strength and its connected shell and deck stability are not addressed in this document. The related criteria may need to be addressed by additional considerations, as deemed necessary by the users of this document.

The mechanical property data supplied as default values make no explicit allowance for deterioration in service nor provide any guarantee that these values can be obtained for any particular craft. Considering the future development in technology and the boat types and small craft outside the scope of this document, other methods than those described in this document exist, supported by appropriate technology, that can be used provided that they lead to equivalent results.

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 operated at a speed appropriate to the prevailing sea state.

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Small craft — Hull construction and scantlings —

Part 5:
Design pressures for monohulls, design stresses, scantlings determination

1 Scope

This document defines the dimensions, design local pressures, mechanical properties and design stresses for the scantlings determination of monohull small craft with a hull length (L_H) or a load line length (see NOTE 1) of up to 24 m. It considers all parts of the craft that are assumed to be watertight or weathertight when assessing stability, freeboard and buoyancy in accordance with ISO 12217.

NOTE 1 The load line length is defined in the IMO "International Load Lines Convention 1966/2005", it can be larger than L_H for craft with overhangs. This length also sets up at 24 m the lower limit of several IMO conventions.

The main core of this document determines the local design pressures and stresses for monohulls and details the possible scantlings methods derived from these pressures and stresses, both for monohulls and multihulls (see NOTE 2). The assessment process requires, where relevant, the application of Annexes.

This document is applicable to small craft, in intact condition, of the two following types:

— recreational craft, including recreational charter vessels;

— small commercial craft and workboats, see Clause 12 and Annex J.

It is not applicable to racing craft designed only for professional racing.

NOTE 2 Local pressures and stresses for multihulls are given in ISO 12215-7.

This document is applicable to the structures supporting windows, portlights, hatches, deadlights, and doors.

For the complete scantlings of the craft, this document is intended to be used with ISO 12215-8 for rudders, ISO 12215-9 for appendages and ISO 12215-10 for rig loads and rig attachments.

This document covers small craft built from the following materials:

— fibre-reinforced plastics, either in single skin or sandwich construction;

— aluminium or steel alloys;

— glued wood or plywood (single skin or sandwich), excluding traditional wood construction;

— non-reinforced plastics for craft with a hull length less than 6 m (see Annex D).

Throughout this document, unless otherwise specified, dimensions are in (m), areas in (m^2), masses in (kg), forces in (N), moments in (N.m), pressures in kN/m^2 (1 kN/m^2 = 1 kPa), stresses and elastic modulus in N/mm^2 (1 N/mm^2 = 1 Mpa). Max(a;b;c) means that the required value is the maximum of a, b, and c; and min(d;e;f) means that the required value is the minimum of d, e, and f.

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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 8666:2016, *Small craft — Principal data*

ISO 12215-9:2012, *Small craft — Hull construction and scantlings — Part 9: Sailing craft appendages*

ISO 12217-1:2015, *Small craft — Stability and buoyancy assessment and categorization — Part 1: Non-sailing boats of hull length greater than or equal to 6 m*

ISO 12217-2:2015, *Small craft — Stability and buoyancy assessment and categorization — Part 2: Sailing boats of hull length greater than or equal to 6 m*

ISO 12217-3:2015, *Small craft — Stability and buoyancy assessment and categorization — Part 3: Boats of hull length less than 6 m*

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 design categories are in line with the European Recreational Craft Directive 2013/53/EU.

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

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

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.

Note 2 to entry: In this document, non-sailing craft are considered as motor craft.

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3.4
second moment of area
second moment
I
for a homogeneous material, sum of the component areas multiplied by the square of the distance from centre of area of each component area to the neutral axis, plus the second moment of area of each component area about an axis passing through its own centroid

Note 1 to entry: The second moment of area is also referred to in other documentation as the moment of inertia.

Note 2 to entry: It is expressed in mm^4 or cm^4.

3.5
section modulus
SM
for a homogeneous material, second moment of area divided by the distance to any point from the neutral axis at which the bending stress is calculated, expressed in mm^3 or cm^3

Note 1 to entry: The minimum section modulus is calculated to the furthest point from the neutral axis.

3.6
craft speed
V
for motor craft, maximum speed in calm water and in m_{LDC} condition that is declared by the manufacturer, expressed in knots

3.7
displacement craft
craft whose maximum speed in flat water and m_{LDC} condition, declared by its manufacturer, is such that $V < 5\sqrt{L_{WL}}$

3.8
displacement mode
mode of running of a craft in the sea such that its mass is mainly supported by buoyancy forces

Note 1 to entry: This is the case where the actual speed in a seaway in m_{LDC} condition is such that its speed/length ratio makes the craft behave as a displacement craft.

3.9
planing craft
craft whose maximum speed in flat water and in m_{LDC} condition, declared by its manufacturer, is such that $V \geq 5\sqrt{L_{WL}}$

Note 1 to entry: This speed/length ratio limit has been arbitrarily set up in this document, but it may vary from one craft to another according to hull shape and other parameters.

3.10
planing mode
mode of running of a craft in the sea such that its mass is significantly supported by forces coming from dynamic lift due to speed in the water

Note 1 to entry: A planing craft in calm water runs in planing mode, but it may be obliged to significantly reduce its speed when the sea gets worse, running in that case in displacement mode.

3.11
non-walking area
area of the working deck, cockpit or superstructures of a monohull at an inclination of more than 25° to the horizontal in the longitudinal direction or more than 55° to the horizontal in the transverse direction

Note 1 to entry: All other areas of the deck, cockpit bottom and superstructures are deemed walking areas.

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4 Symbols

Unless specified otherwise, the symbols shown in Table 1 are used in this document.

Table 1 — Data, factors, parameters

Symbol	Unit	Designation/meaning of symbol	Ref/sub clause
		Linear Dimensions of the craft ,principal lengths and beams	
B_C	m	Chine beam according to Figure 1, at 0,4 L_{WL} from of its aft end	Fig 1, Table 7
GZ $_{MAX<60}$	m	Maximum righting moment lever for light and stable sailing craft with all stability increasing devices active	Table 11
L_H	m	Length of the hull	1
L_{WL}	m	Length of waterline at rest, see Figure 2.	Tables 3, 7, 8, 11, etc.
T_C	m	Max depth of canoe body, see Figure 2.	Tables 12 & 13
Z_C	m	Local height of chine above W_L [see Figure 6 d)]	Fig 6 d, Table 12
Z_Q	m	Local height of a point Q, centre of a panel or stiffener above W_L	Fig 6, Tables 12 & 13
Z_{SDA}	m	Local height of actual side/deck limit above W_L, see Figure 2	Fig 6, Tables 12 & 13
Z_{SDT}	m	Local height of theoretical side/deck limit above W_L, see Figure 2	Fig 6, Tables 3, 12 & 13
		Areas, displacement, angles, speed, accelerations	
V	knots	Maximum speed at m_{LDC} condition, used for motor craft with $V \geq 5\sqrt{L_{WL}}$ and for calculation of k_L for sailing craft with k_{SLS}>1	3.6 to 3.8 & Tables 7 & 8
m_{LDC}	kg	Mass in maximum load condition	3.2, Tables 7, 12 &13
$\beta_{0,4}$	degree	Deadrise angle at 0,4 L_{WL} from its aft end, taken as $10<\beta_{0,4}\leq 30$	Figure 1, 6.1, Table 7
		Panel dimensions	
A_D	m^2	Design area under consideration (panel or stiffener)	Table 9
b	mm	Short unsupported dimension of a panel	Table 5, Figures 3 to 5
l	mm	Long unsupported dimension of a panel	Table 5, Figures 3 to 5
c_b	mm	Transverse camber of a curved panel	A.8.2.2 & Figure A.7
c_l	mm	Longitudinal camber of a curved panel	A.8.2.2 & Figure A.7
		Stiffener dimensions	
s	mm	Small dimension (spacing) of a stiffener between axis	Table 5, Figures 3 & 4
l_u	mm	Large dimension (span) of a stiffener between axis	Table 5, Figures 3 & 4
c_l	mm	Camber of a curved stiffener	A.12.4 & Figure A.7
x	m	Distance of mid panel or stiffener from aft end of L_{WL}	Table 4 & Figure 2
b_b	mm	Base width of top hat stiffeners or equivalent	Figures 3 c), 4 & A.13
		Stiffener characteristics	
b_e	mm	Effective breadth of attached plating connected to a stiffener	A.12.5 & Figure A.13
A_w	cm^2	Area of the shear web of a stiffener	Table A.9, H.4 & G.4
EI_{NA}	N.mm^2	Product of second moment by E modulus at neutral Axis	3.4, Table A.9, H.4
Q	N.mm	First moment of a stiffener	Table A.9, H.4
q	N/mm	Shear flow in the web of a stiffener	Table A.9, H.2.7 & H.4
SM	cm^3	Section modulus of a stiffener	3.5, Table A.9, Annex G & H.4

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Table 1 *(continued)*

Symbol	Unit	Designation/meaning of symbol	Ref/sub clause
Bulkheads, sandwich			
D_b	m	Depth of bulkhead	Table A.13
t_b	mm	Thickness of single skin plywood bulkhead	Table A.7, Annex E, H.4
t_c	mm	Thickness of the core of a sandwich	Table A.7, Annex E, H.4
t_i , t_o	mm	Thickness of inner skin and outer skin of a sandwich	Table A.7, Annex E, H.4
t_s	mm	Thickness of symmetrical skins of a sandwich	Table A.7, Annex E, H.4
Factors and ratios			
A_{RE}	1	Effective aspect ratio of a panel	Table A.2
A_{RG}	1	Geometric aspect ratio of a panel	Table A.2
k_{AM}	1	Assessment method factor	Tables 16 & 17
k_{AR}	1	Area pressure reduction factor	Table 9
k_{AS}	1	Actual/design shear force factor in a stiffener	Table A.12
k_{BB}	1	Boat building factor	Tables 15 & 17
k_{BM}	1	Bending moment factor for stiffener	Table A.8
k_C	1	Curvature correction factor for plating	A.8.2.2 & Table A.3
k_{CH}	1	Chine angle correction factor	A.5.4 & Figure A.2
k_{CS}	1	Curvature correction factor for stiffeners	Table A.10
k_{DC}	1	Design category factor	Table 6
k_{DYN}	1	Dynamic load factor (k_{DYN}; k_{DYN1}; k_{DYN2})	Table 7
k_G	1	"GREEN" factor for laminates see Note b in Table C.6	Tables C.6, C.9 & C.10
k_L	1	Longitudinal pressure distribution factor	Table 8 & Figure 7
k_R	1	Structural component and craft type factor	Table 9
k_{SF}	1	Stiffener shear force correction factor	Table A.8
k_{SH}	1	Panel aspect ratio factor for shear force (k_{SHb}, k_{SHl})	Table A.2
k_{SLS}	1	Slamming pressure factor for light and stable sailing craft	Table 11
k_{SM}	1	Actual/design bending moment factor in a stiffener	Table A.12.3
k_{SUP}	1	Superstructure pressure reduction factor	Table 10
k_2	1	Panel aspect ratio factor for bending moment (k_{2b}, k_{2l})	Tables A.2 & A.4
k_5 to k_{10}	1	Single skin minimum thickness or fibre factor	Table I.1
Pressures			
P_{BMD}	kN/m^2	Motor craft bottom pressure in displacement mode	Table 12
$P_{BMD\ BASE}$	kN/m^2	Motor craft base bottom pressure in displacement mode	Table 12
$P_{BM\ MIN\ PLT}$	kN/m^2	Motor craft bottom min plating pressure (displacement/planing)	Table 12
$P_{BM\ MIN\ STF}$	kN/m^2	Motor craft bottom min stiffener pressure (displ./planing)	Table 12
P_{BMP}	kN/m^2	Motor craft bottom pressure in planing mode	Table 12
$P_{BMP\ BASE}$	kN/m^2	Motor craft base bottom pressure in planing mode	Table 12
P_{DM}	kN/m^2	Motor craft deck and cockpit bottom pressure	Table 12
$P_{DM\ BASE}$	kN/m^2	Motor craft deck base pressure	Table 12
P_{SMD}	kN/m^2	Motor craft side pressure in displacement mode	Table 12
P_{SMP}	kN/m^2	Motor craft side pressure in planing mode	Table 12

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Table 1 *(continued)*

Symbol	Unit	Designation/meaning of symbol	Ref/sub clause
$P_{SMD\ MIN\ PLT}$	kN/m^2	Minimal motor craft side plating pressure (displ./planing)	Table 12
$P_{SUP\ M}$	kN/m^2	Motor craft superstructure pressure	Table 12
P_{BS}	kN/m^2	Sailing craft bottom pressure	Table 13
$P_{BS\ BASE}$	kN/m^2	Sailing craft bottom base pressure	Table 13
$P_{BS\ MIN\ PLT}$	kN/m^2	Sailing craft bottom minimal plating pressure	Table 13
$P_{BS\ MIN\ STF}$	kN/m^2	Sailing craft bottom minimal stiffener pressure	Table 13
P_{SS}	kN/m^2	Sailing craft side pressure	Table 13
$P_{SS\ MIN\ PLT}$	kN/m^2	Sailing craft side minimal plating pressure	Table 13
$P_{SS\ MIN\ STF}$	kN/m^2	Sailing craft side minimal stiffener pressure	Table 13
P_{DS}	kN/m^2	Sailing craft deck and cockpit bottom pressure	Table 13
$P_{DS\ BASE}$	kN/m^2	Sailing craft deck base pressure	Table 13
$P_{SUP\ S}$	kN/m^2	Sailing craft superstructure pressure	Table 13
P_{WB}	kN/m^2	Design pressure, watertight boundaries	Table 14
P_{TB}	kN/m^2	Design pressure, integral tank boundaries	Table 14
Stresses and other data			
σ_d, τ_d	N/mm^2	Design (direct or shear) stress for plate/stiffener	Table 17
σ_u, τ_u	N/mm^2	Ultimate (direct or shear) stress for plate/stiffener	Table 17
σ_{dco}, τ_{dco}	N/mm^2	Design (direct or shear) stress for sandwich core	Table 17
σ_{uco}, τ_{uco}	N/mm^2	Ultimate (direct or shear) stress for sandwich core	Table 17
E, G	kN/m^2	Elasticity or shear modulus for plate/stiffener	Table 17
E_{co}, G_{co}	kN/m^2	Elasticity or shear modulus for sandwich core	Table 17
w	kg/m^2	Dry fibre reinforcement mass per square metre	11.1 & Annexes A, C, H & I
F_d	N, N/mm	Design shear force (in plating, sandwich, stiffener)	Tables A.4 & A.8
M_d	Nm, Nmm/mm	Design bending moment (in plating, sandwich, stiffener)	Tables A.4 & A.8
The symbols are shown by group type and in alphabetical order. Unless otherwise specified, all dimensions, measured in m_{LDC} condition, are according to ISO 8666.			

5 General

5.1 Materials

The materials considered in this document are the main modern building materials listed in Clause 1 and Table 17. This document may be used with other materials, including new fibres and resins, provided that they show similar cohesion, durability, resistance to marine environment and elongation at break as the ones quoted in Table 17.

5.2 Overall procedure for scantlings determination

Table 2 describes the overall procedure of this document for scantlings determination, by steps.

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Table 2 — Overall procedure for scantlings determination

Step N°	Subject	Clause N°
1	Determination of main dimensions, data and areas	6
2	Determination of dimensions of panels and stiffeners	7
3	Determination of pressure adjustment factors	8
4	Determination of design pressures	9
5	Determination of mechanical properties and design stresses (Table 17)	10
6	The structural analysis and scantlings determination shall be achieved using one or a combination of the following methods (see Table 18)	11
	— Method 1(Simplified)	11.2 & Annex A
	— Method 2 (Enhanced) ply by ply analysis	11.3 & Annexes A & H
	— Method 3 (Developed) use of CLT	11.4 & Annex A
	— Method 4 (Direct test)	11.5
	— Method 5 (FEM)	11.6
	— Alternative test (Drop test)	11.7 & Annex D
7	Additional requirements for commercial craft and work boats	12 & Annex J
8	Items to be included in the owner's manual	13

6 Main dimensions, data and areas

6.1 Dimensions and data

Unless otherwise specified, all dimensions shall be measured in accordance with ISO 8666, with the craft in the fully loaded condition, with a mass m_{LDC},expressed in kilograms, as defined in 3.2 and Table 1.

Figure 1 explains local chine beam and deadrise determination for planing craft. For round bilge, the outer limit or chine shall be taken at the point where a line at 50° from the horizontal is tangent to the hull. The chine beam B_C at 0,4 L_{WL} from its aft end, is used for the pressure determination of planing craft.

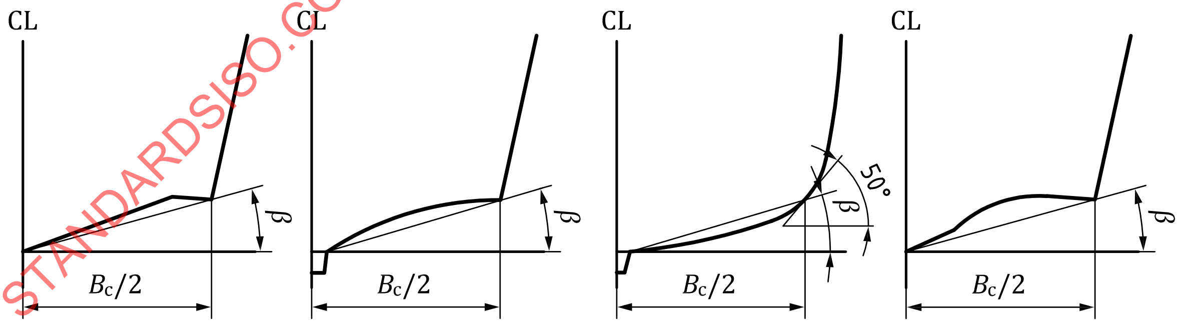

Figure 1 — Measurement of chine beam, B_C, and deadrise angle, β

6.2 Areas

6.2.1 General

The hull shell, deck and superstructures are divided into various areas: bottom, side, decks and superstructures, as shown in Figures 2 and 6 and in Tables 3 and 4. Whatever the structural arrangement of the craft, the areas defined below, and their design pressures defined in Clause 9 apply.

The coordinates x and Z are measured from the aft end of flotation as shown in Figure 2.

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The theoretical hull deck limit Z_{SDT} above waterline, defined in Table 3, sets the limit between side pressure and deck pressure. Its purpose is to avoid penalizing the structure of craft with a high freeboard. In contrast, where $Z_{SDA} < Z_{SDT}$, the deck pressure is increased (see Tables 12 and 13).

Table 3 — Height Z_{SDT} of theoretical hull deck limit according to L_{WL} and x/L_{WL}

$$Z_{SDT} = (0{,}028\,6 \times L_{WL} + 0{,}115) \times \frac{x}{L_{WL}} + 0{,}057\,1 \times L_{WL} + 0{,}229\ (\mathrm{m})$$

For information, pre-calculated values of Z_{SDT} are given below-for three values of x/L_{WL}.

L_{WL} (m)		**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**
		Values of Z_{SDT} (m)									
x/L_{WL}	0,00	0,57	0,69	0,80	0,91	1,03	1,14	1,26	1,37	1,49	1,60
	0,50	0,71	0,86	1,00	1,14	1,29	1,43	1,57	1,71	1,86	2,00
	1,00	0,86	1,03	1,20	1,37	1,54	1,72	1,89	2,06	2,23	2,40

The definitions in Table 4 are only for the purpose of this document, they are based on the definitions of ISO 8666, clarified or implemented where necessary. The areas are limited by "level lines" waterline, chine, or theoretical hull deck joint: Z_{SDT}, see Figure 2.

Table 4 — Definition of bottom, side, deck and superstructure areas and limits

Hull bottom or side, including transom and deck [a]		
Area	**Sailing craft and motor craft in displacement mode**	**Planing craft in planing mode**
Hull bottom and transom bottom	Part of the hull outer shell located below waterline (W_L)	Part of the hull outer shell up to chine for local $\beta \leq 30$ if chine below W_L Part of the hull outer shell up to W_L for local $\beta > 30$ and if chine above W_L. Transom below W_L is excluded and subject to transom side pressure
Hull side and transom side	Part of the hull shell located between bottom and local height Z_{SDT}.	
Deck and cockpit bottom	Lower horizontal or near horizontal area of the craft structure located above hull side. If there are several deck levels, it is the lower one at the considered section. Where $Z_{SDA} \leq Z_{SDT}$ it is subject to side/transom pressure, otherwise it is subject to deck pressure (see Tables 12 & 13)	
Cockpit sides & superstructures		
Area	**Walking area**	**Non-walking area (see 3.10)**
See Table 10 that details the areas and their reduction factor k_{SUP}.		

[a] This definition applies even if this area is not considered part of the working deck by ISO 15085 as long as it is exposed to the weather. The inner decks are not considered in this document as they are not exposed to weather.

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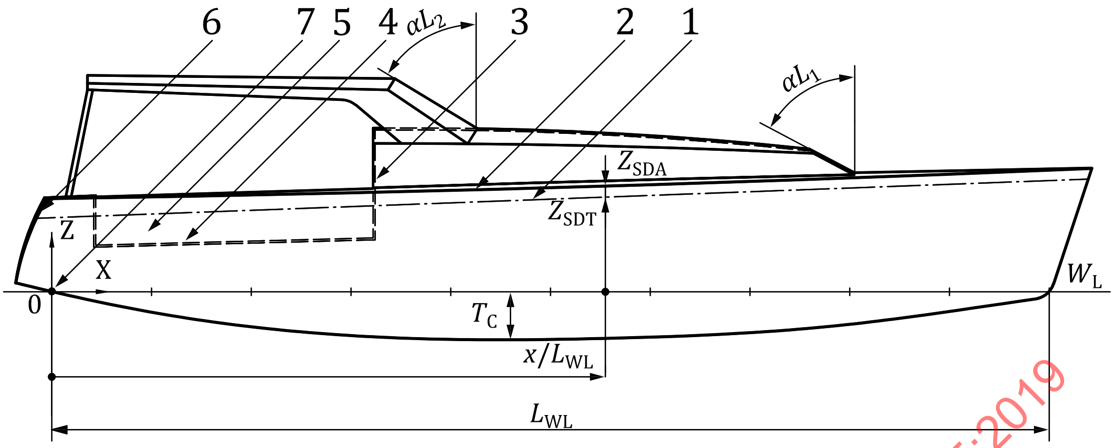

Key

1 theoretical hull deck limit Z_{SDT} above W_L

2 actual hull deck limit Z_{SDA} above W_L

3 protected aft side of superstructure (see Table 10)

4 cockpit bottom

5 cockpit side

6 transom (below & above Z_{SDA})

7 origin of coordinates x, y, z at aft of waterline

Figure 2 — Sketch showing areas

NOTE Figure 2 shows the case where $Z_{SDA,} > Z_{SDT}$ but the opposite case is obviously possible.

7 Dimensions of panels and stiffeners

7.1 General

A plating panel is subject to local pressure loads and, where relevant, to global loads. Longitudinal strength issues due to global loads are not considered in this document as they are seldom significant on small craft, but a recommended analysis method is given in Annex D of ISO 12215-6:2008. Local pressure loads depend significantly on the design surface A_D of the panel (factor k_{AR} defined on Table 9), and hence from stiffener spacing.

NOTE 1 In this document the term 'plating' applies to the surface constituting the exterior envelope of the craft: bottom, side, transom, deck, superstructure, cockpit, etc. The plating is divided in panels.

The structure is frequently arranged such that the plating panels are supported at their boundaries by a set or grid of "secondary" stiffeners directly supporting plating (e.g. stringers), which themselves are supported by another set of "primary" stiffeners (e.g. frames, bulkheads, etc.).

NOTE 2 ISO 12215-6 details the general structural arrangements and primary/secondary stiffeners.

These secondary and sometimes primary stiffeners are often not “dedicated” stiffeners, but “natural” stiffeners (e.g. hard chines, hull/deck connection, round bilges, bunk or coaming flanges, etc.).

Both these structural arrangements are only valid if the 3 following conditions are met:

a) The plating is strong enough to keep its shape and transmit the shear force and bending moment resulting from the pressure load to its supports: the secondary stiffeners.

b) The secondary stiffeners (where installed), are strong enough to keep their shape and transmit the shear force and bending moment from the plating to their supports: the primary stiffeners.

c) The primary stiffeners (where installed), are strong enough (usually much stiffer and stronger than the secondary) to keep their shape and transmit the shear force and bending moment from the secondary stiffeners to the rest of the structure.

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The assessment of the dimensions and spacing of the secondary and primary stiffeners is only valid if the above conditions are fulfilled. This document considers, through various formulas and calculations, that the plating and stiffeners only work in bending, with no membrane effect. The assessment of dimensions shall always be made in parallel with the checking that the various stiffeners take their role in the load transfer path from the local pressure from the sea and waves before being transmitted and finally dissipated into the rest of the structure.

Modern structures, and particularly FRP construction, rely significantly on “natural” stiffeners and curvature (simple or double). In this case, the determination of accommodation or other elements acting as a stiffener may include several 'trial and error' iterations. Some principles and examples of analysis are given below. However, all the cases cannot be predicted which depend on the approach of the designer and assessors using this document. Annex A presents with more details some methods to assess the spacing of these "natural" stiffeners.

To enable an analytic approach as simple as possible, the grid of panels is considered rectangular and the stiffeners are considered to cross each other at right angle. However, the 3D reality challenges this simplification and some equivalences are proposed. This document allows FEM (Finite Elements Method) analysis, that assesses loads and stresses on the various structural element with a greater precision.

7.2 Rectangular grid of panels and stiffeners

Figure 3 shows FRP structures with stringers and frames: hard chines a) and round bilge b) made of top hats. See also Figure 4. The dimensions are summed up in Table 5.

In Figures 3 and 4, for explanation, the value of l_u is called l_s and l_f respectively for stringer and frame, but it shall be called l_u in the rest of this document, same for s_S and s_S for stiffener spacing called s in the following.

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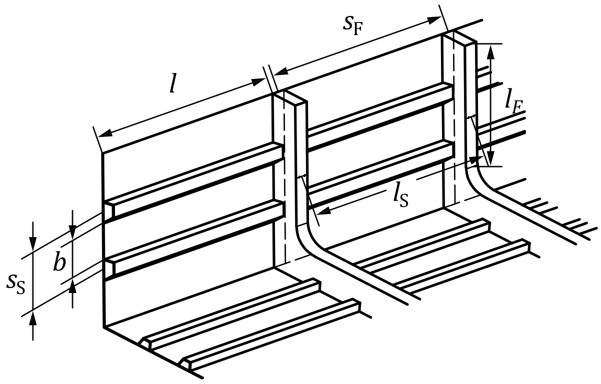
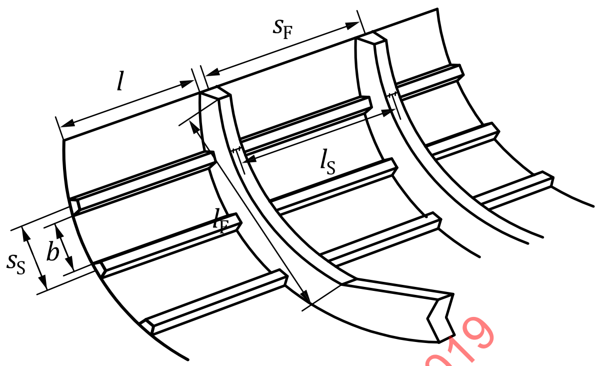
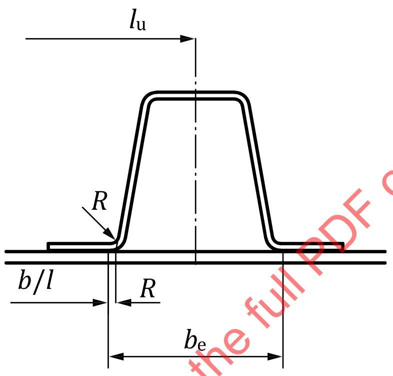


a) Hard chines



b) Round bilge



c) Top hat dimensions

Figure 3 — Sketch explaining the dimensions in Clause 7

Table 5 — Dimensions of panels and stiffeners

Variable	Units	Definition
b and *l*	mm	Respectively the small and large unsupported[a] dimensions of a panel
s and l_u	mm	Respectively the small and large unsupported dimensions for stiffeners, measured at mid support width (in Figure 3, index 'u' is replaced by F for frame and s for stringers). For top hat or composite stiffeners l_u is usually greater than *l* as $l_u = l + b_e$ [see Figure 3 c)]

For top hats, the dimensions *b* and *l* may be taken up to the intersection of the extension of the closest (inner) web with the plating minus one cove radius R, see Figure 3 c).

Subclause A.12.1 and Figure A.9 show examples on how to consider stiffeners not perpendicular to the plating.

If 3 consecutive stiffeners are not equally spaced, *s* shall be taken as their average.

[a] The supports are the support boundaries where the reaction to the plating pressure forces apply. This is normally the closest distance between loaded webs i.e. the closer side of top hats as in Figure 3 c), 4 a) or the single metallic flange axis as in Figure 4 b).

NOTE *b* and s_S are quite similar in metallic construction with T, L or flat bar stringers, but can differ in FRP construction because of the width of top hat stiffeners. Same comment for *l* and l_S for the length of plating and stiffener.

Where there are no definite stiffeners, hard chines or round bilges having the required dimensions and strength may be considered as “natural” stiffeners. Clause A.5 gives methods of analysis of such stiffeners.

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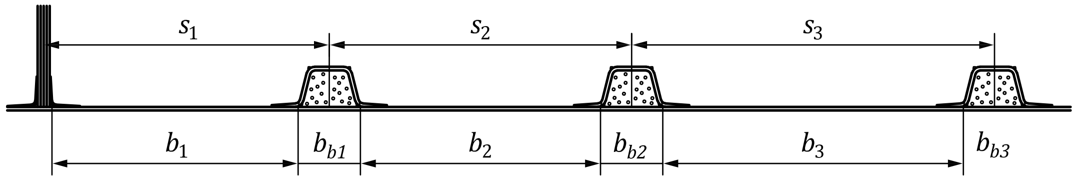
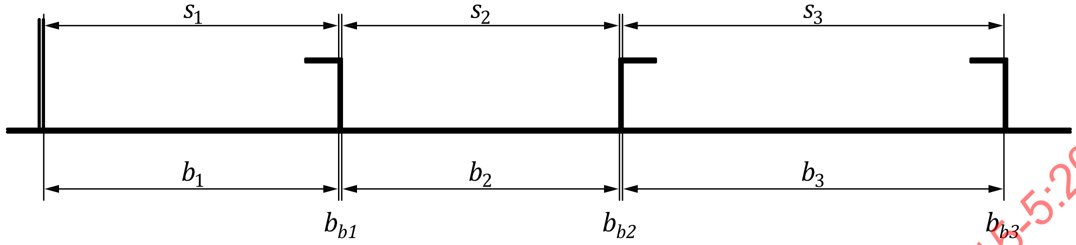
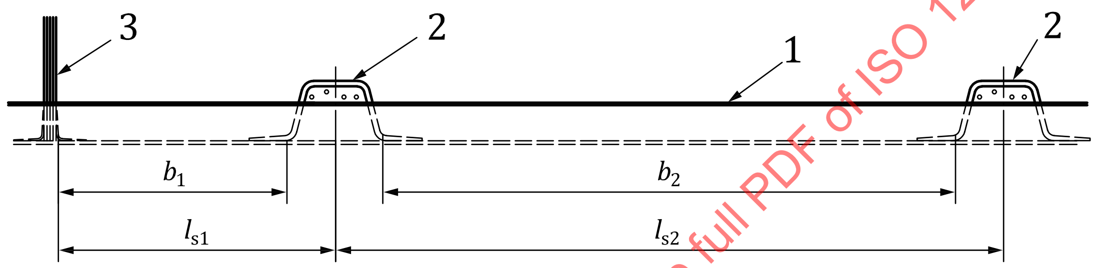


a) Bulkhead and transversal top-hat stiffeners



b) L-shaped stiffeners in metallic construction



c) Continuous stringer between top-hat frames and a bulkhead: b_1 and b_2 are the unsupported lengths of the panels between frames. l_{s1} and l_{s2} are the lengths of the stringer

Key

1 stringer (length l_{S1} or l_{S2})

2 top-hat frame

3 bulkhead

Figure 4 — Examples of b, s, and l_s measurements

7.3 Non-rectangular panels

Non-rectangular panels shall be assessed using equivalent rectangular panels with dimensions $b \times l$, or $s_u \times l_u$. These equivalent rectangular panels shall be assessed on the basis of equal area to the actual panel. Subclauses 7.3.1 and 7.3.2 define the approximation methods that shall be used in that purpose.

7.3.1 Trapezoidal or triangular panels

Figure 5 gives examples (hatched) of equivalent rectangular panels for a trapeze or a triangle and having the same area.

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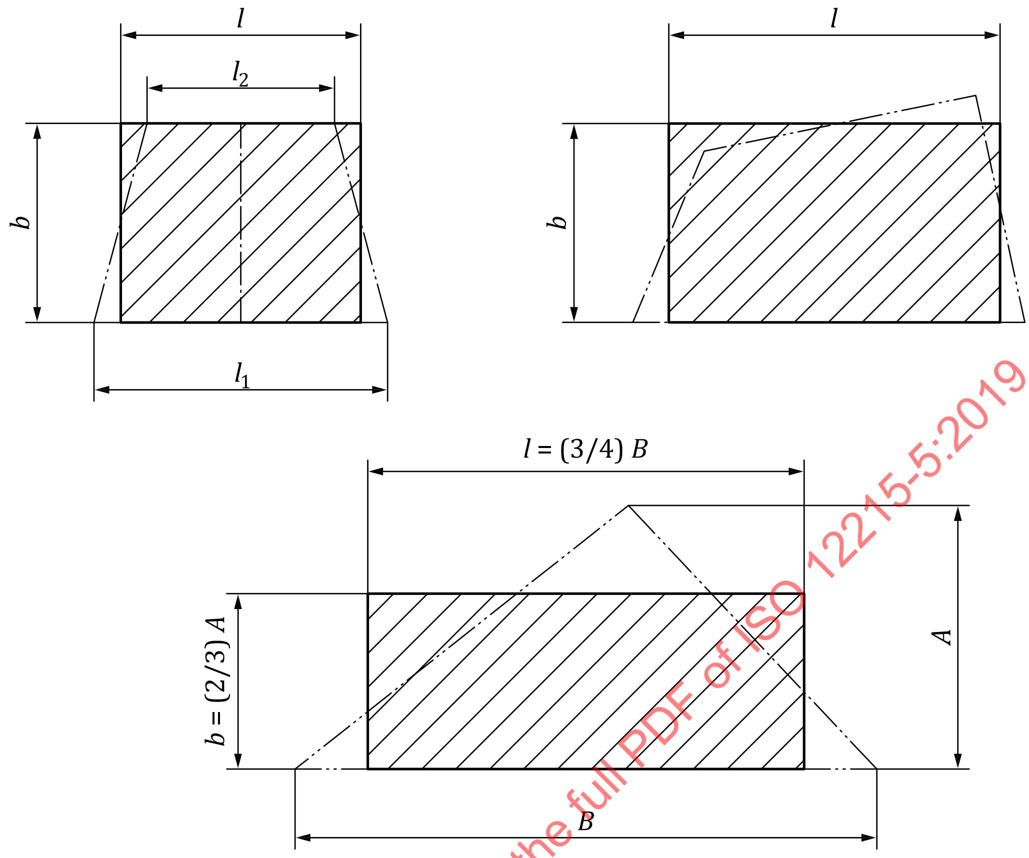

Figure 5 — Examples of equivalent rectangular panels with a trapeze or a triangle

7.3.2 Other shapes

For other shapes such as “crescent” or” banana like” shapes, one shall use the length l and deduct $b = A_D / l$ for equivalent rectangular shapes, where A_D is the design area of the panel plating. Some panels, including thin triangles, defy this analysis, and support lengths l and b have to be estimated, the use of finite elements analysis may be useful for that purpose.

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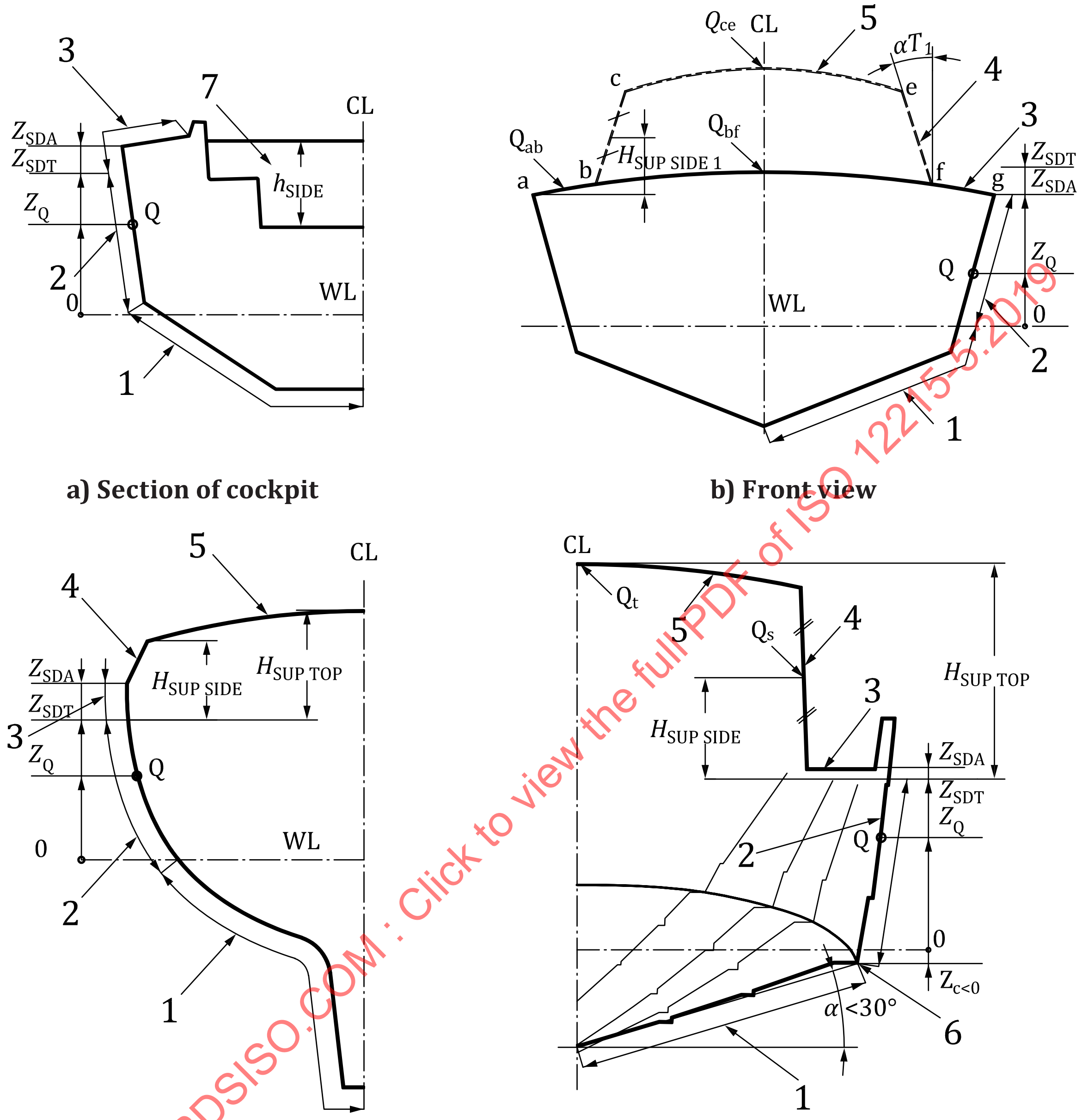
7.4 Pressure on a panel or a stiffener



a) Section of cockpit

b) Front view

c) Sail craft with built-in keel

d) Planing craft

Key

1 bottom area

2 side area

3 deck area

4 superstructures side area

5 superstructures top area

6 chine below W_L at section x and $\beta \leq 30°$

7 closed cockpit

Figure 6 — Definition of areas, and pressure assessment on a panel or stringer

Figure 6 shows typical craft sections at mid-waterline.

a) Section in way of a closed cockpit on a hard chined displacement motor craft with local actual deck height Z_{SDA} greater than theoretical value Z_{SDT} and therefore the part of the topsides above Z_{SDT} is considered subject to deck pressure. According to Table 12, the side pressure is interpolated between 0,8 times the bottom pressure and deck pressure up to Z_{SDT} and is equal to deck pressure

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above Z_{SDT}. The value of h_{SIDE} for the cockpit aft panel, according to Table 10 for side of closed cockpit, is measured from the cockpit bottom up to the middle of panel. Similar method for vertical bottom and back support of seats (non-walking area) and horizontal seat area (walking area).

b) Hard chined displacement motor craft. The actual deck level is lower than the theoretical height: $Z_{SDA} < Z_{SDT}$, the topsides are fully in side area and the actual pressure on the deck in increased as required in Table 12 or 13. The coachroof side transverse angle α_{T1} make it a non-walking area (see 3.10). The side pressure at point Z_Q is calculated according to Table 12. For side deck, the pressure for panel a-b is calculated at point Q_{ab}, and for panel b-f, it shall be calculated at Q_{bf} at mid-panel and top of camber, same for point Q_{ce} at top of coachroof.

c) Sailing craft with faired connection between bottom and keel, and the bottom area goes down to the keel and or tuck. See A.13 and ISO 12215-9 for either keel reinforcement or thicker plating in way of keel). As $Z_{SDA} > Z_{SDT}$ the value of H_{SUP} for coachroof top is measured from Z_{SDT}.

d) Hard-chined planing craft. As the angle of chine (deadrise), calculated according to Figure 1, is $\beta \leq 30°$, the bottom area goes up to the chine. Other forward sections have a deadrise angle $\beta > 30°$ and the bottom front area is considered up to flotation (the chine is anyway above waterline). Z_C is the height of the chine measured from waterline, and as in that section $Z_C < 0$ as it is below waterline, and in Table 12 $Z_Q - Z_C = Z_Q$ + absolute value of Z_C, same logic for $Z_{SDT} - Z_C$. The deck height Z_{SDA} is slightly higher than Z_{SDT} so the upper part of the topsides and outer bulwark are subject to deck pressure. The inner part of the bulwark is subject to cockpit side pressure. The side and top of coachroof are calculated at points Q_s and Q_t (only if the top on coachroof has no intermediate stiffener).

CAUTION — According to 9.1, for design categories A and B planing motor craft, the side panels and stiffeners shall be analysed both in planing and displacement mode, using the worst case. If the chine is below waterline, the side panel is across side and bottom [see Figure 2 a)].

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8 Pressure adjusting factors

8.1 General

The final design local pressure is adjusted by a set of factors according to design, craft type, location, area, etc.

8.2 Design category factor k_{DC}

The design category factor is defined in Table 6.

Table 6 — Values of k_{DC} according to design category

Design category	A	B	C	D
Value of k_{DC}	1	0,8	0,6	0,4

NOTE The design category factor k_{DC}, considers the variation of pressure and slamming loads due to sea loads according to the design category.

8.3 Dynamic load factor k_{DYN}

— For planing craft running in planing mode, the dynamic load factor k_{DYN}, used in the bottom pressure and k_L determination shall be taken as the lesser of $k_{DYN\,1}$ and $k_{DYN\,2}$, as defined in Table 7.

— For sailing and motor craft in displacement mode k_{DYN} is not used for pressure determination, but is used for the determination of k_L in Table 8 and Figure 7 using the values for $k_{DYN} = 3$.

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NOTE The factor k_{DYN2} has been introduced where formula for k_{DYN1} (developed after tests on craft > 20 m) gives unrealistically high values on small and light craft. The dynamic load factor k_{DYN} is considered to be close to the single amplitude vertical acceleration n_{CG} measured with a low pass filter at the craft centre of gravity. This factor is the vertical acceleration supported by the craft, either while slamming in an encountered wave at speed or falling from the crest of a wave into its trough, n_{CG} is expressed in g' s, where 1g is the acceleration due to gravity (9,81 m/s^2).

Table 7 — Values of dynamic load factor k_{DYN}

The dynamic load factor for power monohulls in planing mode, k_{DYN}, is the lesser of k_{DYN1} and k_{DYN2}	
Initial dynamic load factor for power monohulls in planing mode k_{DYN1}	$k_{DYN1}=0,32\left(\frac{L_{WL}}{10\times B_C}+0,084\right)\times\left(50-\beta_{0,4}\right)\times\frac{V^2\times B_C^2}{m_{LDC}}$ [a]
Corrected dynamic load factor k_{DYN2}. where k_{DYN1} > 3	$k_{DYN2}=\frac{0,5\times V}{m_{LDC}^{0,17}}$ not to be taken >6 [b] nor ≤3
CAUTION — For recreational and charter craft, the maximum speed shall not be taken >50 knots, but for “Heavy duty” work boats this speed may be greater (see Annex J).	
[a] $\beta_{0,4}$ is the deadrise angle at 0,4·L_{WL} forward of its the aft end, measured according to Figure 1, not to be taken less than 10°, nor more than 30°.	
[b] The value of k_{DYN} is considered not to be higher than 6: when running in rough sea, the crew usually limits the speed to keep the slamming accelerations within acceptable comfort and safety limits. This limit of 6 may be surpassed for "heavy duty" workboats, see Annex J.	

8.4 Longitudinal pressure distribution factor k_L

The longitudinal pressure distribution factor k_L defined in Table 8, considers the variation of pressure loads according to the lengthwise position on the craft. Figure 7 shows tabulated values of Table 8.

Table 8 — Values of longitudinal pressure distribution factor k_L

General formula for k_L (see Figure 7)	$k_L=\left(1,667-0,222\times k_{DYN}\right)\times\frac{x}{L_{WL}}+0,133\times k_{DYN}$ [a] not to be taken >1
Values of k_L for planing motor craft	Use formula for k_L with 3 ≤ k_{DYN} < 6
Values of k_L for displacement motor and sailing craft where k_{SLS} = 1	Use formula for k_L with k_{DYN} = 3
Values of k_L for light and stable sailing craft where k_{SLS} > 1	For sailing monohulls where k_{SLS} > 1, calculate k_L with k_{DYN} = max (k_{DYN1}; k_{DYN2}) using the maximum previewed speed with apparent wind between 60 and 90° in m_{LDC} condition, with B_C = B_{WL}. k_{DYN} shall not be taken <3.
[a] x in (m) is the longitudinal position of the centre of the panel or middle of stiffener forward of aft end of L_{WL} in m_{LDC}, x/L_{WL} = 0 and 1 are respectively the aft end and fore end of L_{WL}.	
NOTE The value of line segments at x/L_{WL} = 0 are respectly 0,4/0,6/0,8 for k_{DYN} = 3/4,5/6.	

Figure 7 only shows values of k_L for k_{DYN} = 3, 4,5 and 6; for other intermediate values, k_L shall be determined either by calculation according to the formula of Table 8 or by interpolation in the graph.

For work boats where k_{DYN} values may be between 6 and 8 the formula of Table 8 gives k_L = 1 everywhere for k_{DYN} = 8.

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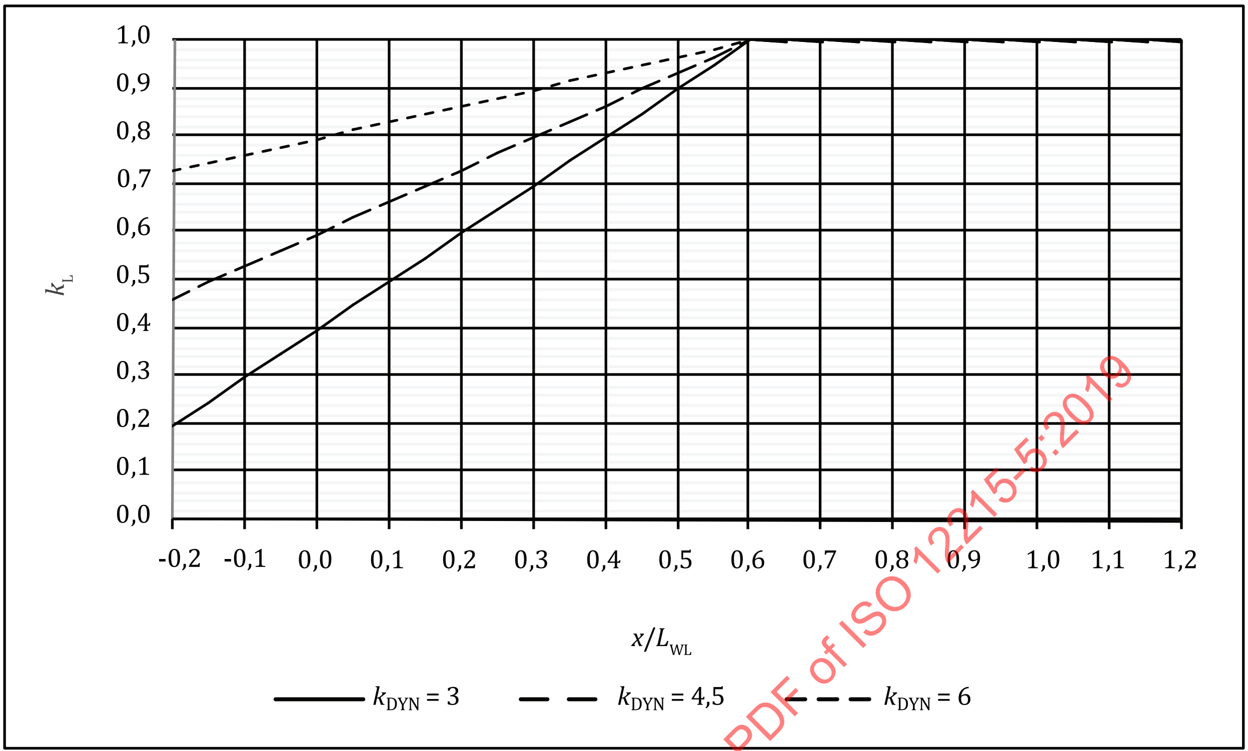

Figure 7 — Longitudinal pressure distribution factor k_L

8.5 Area pressure reduction factor k_{AR}

The area pressure reduction factor k_{AR} is given in Table 9.

Table 9 — Values of area pressure reduction k_{AR}

General formula for k_{AR}	$k_{AR} = \frac{k_R \times 0{,}1 \times m_{LDC}^{0{,}15}}{A_D^{0{,}3}}$ not to be taken <0 nor >1 CAUTION — k_{AR} is different for plating & stiffeners.	
Values of k_R		
For bottom side and deck plating and stiffeners of planing motor craft in planing mode	$k_R = 1$	
For bottom side and deck plating of sailing craft, displacement motor craft and planing motor craft in displacement mode	$k_R = 1{,}5 - 3 \times 10^{-4} \times b$	
For bottom side and deck stiffeners of sailing craft, displacement motor craft and planing motor craft operating in displacement mode	$k_R = 1 - 2 \times 10^{-4} \times l_u$	
Values of design area A_D (m^2)		
For plating	$A_D = (l \times b) \times 10^{-6}$	
For stiffeners	$A_D = (l_u \times s) \times 10^{-6}$ but need not be taken <0,33 $l_u^2 \times 10^{-6}$	
All dimensions as defined in Table 1. NOTE This document considers that the local pressure diminishes when the area of a panel increases, as the panel is subject to an average of high slamming loads on small areas and lower sea loads on larger areas.		

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8.6 Superstructures and deckhouse pressure reduction factor k_{SUP}

The superstructure, coachroof and cockpit side pressure reduction factor k_{SUP} is defined in Table 10. It contributes to the pressure of superstructures and cockpit side defined in Tables 12 and 13

The height H_{SUP} is measured from the actual deck to which the superstructure element is connected to, Z_{SDA} or Z_{SDT}, whichever the lower, to the middle of panel or stiffener, see Figure 6. As the deck pressure increases from its base value where $Z_{SDA} < Z_{SDT}$, so does the superstructure pressure (see Tables 12 & 13).

Table 10 — Values of k_{SUP} for superstructures, deckhouses or cockpits

Superstructures areas	Value of k_{SUP} motor and sail	
	Walking area (see 3.10)	Non-walking area (see 3.10)
Front of superstructures	$\max\left(1-\frac{0,3H_{SUP}}{\cos\alpha_L \times Z_{SDT}};0,67\right)$	$\max\left(1-\frac{0,3H_{SUP}}{\cos\alpha_L \times Z_{SDT}};0,50\right)$
Side of superstructures	$\max\left(1-\frac{0,4H_{SUP}}{\cos\alpha_T \times Z_{SDT}};0,67\right)$	$\max\left(1-\frac{0,4H_{SUP}}{\cos\alpha_T \times Z_{SDT}};0,50\right)$
Side of "open" cockpit[c]	0,67	0,5
Side of "closed" cockpit[c]	Use k_{SUP} 0,67 or 0,5 as above and check that the cockpit pressure is ≥10 × 2 / 3 × h_{SIDE}.	
Top of superstructures, including upper tiers	$\max\left(1-\frac{0,5H_{SUP}}{Z_{SDT}};0,5\right)$	$\max\left(1-\frac{0,5H_{SUP}}{Z_{SDT}};0,35\right)$
Non-protected aft side of superstructures, including upper tiers[b]	Not relevant – see[b]	$\max\left(1-\frac{0,6H_{SUP}}{Z_{SDT}};0,35\right)$
Protected[a] aft side of superstructures, including upper tiers[b]	Not relevant – see[b]	$\max\left(1-\frac{0,7H_{SUP}}{Z_{SDT}};0,35\right)$

H_{sup} (m) is the height of the mid panel or stiffener of a superstructure area at a section x from aft W_L, measured above the actual local deck height Z_{SDA}, or Z_{SDT}, whichever the lower.

h_{SIDE} (m) is the height of the middle of cockpit side panel below overflow level, see Figure 6 a).

Angles α_L and α_T are respectively the longitudinal and transverse angles of the faces (or their tangent when curved) against vertical (see Figure 1).

[a] Protected means "protected from full force of waves" by permanent top, awning, etc. whose vertical projection extends at least outside the bottom of the panel, and ≥0,04 L_H outside the top of the panel, see Figure 2.

[b] Panel on non-walking areas.

[c] ISO 11812 defines "open" recesses where water cannot stay.

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8.7 Pressure correcting factor k_{SLS} for slamming of light and stable sailing craft

The pressure correcting factor k_{SLS} for slamming of light and stable sailing craft is given in Table 11.

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Table 11 — Values of k_{SLS}

<table>
<tr><th>Design category</th><th>Value of k_{SLS} for light and stable sailing craft</th></tr>
<tr><td>C & D</td><td>$k_{SLS} = 1$</td></tr>
<tr><td rowspan="2">A & B</td><td>$k_{SLS} = 1$ where $m_{LDC} > 5\ L_{WL}^3$ otherwise</td></tr>
<tr><td>$k_{SLS} = \left(\dfrac{10\, GZ_{MAX<60} \times L_{WL}^{0,5}}{m_{LDC}^{0,33}} \right)^{0,5}$ but not taken <1</td></tr>
<tr><td colspan="2">Where $GZ_{MAX<60}$, in (m) is the maximum righting moment lever taken at a heel angle ≤60°, with all stability-increasing devices such as canting keels or water ballast at their most effective position, in fully loaded condition. If the maximum righting lever occurs at a heel angle >60°, the value at 60° shall be taken. The crew shall be considered in upwind hiking position in the calculation of the above $GZ_{MAX<60}$.

CAUTION — $GZ_{MAX<60}$ and displacement shall match: ISO 12217-2 normally uses loaded arrival condition m_{LA} to calculate $GZ_{MAX<60}$, and it shall be adjusted for fully loaded m_{LDC} which, where relevant, shall only consider the water ballasts used together, i.e not all water ballast filled.</td></tr>
</table>

NOTE This factor is aimed at sailing craft that are very stable for their displacement (water ballast, canting keels, heavy and deep ballast, etc.). The limitation of the heel angle at 60° considers stability characteristics that can be acting on performances, i.e. at angles below 30°, and not "survival" stability at angles >60°. The effects of eventual foils (possible increased slamming loads to possible increase in speed and dynamic stability) are not considered in k_{SLS} due to lack of data at time of publication of this document, but it is recommended that designers and builders take into accounts their effects, including on the structure.

9 Design pressures

9.1 Design pressure for motor craft

Table 12 defines the design pressures for motor craft.

The bottom pressure of motor craft in any design category shall be the greater of the displacement mode bottom pressure P_{BMD} or the planing mode bottom pressure P_{BMP} (see NOTES 1 & 2)

In design category A or B, the side pressure of planing motor craft shall be the greater of the displacement mode side pressure P_{SMD} or the planing mode side pressure P_{SMP}. (see NOTE 3).

In design category C or D, the side pressure of planing motor craft shall be the one corresponding to planing or displacement mode: the "mode" to consider is the one where the bottom pressure, planing or displacement is the greater. (See NOTE 4).

The pressure for side plating defined in Table 12 is determined by interpolation between the bottom pressure (or part of it) and the deck pressure, and for the same panel, i.e. using the same pressure reduction factors, including k_{AR}, for bottom and deck.

NOTE 1 The reason behind this double requirement is that, in rough seas, craft that usually plane in flat water progress at a slower speed in the same manner as a displacement craft, undergoing eventual breaking waves.

NOTE 2 Craft well into the planing mode with $V/L_{WL}^{0,5} \geq 5$ usually experience P_{BMP} values > P_{BMD}.

NOTE 3 In planing mode, the side pressure may be smaller than in displacement mode as, in the planing mode, the side pressure is interpolated between 0,25 $P_{BMP\ P}$ and deck pressure, whereas, in the displacement mode, the side pressure is interpolated between 0,8 bottom pressure and deck pressure.

NOTE 4 In design category D there is little risk on having to slow down because of rough sea, and this risk is limited in category C.

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Table 12 — Design pressures for motor craft (kN/m²)

CAUTION — k_{AR} and therefore pressures are different for plating and stiffeners, see Table 9.

Motor craft bottom in displacement mode P_{BMD}	$P_{BMD\ BASE} = 2,4\ m_{LDC}^{0,33} + 20$
	$P_{BMD} = \max\left(P_{BMD\ BASE} \times k_{AR} \times k_{DC} \times k_{L} ; P_{BM\ MIN}\right)$ with $P_{BM\ MIN\ PLT} = \max\left[\left(0,45 \times m_{LDC}^{0,33} + 0,9 L_{WL} \times k_{DC}\right) \times k_{L} ; 10 T_{C} ; 7\right]$ for plating, and $P_{BM\ MIN\ STF} = \max\left(0,85 P_{BM\ MIN\ PLT} ; 7\right)$ for stiffeners
Motor craft bottom in planing mode P_{BMP}	$P_{BMP\ BASE} = \dfrac{0,1\ m_{LDC}}{L_{WL} \times B_{C}} \times \left(1 + k_{DC}^{0,5} \times k_{DYN}\right)$
	$P_{BMP} = \max\left(P_{BMP\ BASE} \times k_{AR} \times k_{L} ; P_{BM\ MIN}\right)$, with $P_{BM\ MIN\ PLT}$ and $P_{BM\ MIN\ STP}$ are the same as for displacement.
Motor craft deck and cockpit bottom P_{DM} same for displacement & planing	$P_{DM\ BASE} = 0,31\ m_{LDC}^{0,33} + 12$
	$P_{DM} = \left[0,8 P_{BMD\ BASE} - \left(0,8 P_{BMD\ BASE} - P_{DM\ BASE}\right) \times \min\left(\dfrac{Z_{Q}}{Z_{SDT}} ; 1\right)\right] \times k_{AR} \times k_{DC} \times k_{L}$ Not taken <5 for walking area or <3,5 for non-walking area, both for plating and stiffeners
Motor craft side in displacement mode P_{SMD}	$P_{SMD} = \left[0,8 P_{BMDBASE} - \left(0,8 P_{BMD\ BASE} - P_{DM\ BASE}\right) \times \min\left(\dfrac{Z_{Q}}{Z_{SDT}} ; 1\right)\right] \times k_{AR} \times k_{DC} \times k_{L}$ $P_{SMD\ MIN\ PLT} = \max\left[0,8 P_{BM\ MIN\ PLT} - \left(0,8 P_{BM\ MIN\ PLT} - 5\right) \times \dfrac{Z_{Q}}{Z_{SDT}} ; 0,9 L_{WL} \times k_{DC} ; 5\right]$ for plating, and $P_{SMD\ MIN\ STF} = \max\left(0,85 P_{SMD\ MIN\ PLT} ; 5\right)$ for stiffeners
Motor craft side in planing mode P_{SMP}	$P_{SMP} = \left[0,25 P_{BMP\ BASE} - \left(0,25 P_{BMP\ BASE} - P_{DM\ BASE}\right) \times \min\left(\dfrac{Z_{Q} - Z_{C}}{Z_{SDT} - Z_{C}} ; 1\right)\right] \times k_{AR} \times k_{DC} \times k_{L}$ $P_{SMP\ MIN\ PLT} = \left[\max 0,25 P_{BM\ MIN\ PLT} - \left(0,25 P_{BM\ MIN\ PLT} - 5\right) \times \min\left(\dfrac{Z_{Q} - Z_{C}}{Z_{SDT} - Z_{C}} ; 1\right) ; 0,9 L_{WL} \times k_{DC} ; 5\right]$ for plating, and $P_{SMP\ MIN\ STF} = \max\left(0,85 P_{SMP\ MIN\ PLT} ; 5\right)$ for stiffeners

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Table 12 *(continued)*

Motor craft superstructures and cockpit side P_{SUPM}	$P_{SUP\ M} = \left[0{,}8 P_{BMD\ BASE} - \left(0{,}8 P_{BMD\ BASE} - P_{DM\ BASE}\right) \times \min\left(\frac{Z_{SDA}}{Z_{SDT}};1\right)\right] \times$ $k_{AR} \times k_{DC} \times k_L \times k_{SUP}$ Not taken <5 for walking area or <3,5 for non-walking area, both for plating and stiffeners With k_{SUP} taken from Table 10 according to area
Z_Q is the height of point Q at mid-panel or stiffener above waterline (W_L or chine see Figure 6), Z_C is the height of the chine above waterline, and Z_{SDA} and Z_{SDT} are respectively the height of actual and theoretical hull deck limit above waterline (see Table 4 & Figure 6), all values considered at distance x from aft of L_{WL}. For cockpit bottom Z_Q need not be taken less than Z_{SDA}.	
NOTE 1 The base pressure for planing craft in planing mode contains the k_{DC} factor but at the power 0,5 because the pressure is more governed by impact loads due to speed than sea conditions.	

9.2 Design pressure for sailing craft

Table 13 defines the design pressures for sailing craft.

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Table 13 — Design pressures for sailing craft (kN/m²)

CAUTION — k_{AR} and therefore pressures are different for plating and stiffeners, see Table 9.

Sailing craft bottom P_{BS}	$P_{BS\ BASE} = \left(2m_{LDC}^{0,33} + 18\right) \times k_{SLS}$
	$P_{BS} = \max\left(P_{BS\ BASE} \times k_{AR} \times k_{DC} \times k_L ; P_{BS\ MIN}\right)$ with $P_{BS\ MIN\ PLT} = \max\left[\left(0,3 \times m_{LDC}^{0,33} + 0,66 L_{WL} \times k_{DC}\right) \times k_L ; 10 T_C ; 7\right]$ for plating $P_{BS\ MIN\ STF} = \max\left(0,85 P_{BS\ MIN\ PLT} ; 7\right)$ for stiffeners
Sailing craft deck and cockpit bottom P_{DS}	$P_{DS\ BASE} = 0,5 m_{LDC}^{0,33} + 12$
	$P_{DS} = \left[P_{BS\ BASE} - \left(P_{BS\ BASE} - P_{DS\ BASE}\right) \times \min\left(\frac{Z_Q}{Z_{SDT}} ; 1\right)\right] \times k_{AR} \times k_{DC} \times k_L$ Not taken <5 for walking area or <3,5 for non-walking area, both for plating and stiffeners
Sailing craft side P_{SS}	$P_{SS} = \left[P_{BS\ BASE} - \left(P_{BS\ BASE} - P_{DS\ BASE}\right) \times \min\left(\frac{Z_Q}{Z_{SDT}} ; 1\right)\right] \times k_{AR} \times k_{DC} \times k_L$ $P_{SS\ MIN\ PLT} = \max\left[P_{BS\ MIN\ PLT} - \frac{Z_Q}{Z_{SDT}}\left(P_{BS\ MIN\ PLT} - 5\right) ; 5\right]$ for plating $P_{SS\ MIN\ STF} = \max\left(0,85 P_{SS\ MIN\ PLT} ; 5\right)$ for stiffeners
Sailing craft superstructures and cockpit side P_{SUPS}	$P_{SUP\ S} = \left[P_{BS\ BASE} - \left(P_{BS\ BASE} - P_{DS\ BASE}\right) \times \min\left(\frac{Z_{SDA}}{Z_{SDT}} ; 1\right)\right] \times k_{AR} \times k_{DC} \times k_L \times k_{SUP}$ not taken <5 for walking area or <3,5 for non-walking area, both for plating and stiffeners With k_{SUP} taken from Table 10 according to area
Z_Q is the height of point Q at mid-panel or stiffener above waterline (W_L or chine see Figure 6), Z_{SDA} and Z_{SDT} are respectively the height of actual and theoretical hull deck limit above waterline (see Table 4 & Figure 6), All values considered at distance x from aft of L_{WL}. For cockpit bottom Z_Q need not be taken less than Z_{SDA}.	

9.3 Watertight bulkheads and integral tank boundaries design pressure

9.3.1 General

Table 14 defines the design pressures for watertight bulkheads and integral tanks.

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Table 14 — Design pressures for watertight bulkheads and integral tanks

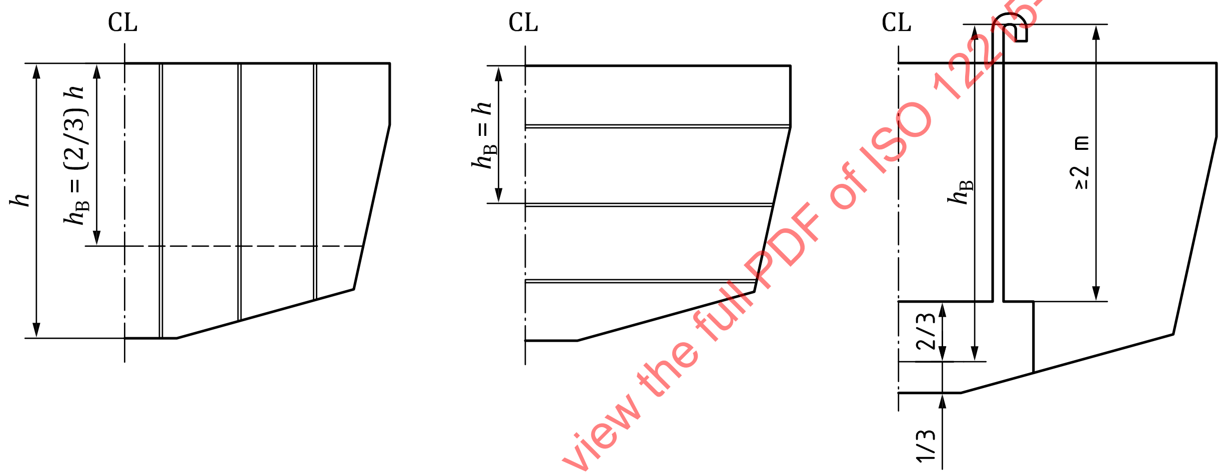
Type of watertight partition	Design pressure (kN/m²)
Watertight bulkhead	$P_{WB} = 7\ h_B$
Integral tank	$P_{WB} = 10\ h_B$

Where h_B is the water head, (m), measured as follows (see Figure 8):

— for plating, the distance from a point 2/3 of the depth of the panel below the top of bulkhead;

— for vertical stiffeners, the distance from a point 2/3 of the depth of the stiffener below top of bulkhead;

— for horizontal stiffeners, the height measured from the stiffener to the top of bulkhead.



a) Watertight bulkhead

b) Integral tank bulkhead

Figure 8 — Watertight and integral tanks bulkheads

Where there are plates of different thicknesses or scantlings, h_B for each panel shall be measured to the lowest point of the panel.

For the determination of the tank design pressure, the top of the overflow shall not be taken <2 m above the top of the tank. Where the tanks form part of the deck, this shall be assessed according to the requirements of this section.

9.3.2 Integral tanks wash plates

Integral tanks shall be subdivided as necessary by internal baffles or wash plates. Baffles or wash plates that support hull framing shall have scantlings equivalent to stiffeners located in the same position.

Wash plates and wash bulkheads shall, in general, have an area of perforation not >20 % of the total area of the bulkhead. The perforations shall be so arranged that the efficiency of the bulkheads as a support is not impaired.

The general stiffener requirement for section modulus may be 50 % of that required for stiffener members of integral tanks.

9.3.3 Collision bulkheads

The scantlings of collision bulkheads, where fitted, shall not be less than required for integral tank bulkheads.

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9.3.4 Non-watertight or partial bulkheads

Where a bulkhead is structural but non-watertight, the scantlings shall be calculated as a stiffener. Clause A.13 sets up recommendations for plywood or sandwich structural bulkheads.

Non-structural or redundant stiffeners are not considered as part of the structure and therefore outside the scope of this document. See A.7.4 for more details.

9.3.5 Centreboards of lifting keel wells

In addition to the requirements of ISO 12215-9, the design pressure of centreboards/lifting keel wells/casing shall be at least 10 Tc below D_{WL}

For sliding/daggerboard type centreboards or foils, it is a good practice to reinforce the aft bottom of the well/hull to avoid damage in case of longitudinal shock on the appendage, e.g. floor, extra laminate, UD belt, crash box, etc.

9.3.6 Transmission of pillar loads

Bulkheads that are required to act as pillars in the way of under-deck girders subjected to concentrated loads and other structures that carry heavy loads shall be dimensioned according to these loads. See ISO 12215-10 for mast step analysis for sailing craft.

9.3.7 Loads from outboard engines

Annex K gives information on loads exerted by outboard engines to the craft's structure. It is not a requirement of this document as it is not a pressure load, but it may be useful for the transom or craft structural assessment. Reference N° [15] gives more information on that point.

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10 Mechanical properties and design stresses

10.1 Boat building quality factor k_{BB}

As a baseline, this document considers that the builder has properly followed the state of the art in terms of building and material supplier requirements, e.g. where relevant:

— building environment (e.g. temperature, hygrometry, etc. during storage and building);

— building process (e.g. preparation process prior to building such as dusting, degreasing, priming, etc.);

— type of material (e.g. proper combination of material, etc.);

— etc.

In addition, and for Fibre reinforced plastics (FRP) material only, the factor k_{BB} reflects the quality of the “as built” material obtained by the boatbuilder. Annex C shall be used for the assessment of the initial mechanical properties of composites, then adjusted by k_{BB}.

Table 15 defines a range of 3 building process quality levels, reflecting reliability of mechanical properties and their corresponding values of k_{BB} shall be used in Table 17.

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Table 15 — Values of k_{BB} factor

Built quality	Builder characteristics	Value of k_{BB}	
		Hand laid	Infused, pre-preg or similar
TESTED	Mechanical properties of the laminates are produced[a], as built, based on test of the mechanical characteristics (modulus, breaking strains, etc.)[b]. Monitoring records, material batch traceability, frequency (once a year as a minimum) and test procedures are drawn up into a quality procedure, such as ISO 9001 or equivalent.	1 on Tested value	1 on Tested value
HIGH	Fibre mass content monitoring, obtained either from sample thickness with theoretical approach, either burning process; for range of representative layups. Monitoring records, material batch traceability, frequency (once a year as a minimum) and test procedures are drawn up into a quality procedure, such as ISO 9001 or equivalent.	0,95 of calculation/ Table value	1 of Calculation/ Table value
LOW	No measurements or checking on fibre mass content. Volume content is taken from Table C.7, according to relevant building process (minimum value where there is a range).	0,75 of calculation/ Table value	0,80 of calculation/ Table value

a Not based on UD layers only.

b Tests are based, for stresses on 90 % of mean values or mean value minus 2 standard deviations, whichever the smaller, and mean value for modulus, see Item 2 of Table C.1.

NOTE Metals, wood/plywood and sandwich cores, are available through industrial processes and/or by selection and their mechanical properties are not significantly dependent on the craft manufacturing process. Build factor k_{BB} is therefore considered as 1, so that Table 17 defines their design stresses without k_{BB}.

10.2 Assessment method factor k_{AM}

The assessment method factor k_{AM} is defined in Table 16.

NOTE This factor has the purpose to "balance" the results from the various assessment methods, to ensure that simpler assessment methods give more conservative results than more scientifically developed ones.

Table 16 — Assessment method factor k_{AM}

Determination of k_{AM}		
Assessment method	Value of k_{AM}	
	FRP & wood	Metal
Method 1 "Simplified" method	0,9	1
Method 2 "Enhanced" (ply by ply) method	0,95	1
Method 3 "Developed" and 5 "FEM" methods	1	1
Method 4 "Direct test"	1	1

10.3 Design stresses according to material and calculation method

The design stresses are defined in Table 17.

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Table 17 — Design stresses for plating and stiffeners according to material

<table>
<tr><th>Material</th><th>Structural element</th><th colspan="2">Direct stress σ_d
N/mm^2</th><th>Shear stress τ_d
N/mm^2</th></tr>
<tr><td rowspan="9">FRP</td><td>Single skin plating simplified method</td><td colspan="2">$\sigma_d = 0{,}5\ \sigma_{uf} \times k_{BB} \times k_{AM}$</td><td>$\tau_d = 0{,}5\ \tau_u \times k_{BB} \times k_{AM}$</td></tr>
<tr><td>Stiffeners[a]</td><td colspan="2">$\sigma_{do} = 0{,}5\ \sigma_{ut} \times k_{BB} \times k_{AM}$</td><td>$\tau_d = 0{,}5\ \tau_u \times k_{BB} \times k_{AM}$</td></tr>
<tr><td>Sandwich outer skin</td><td colspan="2">$\sigma_d = 0{,}5\ \sigma_{ut} \times k_{BB} \times k_{AM}$</td><td>$\tau_d = 0{,}5\ \tau_u \times k_{BB} \times k_{AM}$</td></tr>
<tr><td>Sandwich inner skin[a,b]</td><td colspan="2">$\sigma_{di} = \min[0{,}5\ \sigma_{uc}\ ;\ 0{,}3(E_c \times E_{CO} \times G_{CO})^{0{,}33}] \times k_{BB} \times k_{AM}$</td><td>$\tau_d = 0{,}5\ \tau_u \times k_{BB} \times k_{AM}$</td></tr>
<tr><td rowspan="5">Sandwich core or bulking material

Use minimum or σ_{uco} or τ_{uco} core value given by core manufacturer/ provider in directions b and l, where relevant (see Table A.4)</td><td colspan="2">Core compressive stress perpendicular to faces</td><td>Core shear stress</td></tr>
<tr><td>End grain balsa</td><td>$\sigma_{dcco} = 0{,}5\ \sigma_{ucco} \times k_{AM}$[c]</td><td>$\tau_{dco} = 0{,}5\ \tau_{uco} \times k_{AM}$[c]</td></tr>
<tr><td>Elongation at break ≤35 %</td><td>$\sigma_{dcco} = 0{,}55\ \sigma_{ucco} \times k_{AM}$[d]</td><td>$\tau_{dco} = 0{,}55\ \tau_{uco} \times k_{AM}$[d]</td></tr>
<tr><td>Elongation at break >35 %[d]</td><td>$\sigma_{dcco} = 0{,}65\ \sigma_{ucco} \times k_{AM}$[d]</td><td>$\tau_{dco} = 0{,}65\ \tau_{uco} \times k_{AM}$[d]</td></tr>
<tr><td>Honeycomb</td><td>$\sigma_{dcco} = 0{,}5\ \sigma_{ucco} \times k_{AM}$[e]</td><td>$\tau_{dco} = 0{,}5\ \tau_{uco} \times k_{AM}$[e]</td></tr>
<tr><td rowspan="2">Aluminium alloy</td><td>Plating</td><td colspan="2">$\sigma_d = \min(0{,}6\ \sigma_{uw}\ ;\ 0{,}9\sigma_{yw})$</td><td>$\tau_d = 0{,}58\ \sigma_d$</td></tr>
<tr><td>Stiffeners</td><td colspan="2">$\sigma_d = 0{,}7\ \sigma_{uw}$ [f]</td><td>$\tau_d = 0{,}58\ \sigma_d$</td></tr>
<tr><td rowspan="2">Steel</td><td>Plating</td><td colspan="2">$\sigma_d = \min(0{,}6\ \sigma_u\ ;\ 0{,}9\sigma_y)$</td><td>$\tau_d = 0{,}58\ \sigma_d$</td></tr>
<tr><td>Stiffeners</td><td colspan="2">$\sigma_d = 0{,}8\ \sigma_y$</td><td>$\tau_d = 0{,}58\ \sigma_d$</td></tr>
<tr><td rowspan="2">Laminated wood & plywood</td><td>Plating</td><td colspan="2">$\sigma_d = 0{,}5\ \sigma_{uf} \times k_{AM}$[f]</td><td>$\tau_d = 0{,}5\ \tau_u \times k_{AM}$</td></tr>
<tr><td>Stiffener</td><td colspan="2">$\sigma_d = 0{,}45\ \sigma_{uf} \times k_{AM}$[g]</td><td>$\tau_d = 0{,}45\ \tau_u \times k_{AM}$</td></tr>
<tr><td>Plywood on edge</td><td>Stiffener</td><td colspan="2">$\sigma_d = 0{,}45\ \sigma_{uf} \times k_{AM}$[g]</td><td>$\tau_d = 0{,}45\ \tau_u \times k_{AM}$</td></tr>
<tr><td>Solid stock wood</td><td>Stiffener</td><td colspan="2">$\sigma_d = 0{,}4\ \sigma_{uf} \times k_{AM}$[g]</td><td>$\tau_d = 0{,}4\ \tau_u \times k_{AM}$</td></tr>
<tr><td colspan="5">CAUTION — k_{BB} is a boatbuilding quality factor and only concerns FRP, see Annex C.
Mechanical properties for core ($\sigma_{co}\ \tau_{co}$; E_{co} & G_{co}) shall be taken from "minimal "manufacturer/provider value.
The requirement for inner skin considers wrinkling effects, even if not formally stated.</td></tr>
</table>

[a] σ_c is considered where stressed in compression (usually the stiffener top flange) and σ_t is considered where stressed in tension (usually the plating); both verifications need to be calculated; see Annex C on how to assess σ_c. For sandwich inner skin, there is an additional requirement $0{,}3(E_c \times E_{CO} \times G_{CO})^{0{,}33}$ that prevents skin wrinkling.

[b] E_C is the compressive E modulus of inner skin in direction b, 0/90° plane axis of panel E_{CO} is the compressive E modulus of core perpendicular to skins, G_{CO} is the core shear modulus in the direction parallel to load.

[c] Where the balsa exhibits a low degree of variability in mechanical properties and measures are taken to seal the core by resin encapsulation in cases where it is used, factor 0,5 may be raised at 0,55 τ_u.

[d] According to core material type.

[e] Honeycomb may have different values in *b* and *l* directions, see Table A.4.

[f] For welded aluminium and where the maximum stress is within the HAZ (Heat Affected Zone). From Eurocode 9 and MIG welding, the HAZ distance from the closest weld end is 20 mm for t < 6; 30 mm for t 6 < t < 12, and 35 for 12 < t <. If aluminium is not welded, i.e. riveted, glued, etc. or where the analysed area is clearly outside the HAZ; the non-welded properties may be used. Documented as welded data may also be used.

[g] The ultimate flexural strength of laminated wood or plywood plating is measured parallel to the *b* direction of the panel.

NOTE These design stresses apply in the direction of load i.e. along the small dimension b, of a panel, and for stiffeners along its length, this also applies for the attached plating to the stiffener. For orthotropic panels, see A.9 the design stresses may be needed in the *b* and *l* direction. For sandwich plating and stiffeners, the stress is either a tensile or compressive strength according to the distance from the neutral axis, see Annex H for more explanations.

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11 Methods for structural analysis and scantlings determination

11.1 The six available methods

Six methods for structural analysis and scantlings determination are defined in Table 18, sorted out by level of simplicity. Several analysis methods may be used for the same boat. The detailed application of the methods is given in the Annexes.

Table 18 — Methods for structural analysis and scantlings determination of plating and stiffeners

Analysis method	Material	Method type	Element checked	Clauses & Tables	Material properties
1 Simplified	Metal, & wood (plywood & cold moulded)	Formula for t_d	Single skin	A.1 to A.9 & A.10.1 σ_d from Table 17	Annexes B for metal G for wood
	GRP	Formula for t_d transformed in w_f	Single skin & sandwich	A.1 to A.9 & A.10.2 E & H.3 for sandwich σ_d from Table 17	Annexes C for GRP G for wood
	GRP	F_d, M_d, SM, t_{web}	Stiffener	A.1 to A.9, A.12, G &H.4 for stiffeners, A.13 for bulkheads σ_d from Table 17	Annex C
2 Enhanced	Metal, wood & quasi isotropic FRP	Ply by ply analysis F_d, M_d, t_{web}	Plating (single skin & sandwich) stiffeners	A.1 to A.9 & A.11 &H3 sandwich A12 & H4 stiffeners, A13 & H4 bulkheads σ_d from Table 17	Annexes B, C & F
3 Developed	All FRP	Same as above & CLT			
4 Direct test	Any but mostly FRP	F_d, M_d, SM & bending test		11.5	Not relevant
5 FEM	Any, including Developed FRP	3D Finite elements method	Plating (single skin & sandwich) stiffeners & Global	11.6 & Pressures from Tables 12 & 13 σ_d from Table 17	Annexes B, C & F
Alternative test					
6 Drop test	FRP & non-reinforced plastic	Test	Any/All	Annex D	Not relevant

CAUTION — For FRP, the thickness required from Table A.5, or wherever such thickness appears in this document shall not be measured, but translated into a mass of dry fibre reinforcement w_f (kg/m^2) using the fibre content in volume ϕ or in mass ψ according to Tables C.2 or C.7, and compared to the actual reinforcement mass.

11.2 Method 1: "Simplified" method

The "Simplified" method is only valid for:

— Single skin or sandwich GRP (glass reinforced plastics) with the same properties in directions *b* and *l* and made from the fiberglass plies listed in Tables C.5 to C.10;

— metals and wood (plywood or laminated wood, see Annex F).

This method is explained in detail in Clause A.10 and left column of Table A.5, for single skin or sandwich plating and for stiffeners with the following inputs, where relevant:

— design pressure defined in Tables 12 to 14;

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— design stresses defined in Table 15 to 17 and in Annex B for metals, Annex C for GRP, and Annex F for wood/plywood laminates;

— for sandwich specific requirements according to Table A.6 for stresses in skins and Table A.7 for core strength.

Annexes E and H may be used for section modulus (*SM*) or shear force and bending moment calculation.

11.3 Method 2: "Enhanced" method (ply by ply analysis)

The "Enhanced" method is applicable to plating and stiffeners made of the same materials as in the simplified method plus general orthotropic materials, see Note, made of the plies listed in Tables C.5 to C.10.

This method is explained in detail in the right column of Table A.5 and in H.1 with the same inputs as for the simplified method.

For stiffeners, Clauses A.12 to A.14 apply, verifying that the actual bending moment and shear force are larger than the design values of Tables H.6 to H.8 or by the pre-calculated values of Annex G.

NOTE Isotropic materials have the same properties in all directions, general orthotropic (anisotropic) have different properties at 0 and 90°, but some orthotropic materials have the same properties in the 0 and 90° directions relatively to the panel dimensions *b* and *l*.

11.4 Method 3: "Developed" method for any laminate, including non-balanced laminates

The "developed" method is valid for any type of laminate, including the non-balanced ones. The inputs are the same as for the enhanced method, see also right column of Table A.5.

It uses CLT (Classic laminate Theory) which analyses the laminates ply by ply as Annex H, but usually checks the strain or stresses in the two directions *b* and *l* using Tsai-Wu or Tsai-Hill, or other criteria for strength. A great number of CLT software is available in the market. One shall check whether the CLT software considers wrinkling on the inner skin of a sandwich, and the shear stress in the core.

NOTE The enhanced method ply by ply uses ε_f for single skin in Annex H, but not the Tsai-Wu analysis of stresses SRM method in Annex C. For other laminates (non-balanced i.e. using triaxial fabric or UDs in only one direction) the enhanced method needs CLT method with Tsai-Wu. Thus this document introduces k_{AM} to rectify the results of the various methods to have the simplified method more conservative.

11.5 Method 4: "Direct test method"

The ultimate bending moment and shear force of a laminate panel/strip (single skin or sandwich) or of a stiffener with its attached plating are tested on a bending machine/bench, to check that it is at least equal to the required value. This allows to disregard the properties of each ply.

As for the test standards quoted in Table C.1, the calculation strength (bending moment and shear force) shall be taken as 90 % of the mean ultimate strength or the mean value minus two standard deviations, whichever is the lesser. The design bending moment and shear force shall be 0,5 × k_{BB} of this result, with k_{AM} = 1, see Table 16.

As testing usually induces large deflection, the reaction forces at end supports may not be parallel to the load force(s). In that case the actual bending moment may need to be recalculated to consider misalignment, unless a specific support device corrects it.

11.6 Method 5: "FEM" Finite Element Method

11.6.1 General considerations

This method, mainly applicable to "developed" FRP construction, recognizes that structural components are best analysed using 3-D numerical procedures, now easily accessible. It uses Tables 12 & 13 for the

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design pressure and Table 17 for the design stress or strain. The mechanical properties of the materials shall be derived from the relevant Annex (Annex B, C, or F).

The recommended method, only applicable for linear analysis, is:

1) apply a unit pressure to the analysed elements, taking care how the model is “held” and ensure that results of outside forces and moments is nil;

2) calculate the stresses σ_i in each analysed element due to the unit pressure;

3) check on significant elements that $\sigma_i \times P_d \leq \sigma_d$, where P_d is the design pressure, determined for each panel with all the relevant factors. See Note for an alternative calculation.

The selection of the stress assessment method and software are subject to the criteria given in this subclause.

The FEM method may also be applied, as suggested in 7.3.2 and elsewhere, to analyse specific panels or arrangements, and, where possible, determine a policy for natural stiffeners, etc.

NOTE As P deck ≈ 0,25 P bottom and P side ≈ 0,6 P bottom, therefore, one could use a pressure have unit pressure for bottom, 0,6 for side and 0,25 for deck.

IMPORTANT — It is considered a prudent design practice to compare the scantlings derived from this method 5 with those derived from the enhanced method (see 11.3). A technical explanation shall be provided in cases where these 3D numerical procedures give significantly lower scantlings than those given by the enhanced method.

11.6.2 General guidance for assessment by 3-D numerical procedures

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 analysis (FEA).

11.6.3 Boundary assumptions and load application

No explicit boundary assumptions are specified within this document. The analyst shall ensure that the critical area to be analysed is located well away from the model boundaries.

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 analysed.

11.6.4 Model idealisation

Models may be of beam-element, plate or brick type. Where beam elements are adopted, effective plating dimensions shall, unless otherwise documented, be obtained from A.12.5 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 models, sufficient elements shall be used between frames to replicate local bending effects.

Unless a non-linear analysis is used, analysts should make sure 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 A.12.6.

11.7 Method 6: Alternative test: Drop test

The drop test, specified in Table 2 and Annex D, only applies to craft with L_H < 6 m. For this size of craft, the related double curvature and/or monocoque effects and robustness cannot be fully taken into account by the methods in 11.2 to 11.6. The drop test method offers an alternative particularly

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applicable to craft made of non-reinforced plastics, where thickness and dimensions are not easy to measure, and where the large deflections may not be dealt with by the theory applied in this document.

11.8 "Good practice" minimal thickness

This document does not require any minimal thickness for craft other than "heavy duty" workboats, see Clause 12, but for information only, informative Annex I gives "good practice" values.

12 Craft for professional use: Commercial craft and workboats

For commercial craft and workboats, Annex J shall be applied in addition or replacement of the other requirements of this document. It gives additional requirements for the assessment of commercial craft for professional use (bareboat rental & charter, workboats of light or heavy-duty type).

13 Owner's manual

13.1 General

Where relevant, the information in 13.2 to 13.4 shall be included in the owner's manual.

13.2 Normal mode of operation

"CAUTION — The owner is responsible for ensuring that the normal mode of operation is maintained. This means that the speed of the craft needs to be matched to the prevailing sea state, the craft being used "with good seamanship behaviour.”

13.3 Information to take care of sandwich plating

Where sandwich outer skin is thinner than the "good practice" values of Annex I, include the following information in the owner's manual, or any equivalent or more detailed information:

"CAUTION — The outer skin of the craft is strong enough to resist the design pressure but not local damage from hitting hard/sharp objects. If the outer skin is damaged, it shall be repaired immediately.”

13.4 Information required by Annex J for commercial craft and workboats

Where relevant, include the information required by J.3.

14 Application form

The application form of Annex L, or equivalent, may be used to detail how this document has been applied.

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Annex A
(normative)

Application of methods of analysis 1 to 3 of Table 18

A.1 Purpose of this Annex

Where one of the methods of analysis 1 to 3, as defined in Tables 2 and 18 has been chosen for the craft structural analysis, this Annex shall be used. This Annex is common to methods 1, 2 and 3.

A.2 Panel assessment

A.2.1 General case: Dedicated and regularly spaced secondary stiffeners

In traditional metal or wood single skin construction the "secondary stiffeners", i.e. the ones that directly support the plating, see 7.1, are "dedicated " stiffeners like stringers, frames, beams, floors, where their spacing do not varying too significantly between one and another, and subclause 7.1 can be easily applied. In that case, this document considers that the plating is fully fixed (clamped) at its connection with the secondary stiffeners, as it is subject to a near constant pressure over near constant support spacing, and the application of subclause A.7 is fully relevant.

A.2.2 Panel assessment in other cases

The history of small craft structure, and particularly the advent of FRP construction have led to different structural arrangement than in metal craft, taking advantage of curved shapes, accommodations, etc. and the structural arrangement often rely on the following type of stiffeners:

— Dedicated stiffeners, e.g. stringers, girders, bunk edges, frames, liners, tray mouldings, etc.

— Natural stiffeners, e.g. angled centreline, deck/hull angles, hard chines and round bilges, etc.

Figures A.1 and A.2 show a variety of natural and dedicated stiffeners. Figures A.1a) and A.1 c) show sections without dedicated natural stiffeners but with three natural stiffeners, s_1, s_2, s_3 made by the hull-deck joint and the centreline. In Figure A.1 d), the centreline has no chine or Vee and cannot be considered as a stiffener, and there are only two natural stiffeners, the hull/deck angles. Figure A.1 b) shows a section where the liner adds two dedicated stiffeners each side s_2, s_3, s_5 and s_6.

A.3 Determination of the short dimension and curvature of a panel

Draw a straight line between the closest points of these stiffeners. Measure b and the camber c, (See Figure A.1) then calculate k_C according to Table A.3 and Figure A.8.

A.4 Very large panels

Find the minimum distance between the two closest "natural" stiffeners. In the case of Figure 6 d), the only natural stiffeners are the two deck/hull angles as the centreline is not stiff enough to be a natural stiffener. Measure the camber of the panel, c, and calculate k_C according to Table A.3 and Figure A.8.

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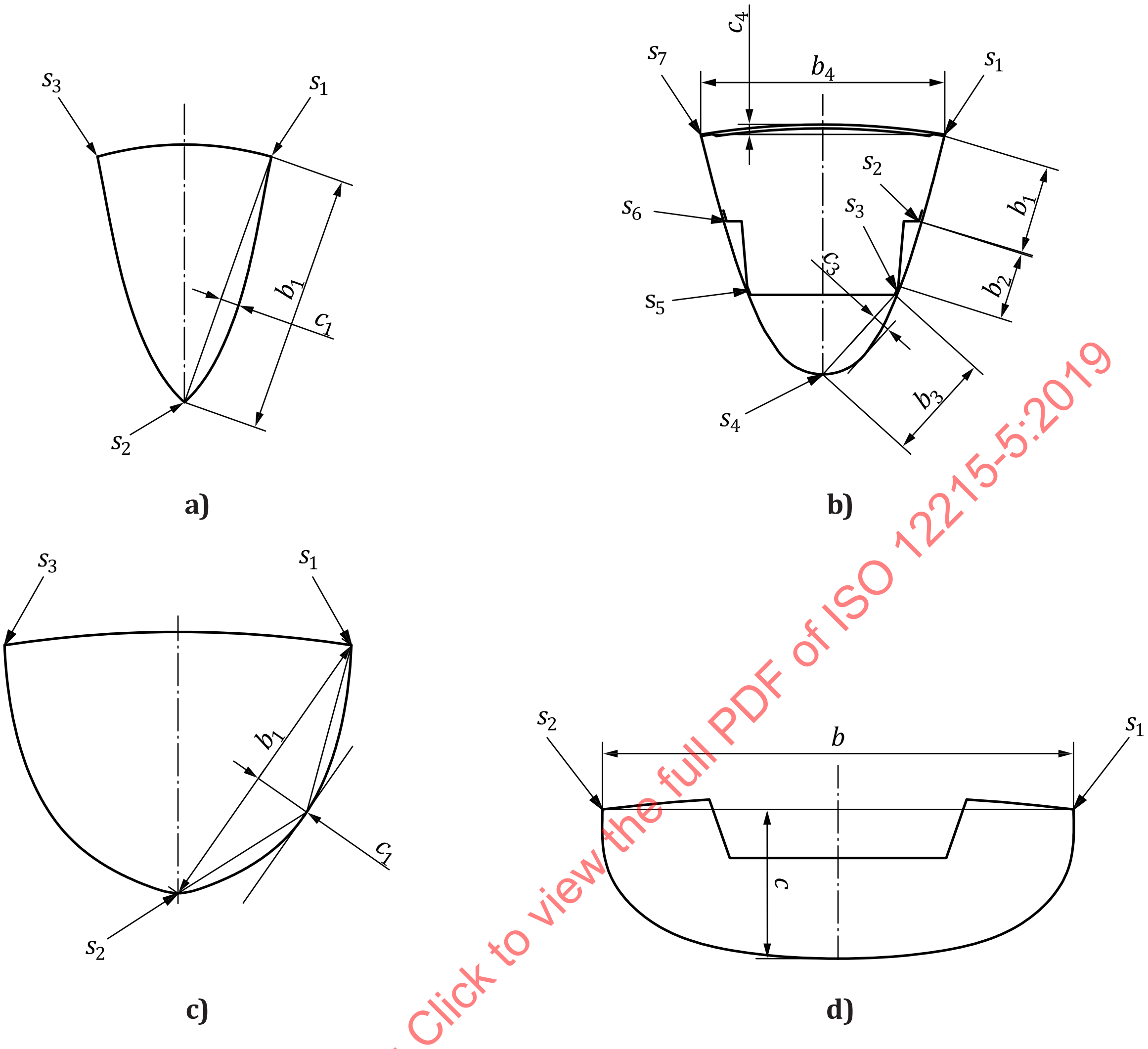

Key

s_1, s_2, s_3, s_4. s_5, s_6, s_7 stiffeners

Figure A.1 — Examples of panel size and curvature assessment

In Figure A.1 d) considering the whole bottom as one panel with camber c will probably lead to over conservative assessment and the solution in Figure A.3 a) to d) are probably more appropriate.

A.5 Case where round bilged and hard chined panels act as "natural" stiffeners

A.5.1 General

To find out whether a "round bilge" acts as a stiffener, the following method is recommended, see Figure A.3. Other documented methods are acceptable, including through the use of FEM.

A.5.2 Case a: For curved or U-shaped panels:

Find, if possible, a circle that corresponds approximatively to the shape of the hull. Its connection to the hull is usually at the tangent point with a parallel to the diagonal between bottom at C_L and deck edge.

— If the radius R of this circle is ≤0,40 L_{Diag} the length of the diagonal, and if the chord of contact or intersection between the circle and the hull is >0,8 R, the "turn of the bilge" is considered strong

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enough to be a "natural" stiffener, and the panels b1, b2 are determined between angles and tangent points, as in Figures A.3 a) to A.3 c).

— If the radius R of this circle is >0,40 L_{Diag}, the length of the diagonal, the "turn of the bilge" of section is not eligible as natural stiffener and the panel shall be assessed between "eligible" natural stiffener as, in Figure A.3 d), the deck edge and the keel.

A.5.3 Case b: Where a centred circle can be inscribed in the bottom panel

This type of section is frequently found in the front ¼ of flotation on many sailing crafts, see Figure A.3 b). The curved centred panel is considered as a natural stiffener if the distance between tangents points (the chord length) is >0,8 R.

A.5.4 Hard chined sections

For hard chined sections the length b used for calculation shall be taken as the actual b between chines, multiplied by the correction factor k_{CH} taken from Figure A.2 according to chine average angle, see Figure A.3 e). In that case $b \times k_{CH}$ shall be used instead of b for all calculations: A_D, k_{AR}, pressure, etc. Where the requirements of this subclause are followed, the plating and the chines, acting as longitudinal framing, are considered to fulfil the requirements of this document.

NOTE In that case, the whole hull section acts as a self-stiffened arch.

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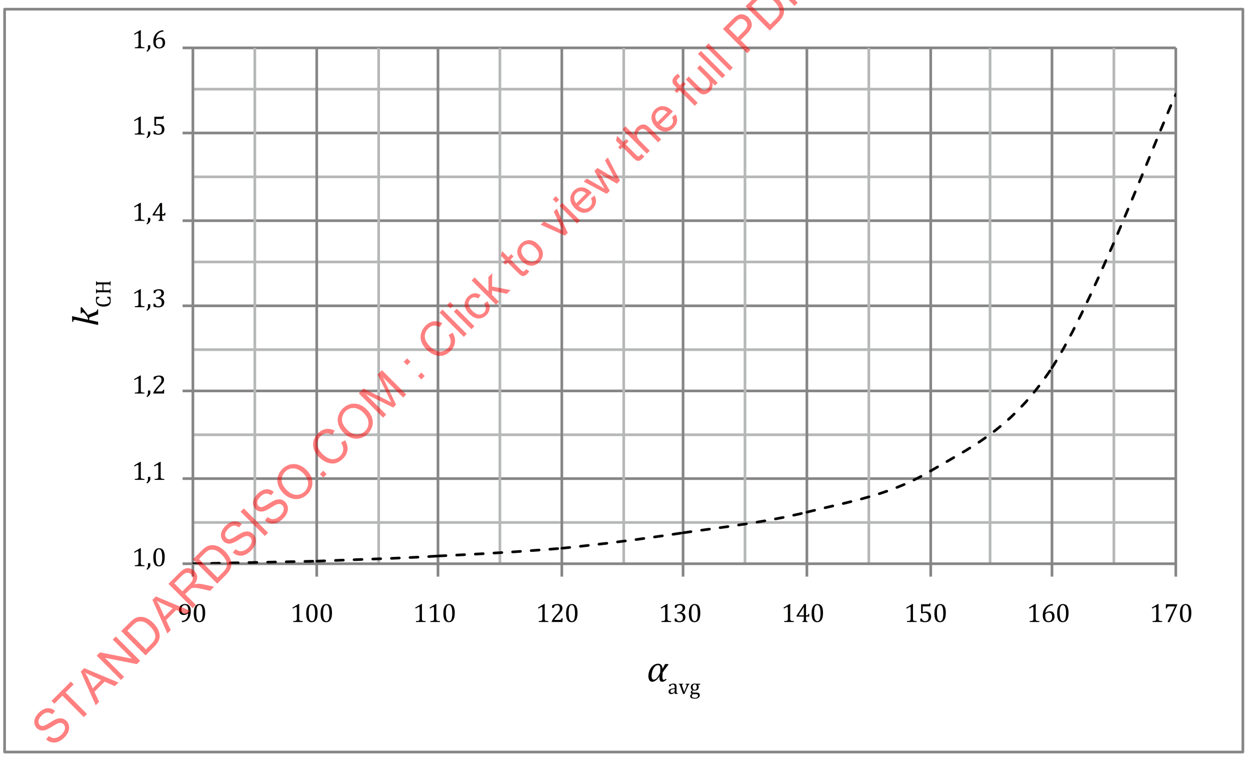

The curve may be approximated by the following formula:

k_{CH}= 1,493 6·10$^{-9}\alpha^5$ – 8,894 8·10$^{-7}\alpha^4$ + 2,107 6·10$^{-4}\alpha^3$ – 2,479 9·10$^{-2}\alpha^2$ + 1,448 4α – 32,578 3

Key

α_{avg} chine average, $\alpha_{avg} = 0{,}5(\alpha_i + \alpha_{i+1})$

k_{CH} correction factor

Figure A.2 — Correction factor k_{CH} according to the chine average angle

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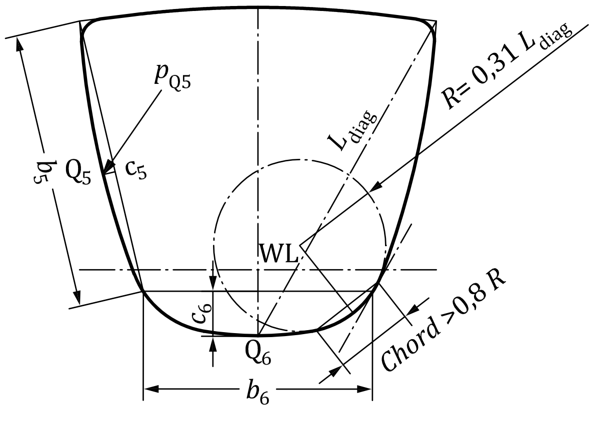
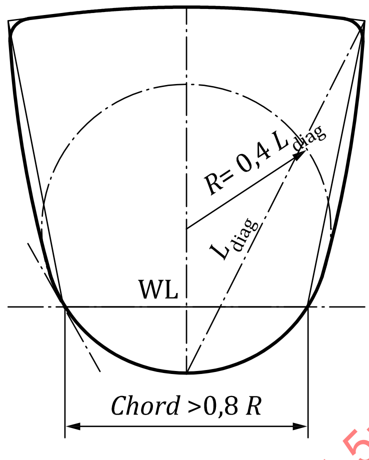
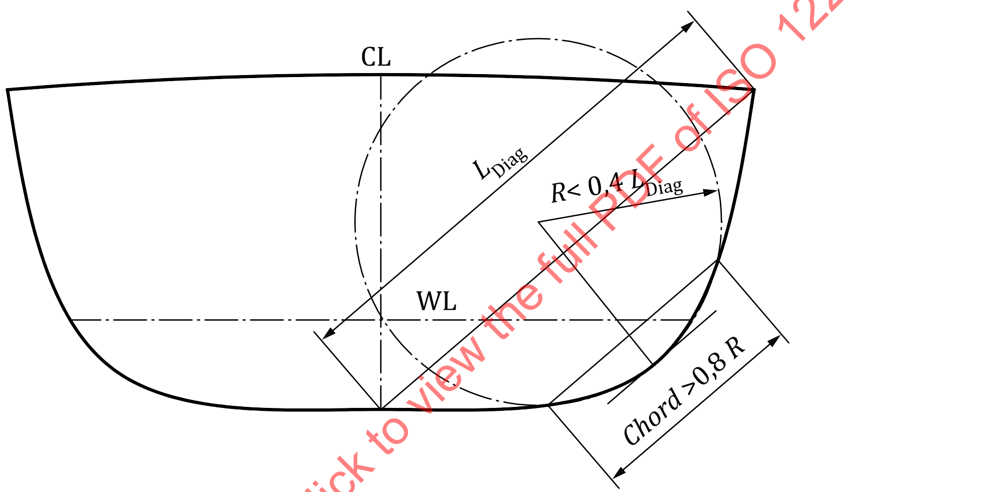


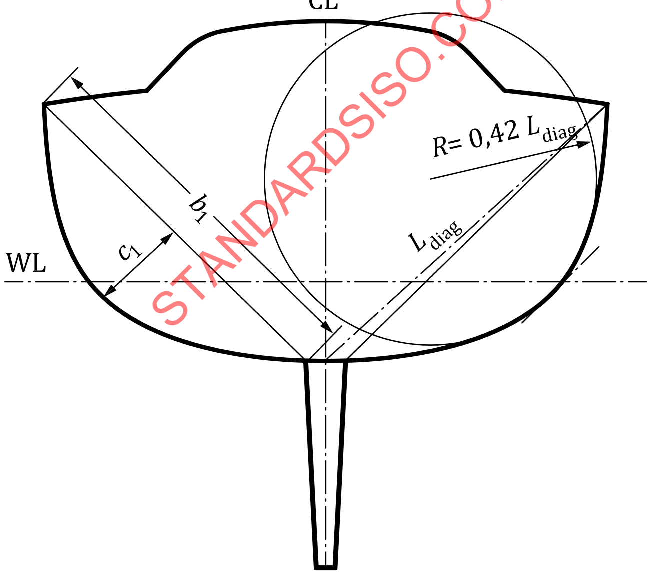
a) "High" round bilged section



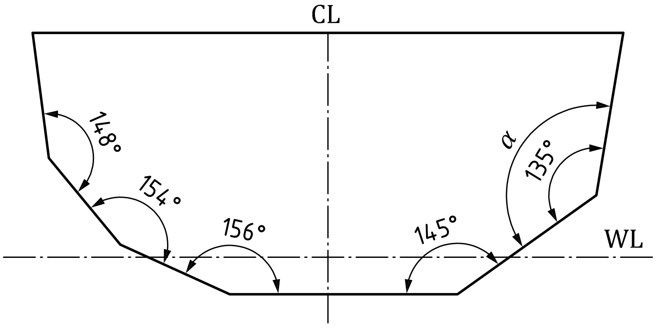
b) Circle centred section



c) "Flat" round bilged section



d) Section not eligible for natural stiffener



e) Hard chined section

Figure A.3 — Round bilged and hard chined sections

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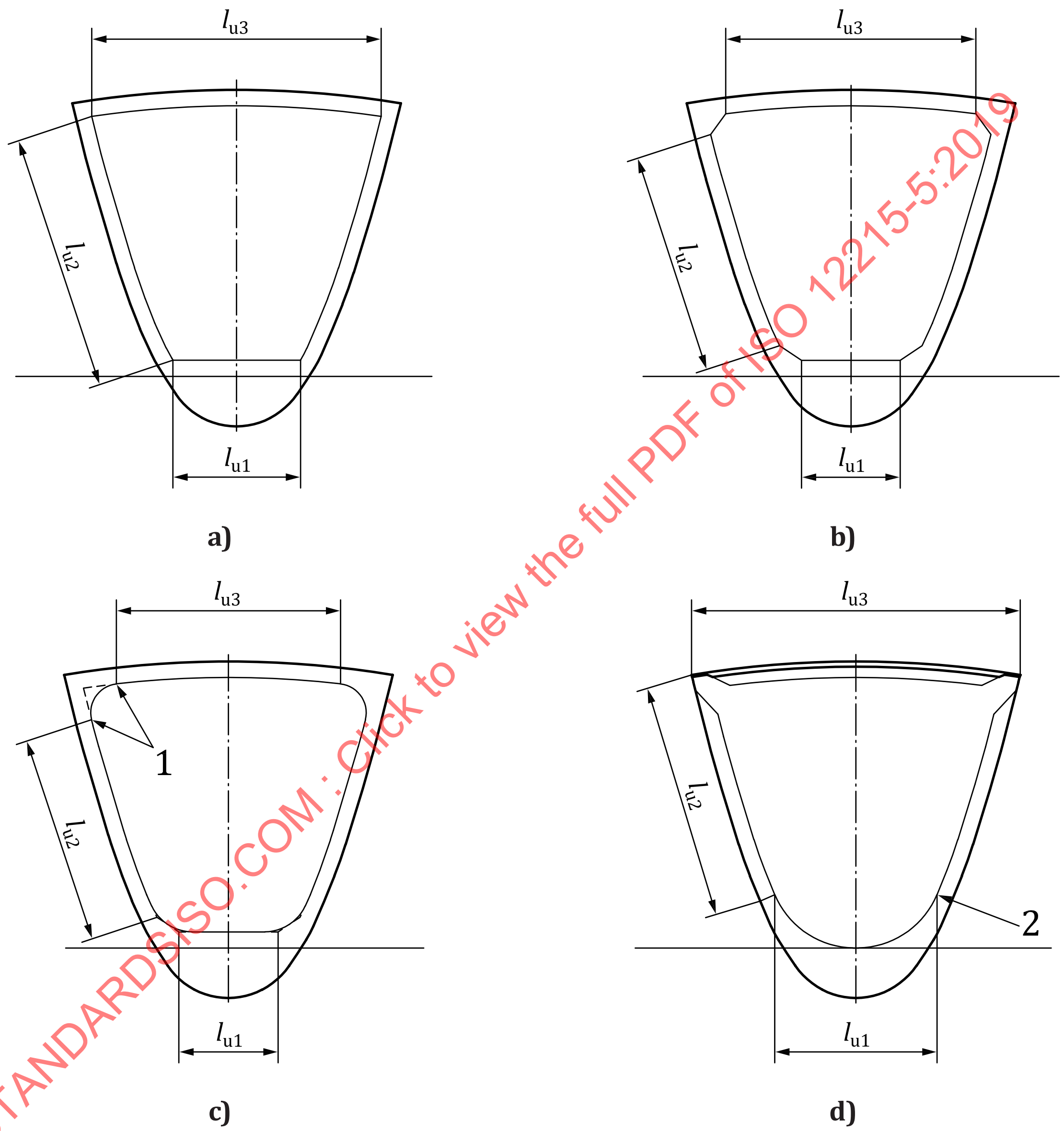
A.6 Examples of stiffener dimension assessment

A.6.1 General

Figure A.4 gives some examples of stiffener dimension assessment, where l_u is the long unsupported dimension of a stiffener. In the case of a top-hat stiffener, l_u is the distance between the centrelines of top-hats [Figure A.4 c)]. A similar method as the one for plating may be used.



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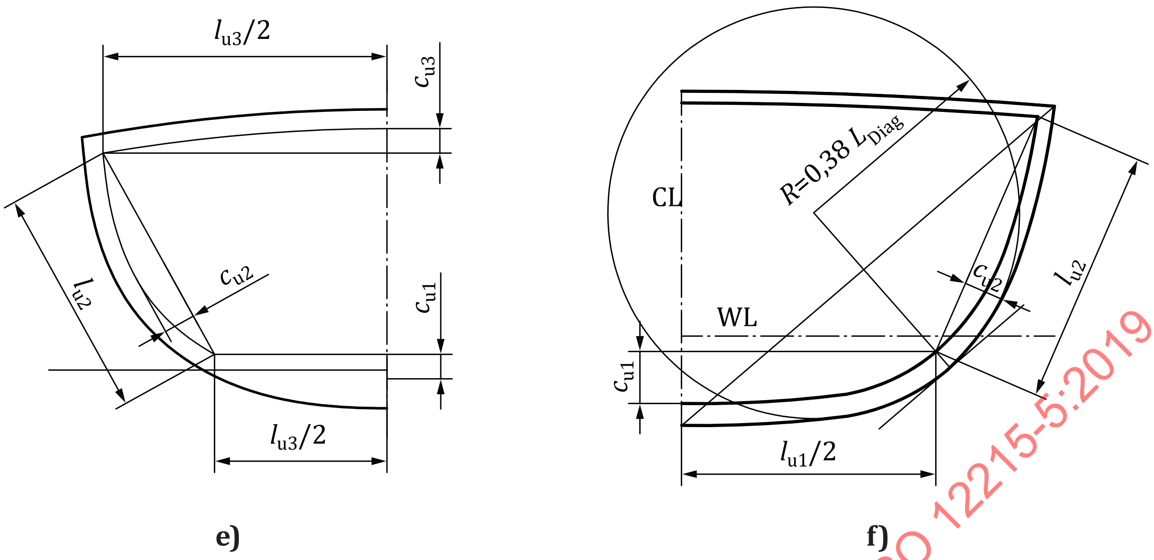

Key

1 closest tangent point

2 tangent of connection between floor and frame

Figure A.4 — Examples of stiffener dimensions on a FRP craft

A.6.2 Explanation of Figures A.4 a) to A.4 f)

a) Continuous stiffeners not connected by gussets or radius l_{u1} for floor, l_{u2} for frame, l_{u3} for beam.

b) Stiffeners with gussets at the junctions: l_u is measured inside the gusset junction.

c) Gussets with tangential junctions: the ends of l_u are at the closest tangent points (Key 1).

d) Frames and beams with sniped ends to allow the deck to be attached at a late stage of building without subsequent lamination.

e) Curved stiffeners with clear limit floor/frame showing how to define the lengths l_u and camber c_u to assess k_{CS}.

f) Curved stiffeners without clear limit floor/frame: use the same method as in A.5.

NOTE In Figure A.4 a), b) and c), the beam and frame are fully fixed at both ends, whereas in Figure A.4 d), the frame is simply supported at its top end. The limit floor/frame (Key 2 in Figure A.4) is at their tangent or junction point, i.e. a change in the stiffener height.

Table A.8 and Figures A.10 and A.11 give shear force and bending moment according to type of end connection. In Figure A.4 d), the frame shall be considered simply supported at its top and fully fixed at its connection to the floor, whereas the floor shall be considered as Fully Fixed at both ends and the beam as Simply Supported at both ends.

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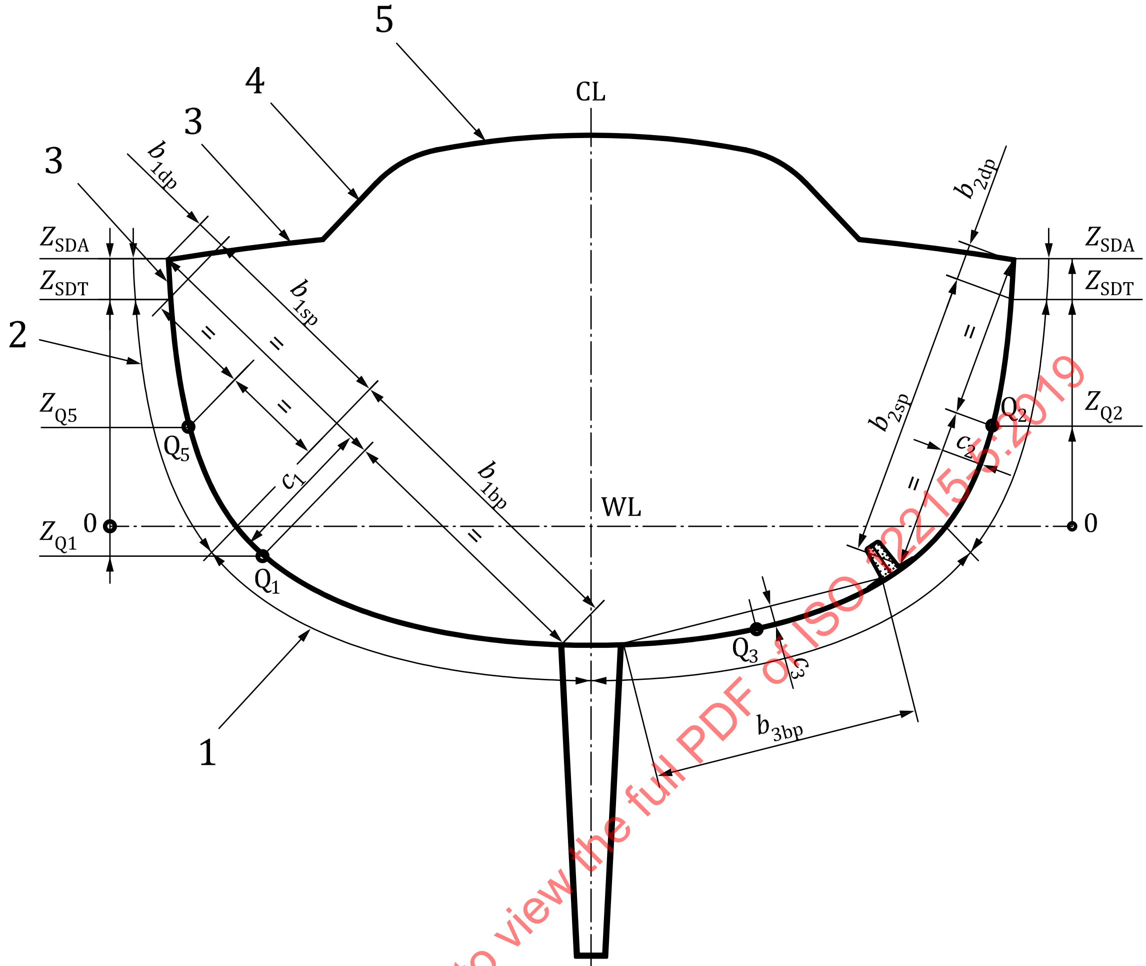

a) Pressure on a panel without and with stringer

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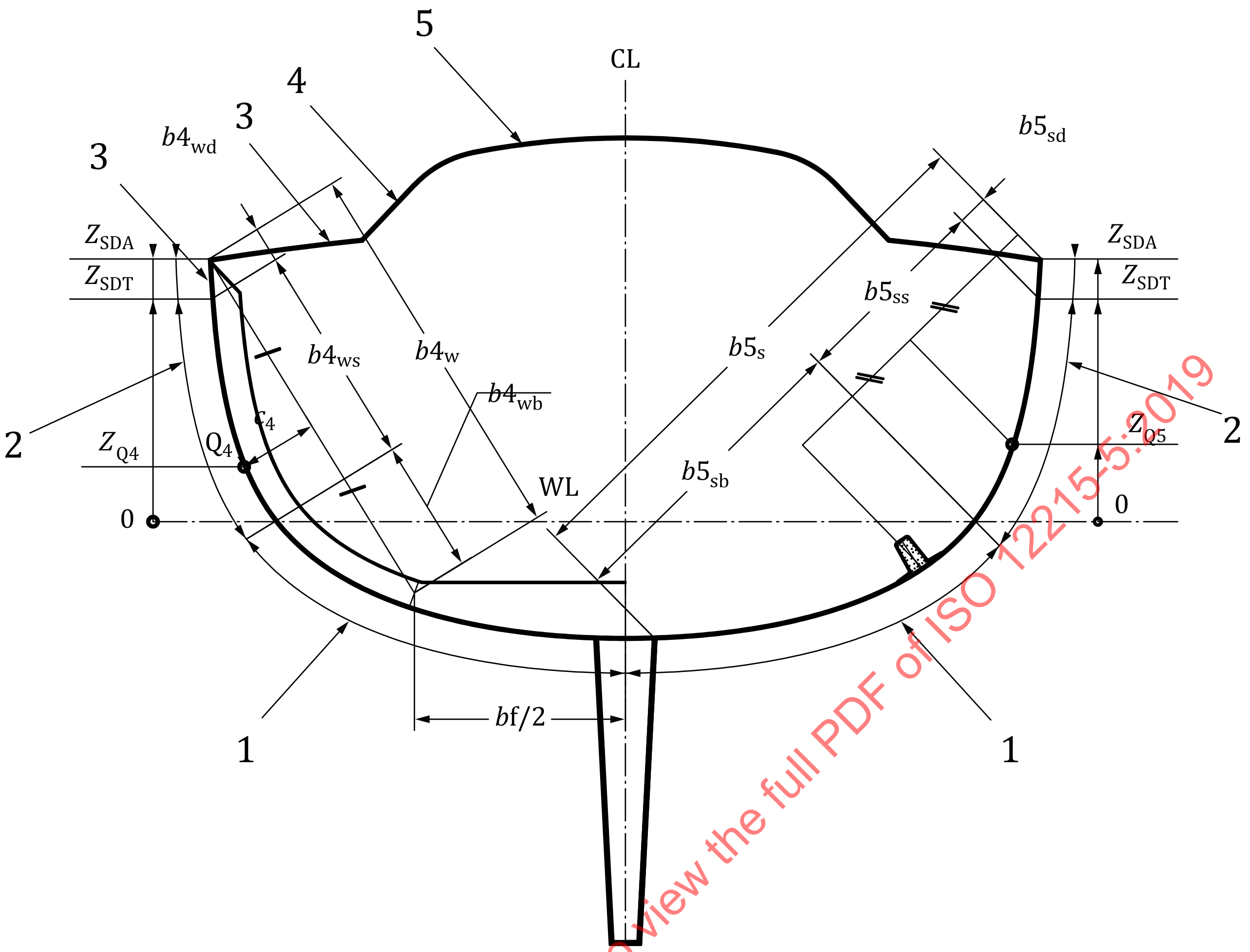

b) Pressure on a frame (left) and stringer (right)

Key

1 bottom area
2 side area
3 deck area
4 superstructures side area
5 superstructures top area

Figure A.5 — Definitions of areas, and pressure assessment of panel or stiffener

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A.7 Calculation of the scantlings of a panel or stiffener across several areas

A.7.1 General

For the scantlings calculation of a large panel across several areas, one may use one of the methods presented here, the method with constant thickness is easy to apply, whereas the method with variable thickness is more appropriate for a vertical panel across bottom, side and, where relevant deck where *b* is closer to vertical than horizontal.

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A.7.2 Examples of determination of panels or stiffeners with constant thickness or section modulus

This method considers that the pressure applied to a panel is based on its weighted average pressure. Same approach for a stiffener whose pressure is the one of the area it is supporting.

The pressure on a panel or its stiffener is not constant, even if it is only in one area, as the pressure varies with its size (k_{AR}), longitudinal position (k_L), and, where relevant, vertical position. Where a panel or stiffener extends over two or three areas, its base design pressure is determined as a constant pressure over the entire design area, calculated as a weighted average between the pressures, as shown in the following example:

Determine:

— the limits and dimensions of the panel or stiffened area for a stiffener i.e. the adjacent(s) panels(s) to the stiffener.

— k_{AR} and k_L for the panel or stiffener, corresponding to centre of area of the panel. In that context the pressure corresponding to the "middle" of a panel is the one of the intersection of a perpendicular to the middle of its transverse chord with the hull [see Figures A.5 a) and b)]

— the pressure on each part of the panel or stiffener area according to each pressure area (bottom, side, deck, etc).

— the final average pressures. Table A.1 shows examples of calculation for Figures A.5 a) and b), where the first indexes b, s and d, mean respectively the lengths and pressures for bottom, side, and deck. The second index p, s and f mean respectively panel, stringer and frame.

The averaged bottom/side/deck pressure P_{Q1} of the whole panel is calculated at point Q_1, the intersection of a perpendicular to mid chord with the hull according to the first formula of Table A.1. The pressures P_{1bott} and P_{1deck} are constant, but the side pressure is variable between Z_{Q1} and Z_{SDT}, and it shall be measured at point Q_5 where a perpendicular to the chord b_{1SP} at its middle intersects the hull, see left of Figure A.5 a). Same for points at middle of panels 1, 2 and 3.

For the frame on the left side of Figure A.5 b) the chord is measured between the ends of the frame at mid height (as the top part is sniped, it is its apex). The camber c_4 is measured between hull and mid height.

Apply the relevant Clauses A.7 to A.12 for single skin /sandwich panels, or stiffener.

NOTE The plating in Figure A.5 a) left and particularly the frame may (should) be calculated as simply supported or semi-fixed at its top end.

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Table A.1 — Example of pressure determination on panels and stiffeners

Panels –See Figure A.4 a)	
Definition	Pressure determination
Figure A.5 a) left unstiffened panel	$P_{Q1}=\dfrac{(P_{1bott}\times b_{1bp})+(P_{1side}\times b_{1sp})+(P_{1deck}\times b_{1dp})}{b_{1p}}$ with $b_{1p}=b_{1bp}+b_{1sp}+b_{1dp}$ The averaged pressure of the panel P_{1Q} is calculated at point Q_1, the intersection of a perpendicular to mid chord with the hull.
NOTE Point Q_1, perpendicular to the middle of the chord is just below W_L and the bottom panel should therefore be divided in two parts with side and bottom pressure, but this was considered too complex for a very small difference.	
CAUTION The examples are made in a transverse section, but shall be applied to the whole panel of stiffened area, and the point Q of Figure A.5 shall be made with the same lengthwise approach at the centre of the panel area.	

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Table A.1 *(continued)*

Figure A.5 a) right 2 panels with a stringer	$P_{Q2} = \dfrac{(P_{2bott} \times b_{2bp}) + (P_{2side} \times b_{2sp}) + (P_{2deck} \times b_{2dp})}{b_{2p}}$ and $P_{Q3} = P_{3\ bott}$
Stiffeners –See Figure A.4 b)	
Figure A.5 b) left Frame + floor	$P_{F4} = \dfrac{(P_{4bott} \times b_{4bf}) + (P_{4side} \times b_{4sf}) + (P_{4deck} \times b_{4df})}{b_{4f}}$ Pressure on frame
NOTE Point Q_4 found as for Q_1. Camber C_4 measured from chord to mid frame. Top of frame considered SS (see A.12).	
Figure A.5 b) right Stringer	$P_{S5} = \dfrac{(P_{5bott} \times b_{5bs}) + (P_{5side} \times b_{5ss}) + (P_{5deck} \times b_{5ds})}{b_{5s}}$ Pressure on stringer
CAUTION The examples are made in a transverse section, but shall be applied to the whole panel of stiffened area, and the point Q of Figure A.5 shall be made with the same lengthwise approach at the centre of the panel area.	

A.7.3 Same example but with variable thickness or section modulus

1. Calculate the required thickness (or design bending M_t for sandwich) as if the whole panel was in bottom area and apply this thickness below W_L.

2. Calculate the required thickness (or design bending M_t for sandwich) as if the whole panel was in deck area and apply this thickness in upper topside.

3. Interpolate the thickness between bottom thickness and deck thickness for topsides ensuring the thickness or resisted bending moment is always greater than required.

Worked example:

t_p required for bottom (with, for example, pressure 13,5 KN/m^2) = 10,1 mm

t_p required for deck (with, for example, pressure 5 KN/m^2) = 10,1 × (5/13,5)^{0,5} = 6,1 mm

t_p required above W_L = interpolation from 10,1 to 6,1 mm, maybe in function of the local side pressure that varies with height.

This applies to Figure A.5 a) left, but could also apply to other figures such as Figure A.5 a) right where the side thickness could be interpolated between bottom thickness at W_L and deck thickness at summit of topsides.

A.7.4 Non-structural or redundant stiffeners

Panel dimensions, when taken as the distance between frames (or the distance between top-hat webs) require that the stiffeners that make up the panel boundary are able to comply with the strength criterion of this document.

Where a stiffener does not comply or where the stiffener is not intended to reduce the panel dimensions, the panel may be analysed with the stiffener considered non-effective. This leads to a large increase in the panel size, but the long side becomes the small side and may benefit from greater camber. If the resulting larger panel complies with this document, then the stiffener may be designated as “non-structural”.

Builders and designers are cautioned as to this term. “Non-structural” means that the adjacent panels have been assessed on the basis that the panel is not deriving any support from the stiffener, i.e. as if the stiffener were not physically there. However, the stiffener attracts a load in proportion to its stiffness relative to the adjacent structure. This means that this non-structural stiffener could fail in service, even though such a failure would not directly result in adjacent panel failure as would normally be the case for a “structural” stiffener. Should the “non-structural” stiffener fail, this could cause cracking

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of the adjacent structure, which could result in further failure. It is not considered a good practice. Builders and designers are advised to clearly explain this in the owner's manual as any such cracking may need to be monitored.

A.8 Plating and stiffeners — Scantlings formulas for methods 1 to 3 of Table 2

A.8.1 Preliminary

This Clause is only valid for the "simplified", "enhanced" and "developed" methods, as the FEM method computes directly the stresses.

A.8.2 Thickness adjustment factors for plating

A.8.2.1 Aspect ratio factors k_2 for bending moment and shear force k_{SH}

The aspect ratio factors for bending moment k_2 and shear force, k_{SH} for rectangular panels, given in Table A.2 are based on the effective aspect ratio A_{RE} defined in bottom note a) of Table A.2. See Figure A.6.

Table A.2 — Values of k_2 and k_{SH} in function of effective aspect ratio A_{RE} for fully fixed rectangular isotropic or orthotropic panels

Panel effective aspect ratio A_{RE}[a]	**Transverse factor k_{2b}**[b] for transverse bending moment	**Longitudinal factor k_{2l}** for longitudinal bending moment	**Factor k_{SHb}** for shear force in b direction (in middle of side l)	**Factor k_{SHl}** for shear force in l direction (in middle of side b
>2,0	0,500	0,337	0,520	0,460
2,0	0,494	0,337	0,516	0,460
1,9	0,490	0,339	0,516	0,459
1,8	0,484	0,339	0,516	0,459
1,7	0,476	0,339	0,515	0,458
1,6	0,465	0,339	0,515	0,458
1,5	0,451	0,339	0,512	0,458
1,4	0,432	0,337	0,506	0,457
1,3	0,409	0,335	0,496	0,457
1,2	0,380	0,329	0,482	0,454 7
1,1	0,345	0,320	0,462	0,447
1,0	0,305	0,305	0,436	0,436

Approached value of these factors with formula: $k_i = \mathrm{A}(l/b)^5 + \mathrm{B}(l/b)^4 + \mathrm{C}(l/b)^3 + \mathrm{D}(l/b)^2 + \mathrm{E}(l/b) + \mathrm{F}$

	A	B	C	D	E	F	
k_{2b}	−0,010 3	0,079 0	−0,144 1	−0,278 0	1,164 5	−0,506 5	with k_{2b} = 0,5 for l/b>2
k_{2l}	0,022 7	−0,249 7	1,084 6	−2,325 5	2,459 2	−0,686 0	with k_{2l} = 0,337 for l/b>2
k_{SHb}	−0,003 2	−0,019 4	0,332 5	−1,258 6	1,918 3	−0,533 9	with k_{SHb} = 0,52 for l/b>2
k_{SHl}	0,037 2	−0,384 1	1,553 0	−3,072 5	2,979 2	−0,676 7	with k_{SHl} = 0,46 for l/b>2

[a] $A_{RE} = (l/b) \times (EI_b/EI_l)^{0,25}$ is the "Effective" aspect ratio, whereas $A_{RG} = l/b$ is the geometric aspect ratio, where EI_b and EI_l are respectively the stiffness of the panel per unit width in the b and l direction.

For isotropic or orthotropic panels where $EI_b = EI_l$, $A_{RE}=A_{RG}=l/b$ shall be used in the first column.

For orthotropic panels, where(EI_b/EI_l)>1, $A_{RE} = (l/b) \times (EI_b/EI_l)^{0,25}$ shall be used in the first column.

[b] For laminated wood panels, k_2 = 0,5 in all cases.

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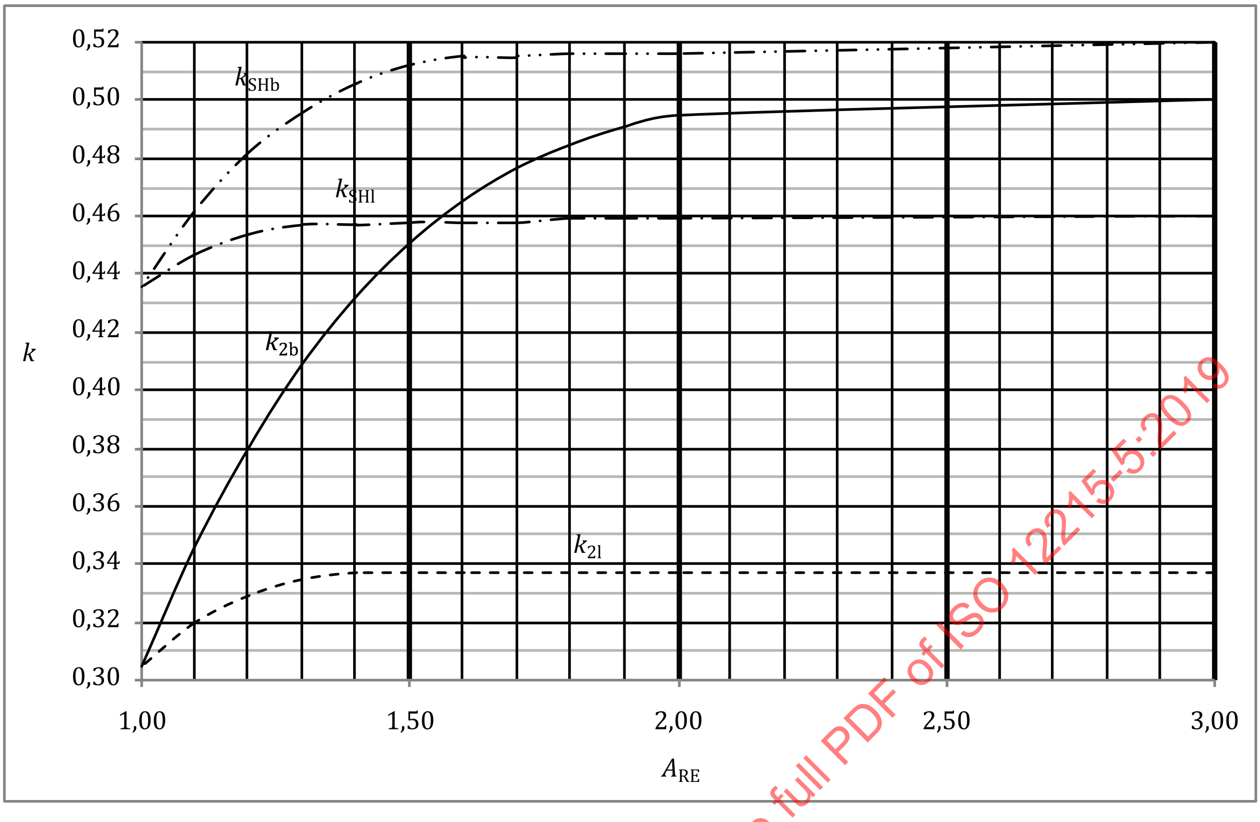

Figure A.6 — Curves for k_{2b}, k_{2l}, k_{SHb} & k_{SHl}

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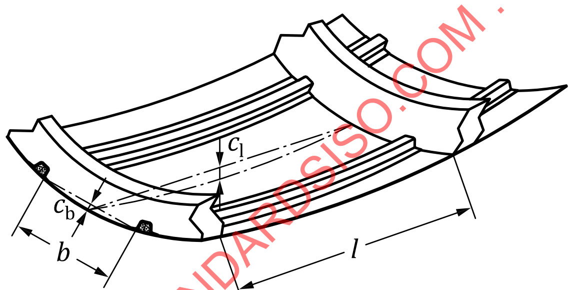
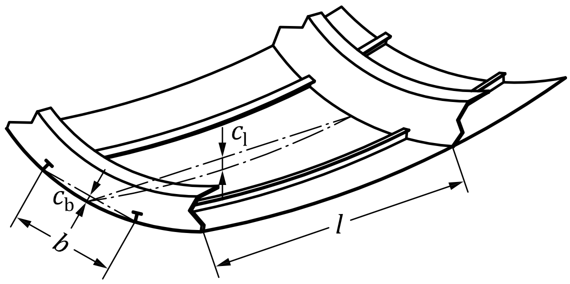
A.8.2.2 Curvature correction factor for plating

A.8.2.3 k_C



a) Top-hat type stiffeners (FRP)



b) T or L shape stiffeners (Metal)

Figure A.7 — Measurement of dimensions c_b, b, c_l and l

The curvature correction factor k_C is given in Table A.3 and tabulated in Figure A.8. It is a function of both the transverse curvature ratio c_b/b and the longitudinal curvature ratio c_l/l, see Figure A.7. It applies both for convex and concave curvature and shall not be taken <0,5.

Other documented data for k_C, for single and double curvature and adjusting t, F_d and M_d of Table A.4, and based on test/calculation, may be used instead of the ones of Table A.3.

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Table A.3 — Values of k_c in function of c_b/b and c_l/l

c_b/b	Values of c_l/l			
	0 to 0,030	0,060	0,080	0,100
0 to 0,030	1,000	0,910	0,806	0,722
0,050	0,890	0,814	0,727	0,656
0,075	0,783	0,719	0,650	0,592
0,100	0,702	0,648	0,592	0,543
0,125	0,643	0,596	0,549	0,508
0,150	0,599	0,558	0,518	0,500 (min)
0,175	0,567	0,529	0,500 (min)	0,500 (min)
0,200	0,538	0,504	0,500 (min)	0,500 (min)
0,225	0,510	0,500 (min)	0,500 (min)	0,500 (min)
Intermediate values shall be calculated by interpolation between two values of c_l/l for the same value of c_b/b.				
The above values may be approached as $k_c = a(c_b/b)^3 + b(c_b/b)^2 + (c_b/b) + d$ with				
a	−59,161	−52,061	−42,596	−35,496
b	34,928	30,737	25,148	20,957
c	−7,971 7	−7,015 1	−5,739 6	−4,783
d	1,209	1,094 5	0,956 9	0,847 4
c_b = camber of the panel in the b (transverse) dimension		c_l = camber of the panel in the l (longit.) dimension		
c_b/b = transverse curvature ratio; not to be taken <0,03		c_l/l = longitudinal curvature ratio; not taken <0,03		

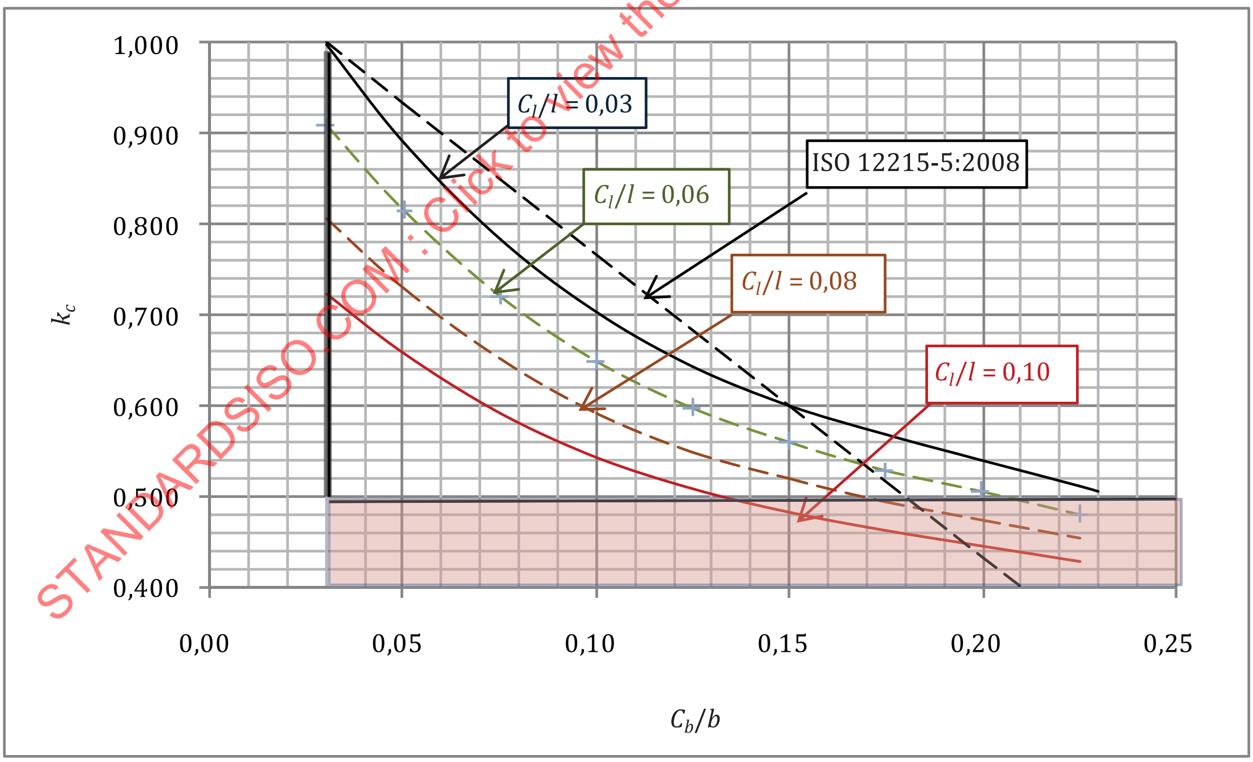

Figure A.8 — Values of k_c according to Table A.3

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A.9 Design shear force and bending moment on a rectangular panel

The design shear force and bending moment on a rectangular panel with fully fixed edges (FF) at its boundaries are defined in Table A.4; whose requirements apply both to single skin and sandwich.

Table A.4 — Design shear force and bending moment on a rectangular panel

Force or moment	Unit	Formula
Design shear force in the *b* direction	N/mm	$F_{db} = k_c \times k_{SHb} \times P \times b \times 10^{-3}$
Design shear force in the *l* direction	N/mm	$F_{dl} = k_c \times k_{SHl} \times P \times b \times (EI_l/EI_b)^{0,25} \times 10^{-3}$
Design bending moment in the *b* direction	N.mm/mm	$M_{db} = -1/6 \times k_{2b} \times P \times b \times 10^{-3}$
Corrected design bending moment in the *b* direction	N.mm/mm	$M_{db\ corr} = M_{db} \times k_c$
Design bending moment in the *l* direction	N.mm/mm	$M_{d\ l} = -1/6 \times k_{2l} \times P \times b^2 \times (EI_l/EI_b)^{0,5} \times 10^{-3}$
Corrected design bending moment in the *l* direction	N.mm/mm	$M_{d\ l\ corr} = M_{dl} \times k_c$

b shall be taken as the lesser of the panels dimensions, so the geometric aspect ratio A_{RG} is always >1.

The factors k_{SHb}, k_{SHl}, k_{2b},, k_{2l}, EI_b and EI_l shall be as defined in Table A.2 using A_{RE} as indicated there.

In most cases EI_b/EI_l will be >1, in which case A_{RE} will be > A_{RG} and never<1.

In some cases EI_b/EI_l will be <1, which is not regarded as good practice, but provided $EI_b/EI_l \leq A_{RG}{}^4$, A_{RE} will still be >1 and the approach is valid. Otherwise one will have to validate the panel using FEM.

NOTE The bending moments are negative at the fully fixed supports, see Figure A.11 a) that corresponds to $A_{RE} \geq 2$.

CAUTION — The formulas of Table A.4 are only valid where the panel is fully fixed at 4 edges. This is therefore not true where a topside panel is not held transversely and in rotation by a deck or a stiff beam shelf. In that case the factors k_{2b} and k_{2l} shall be determined by specific formulas (Reference [16]) or from FEM.

A.10 Requirement for thickness or bending moment due to pressure

A.10.1 General

The requirements according to analysis methods 1 to 3 of Table 2 are given in Table A.5.

Table A.5 — Requirements according to the analysis method

SIMPLIFIED method (1) GRP according to 11.2, metals and laminated wood/plywood	ENHANCED (2) or DEVELOPED (3) methods FRP glass, carbon and aramid metals and laminated wood/plywood
Single skin laminates	
$t_p = b \times k_c \times \sqrt{\dfrac{P \times k_{2b}}{1\,000 \times \sigma_d}}$ with $\sigma_d{}^{a,b}$ as defined in Table 17 k_c from Table A.3 and k_{2b} from Table A.2 See also C.4 for materials not in Tables C.6 to C.9 t_p transformed into w_f, mass of dry fibre, see 11.1	Under F_{db} & $M_{db\ corr}$ in direction *b* or F_{dl} and $M_{dl\ corr}$ in direction *l* Derived from Table A.4 & using Clause H2, For any ply of laminate $\sigma \leq \sigma_d{}^{a,b}$ in the *b* and *l* directions , where relevant, as defined in Table 17
Sandwich laminates	

[a] Mechanical properties taken for Table C.6 to C.9 for GRP and along the stressed direction *b* or *l*. See also C.4 for materiels not in Table C.6 to C.9. Annex F for wood, Annex B for metals. Apply Table 15 to determine k_{BB}.

[b] Mechanical properties of FRP shall be obtained through Annex C, and of cold moulded wood from Annex F.

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Table A.5 *(continued)*

SIMPLIFIED method (1) **GRP according to 11.2, metals and laminated wood/plywood**	**ENHANCED (2) or DEVELOPED (3) methods** **FRP glass, carbon and aramid** **metals and laminated wood/plywood**
Section modulus: $SM_{o,i} \geq \frac{P \times b^2 \times k_{2b} \times k_C \times 10^{-5}}{6\,\sigma_{d\,o,i}} = \frac{M_{db}}{\sigma_{d\,o,i}} \left(cm^3 / cm\right)$ Core shear check: $t_s = t_c + \frac{(t_o + t_i)}{2} \geq \frac{P \times b \times k_c \times k_{SHb}}{1\,000 \times \tau_{dco}}$ from Table A.3 and k_{2b} and k_{SHb} from Table A.2 Use Table A.6 for skins and Table A.7 for core SM found in Annex E, $\sigma_{do,i}$ design stress in Table 17 t_i or t_o transformed into w_f, mass of dry fibre, see 11.1	Under F_{db} & $M_{db\ corr}$ in direction b or F_{db} & $M_{dl\ corr}$ in direction l Derived from Table A.4 with k_c from Table A.3, k_{2b} and k_{SHb} from Table A.2 Use Table A.6 for skins and Table A.7 for core & use Clause H3 for sandwich analysis, For any ply of laminate $\sigma \leq \sigma^{a,b}$ in the b and l directions as relevant, as defined in Table 17
Stiffeners	
Section modulus $SM \geq \frac{0{,}083 \times k_{CS} \times P \times s \times l_u^2 \times 10^{-6}}{\sigma_{d\ t/c}} \left(cm^3\right)$ For top flange $\sigma_u = \sigma_{uc}$ and for bottom flange $\sigma_u = \sigma_{ut}$ Web shear $A_{wa} \geq A_{wd} = \frac{P \times b \times l_u \times k_{SA}}{\tau_d} \times 10^{-6}\ (cm^2)$ where A_W = h × (sum of two webs in a top hat) (cm^2) or web section for other shapes, A_{wd} is the design web shear area and A_{wa} is the actual area. k_{SA} = 5 stiffeners attached to plating, and k_{SA} = 7,5 floating stiffeners SM found in Annex G, k_{2b} & k_{SHb} in Table A.2, k_{CS} in Table A.10, design stresses in Table 17 Use Table A.11 for attached plating and Table A.12 for slenderness requirements	Under F_d and M_d derived from Table A.8 $\sigma \leq \sigma_d$ and $\tau \leq \tau_d$ from Table A.9, k_{CS} from Table A.10 Attached plating from Table A.11 Use Clause H4 for stiffener analysis, For any ply of laminate $\sigma \leq \sigma_d^{a,b}$ in the stiffener direction, as defined in Table 17 Check conformity to Table A.12 for slenderness

[a] Mechanical properties taken for Table C.6 to C.9 for GRP and along the stressed direction b or l. See also C.4 for materiels not in Table C.6 to C.9. Annex F for wood, Annex B for metals. Apply Table 15 to determine k_{BB}.

[b] Mechanical properties of FRP shall be obtained through Annex C, and of cold moulded wood from Annex F.

A.10.2 Use of bulking material and of "effective" core in bending

A.10.2.1 General

A bulking material is a core material (thick fabric, resin-rich felt, syntactic foam, etc.) intended to increase the thickness and therefore the strength and stiffness of a laminate. The bulking material functions either as an element only carrying shear (like in a sandwich) or as an element of the laminate working both in shear transmission and bending.

A.10.2.2 Resin-saturated foam/felt and syntactic foam

Resin saturated foam or felt shall be analysed using H.3.2 i.e a sandwich with a core effective in bending. The mechanical properties of resin saturated foam/felt and syntactic foam shall be the ones given by the product manufacturer or derived from tests.

NOTE Syntactic foams are generally used for stiffening superstructures and cockpits, but generally not in hull sides or bottom.

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A.10.2.3 Plywood “cores” and other "effective" cores

Where plywood is used as a “core”, the elastic constants are normally sufficiently large, compared with that of the FRP skins, for having the plywood contributing significantly to the bending strength and stiffness. For this reason, plywood “cored” panels shall be treated neither as bulking material nor as a conventional foam/balsa-cored sandwich. The same applies for any material "effective in bending" i.e. the ones than bring a significant contribution to the bending strength. Subclause H.3.2 provides details on the calculation procedure to be used.

A.10.3 Detail for assessment of metal plating

The required thickness for metal by the following does not take into account any corrosion margin or the effect of fabrication techniques. Coating is considered to be used where needed.

A.10.4 Detail for assessment of wood or plywood plating

Laminated wood means cold-moulded wood or “strip planking” (see Annex F for detailed explanations).

The structure made of a wood core with FRP skins that are designed to contribute to the plating strength is not covered in this section. See H.3.2, assuming a structurally effective core, i.e. not as a sandwich construction.

The method given in Tables A.4 and A.5 is not applicable to monocoque shell structures, i.e. those characterised by thick skin with few frames. ‘Cold-moulded’ in this context means few thin veneers (not generally less than 3) laid over closely spaced stringers. The closeness of the stringers means that curvature effects are minimal. Plywood panels are assumed to be flat or nearly so and of similar stiffness in the two directions.

For cases where the curvature is not negligible, and/or the panel has significantly different stiffness in the two directions, Annex H or more developed methods may be used.

A.11 FRP sandwich plating

A.11.1 General

This subclause applies to sandwich panels according to sandwich theory i.e. the ones where the outer and inner skins are thin in comparison to the core thickness, the core elastic modulus is small compared with that of the skins and the core failure strain in tension or compression exceeds that of the skins.

Sandwich with significantly non-isotropic skins, or where the mechanical properties differ significantly in the *b* and *l* directions, or with an effective core shall be analysed or checked using Annex H; or CLT.

A.11.2 Requirements for sandwich: Design stress in skins, core shear stress, and stability

Table A.6 details how to analyse the stress in skins, similar or dissimilar, and Table A.7 sets up the requirements for core strength.

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Table A.6 — Requirements for stress in sandwich skins due to bending

Location	Similar skin material	Dissimilar skin material
Outer skin	$\sigma_{to} = \frac{M_{dbcorr}}{SM_{ou}} \leq \sigma_{do}$ [a]	$\sigma_{to} = \frac{M_{dbcorr} \times z_{ou} \times E_{ou}}{\sum E_i \times I_i} \leq \sigma_{do}$ [b]
Inner skin	$\sigma_{ci} = \frac{M_{dbcorr}}{SM_{in}} \leq \sigma_{di}$ [a,c]	$\sigma_{ci} = \frac{M_{dbcorr} \times z_{in} \times E_{in}}{\sum E_i \times I_i} \leq \sigma_{di}$ [b,c]

$M_{db\ corr}$ to be taken in the *b* direction and, where relevant also in *l* direction (see Table A.4), M_d, *SM*, *E* and *I* are calculated for a strip 1 cm wide. σ_{do} and σ_{di} are defined in Table 17.

[a] *M* in (N.mm/mm), *SM* in (cm^3 / cm) and σ in (N/mm^2) See Annexes E and H.

[b] *M* in (N.mm/mm), z_{ou} and z_{in} are respectively distances from outer skin and inner skin from neutral axis (cm) *E* in (N/mm^2), *I* (cm^4/cm) and σ in (N/mm^2) See Annexes E and H.

[c] For inner skin σ_{di}, defined in Table 17, is a compression stress defined to avoid skin wrinkling.

NOTE 1 These formulas derive from the fact that for a fixed-ended panel, the maximum bending moment at supports governs and the external (outer) skin works in tension.

NOTE 2 In order to have an easily manageable number, it is customary to specify the requirements for sandwich in cm^3/cm for section modulus, *SM*, and in cm^4/cm for second moment, *I*. These requirements can be converted to mm^3/mm and mm^4/mm by multiplying the values of *SM* and *I* given in this subclause by 100 and 1 000 respectively.

Table A.7 — Requirements on core strength

Shear force capacity[a]	Min design shear stress[b]	Min design core compressive strength[c]
$t_s \geq \frac{F_d}{\tau_{dco}}$	$\tau_{dco} \geq \min\left[\max(0{,}7 - 0{,}12 \times L_{WL}; 0{,}3); 0{,}58\right]$	$\sigma_{dcco} \geq 0{,}008 \times P_{BASE}$ with σ_{dcco} (N/mm^2) and P_{BASE} (KN/m^2)

[a] $ts = tco + 0{,}5\,(ti + to)$ is the thickness between cgs of skins, where t_{co}, t_i and t_o are respectively the core, inner skin and outer skin thickness.

[b] This requirement is a general requirement to have cores with a minimum shear strength.

[c] Only applies to bottom plating. For side plating 70 % of this value shall be used. Where σ_{dcco} is the core design compressive strength, minimal value from the manufacturer (N/mm^2) from Table 17.

NOTE The design stress for inner skin of sandwich in Table 17 is a stability criterion against skin wrinkling as the inner skin is compressed at maximum bending moment (ends of the panel).

NOTE 3 The requirements of Table A.7 check respectively that the shear stress in the core is below the design shear stress, that the minimal design shear stress is high enough, and that the compressive strength is high enough to avoid very local impact compressing the core beyond the limit inducing delamination.

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A.11.3 Local reinforcement of the inner skin to improve wrinkling resistance

Additional inside skin plies, applied in way of stiffeners, may be used for increasing the inside skin wrinkling stress. These local pad layers shall be continuous underneath the stiffener (stiffener tabbing cannot be used for this reason) and shall extend 0,2 *b* each side of the support, so that the basic laminate can meet the reduced bending moment (assuming the Bending moment reduces to 0 at 20 % of the span from the edge) at the edge of the pad layer.

A.12 Requirements for stiffeners

A.12.1 General

Plating shall be supported by an arrangement of stiffening members, see 7.1.

The relative strength/stiffness of primary and secondary stiffening members shall be such that loads are effectively transferred from secondary to primary, then to shell and bulkheads. See ISO 12215-6 for definition of primary and secondary stiffeners.

For structural tray mouldings or egg box structures, see also ISO 12215-6.

Figure 4 shows how to determinate the stiffener spacing. Where the stiffener is not perpendicular to the plating, its characteristics shall be calculated with the value H for the top hat or metal stiffener which shall then be multiplied by 1/cos α, as shown in Figure A.9.

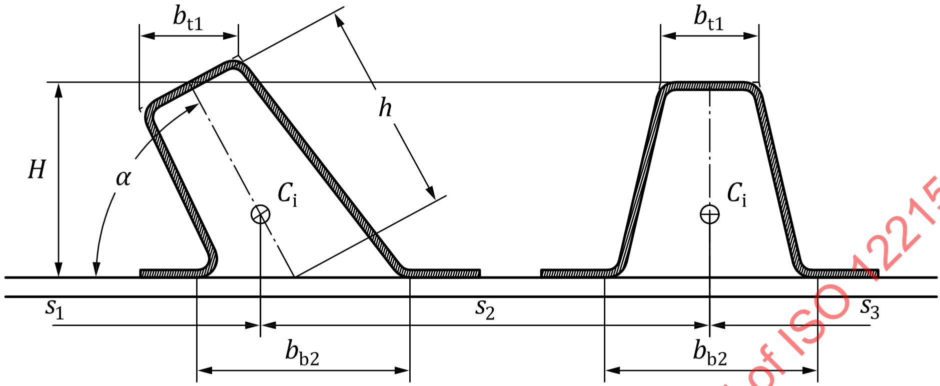

Figure A.9 — Case where stiffeners are not perpendicular to the plating

A.12.2 Shear force and bending moment due to pressure loads

The shear forces and bending moments in stiffeners due to pressure loads are given in Table A.8 and Figures A.10 and A.11. The stiffeners shall be analysed using the simplified method or a more developed one.

Where transverse stiffeners also act as ballast keel floor the total bending moments shall be assessed as per ISO 12215-9.

When the height of a stiffener varies to follow the change of the required bending moment and shear force, these changes shall be regular and shall avoid steps.

In the case of end bay, e.g. stopping a stringer at a watertight bulkhead, one shall take care to keep the stringer web high enough to transmit by shear stress the shear force at end 2 of Table A.8.

Table A.8 — Design shear force and bending moment in a stiffener according to type of end connections

<table>
<tr><th>Item</th><th>Unit</th><th colspan="4">Formula</th></tr>
<tr><td>Design shear force</td><td>N</td><td colspan="4">$F_d = k_{SF} \times k_{CS} \times P \times s \times l_u \times 10^{-3}$</td></tr>
<tr><td>Design bending moment</td><td>Nm</td><td colspan="4">$M_d = k_{BM} \times k_{CS} \times P \times s \times l_u^2 \times 10^{-6}$</td></tr>
<tr><td colspan="6">The values of the factors k_{SF} and k_{BM} vary according to the position in the beam and type of end connection. As the design shear force or bending moment cannot be nil, this document requires to avoid the 0 value "jumping" from 50 % of the closest max value to 50 % of the closest min value, see Figure A.11.</td></tr>
<tr><td colspan="2"></td><td></td><td>End 1</td><td>Middle[a]</td><td>End 2</td></tr>
<tr><td colspan="2" rowspan="4">FULLY FIXED (FF)
i.e. intermediate bays of multi-supported stiffener held by stiffer supports
See Figure A.10 a) and Figure A.11 a)</td><td>k_{SF} Theory</td><td>0,5</td><td>0</td><td>−0,5</td></tr>
<tr><td>k_{SF} Practical</td><td>0,5</td><td>±0,25</td><td>−0,5</td></tr>
<tr><td>k_{BM} Theory</td><td>−0,083</td><td>+0,042</td><td>−0,083</td></tr>
<tr><td>k_{BM} Practical</td><td colspan="3">See Figure A.11 a)</td></tr>
<tr><td colspan="6">[a] For end bay the step in shear force is where the (dotted) line crosses F=0 (see Figure A.11).</td></tr>
</table>

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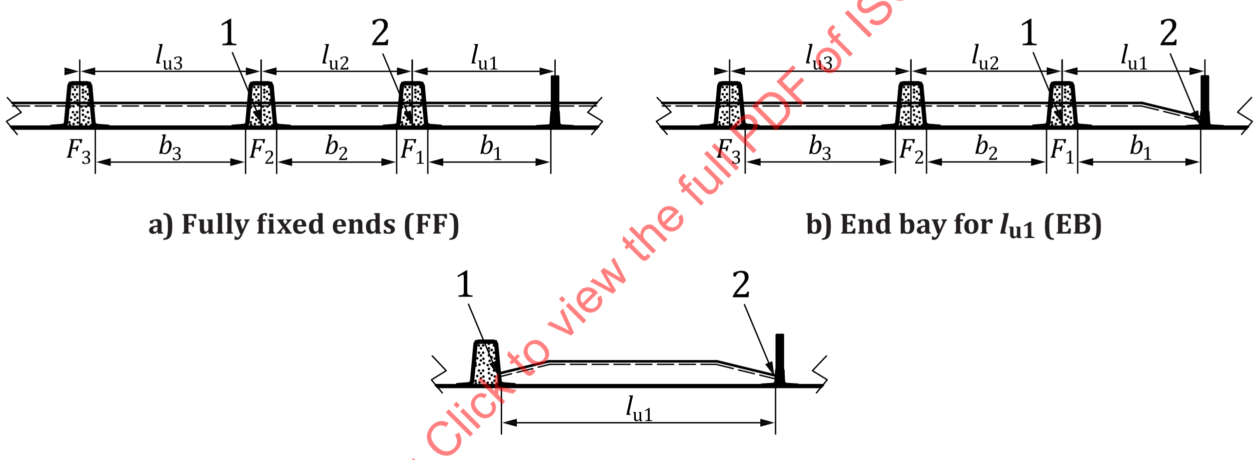
Table A.8 *(continued)*

Item	Unit	Formula			
END BAY (EB) i.e. end bay of multi-supported stiffener held by stiffer supports See Figure A.10 b) and Figure A.11 b) Note: End 1 is fully fixed, and end 2 is simply supported		k_{SF} Theory	0,625	0	−0,375
		k_{SF} **Practical**	**0,625**	**0,312/−0,185**	**−0,5**
		k_{BM} Theory	−0,125	0,07	0
		k_{BM} **Practical**	See Figure A.11 b)		
SIMPLY SUPPORTED (SS) i.e. One bay alone ending at supports with no significant clamping moment. Shear force transmitted by the connection between plating and support. See Figure A10 c) and Figure A.11 c)		k_{SF} Theory	0,5	0	−0,5
		k_{SF} **Practical**	**0,5**	**±0,25**	**−0,5**
		k_{BM} Theory	0	+0,125	0
		k_{BM} **Practical**	See Figure A.11 c)		

[a] For end bay the step in shear force is where the (dotted) line crosses F=0 (see Figure A.11).



a) Fully fixed ends (FF)

b) End bay for l_{u1} (EB)

c) Simply supported end (SS)

Key

1 end 1

2 end 2

Figure A.10 — Examples of stiffeners with FF, EB and SS ends

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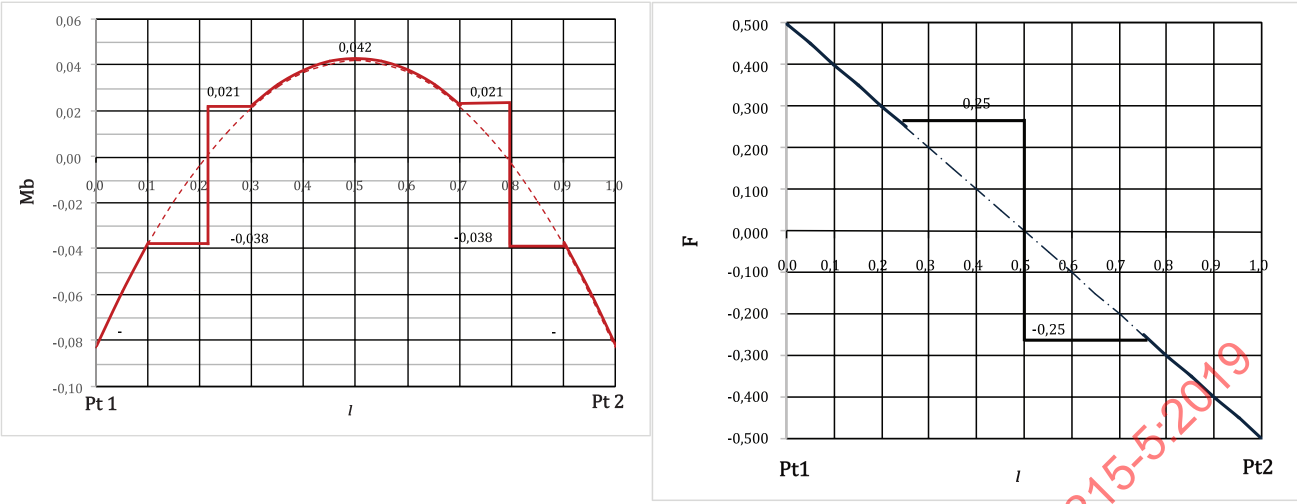
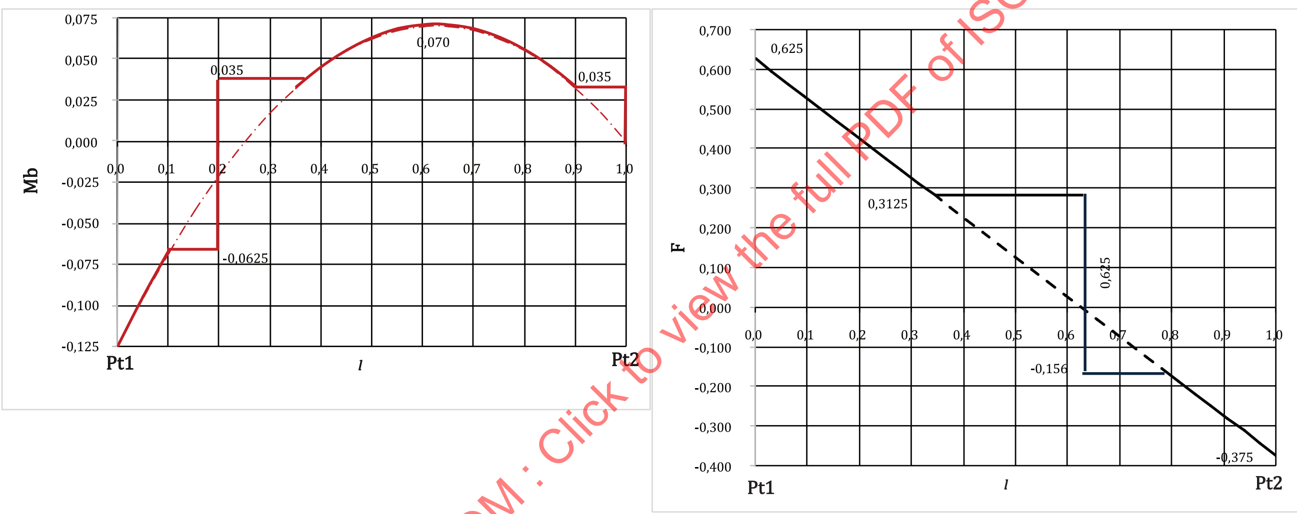
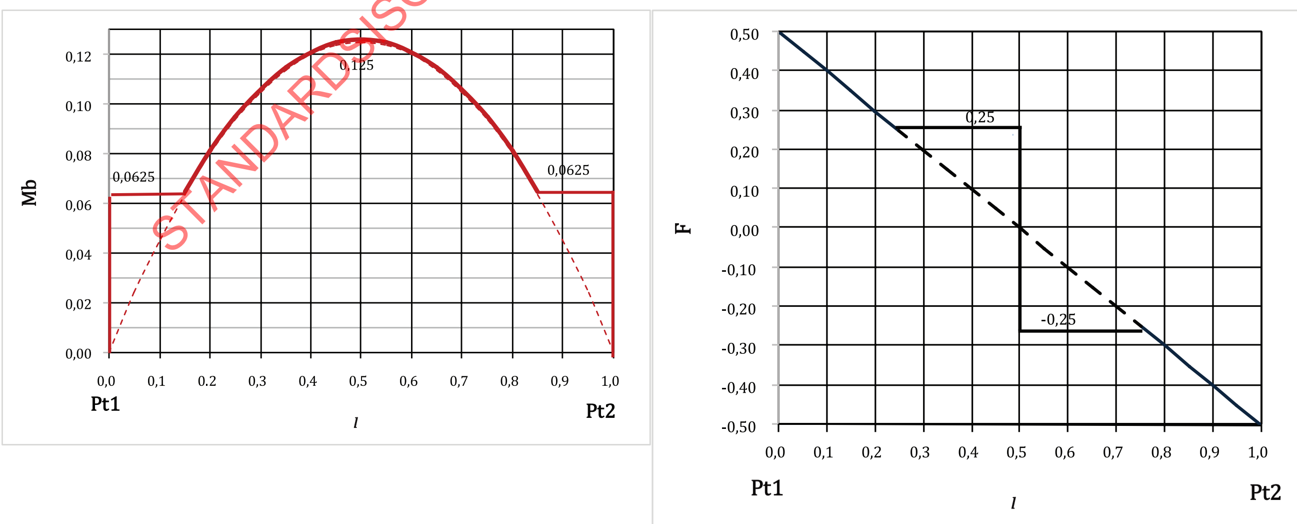


a) Fully fixed ends (FF)



b) End bay (EB) -FF/SS)



c) Simply supported ends (SS)

Figure A.11 — Bending moment and shear force diagram (see Table A.8)

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NOTE The diagram of bending moments is on the left and diagram of shear force on the right. Theoretical values in semi-dotted lines and minimum practical values in plain line.

A.12.3 Stresses in stiffeners

Table A.9 gives the formulas for stresses within a stiffener.

Table A.9 — Shear and tensile/compressive stresses in a stiffener

Item	Unit	Formula
GENERAL FORMULAS to be checked for each ply i		
Shear flow	N/mm	$q = \frac{F_d \times Q}{EI_{NA}}$
First moment (see Annex H)	Nmm	$Q = \sum E \times A_w \times (Z_i - Z_{NA})$
Requirement on shear stress	N/mm^2	$\tau_i = \frac{q}{t_i}$ with t_i = total thickness of web
Requirement on bending stress	N/mm^2	$\sigma_{i\,CRIT} = \frac{M_d}{SM_{i\,CRIT}} \le \sigma_d$
Section modulus	mm^3	$SM_i = \frac{\sum E_i \times I_{i\,NA}}{Z_{CRIT} \times E_{CRIT}}$
SIMPLIFIED FORMULAS For homogeneous materials or materials used in the "simplified" method		
Requirement on shear stress	N/mm^2	$\tau = \frac{F_d}{H_S \times t} \le \tau_d$ for stiffeners with attached plating $\tau = 1,5\frac{F_d}{H_S \times t} \le \tau_d$ for floating stiffeners (no attached plating)[a] with t = total thickness of web and H =height (mm) between CGs of bottom and top flanges
Requirement on bending stress	N/mm^2	$\sigma_{CRIT} = \frac{M_d \times Z_{CRIT}}{I} \le \sigma_d$
Section modulus	mm^3	$SM = \frac{I_{NA}}{Z_{CRIT}}$

Z_{CRIT} is the "critical" section usually either the top of the top flange or the bottom of bottom flange (outside plating).

Annex H and Annex B of ISO 12215-6:2008 give explanations and examples of all calculations above.

[a] For the case of strip planking construction where the planking grain is perpendicular to the stiffener grain. Wood stiffeners are usually made with "dissimilar" materials as the mechanical properties of a stiffener (stringer, frame) made of solid or laminated wood (along the grain) are generally much stronger than the plating. See G.4 for detailed explanations.

Dissimilar materials are those in which mechanical properties differ by ≥ ±20 % from each other. For such stiffeners, the allowable bending moment does not necessarily correspond to the stress at the farthest fibre of the neutral axis. Therefore, the criteria shall be the allowable bending moment, the required $\sum EI$ and allowable shear load. The value of Fd (Md) is that value of shear force (bending moment) which corresponds to the first ply in the laminate stack to reach the allowable design stress for that ply.

A.12.4 Curvature factor for stiffeners k_{CS}

Stiffeners are normally curved in one direction, their l_u direction. Table A.10 gives the values of k_{CS}, in function of its longitudinal camber c_l. k_{CS} shall not be taken <0,6.

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Table A.10 — Values of k_{CS} curvature factor for stiffeners

C_l/l_u	0,03	0,04	0,05	0,06	0,07	0,08	0,09	0,10	0,11	0,12
k_{CS}	1,00	0,97	0,94	0,90	0,86	0,82	0,77	0,72	0,66	0,61
The values are approached by $k_{CS} = -17{,}309 \cdot (cl/l)^2 - 1{,}804\,2 \cdot (cl/l) + 1{,}071\,7$ and are derived from the first line of Table A.3 for $C_b/b = 0{,}03$.										

A.12.5 Attached plating effective breadth b_e

The lower flange of stiffening members working in bending is a band of the plating called "effective breadth of plating" or "attached plating" as shown in Figure A.13.

NOTE Without this band of plating, that makes the stiffener plus attached plating working as an I-shaped beam, the strength of the stiffener would be significantly lower.

The breadth of effective attached plating shall be taken from Table A.11. The attached plating is the width of the plating considered as the outer flange of a stiffener, see Figure A.13.

Figure A.12 represents the computed values of Table A.11 for GRP with E/G = 3,3.

Table A.11 — Value of b_e/b in function of l/s for various types of end connection

1- THEORERICAL EQUATIONS		
Fully fixed at ends	**End bay of multi supported**	**Simply supported at ends**
Calculate $\frac{b_e}{s}$ then b_e from formulas and add b_b, the total not being taken >s		
$\frac{b_e}{s} = \frac{1}{1+2{,}478\times\left(\frac{E}{G}\right)\times\left(\frac{s}{l_u}\right)^2}$	$\frac{b_e}{s} = \frac{1}{1+1{,}467\times\left(\frac{E}{G}\right)\times\left(\frac{s}{l_u}\right)^2}$	$\frac{b_e}{s} = \frac{1}{1+0{,}825\times\left(\frac{E}{G}\right)\times\left(\frac{s}{l_u}\right)^2}$

where
— $\frac{b_e}{s}$ is the ratio between the breadth of the attached plating and the actual stiffener spacing, not to be taken<0,1;
— for top hat stiffeners, the final attached plating breadth is $b_e + b_b$ + 2 cove radius as the base width may be added, see Figure A.13 a), but shall not be taken >s;
— for L, T or I shaped metal stiffeners the effective breadth is b_e only, see Figure A.13 b);
— s is the actual spacing between stiffeners (see Figure A.13);
— l_u is the unsupported length of the stiffener;
— E and G are respectively the inplane elastic and shear modulus of the attached plating, measured in the direction of the stiffener:
  — for metal and homogeneous materials E/G = 2,6;
  — for plywood, E/G shall be taken from Annex F (Table F.3.), it is typically close to 7;
  — for FRP, E/G shall be taken from Annex C, it is typically close to 3, 3 for GRP and need not be taken >6.		

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Table A.11 *(continued)*

The effective breadth may be applied to inner and outer skins and any pad and/or bonding angle which lies within this width.									
For stiffeners along an opening, the effective breadth shall be taken as 50 % of the breadth given above.									
In any case the mechanical properties of the attached plating shall be those parallel to the stiffener.									
For strip planking, with longitudinal planks and transverse frames od bulkheads, as E_t/E_l = 0,05 in wood, same for σ_τ/σ_l the width of attached plating is nil and only the stiffener I and SM shall be considered.									
2- PRE-COMPUTED VALUES FOR FULLY FIXED ENDS AND 3 VALUES OF *l/s* for GRP, metal & plywood									
	GRP (E/G = 3,3)			**METAL (E/G = 2,6)**			**PLYWOOD (E/G = 7)**		
Panel AR	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large
l_u/s	1	1,5	2	1,5	2	3	1	2	3
b_e/s	0,11	0,22	0,33	0,26	0,38	0,65	0,05	0,19	0,34
NOTE The formulas of Item 1 are derived from: $b_e/s = 1/(1 + 3{,}3E/G\ (2/l_{00})$ where $l_{00} = l\,(1 - 0{,}667\ k_{EF})^{0,5}$ is the distance between points of zero bending moment, and k_{EF} is the ratio between moment at end/moment fully fixed = 1 for fully fixed ends, 0,667 for end bay and 0,00 for Simply supported ends (see Figure A.11).									

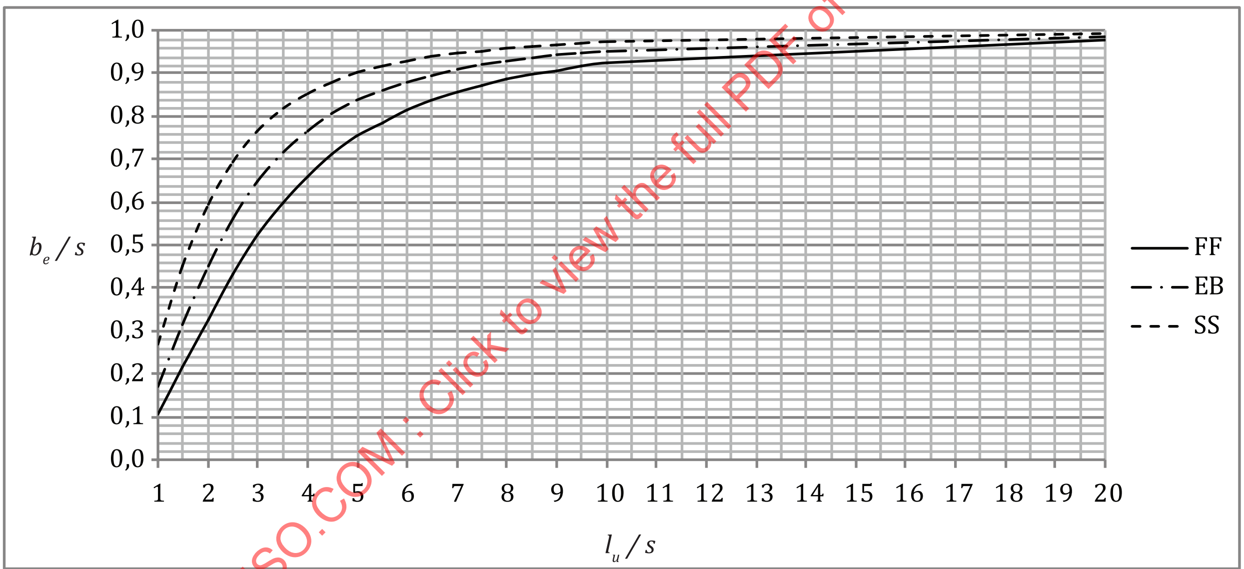

Figure A.12 — Values of attached plating breadth ratio b_e/s in function of l_u/s with E/G = 3,3

For wood stiffeners, the amount of effective plating may vary significantly according to the relative direction of the grain of the plating to the grain of the stiffener. In the case of strip planking frames where the grain of the plating is perpendicular to the grain of the frame, the effective plating is negligible, and the frame shall be considered as “floating”. Clause G.4 gives explanations and requirements on wooden frames and shall be used.

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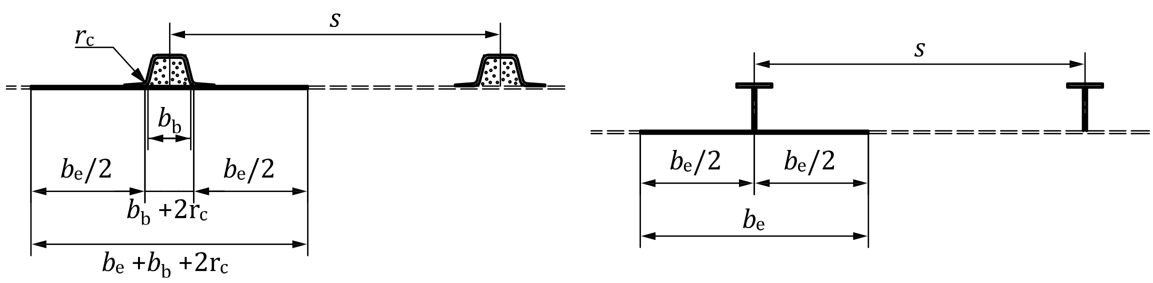

a) FRP top hat stiffener **b) Metallic stiffener**

Figure A.13 — Sketch showing the attached plating around a stiffener (top hat, L and chine)

A.12.6 Overall dimensions of stiffeners

A.12.6.1 Geometry

The transposition of a minimum section modulus, second moment of area, and shear web requirements into a stiffener geometry may be made using the formulas and Tables of Annexes G and H, and the mechanical properties of Table 17.

A.12.6.2 Maximum proportions between dimensions within a stiffener

The maximum value of stiffener dimensions proportion h/t_w and d/t_f for I- T- or L-shaped stiffeners, or $h/(t_w/2)$ and d/t_f for top hats as shown in Figure A.14 shall be taken from Table A.12. These ratios normally preclude the risk of local buckling of the stiffener.

Table A.12 — Maximum values of h/t_w and d/t_f

1- Where the actual stresses σ_{act} in flange or τ_{act} in mid web are the design stresses of Table 17					
Material	**Flat bar web**	**T or L shaped stiffener**		**Top hat stiffener**	
	h/t_w max	Web h/t_w max	Flange d/t_w max	Web $h/(t_w/2)$ max	Flange d/t_f max
Metal	$0{,}50\times\left(\frac{E}{\sigma_{yw}}\right)^{0{,}5}$	$1{,}29\times\left(\frac{E}{\tau_{yw}}\right)^{0{,}5}$	$0{,}50\times\left(\frac{E}{\sigma_{yw}}\right)^{0{,}5}$	$1{,}29\times\left(\frac{E}{\tau_{yw}}\right)^{0{,}5}$	$1{,}29\times\left(\frac{E}{\sigma_{yw}}\right)^{0{,}5}$
FRP	$1{,}12\times\left(\frac{E}{\sigma_{uf}}\right)^{0{,}5}$	$2{,}80\times\left(\frac{E}{\tau_{u}}\right)^{0{,}5}$	$1{,}12\times\left(\frac{E}{\sigma_{uf}}\right)^{0{,}5}$	$2{,}80\times\left(\frac{E}{\tau_{u}}\right)^{0{,}5}$	$2{,}80\times\left(\frac{E}{\sigma_{uf}}\right)^{0{,}5}$
Plywood	$0{,}90\times\left(\frac{E}{\sigma_{uf}}\right)^{0{,}5}$	$1{,}90\times\left(\frac{E}{\tau_{u}}\right)^{0{,}5}$	$0{,}90\times\left(\frac{E}{\sigma_{uf}}\right)^{0{,}5}$	$1{,}90\times\left(\frac{E}{\tau_{u}}\right)^{0{,}5}$	$1{,}90\times\left(\frac{E}{\sigma_{uf}}\right)^{0{,}5}$

[a] $k_{AS} = \frac{A_{wa}}{A_{wd}} = \frac{\tau_d}{\tau_{act}} = C_{F\tau}$ =design/actual shear stress required by Table 17 (See H.4.2), where A_{wa} is the actual web area and A_{wd} is the design web area defined in Table A.5

[b] $k_{SM} = \frac{\sigma_d}{\sigma_{act}} = C_{F\sigma}$ = design/actual bending stress required by Table 17 (see H.4.2).

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Table A.12 *(continued)*

2- Conservative pre-calculated values for some typical materials where actual stress is the design stress					
Steel E24	**15**	50	15	50	38
Aluminium 5083 H111	12	40	12	40	30
Aluminium 6060 T6	14	46	14	46	35
GRP all CSM contact	8	32	8	32	21
GRP M300/R500 contact	8	41	8	41	21
GRP DB±45 contact	8	23	8	23	21
Plywood 450 kg/m^3	10	40	10	40	22
3- Where the actual stresses σ_{act} or τ_{act} are lower than the design stresses of Table 17, multiply the above values by					
	Flat bar web	T or L shaped stiffener		Top hat stiffener	
	h/t_w max	Web h/t_w max	Flange d/t_w max	Web $h/(t_w/2)$ max	Flange d/t_f max
All material	1	$k_{AS}^{0,5}$ [a]	1	$k_{AS}^{0,5}$	$k_{SM}^{0,5}$ [b]

a $k_{AS} = \frac{A_{wa}}{A_{wd}} = \frac{\tau_d}{\tau_{act}} = C_{F\tau}$ =design/actual shear stress required by Table 17 (See H.4.2), where A_{wa} is the actual web area and A_{wd} is the design web area defined in Table A.5

b $k_{SM} = \frac{\sigma_d}{\sigma_{act}} = C_{F\sigma}$ = design/actual bending stress required by Table 17 (see H.4.2).

CAUTION — The requirements of Table A.12 apply to webs and flanges of top hat stiffeners that are not supported by a structurally effective core (for example a polyurethane former). Where the stiffeners web is in sandwich construction, or if the core of a Top hat meets the requirements of Table A.7 the web skins are stabilized by the core, and their critical skin buckling can be assessed by Table C.2 of ISO 12215-7:—[1]) or another documented method, checking that the actual shear stress in not greater than 50 % of the critical shear stress nor greater than τ_d defined in Table 17.

NOTE The slenderness ratios in Table A.12 are intended to prevent instability, i.e. shear buckling of the web and inplane buckling of the flange. The formulae have been derived by relating the buckling stress to a multiple of the calculated stress under the design load. Similar formulae may be derived for complex lay-ups or sandwich by using the flexural rigidity (EI) in place of the single skin stiffness ($Et^3/12$) in standard buckling formulas and comparing this with the calculated stress to ensure a margin equivalent to that implied in Table A.12.

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1) Under preparation. Stage at the time of publication: ISO/FDIS 12215-7:2019.

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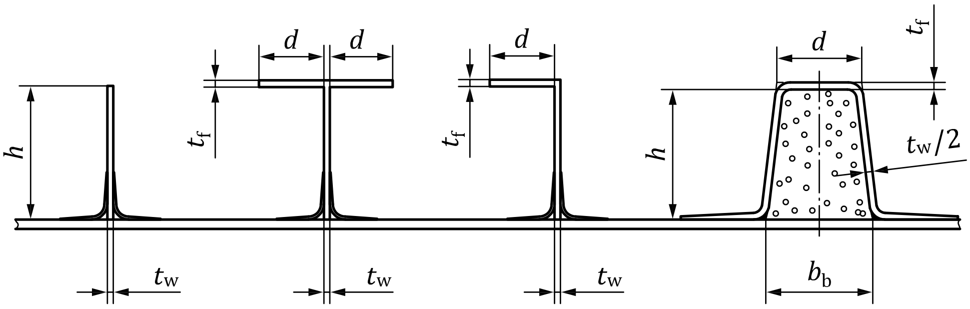

Key

1 flat bar
2 T
3 L
4 top hat

Figure A.14 — Proportions of stiffeners

A.12.6.3 Connection between the stiffener and the plating

The connection between the stiffener and the plating shall be able to transmit, with a large safety margin, the shear forces given in Table A.8. H.4.2 gives an example of such a calculation, Annex B of ISO 12215-6:2008 also gives "Established practice" details.

A.13 Structural bulkheads

A.13.1 General

Unless specifically engineered, including for local loads, mast compression, keel loads, mast pillar, rig attachments, etc. using, where relevant, parts of this standard, the following requirements on bulkheads apply.

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Table A.13 — Characteristics of bulkheads

Item	Unit	Formula[a]
Solid plywood bulkheads	mm	$t_b = 7{,}0\ D_b$[a]
Sandwich bulkhead with identical plywood skins	mm²	$t_{io} \times t_c \geq \frac{t_b^2}{6}$ strength criterion and
	mm³	$t_{io} \times \frac{t_c^2}{2} \geq \frac{t_b^3}{12}$ stiffness criterion
Sandwich bulkhead with identical FRP skins	mm²	$t_{io} \times t_c \geq \frac{t_b^2}{6} \cdot \left(\frac{25}{\sigma_d}\right)$ strength criterion and
	mm³	$t_{io} \times \frac{t_c^2}{2} \geq \frac{t_b^3}{6} \cdot \left(\frac{4\,000}{E_{io}}\right)$ stiffness criterion

Metal bulkheads shall be calculated as watertight bulkheads.

[a] D_b is the depth of the bulkhead from bottom of canoe body to actual side/deck connection (m).

t_{io} and t_s are respectively the inner and outer skins and core thickness (mm).

The minimum design shear stress of the core shall be as required in Table 17 and Table A.7.

A.14 Structural support for sailing craft ballast keel

A.14.1 General

The requirements on floors, girders, keelsons, etc. supporting loads connected to sailing craft ballast keel (heeling, vertical or longitudinal grounding or docking) are given in ISO 12215-9.

A.14.2 Reminder of requirements of ISO 12215-9

Annex D of ISO 12215-9:2012 requires that, unless specifically engineered and documented, the thickness and/or structural arrangement of the bottom shell or keel skeg plating in an area located longitudinally and transversally within 0,2 T_{MAX} from the ballast keel junction with the hull, shall be such that the design pressure of the plating is 1,8 times the bottom pressure defined in this document, including the factor k_{SLS}. This may be obtained by extra thickness or closer spacing of stiffeners. See Table A.14.

Table A.14 — Excerpt of Table D.2 of ISO 12215-9:2012

An "established practice" equivalent to 1,8 times the pressure, is to have a hull thickness of

$$t_{H\,min} = 0{,}06 b_s^{0{,}95} A_R \left(1 - 0{,}25 A_R\right) \frac{m_{LDC}^{0{,}175}}{\sigma_D^{0{,}5}} \quad \text{with}$$

— A_R = panel aspect ratio (not less than 1,0 nor greater than 2,0).

— Design stress $\sigma_d = 0{,}5\ \sigma_{uf}$ (FRP and wood), $\sigma_d = 0{,}9\ \sigma_{Yield}$ (metals).

— b_s = in mm, is the distance between adjacent stiffeners, floor or girder webs, whichever is the shorter distance (mm) not to be taken less than 350 + 5 L_{WL} (FRP) or 250 + 5 L_{WL} (other materials).

NOTE The hull thickness t_{Hmin} correspond to the requirements of ISO 12215-5 around the keel area idem for the values of σ_d above which differ from the design stress σ_d in this part of ISO 12215.

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Annex B
(normative)

Mechanical properties and design stress of metals

Unless otherwise specifically documented, the mechanical properties and design stress of metal plating and metal stiffeners shall be taken from Table B.1 and Table B.2, respectively. For aluminium alloys, data are derived from EN 14195-1.

Table B.1 — Mechanical properties and design stress of metal plating

Design stress for plating											
Mild steel σ_d=min(0,6 σ_u; 0,9 σ_y) and τ_d =0,58 σ_d			Temper	σ_u	σ_{uw}	σ_y	σ_{yw}	σ_d/σ_u	σ_d/σ_y	σ_d	τ_d [a]
E24 / A				400	400	235	235	0,6	0,9	212	123
E32 - AH 32				470	470	315	315	0,6	0,9	282	164
E36 - AH 36				490	490	355	355	0,6	0,9	294	171
Aluminium alloys (non-heat treatable) σ_d=min(0,6 σ_{uw}; 0,9 σ_{yw}) and τ_d =0,58 σ_d											
EN reference	Product and thickness	Composition	Temper	σ_u	σ_{uw}	σ_y	σ_{yw}	σ_d/σ_u	σ_d/σ_y	σ_d [b]	τ_d [a]
EN AW-5052	Sheet, strip, plate $3 < t < 50$	Al,Mg 2,5	H32	210	170	160	65	0,6	0,9	59	34
EN AW-5052	Sheet, strip, plate $3 < t < 50$	Al,Mg 2,5	H34	235	170	180	65	0,6	0,9	59	34
EN AW-5754	Sheet, strip, plate $3 < t < 50$	Al,Mg 3	0/H111	225	190		80	0,6	0,9	72	42
EN AW-5754	Sheet, strip, plate $3 < t < 50$	Al,Mg 3	H24	240	190	190	80	0,6	0,9	72	42
EN AW-5154A	Sheet, strip, plate $3 < t < 50$	Al,Mg 3,5	0/H111	215	215	85	85	0,6	0,9	77	44
EN AW-5154A	Sheet, strip, plate $3 < t < 50$	Al,Mg 3,5	H24	240	215	200	85	0,6	0,9	77	44
EN AW-5086	Sheet, strip, plate $3 < t < 50$	Al,Mg 4	0/H111	240	240	100	100	0,6	0,9	90	52
EN AW-5086	Sheet, strip, plate $3 < t < 50$	Al,Mg 4	H34	275	240	185	100	0,6	0,9	90	52
EN AW-5083	Sheet, strip, plate $t < 6$	Al,Mg 4,5 Mn 0,7	0/H111	275	270	125	125	0,6	0,9	113	65
EN AW-5083	Sheet, strip, plate $3 < t < 50$	Al,Mg 4,5 Mn 0,7	H32	305	270	215	125	0,6	0,9	113	65
AA 5059 Alustar	Sheet, strip, plate $3 < t < 50$	Al,Mg 5-6	0/H111	330	300	160	160	0,6	0,9	144	84

[a] This value is not explicitly required in this part of ISO 12215; it is taken as 0,58 σ_d for ductile materials.

[b] The value of design stress is for welded aluminium. For unwelded aluminium (riveted or glued), σ_d = min (0,6σ_{uw} or 0,9σ_{yw}) unwelded.

NOTE σ_u and σ_y are tensile stresses.

The value of E modulus of metal is required in some formulas (e.g. Tables A.9, A.11 & A.12, etc.) and, unless specifically documented, the default following values may be used:

Mild steel: E= 210 000 N/mm^2 Aluminium alloys E: = 70 000 N/mm^2.

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Table B.1 *(continued)*

AA 5059 Alustar	Sheet, strip, plate 3 < *t* < 50	Al,Mg 5-6	H34	370	300	270	160	0,6	0,9	144	84
EN AW-5383	Sheet, strip, plate 3 < *t* < 50	Al,Mg 4,5 Mn 0,9	0/H111	290	290	145	145	0,6	0,9	131	76
EN AW-5383	Sheet, strip, plate 3 < *t* < 50	Al,Mg 4,5 Mn 0,9	H34	305	290	220	145	0,6	0,9	131	76

[a] This value is not explicitly required in this part of ISO 12215; it is taken as 0,58 σ_d for ductile materials.

[b] The value of design stress is for welded aluminium. For unwelded aluminium (riveted or glued), σ_d = min (0,6σ_{uw} or 0,9σ_{yw}) unwelded.

NOTE σ_u and σ_y are tensile stresses.

The value of E modulus of metal is required in some formulas (e.g. Tables A.9, A.11 & A.12, etc.) and, unless specifically documented, the default following values may be used:

Mild steel: E= 210 000 N/mm^2 Aluminium alloys E: = 70 000 N/mm^2.

Table B.2 — Mechanical properties and design stress of metal stiffeners

Design stress for stiffeners											
Mild steel σ_d =0,8 σ_y and τ_d =0,58 σ_d				σ_u	σ_{uw}	σ_y	σ_{yw}	σ_d/σ_y	σ_d	τ_d	
E24 / A				400	400	235	235	0,8	188	109	
E32 - AH 32				470	470	315	315	0,8	252	146	
E36 - AH 36				490	490	355	355	0,8	284	165	
Aluminium alloys (non-heat treatable) σ_d =0,7 σ_{yw}											
EN reference	**Product and thickness**	**Composition**	**Temper**	σ_u [a]	σ_{uw} [a]	σ_y	σ_{yw}	σ_d/σ_{yw}	σ_d [b]	τ_d	
EN AW-5052	Sheet, strip, plate 3 < *t* < 50	Al,Mg 2,5	H32	210	170	160	65	0,7	46	26	
EN AW-5052	Sheet, strip, plate 3 < *t* < 50	Al,Mg 2,5	H34	235	170	180	65	0,7	46	26	
EN AW-5754	Sheet, strip, plate 3 < *t* < 50	Al,Mg 3	0/H111	225	190	80	80	0,7	56	32	
EN AW-5754	Sheet, strip, plate 3 < *t* < 50	Al,Mg 3	H24	240	190	190	80	0,7	56	32	
EN AW-5154A	Sheet, strip, plate 3 < *t* < 50	Al,Mg 3,5	0/H111	215	215	85	85	0,7	60	35	
EN AW-5154A	Sheet, strip, plate 3 < *t* < 50	Al,Mg 3,5	H24	240	215	200	85	0,7	60	35	
EN AW-5086	Sheet, strip, plate 3 < *t* < 50	Al,Mg 4	0/H111	240	240	100	100	0,7	70	41	
EN AW-5086	Sheet, strip, plate 3 < *t* < 50	Al,Mg 4	H34	275	240	185	100	0,7	70	41	
EN AW-5083	Sheet, strip, plate *t* < 6	Al,Mg 4,5 Mn 0,7	0/H111	275	275	125	125	0,7	88	51	
EN AW-5083	Sheet, strip, plate 3 < *t* < 50	Al,Mg 4,5 Mn 0,7	H32	305	275	215	125	0,7	88	51	

[a] The ultimate values are given for information only as the design stress is based on yield strength in welded conditions.

[b] The value of design stress is for welded aluminium. For unwelded aluminium (riveted or glued), σ_d = min (0,6σ_{uw} or 0,9σ_{yw}) unwelded a.

NOTE σ_u and σ_y are tensile stresses.

The value of *E* modulus of metal is required in some formulas (e.g. Table A.9, A.11 & A.12, etc.) and, unless specifically documented, the default following values may be used:

Mild steel *E* = 210 000 N/mm^2 Aluminium alloys *E* = 70 000 N/mm^2.

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Table B.2 *(continued)*

AA 5059 Alustar	Sheet, strip, plate $3 < t < 50$	Al,Mg 5-6	0/H111	330	300	160	160	0,7	112	65
AA 5059 Alustar	Sheet, strip, plate $3 < t < 50$	Al,Mg 5-6	H32	370	300	270	160	0,7	112	65
EN AW-5383	Sheet, strip, plate $3 < t < 50$	Al,Mg 4,5 Mn 0,9	0/H111	290	290	145	145	0,7	102	59
EN AW-5383	Sheet, strip, plate $3 < t < 50$	Al,Mg 4,5 Mn 0,9	H32	305	290	220	145	0,7	102	59
Aluminium alloys (heat treatable) $\sigma_d = 0{,}7\ \sigma_{yw}$ and $\tau_d = 0{,}58\ \sigma_d$										
EN AW-6060	Profiles, bars, Tubes $3 < t < 25$	Al,Mg Si	T5,T6	190	95	150	65	0,7	46	26
EN AW-6061	Profiles, bars, Tubes $3 < t < 25$	Al,Mg1, Si Cu	T5,T6	260	165	240	115	0,7	81	47
EN AW-6061	Closed profiles	Al,Mg1, Si Cu	T5,T6	245	165	205	115	0,7	81	47
EN AW-6063	Profiles, bars, Tubes $3 < t < 25$	Al,Mg 0,7 Si	T5	150	100	110	65	0,7	46	26
EN AW-6063	Profiles, bars, Tubes $3 < t < 52$	Al,Mg 0,7 Si	T6	205	100	170	65	0,7	46	26
EN AW-6005A	Profiles, bars, Tubes $3 < t < 51$	Al,Si,Mg (A)	T5,T6	260	165	215	115	0,7	81	47
EN AW-6005A	Closed profiles $3 < t < 50$	Al,Si,Mg (A)	T5,T6	250	165	215	115	0,7	81	47
EN AW-6082	Profiles, bars, Tubes $3 < t < 25$	Al,Si 1,Mg,Mn	T5,T6	310	170	260	115	0,7	81	47
EN AW-6082	Closed profiles	Al,Si 1,Mg,Mn	T5,T6	290	170	240	115	0,7	81	47
EN AW-6106	Profiles, bars, Tubes $3 < t < 25$	Al,Mg,Si,Mn	T6	240	240	195	195	0,7	81	47

[a] The ultimate values are given for information only as the design stress is based on yield strength in welded conditions.

[b] The value of design stress is for welded aluminium. For unwelded aluminium (riveted or glued), σ_d = min ($0{,}6\sigma_{uw}$ or $0{,}9\sigma_{yw}$) unwelded a.

NOTE σ_u and σ_y are tensile stresses.

The value of E modulus of metal is required in some formulas (e.g. Table A.9, A.11 & A.12, etc.) and, unless specifically documented, the default following values may be used:

Mild steel E = 210 000 N/mm^2 Aluminium alloys E = 70 000 N/mm^2.

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Annex C
(normative)

FRP laminates properties and calculations

C.1 Status of this Annex

This Annex shall be used for the analysis methods 1 to 3 of Table 2. For the analysis method 5 (FEM), other documented values may be used but it should be checked that their values do not differ from the ones in this Annex by a large margin.

C.2 Determination of the mechanical properties

C.2.1 Tests and test standards

Mechanical properties to be used as input in determining the bending moment, stiffness and shear capabilities of FRP laminates and stiffeners may be derived either by testing of representative samples using the appropriate ISO or ASTM test standards or by calculation or by a combination of the two.

Table C.1 — Examples of test standard references and specific tests

1-Examples of test standards
Tensile properties: ISO 527-4, ISO 527-5
Flexural properties: ISO 178
Compressive properties: ISO 14126
Inplane shear properties: ISO 14129
Interlaminar shear stress: ISO 14130
Through-thickness « flatwise » tensile properties: ASTM D7291
2-General application of the above standards
Where an International Standard does not exist, a national standard may be used instead. The number of samples to be tested shall be as laid down in international or national standards but shall not be less than five samples for any given property.
When determining the flexural strength, the gel coat side of the specimen shall be stressed in tension.
Unless specifically stated in the test standard, the mechanical properties used in the calculations shall be corrected from test values as follows: — for strength 90 % of the mean ultimate strength or the mean value minus two standard deviations whichever is the lesser; — for elastic modulus, the mean value.

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Table C.1 *(continued)*

3-Alternative method for testing compression strength of UDs
It is often difficult to apply ISO 14126, particularly for carbon-based UD
An alternative method based on four-point bending tests can be used to measure compressive stress of unidirectional composites (glass, carbon fibres).
Comparing to « pure » compressive tests (ISO 14126), the advantages of four-point bending tests are the followings: — sample geometry (no end tabs, tolerances); — common tooling's; — adapted for thick laminates; — possibility to measure ultimate compressive stress of unidirectional layers inside real scantlings.
In order to prevent early damages under load points, bi-axial layers (0/90 or +−45) on sample facings and load tabs can be used.
Sample failures are validated when the failure occur at the upper face between the 2 load points.
From ply thickness measurements, an ultimate compressive strength in the UD is then calculated using the recorded force at failure.
These tests may be conducted using the specifications of ASTM D6272 standard.

As a minimum, the fibre mass fraction (ψ) shall be measured by weighing a resin-consolidated panel of known fibre mass, see Example 1. Resin ignition tests may also be used. The panels used for this purpose shall be representative of the as built quality. Where it is not practical to take suitably sized panels from the actual or previous craft, special care must be taken to ensure that laboratory made samples are representative.

Table C.2 gives the relations between the mass fraction ψ, the volume fraction ϕ, the ratio t/w and laminate density ρ.

NOTE 1 The above requirements aim at taking the appropriate steps to ensure that the mechanical capability (not simply mechanical properties, but also taking geometry into account) and properties of the as-built laminate are equal or superior to those at the design stage.

C.2.2 Topics on tests and calculation

Many CLT software consider a linear behaviour $\sigma = E \times \varepsilon$, which is not true in reality: when testing a laminate, one can see that, after an initial linear behaviour, the stress/strain plot gets curved. This is due to micro cracks or damages occurring after the failure of some, non-critical, plies.

It is practically difficult to measure ε_u real, and when the initial elastic modulus, E initial, and $\sigma_{u\ test}$ are measured, one shall take E calculation = E initial and $\varepsilon_{calc} = \dfrac{\sigma_{test}}{E_{initial}}$, see Figure C.1.

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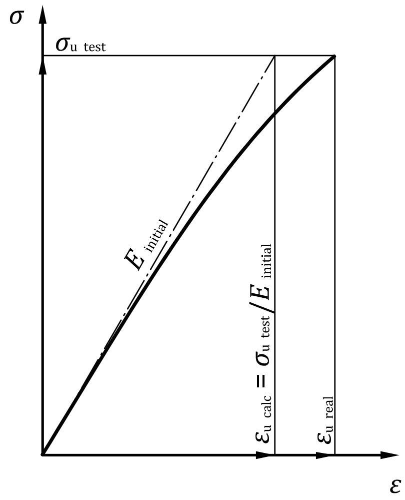

Figure C.1 — Determination of ε_u

Table C.2 — Values of t/w, composite density ρ_c according to fibre content by volume ϕ or mass ψ

$\psi = \dfrac{\phi \times \rho_f}{\phi \times \rho_f + (1-\phi)\times \rho_m}$	$\phi = \dfrac{\psi}{\psi + (1-\psi)\times \dfrac{\rho_f}{\rho_m}}$	$\dfrac{t}{w} = \dfrac{1}{\phi \times \rho_f}$
$\rho_c = \rho_f \times \phi + \rho_m \times (1-\phi)$ or $\rho_c = \dfrac{\rho_f \times \rho_m}{\rho_f + \psi(\rho_m - \rho_f)}$		$t = \dfrac{w}{\rho_f \times \rho_m}\left(\dfrac{\rho_f}{\psi} + \rho_m - \rho_f\right)$
t	Thickness of the laminate	mm
w	Dry mass of fibre	kg/m2
ϕ	Fibre content by volume in the laminate (dry fibre volume/laminate volume)[a]	1
ψ	Fibre content by mass in the laminate (dry fibre mass/laminate mass).	1
ρ_f, ρ_m	Density, respectively of fibre and matrix, may be taken from Table C.2 or from manufacturer's information	kg/m3
[a] For guidance purposes see also Table C.7.		

C.2.3 Use of flexural strain and strength

The values of flexural stresses as tested with ISO 178 or equivalent give significantly high stresses compared with tensile/compression. Reference [25] quotes $\sigma_{uf} = k_G \times \sigma_{ut} / (1 + \sigma_{ut}/\sigma_{uc})$ for GRP with k_G ranging from 2,5 to 3 according to the type of laminates, similar values for Carbon and Aramid. This high values of σ_{uf} induced that ISO 12215-5:2008 required single skin laminates using σ_f that were always thinner than the ones required by the ply by ply analysis of Annex H, using σ_t.or σ_c. However as the -thinner- laminates designed with σ_f did not prove to be underbuilt in practice, this revision document allows the use of $\pm\sigma_f$ instead of σ_t/ σ_c for the ply by ply analysis of single skin laminates in Annex H. The reason is that these laminates are likely to operate in the large deflection regime, particularly under high slam pressures. As the scantling formulas are based on the more conservative small deflection theory, the use of in plane ultimate strains may be a case of "double penalty". Sandwich panels, being stiffer are more likely to be operating within the small deflection regime and hence the use of inplane strains is appropriate. CLT theory method usually only apply σ_t/σ_c. Tables C.6 and C.9/C.10 detail the values of ε_{uf}.

C.2.4 Mechanical properties for the simplified method

The "simplified" method described in 11.2 and Table A.5 only considers Glass Reinforced Plastics (not Carbon composites). Unless derived from tests, according to C.2, the mechanical properties shall be

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derived from Tables C.6 to C.10. These tables do not give the values for one "thick" layer of a mixing of the plies given in Table C.6, like, for example, Mat/Roving. Clause C.4 and Table C.11 give some examples on such calculations.

C.2.5 Elastic constants using 'CLT' method (classical laminate theory)

In the 'CLT' method, the elastic constants are derived from manufacturers' fibre and resin properties for a known fibre volume content using well-established and empirically modified rule of mixtures formulas. It is not necessary to provide these formulas within the document since they are documented in the "Law of mixtures" and Classical Lamination theory (CLT). As for single skin, the flexural stress is used, it is recommended to replace the design strains ε_{ut} or ε_{uc} by $\pm\varepsilon_{uf}$ otherwise the scantlings could be conservative compared to the simplified or enhanced method.

NOTE For guidance, the Bureau Veritas or DNV-GL publications listed in the bibliography were among the source references used in developing Tables C.5 and C.6. Elastic constants of woven roving, double-bias (+45/−45), etc. may be obtained separately from the [A] submatrix by combining unidirectional plies at the appropriate orientation (a symmetrical layup being recommended to eliminate in-plane/out of plane coupling).

C.2.6 Elastic constants using 'SRM' method (simplified regression method)

For the builders or designers not wishing to use the CLT method, the simpler Simplified Regression Method (SRM) is proposed, both methods work similarly for cross plies, but treat angle plies differently, see details in C.2.5. Table C.4 shows physical and mechanical properties used in the CLT method, and Table C.5 gives the main mechanical properties of UD and of several "typical" plies/multiplies.

Table C.3 sums up the "flow chart" of the procedure to follow in either SRM/Ply stack analysis or CLT.

Table C.3 — Procedure to obtain mechanical properties and allowable bending moment and shear forces for single skin or sandwich plating

STAGE 1-PLY ELASTIC CONSTANTS AND BREAKING STRAINS	
Obtained from; Test data or Simplified regression formulas (Tables C.4 to C.8 tabulated in Tables C.9 & C.10) or Other verified formulae (Tables C.2 & C.5)	
STAGE 2-MODIFY PROPERTIES TO REFLECT BOAT BUILDING CHARACTERISTICS k_{BB} (Table 16)	
Obtained from; Same formulas as above but modified following tests and details and by k_{BB} in Table 16	
STAGE 3-OBTAIN LAST PLY FAILURE BENDING MOMENT AND SHEAR FORCES	
For single skin laminates use $\sigma_d = 0{,}5 \pm \sigma_{uf} \times k_{BB}$ For sandwich laminates, depending on stress sense use $\sigma_d = \sigma_{ut}$ or σ_{uc} or wrinkling $\times\, k_{BB}$ Obtain flexural stiffness for deflection checks	
OPTION 1 Annex H: Simplified laminate stack method	**OPTION 2** CLT (Classical Lamination Theory)[a]
Multiply the previous design stress by $k_{AM} = 0{,}95$ for FRP according to Table 16 (Enhanced method) Caution: the strains and stresses are along fibre	Multiply the previous design stress by $k_{AM} = 1$ for FRP according to Table 16 (developed method) Caution; CLT software may not always check wrinkling, then a manual check is needed For DBx and Qx input as angled WR combination and transformed into 1-2 system for assessment Failures are based on any of the generally recognized failure envelope formulas.

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Table C.3 *(continued)*

STAGE 4-OBTAIN ACTUAL vs REQUIRED LAST PLY FAILURE BENDING MOMENT AND SHEAR FORCES
Use Annex H or CLT software to find last ply failure stress (see NOTE), calculate design stress per Table 17 and find the compliance factor CF=σ design/ σ actual that shall be ≥1
[a] For sandwich check whether CLT software can obtain shear force internally (need to have transverse shear stiffness with 4 × 4 matrix) otherwise use method in Annex H for sandwich.
NOTE The last ply failure is usually the first ply failure, but this is not always the case, particularly when one mix stiff (carbon) and non stiff plies (GRP), or when using UD plies at 90° from mains stress direction. For example in a ply with 90 % UD in the sense of maximal stress and 10 % UD perpendicular to it, the transverse ply fails first but 90 % of the strength remains.

C.2.7 Final mechanical properties

This Annex proposes several methods to define the mechanical properties of the laminate, but their final values depend significantly on the “as built” quality of the material achieved by the boatbuilder. Therefore, the final "design" mechanical properties used for calculation of composites in Table 17 needs to be adjusted by the factors k_{BB} and k_{AM} defined in Table 16.

Tables C.4 to C.10 may be implemented for other fibres or matrices.

Table C.4 — Physical and mechanical properties of fibres and matrices

			Reinforcement fibres			Matrices
			E Glass	Aramid	Carbon HS	Polyester/epoxy
Specific gravity ρ (ρ_f or ρ_m)		t/m³	2,56	1,44	1,78	1,2
Elastic modulus E (E_{f1} , E_{f2} or E_m)	E_{f1}// Fibres	N/mm²	73 000	124 000	235 000	3 300
	E_{f2}⊥ Fibres	N/mm²	73 000	6 900	20 000	3 300
Shear modulus G (G_f or G_m)		N/mm²	30 000	2 800	50 000	1 222
Poisson's ratio ν (ν_f or ν_m)		1	0,22	0,36	0,27	0,32

NOTE The standard formulas in the CLT method are either exact linear (major modulus and Poisson’s ratio) or very nearly quadratic (minor modulus and shear modulus). The CLT method requires input data which may not be readily available from manufacturers, such as transverse modulus of fibre and resin Poisson’s ratio. Furthermore, there is no fixed relationship between for example modulus of polyester versus that of epoxy which holds for all commercially available resin. Consequently, the source references above together with predictions from formulas used either using Reference [24] or by the National Physical Laboratory (UK) (which include empirical correction factors) have been used for generic fibres and resin as defined in Table C.4.

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Table C.5 — Formulas for UD and laminates of Tables C.6 and C.7

<table>
<tr><th colspan="4">1-Theoretical formulas for UD</th></tr>
<tr><td colspan="2">$E_{UD1} = 0{,}975 \times \left[E_{f1} \times \phi + E_m \times (1-\phi)\right]$</td><td colspan="2">$E_{UD2} = E_m \dfrac{1+\zeta \times \eta_E \times \phi}{1-\eta_E \times \phi}$ with $\zeta = 1$ and $\eta_E = \dfrac{E_{f2}/E_m - 1}{E_{f2}/E_m + \zeta}$</td></tr>
<tr><td colspan="2">$G_{UD12} = G_m \dfrac{1+\zeta \times \eta_G \times \phi}{1-\eta_G \times \phi}$ with $\zeta = 1$ and $\eta_G = \dfrac{G_f/G_m - 1}{G_f/G_m + \zeta}$</td><td colspan="2">$\nu_{UD} = \nu_f \times \phi + \nu_m \times (1-\phi)$ Poisson's ratio</td></tr>
<tr><td colspan="2">$\tau_{UIL} = 22{,}5 - \dfrac{33\phi}{\phi + 0{,}89}$ interlaminar shear stress</td><td colspan="2">$\nu_{UD\,21} = \nu_{UD\,12} \dfrac{E_{UD2}}{E_{UD1}}$</td></tr>
<tr><td colspan="4">The above formulas are derived from Halpin-Tsai formulas, where ϕ is the fibre content in volume, and other variables defined in Table C.4</td></tr>
<tr><th colspan="4">2-Formulas for other laminates: CSM; biaxial 0/90 (BD+); double bias ±45 (DB×), and quadriaxial (Q×)</th></tr>
<tr><td colspan="4">Except for E glass chopped strand mat, the formulas apply to any "building" FRP fibre (Glass, carbon, Aramid, etc.)</td></tr>
<tr><td>Material</td><td>Young's modulus</td><td>Shear modulus</td><td>Major Poisson's ratio</td></tr>
<tr><td>E Glass Chopped strand mat</td><td>$E_{CSM} = 3/8\ E_{UD1} + 5/8\ E_{UD2}$</td><td>$G_{CSM} = 1/8\ E_{UD1} + 1/4\ E_{UD2}$</td><td>$\nu_{CSM} = E_{CSM}/2\ G_{CSM} - 1$</td></tr>
<tr><td>BD+
0/90 Biaxial or woven roving</td><td>$E_{BD+} = 0{,}5\ (E_{UD1} + E_{UD2})$</td><td>$G_{BD+} = G_{UD12}$</td><td>$\nu_{BD+} = \nu_{UD12} \dfrac{E_{UD2}}{E_{BD+}}$</td></tr>
<tr><td>DB×
±45° Double bias</td><td>$E_{DBx} = \dfrac{4E_{BD+}}{\dfrac{E_{BD+}}{G_{BD+}} + 2(1-\nu_{BD+})}$</td><td>$G_{DBx} = \dfrac{E_{BD+}}{2(1+\nu_{BD+})}$</td><td>$\nu_{DBx} = \dfrac{E_{DBx}}{4E_{BD+}} \left[\dfrac{E_{BD+}}{G_{BD+}} - 2(1-\nu_{BD+})\right]$</td></tr>
<tr><td>Q× Quadriaxial
0/45/90/−45°</td><td>$E_{QX} = 0{,}5[A_{11} - A_{12}^2/A_{11}]$</td><td>$G_{QX} = 0{,}5\ (G_{BD+} + G_{DBx})$</td><td>$\nu_{QX} = A_{12}/A_{11}$</td></tr>
<tr><td colspan="4">with $A_{11} = \dfrac{E_{BD+}}{1-\nu_{BD+}^2} + \dfrac{E_{DBx}}{1-\nu_{DBx}^2}$ and $A_{12} = \dfrac{\nu_{BD+} \times E_{BD+}}{1-\nu_{BD+}^2} + \dfrac{\nu_{DBx} \times E_{DBx}}{1-\nu_{DBx}^2}$</td></tr>
</table>

C.2.8 Breaking strains — Both methods CLT or SRM

The breaking strains, to be used in Table C.8 are given in Table C.6.

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Table C.6 — Breaking strains in %

Breaking strains[a] (ultimate strength/initial *E* modulus) in %			
Type of fibre & resin		E Glass & polyester	HS Carbon & epoxy
$\varepsilon_{ufi} = k_G\, \varepsilon_{uti}/(1 + \varepsilon_{uti}/\varepsilon_{uci})$ with i = 1 or 2 and k_G[b]= 2,50 or 2,94, see columns 3 and 4.		k_G = 2,50	k_G = 2,94
Unidirectional quoted "UD"	ε_{ut1}	1,90	1,00
	ε_{ut2}	0,50	0,50
	ε_{uc1}	1,40	0,70
	ε_{uc2}	1,40	1,90
	ε_{uf1}[b]	2,02	1,21
	ε_{uf2}[c]	0,92	1,16
	γ_{u12}	1,70	1,50
CSM Chopped strand mat	ε_{ut}	1,35	Not applicable
	ε_{uc}	1,70	
	ε_{uf}[b]	1,88	
	γ_{u12}	2,00	
WR/bidirectional 0/90° quoted" BD+"	ε_{ut}	1,55	1,00
	ε_{uc}	1,40	0,70
	ε_{uf}[b]	1,84	1,21
	γ_u	1,70	1,40
Double bias ±45 quoted "DB×"°	ε_{ut}	1,06	0,77
	ε_{uc}	1,02	0,75
	ε_{uf}[b]	1,30	1,12
	γ_u	1,80	1,02
Quadriaxial 0/45/90/_45 quoted "Q×"°	ε_{ut}	1,30	0,92
	ε_{ut}	1,20	0,74
	ε_{uf}[b]	1,56	1,21
	γ_u	1,70	1,02

[a] Design strain (%) = 0,5 × breaking strain. Design stress= 0,5 × Associated modulus × breaking strain/100 Associated modulus means use E_{UD2} with ε_{UC2} to obtain compressive strength perpendicular to fibres for a unidirectional, G_{BX} with γ_U to obtain the shear strength for a biaxial, etc.

[b] The experimental factor k_G is proposed by Green in Reference [25] to correlate flexural strain with tensile and compressive strains in the fibre direction for UD and generally in composites.

[c] The value in b above has been applied to transverse strains on UD, but this is pending validation, σ_{uf2} being anyway << σ_{uf1}.

NOTE Table C.6 is based on published values in two classification rules, ISO 12215-5:2008 and data supplied by industry.

NOTE Tables C.6, C.7, C.9 and C.10 are only computed for *E* glass/polyester and *HS* Carbon/epoxy. Other building fibres (Other type of glass or carbon, Aramid, etc) or resins may be used provided documented values are used.

C.2.9 Practical use of CLT & SRM methods

C.2.9.1 Preliminary

When using the CLT method, panel coordinate system strains (ε_x, ε_y and γ_{xy}) are transformed into individual ply coordinate system strains (ε_1, ε_2 and γ_{12}) and hence a double-bias cloth is transformed into a WR/BD+ and the above strains may be used.

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In SRM method, there is no transformation and it is necessary to determine E_{DBx} etc. for use in the laminate stack (see Annex H), it is also necessary to determine the breaking strain at 45 degrees to the fibres.

For built-in panels, the traditional approach is to use a single uniaxial stress or strain load case. Using the maximum stress or strain criterion, a double bias subjected to such a strain fails when; $\varepsilon_{DB} = 2\ \gamma_{U12}$ $[G_{BX}/E_{DB}]$ (with γ_{U12} taken from Table C.7 for WR/BD+).

C.2.9.2 Use of CLT and SRM methods

The Classical Lamination Theory (CLT) method is intended for the ones using complex layups, often including UD plies at 0 and 90 degrees and/or triaxial or unbalanced biaxial cloths (different fibre mass in warp and weft) as well as asymmetrical layups up which generate D_{16}, D_{26} and $B_{ij} \neq 0$ in the stiffness matrix, therefore introducing complex coupling effects.

Users may apply SRM method properties as input into validated CLT software (commercial or in-house) with the load vector determined using the simple methods of the document.

However, when using UD-90 plies which generally have low tensile strain (ε_{ut2}) as indicated in Table C.6, CLT or Annex H are liable to give a low bending capability value as the method underpinning this document is first ply to fail. Analysing the stack as last ply to fail is normally outside the scope of this Annex.

The SRM method is intended for users who generally use combinations of biaxial, double bias and quadriaxial with or without mat, to achieve a reasonably balanced laminate.

The simple formulae for bending moments and shear forces using this standard generally do not consider more than one significant stress acting at any given point, i.e. the load vector generally consists of just Mx or My or Nxy). This permits a laminate to be analysed using the laminate stack method outlined in Annex H.

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C.2.10 Ply thickness

Ply theoretical thickness shall be calculated using the formulas of Table C.2 (top right cells), or according either to volume fraction ϕ, or mass fraction ψ or using the pre-computed values of Table C.7, C.9 or C.10

Table C.7 considers that fibre content in volume ϕ is mainly connected to the lamination process, and the fibre content in mass ψ is then calculated from the density of fibre and matrix (resin).

Table C.7 — "Guidance values" for fibre content

Lamination process	Material	Fibre content in volume	Fibre content in mass ψ , t/w and composite density ρ_c					
			Glass ρ_f =		2,56	Carbon HR ρ_f =		1,78
		ϕ	ψ	t/w	ρ_c	ψ	t/w	ρ_c
Hand layup simple surface	CSM	0,167	0,300	2,34	1,43	—	—	—
	Woven Roving	0,300	0,478	1,302	1,61	0,389	1,87	1,37
	Rovimat	0,246	0,410	1,588	1,53	—	—	
	Multidirectional	0,319	0,500	1,225	1,63	0,410	1,76	1,39
	Unidirectional	0,364	0,550	1,073	1,70	0,459	1,54	1,41
Hand layup Complex surface	CSM	0,134	0,248	2,924	1,38	—	—	—
	Woven Roving	0,240	0,403	1,628	1,53	0,319	2,34	1,34
	Rovimat	0,197	0,343	1,985	1,47	0,267	2,85	1,31
	Multidirectional	0,255	0,422	1,531	1,55	0,337	2,20	1,35
	Unidirectional	0,291	0,467	1,341	1,60	0,378	1,93	1,37
These values are given as a guide only and are considered achievable by the industry, but it is the responsibility of the builder to check the values that his building methods are currently achieving. For complex surfaces, the fibre content in volume is 80 % of the ones for simple surfaces.								

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Table C.7 *(continued)*

Lamination process	Material	Fibre content in volume	Fibre content in mass ψ , t/w and composite density ρ_c					
			Glass ρ_f =		2,56	Carbon HR ρ_f =		1,78
		ϕ	ψ	t/w	ρ_c	ψ	t/w	ρ_c
RTM ECO	Any material	0,135	0,250	2,894	1,38	0,188	4,16	1,28
Infusion	CSM	0,21 - 0,30	0,36 - 0,48	1,86 - 1,30	1,49 - 1,61	0,28 - 0,39	2,68 - 1,87	1,32 - 1,37
	Woven Roving	0,42 - 0,50	0,61 - 0,68	0,93 - 0,78	1,77 - 1,88	0,52 - 0,60	1,34 - 1,12	1,44 - 1,49
	UD/Multidirectional	0,45 - 0,53	0,64 - 0,71	0,64 - 0,71	1,81 - 1,92	0,54 - 0,63	1,25 - 1,06	1,46 - 1,61
Prepreg void	UD/Multidirectional	0,530	0,706	0,737	1,92	0,626	1,06	1,51
Prepreg autoclave	UD/Multidirectional	0,530	0,706	0,737	1,92	0,626	1,06	1,51
These values are given as a guide only and are considered achievable by the industry, but it is the responsibility of the builder to check the values that his building methods are currently achieving. For complex surfaces, the fibre content in volume is 80 % of the ones for simple surfaces.								

C.3 Final calculation of E, G and ultimate stress

C.3.1 General calculation

Table C.8 — Final calculation of E, G , σ_u or τ_u*

$E = E_{\text{TABLE C 5}}$	$\sigma_U = E_{\text{TABLE C 5}} \times \varepsilon_{\text{TABLE C 6}}$
$G = G_{\text{TABLE C 6}}$	$\tau_U = G_{\text{TABLE C 5}} \times \gamma_{\text{TABLE C 6}}$

The calculations of Table C.8 are pre-computed in Table C.9 for Glass composites and in Table C.10 for High strength carbon composites.

CAUTION — The design stress defined in Table 17 shall then be determined using, the relevant value of k_{AM} and k_{BB} from Tables 15 & 16.

C.3.2 Builder's responsibility

The use of any property data given in this Annex does not imply that these are achievable in practice for any particular craft. It is entirely the responsibility of the builder or his representative to demonstrate this. The tables giving mechanical properties in this Annex shall be adjusted by the factor k_{BB} of Table 16 and used with care. It is subjective in nature and compliance with the table does not imply any guarantee that mechanical properties taken from this Annex are achieved for any particular craft in any particular location.

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Table C.9 — Computed values of Table C.5 to C.8 for glass laminates (with k_{BB} = 1)

E GLASS																		
ρ_f= 2,56			UD				CSM (Mat)			BD+ 0/90°			± 45° DBx Double bias			Quadraxial 0/45/90/-45		
ρ_m = 1,2			ν_f = 0,22				$G_{CSM}=1/8\,E_{UD1}+1/4\,E_{UD2}$											
Ef1= 73 000			ν_m = 0,32				$\upsilon_{CSM}=E_{CSM}/G_{CSM}-1$											
Ef2= 73 000			ξ = 1															
Em= 3 300			ηE= 0,913															
Gf= 30 000			ηG= 0,922															
Gm= 1 222																		
ϕ Vol	ψ Mass	t/w $1/(\phi^*\rho_f)$	E_{UD1}	E_{UD2}	G_{UD12}	ν_{UD12}	E_{CSM}	G_{CSM}	ν_{CSM}	E_{BD+}	G_{BD+}	ν_{BD+}	E_{DBx}	G_{DBx}	ν_{DBx}	E_{Quad}	G_{Quad}	ν_{Quad}
0,140	0,258	2,79	12 732	4 268	1 584	0,31	7 442	2 658	0,40	8 500	1 584	0,15	4 817	3 684	0,52	6 911	2 634	0,31
0,160	0,289	2,44	14 091	4 430	1 645	0,30	8 053	2 869	0,40	9 260	1 645	0,15	5 047	4 042	0,53	7 459	2 844	0,31
0,167	0,300	2,34	14 566	4 488	1 667	0,30	8 267	2 943	0,40	9 527	1 667	0,14	5 129	4 168	0,54	7 653	2 917	0,31
0,180	0,319	2,17	15 450	4 599	1 708	0,30	8 668	3 081	0,41	10 024	1 708	0,14	5 282	4 402	0,55	8 013	3 055	0,31
0,200	0,348	1,95	16 809	4 775	1 774	0,30	9 288	3 295	0,41	10 792	1 774	0,13	5 523	4 764	0,56	8 572	3 269	0,31
0,220	0,376	1,78	18 168	4 960	1 844	0,30	9 913	3 511	0,41	11 564	1 844	0,13	5 770	5 127	0,56	9 137	3 485	0,31
0,240	0,403	1,63	19 527	5 153	1 916	0,30	10 544	3 729	0,41	12 340	1 916	0,12	6 025	5 491	0,57	9 708	3 704	0,31
0,260	0,428	1,50	20 886	5 356	1 992	0,29	11 180	3 950	0,42	13 121	1 992	0,12	6 289	5 858	0,58	10 285	3 925	0,31
0,280	0,453	1,40	22 246	5 568	2 072	0,29	11 822	4 173	0,42	13 907	2 072	0,12	6 562	6 226	0,58	10 869	4 149	0,31
0,300	0,478	1,30	23 605	5 792	2 156	0,29	12 471	4 398	0,42	14 698	2 156	0,11	6 846	6 595	0,59	11 460	4 376	0,31
0,319	0,500	1,22	24 896	6 014	2 240	0,29	13 095	4 616	0,42	15 455	2 240	0,11	7 126	6 949	0,59	12 028	4 594	0,31
0,340	0,524	1,15	26 323	6 273	2 337	0,29	13 792	4 859	0,42	16 298	2 337	0,11	7 449	7 341	0,59	12 664	4 839	0,31
0,360	0,545	1,09	27 682	6 534	2 436	0,28	14 465	5 094	0,42	17 108	2 436	0,11	7 770	7 717	0,60	13 280	5 076	0,31
0,380	0,567	1,03	29 041	6 809	2 539	0,28	15 146	5 332	0,42	17 925	2 539	0,11	8 107	8 095	0,60	13 904	5 317	0,31
0,400	0,587	0,98	30 401	7 100	2 649	0,28	15 838	5 575	0,42	18 750	2 649	0,11	8 460	8 476	0,60	14 539	5 563	0,31
0,420	0,607	0,93	31 760	7 409	2 766	0,28	16 540	5 822	0,42	19 584	2 766	0,11	8 831	8 860	0,60	15 185	5 813	0,31
0,440	0,626	0,89	33 119	7 736	2 889	0,28	17 254	6 074	0,42	20 427	2 889	0,10	9 222	9 247	0,60	15 844	6 068	0,31
0,460	0,645	0,85	34 478	8 083	3 021	0,27	17 981	6 331	0,42	21 281	3 021	0,10	9 634	9 637	0,59	16 515	6 329	0,30
0,480	0,663	0,81	35 837	8 454	3 161	0,27	18 723	6 593	0,42	22 145	3 161	0,10	10 069	10 031	0,59	17 202	6 596	0,30
0,500	0,681	0,78	37 196	8 849	3 311	0,27	19 479	6 862	0,42	23 023	3 311	0,10	10 530	10 429	0,59	17 904	6 870	0,30
0,530	0,706	0,74	39 235	9 495	3 556	0,27	20 647	7 278	0,42	24 365	3 556	0,10	11 276	11 034	0,59	18 992	7 295	0,30

E GLASS																										
ρ_m = 1,2			UD							CSM				BD+ 0/90°				± 45° DBx Double bias				Quadrax 0/45/90/-45				all plies inter laminar stress
ρ_f= 2,56			k_G = 2,50 $\varepsilon_{ufi}=k_G\,\varepsilon_{uti}/(1+\varepsilon_{uti}/\varepsilon_{uci})$ with i=1 or 2							$\varepsilon_{uf}=k_G\,\varepsilon_{ut}/(1+\varepsilon_{ut}/\varepsilon_{uc})$				$\varepsilon_{uf}=k_G\,\varepsilon_{ut}/(1+\varepsilon_{ut}/\varepsilon_{uc})$				$\varepsilon_{uf}=k_G\,\varepsilon_{ut}/(1+\varepsilon_{ut}/\varepsilon_{uc})$				$\varepsilon_{uf}=k_G\,\varepsilon_{ut}/(1+\varepsilon_{ut}/\varepsilon_{uc})$				
Ef1= 73 000			Values of strains (%)																							
Ef2= 73 000			ε_{Ut1}	ε_{Ut2}	ε_{Uc1}	ε_{Uc2}	ε_{Uf1}	ε_{Uf2}	γ_{U12}	ε_{Ut}	ε_{Uc}	ε_{Uf}	γ_U	ε_{Ut}	ε_{Uc}	ε_{Uf}	γ_U	ε_{Ut}	ε_{Uc}	ε_{Uf}	γ_U	ε_{Ut}	ε_{Uc}	ε_{Uf}	γ_U	
Em= 3 300, Gf= 30 000, Gm= 1 222			1,90	0,50	1,40	1,40	2,02	0,92	1,70	1,35	1,70	1,88	2,00	1,55	1,40	1,84	1,70	1,06	1,02	1,30	1,80	1,30	1,20	1,56	1,70	
ϕ	ψ	t/w	Values of stresses (N/mm²)																							τ_{il}
Vol	Mass	$1/(\phi^*\rho_f)$	σ_{Ut1}	σ_{Ut2}	σ_{Uc1}	σ_{Uc2}	σ_{Uf1}	σ_{Uf2}	τ_U	σ_{Ut}	σ_{Uc}	σ_{Uf}	τ_{UST}	σ_{Ut}	σ_{Uc}	σ_{Uf}	τ_{UST}	σ_{Ut}	σ_{Uc}	σ_{Uf}	τ_{UST}	σ_{Ut}	σ_{Uc}	σ_{Uf}	τ_{UST}	τ_{il}
0,140	0,258	2,79	242	21	178	60	257	39	27	100	127	140	53	132	119	156	27	51	49	63	66	90	83	108	45	18,0
0,160	0,289	2,44	268	22	197	62	284	41	28	109	137	151	57	144	130	170	28	53	51	66	73	97	90	116	48	17,5
0,167	0,300	2,34	277	22	204	63	294	41	28	112	141	156	59	148	133	175	28	54	52	67	75	99	92	119	50	17,3
0,180	0,319	2,17	294	23	216	64	311	42	29	117	147	163	62	155	140	184	29	56	54	69	79	104	96	125	52	16,9
0,200	0,348	1,95	319	24	235	67	339	44	30	125	158	175	66	167	151	198	30	59	56	72	86	111	103	134	56	16,4
0,220	0,376	1,78	345	25	254	69	366	46	31	134	169	186	70	179	162	213	31	61	59	75	92	119	110	143	59	16,0
0,240	0,403	1,63	371	26	273	72	394	47	33	142	179	198	75	191	173	227	33	64	61	78	99	126	116	151	63	15,5
0,260	0,428	1,50	397	27	292	75	421	49	34	151	190	210	79	203	184	241	34	67	64	82	105	134	123	160	67	15,0
0,280	0,453	1,40	423	28	311	78	448	51	35	160	201	222	83	216	195	256	35	70	67	85	112	141	130	170	71	14,6
0,300	0,478	1,30	448	29	330	81	476	53	37	168	212	235	88	228	206	270	37	73	70	89	119	149	138	179	74	14,2
0,319	0,500	1,22	473	30	349	84	502	55	38	177	223	246	92	240	216	284	38	76	73	93	125	156	144	188	78	13,8
0,340	0,524	1,15	500	31	369	88	530	58	40	186	234	259	97	253	228	300	40	79	76	97	132	165	152	198	82	13,4
0,360	0,545	1,09	526	33	388	91	558	60	41	195	246	272	102	265	240	315	41	82	79	101	139	173	159	207	86	13,0
0,380	0,567	1,03	552	34	407	95	585	63	43	204	257	285	107	278	251	330	43	86	83	105	146	181	167	217	90	12,6
0,400	0,587	0,98	578	36	426	99	613	65	45	214	269	298	112	291	263	345	45	90	86	110	153	189	174	227	95	12,3
0,420	0,607	0,93	603	37	445	104	640	68	47	223	281	311	116	304	274	360	47	94	90	115	159	197	182	237	99	11,9
0,440	0,626	0,89	629	39	464	108	667	71	49	233	293	325	121	317	286	376	49	98	94	120	166	206	190	247	103	11,6
0,460	0,645	0,85	655	40	483	113	695	74	51	243	306	338	127	330	298	391	51	102	98	125	173	215	198	258	108	11,3
0,480	0,663	0,81	681	42	502	118	722	78	54	253	318	352	132	343	310	407	54	107	103	131	181	224	206	268	112	10,9
0,500	0,681	0,78	707	44	521	124	750	82	56	263	331	366	137	357	322	423	56	112	107	137	188	233	215	279	117	10,6
0,530	0,706	0,74	745	47	549	133	791	87	60	279	351	388	146	378	341	448	60	120	115	147	199	247	228	296	124	10,2

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Table C.10 — Computed values of Tables C.5 to C.8 for carbon HS laminates (with k_{BB} = 1)

CARBON HR															
ρ_f=	1,78		UD				BD+ 0/90°			± 45° DBx Double bias			Quadrax. 0/45/90/-45		
ρ_m =	1,2		ν_f=	0,27											
Ef1=	235 000		ν_m =	0,32											
Ef2=	20 000		ξ =	1											
Em=	3 300		ηE=	0,717											
Gf=	50 000		ηG=	0,952											
Gm=	1 222														
ϕ Vol	ψ Mass	t/w 1/(ϕ*ρ_f)	E_{UD1}	E_{UD2}	G_{UD12}	ν_{UD12}	E_{BX}	G_{BX}	ν_{BX}	E_{DB}	G_{DB}	ν_{DB}	E_{Quad}	G_{Quad}	ν_{Quad}
0,140	0,195	4,01	34 845	4 036	1 598	0,31	19 440	1 598	0,06	5 540	9 127	0,73	14 151	5 363	0,32
0,160	0,220	3,51	39 363	4 155	1 661	0,31	21 759	1 661	0,06	5 811	10 268	0,75	15 742	5 965	0,32
0,180	0,246	3,12	43 881	4 278	1 728	0,31	24 079	1 728	0,06	6 085	11 409	0,76	17 338	6 568	0,32
0,200	0,271	2,81	48 399	4 404	1 797	0,31	26 402	1 797	0,05	6 366	12 552	0,77	18 938	7 174	0,32
0,220	0,295	2,55	52 917	4 536	1 870	0,31	28 726	1 870	0,05	6 655	13 695	0,78	20 542	7 782	0,32
0,240	0,319	2,34	57 435	4 671	1 946	0,31	31 053	1 946	0,05	6 953	14 839	0,79	22 152	8 393	0,32
0,260	0,343	2,16	61 953	4 812	2 026	0,31	33 383	2 026	0,04	7 262	15 984	0,79	23 766	9 005	0,32
0,280	0,366	2,01	66 472	4 957	2 111	0,31	35 714	2 111	0,04	7 584	17 130	0,80	25 386	9 620	0,32
0,300	0,389	1,87	70 990	5 108	2 199	0,31	38 049	2 199	0,04	7 920	18 276	0,80	27 011	10 238	0,32
0,320	0,411	1,76	75 508	5 264	2 293	0,30	40 386	2 293	0,04	8 271	19 423	0,80	28 642	10 858	0,32
0,340	0,433	1,65	80 026	5 427	2 392	0,30	42 726	2 392	0,04	8 639	20 571	0,81	30 280	11 482	0,32
0,360	0,455	1,56	84 544	5 595	2 497	0,30	45 070	2 497	0,04	9 025	21 721	0,81	31 924	12 109	0,32
0,380	0,476	1,48	89 062	5 770	2 608	0,30	47 416	2 608	0,04	9 432	22 870	0,81	33 576	12 739	0,32
0,400	0,497	1,40	93 581	5 953	2 726	0,30	49 767	2 726	0,04	9 862	24 021	0,81	35 236	13 374	0,32
0,420	0,518	1,34	98 099	6 142	2 851	0,30	52 121	2 851	0,04	10 315	25 173	0,81	36 905	14 012	0,32
0,440	0,538	1,28	102 617	6 340	2 985	0,30	54 478	2 985	0,03	10 796	26 326	0,81	38 583	14 655	0,32
0,460	0,558	1,22	107 135	6 546	3 127	0,30	56 841	3 127	0,03	11 307	27 480	0,81	40 271	15 304	0,32
0,480	0,578	1,17	111 653	6 762	3 280	0,30	59 207	3 280	0,03	11 850	28 636	0,81	41 971	15 958	0,32
0,500	0,597	1,12	116 171	6 986	3 443	0,30	61 579	3 443	0,03	12 430	29 792	0,80	43 683	16 618	0,31
0,520	0,616	1,08	120 689	7 221	3 619	0,29	63 955	3 619	0,03	13 050	30 950	0,80	45 409	17 285	0,31
0,530	0,626	1,06	122 948	7 343	3 712	0,29	65 146	3 712	0,03	13 376	31 530	0,80	46 278	17 621	0,31

CARBON HR																						
ρ_f=	1,78		UD							BD 0/90°				± 45° DBx Double bias				Quadrax. 0/45/90/-45				all plies inter laminar stress
ρ_m =	1,2		k_G= 2,94																			
Ef1=	235 000		$\varepsilon_{ufi}=k_G\ \varepsilon_{uti}/(1+\varepsilon_{uti}/\varepsilon_{uci})$ with i=1 or 2							$\varepsilon_{uf}=k_G\ \varepsilon_{ut}/(1+\varepsilon_{ut}/\varepsilon_{uc})$				$\varepsilon_{uf}=k_G\ \varepsilon_{ut}/(1+\varepsilon_{ut}/\varepsilon_{uc})$				$\varepsilon_{uf}=k_G\ \varepsilon_{ut}/(1+\varepsilon_{ut}/\varepsilon_{uc})$				
Ef2=	20000																					
Em=	3300		Values of strains (%)																			
Gf=	50000		ε_{Ut1}	ε_{Ut2}	ε_{Uc1}	ε_{Uc2}	ε_{Uf1}	ε_{Uf2}	γ_{U12}	ε_{Ut}	ε_{Uc}	ε_{Uf}	γ_U	ε_{Ut}	ε_{Uc}	ε_{Uf}	γ_U	ε_{Ut}	ε_{Uc}	ε_{Uf}	γ_U	
Gm=	1222		1,00	0,50	0,70	1,90	1,21	1,16	1,50	1,00	0,70	1,21	1,40	0,77	0,75	1,12	1,02	0,92	0,74	1,21	1,02	
ϕ	ψ	t/w	σ_{Ut1}	σ_{Ut2}	σ_{Uc1}	σ_{Uc2}	σ_{Uf1}	σ_{Uf1}	τ_U	σ_{Ut}	σ_{Uc}	σ_{Uf}	τ_{UST}	σ_{Ut}	σ_{Uc}	σ_{Uf}	τ_{UST}	σ_{Ut}	σ_{Uc}	σ_{Uf}	τ_{UST}	τ_{il}
Vol	Mass	1/(ϕ*ρ_f)	Values of stresses (N/mm²)																			
0,140	0,195	4,01	348	20	244	77	422	47	24	194	136	235	22	43	42	62	93	130	105	171	55	18,0
0,160	0,220	3,51	394	21	276	79	477	48	25	218	152	263	23	45	44	65	105	145	116	190	61	17,5
0,180	0,246	3,12	439	21	307	81	531	50	26	241	169	292	24	47	46	68	116	160	128	209	67	16,9
0,200	0,271	2,81	484	22	339	84	586	51	27	264	185	320	25	49	48	71	128	174	140	228	73	16,4
0,220	0,295	2,55	529	23	370	86	641	53	28	287	201	348	26	51	50	74	140	189	152	248	79	16,0
0,240	0,319	2,34	574	23	402	89	695	54	29	311	217	376	27	54	52	78	151	204	164	267	86	15,5
0,260	0,343	2,16	620	24	434	91	750	56	30	334	234	404	28	56	54	81	163	219	176	287	92	15,0
0,280	0,366	2,01	665	25	465	94	805	58	32	357	250	432	30	58	57	85	175	234	188	306	98	14,6
0,300	0,389	1,87	710	26	497	97	859	59	33	380	266	461	31	61	59	88	186	248	200	326	104	14,2
0,320	0,411	1,76	755	26	529	100	914	61	34	404	283	489	32	64	62	92	198	264	212	345	111	13,8
0,340	0,433	1,65	800	27	560	103	969	63	36	427	299	517	33	67	65	96	210	279	224	365	117	13,4
0,360	0,455	1,56	845	28	592	106	1 023	65	37	451	315	546	35	69	68	101	222	294	236	385	124	13,0
0,380	0,476	1,48	891	29	623	110	1 078	67	39	474	332	574	37	73	71	105	233	309	248	405	130	12,6
0,400	0,497	1,40	936	30	655	113	1 133	69	41	498	348	602	38	76	74	110	245	324	261	425	136	12,3
0,420	0,518	1,34	981	31	687	117	1 188	71	43	521	365	631	40	79	77	115	257	340	273	445	143	11,9
0,440	0,538	1,28	1 026	32	718	120	1 242	74	45	545	381	660	42	83	81	121	269	355	286	465	149	11,6
0,460	0,558	1,22	1 071	33	750	124	1 297	76	47	568	398	688	44	87	85	126	280	370	298	486	156	11,3
0,480	0,578	1,17	1 117	34	782	128	1 352	79	49	592	414	717	46	91	89	132	292	386	311	506	163	10,9
0,500	0,597	1,12	1 162	35	813	133	1 406	81	52	616	431	745	48	96	93	139	304	402	323	527	170	10,6
0,520	0,616	1,08	1 207	36	845	137	1 461	84	54	640	448	774	51	100	98	146	316	418	336	548	176	10,3
0,530	0,626	1,06	1 229	37	861	140	1 488	85	56	651	456	789	52	103	100	149	322	426	342	558	180	10,2

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C.4 Determination of mechanical properties of materials not quoted in Tables C.5 to C.10

C.4.1 General

Single skin or sandwich plating layers made from other materials than those in Tables C.5 to C.10 shall be specifically considered, either as alternative layers to be used in the enhanced method (ply by ply in Annex H) or as a one "thick" layer to be used in the simplified method. The one "thick" layer method is valid if the flexural strength of the various plies do not differ more than 25 % to 30 %. from the average value of all plies. Table C.11 shows an example of such a calculation for Mat+ layers of Rovimat, considered as one ply.

Where layers close to the outer or inner surface of the laminate have a strength that differ more than30 % of the average (e.g. resin rich drainage ply), the full laminate will be better analysed with Table H.2. Inverting the single skin formula for the simplified method of Table A.5, the actual bending stress of the "global" ply shall be determined as $\sigma_a = 6 \times M_{db\ corr}/t_a{}^2$ (see last rows of Table H.2), where $M_{db\ corr}$ is given in Table A.4 and t_a is the actual thickness.

C.4.2 Example

A GRP builder using an outer ply made of 2 Mat300 with ϕ = 0,167, and Rovimat R800/M300 with ϕ = 0,300 for roving and ϕ = 0,167 for mat, may use Table C.11 to derive first the properties of a Rovimat layer, then the properties of several compositions and mechanical properties.

Table C.11 — Pre-calculated table for 2 Mat 300, Rovimat 800/300 and their combination

1		w	ϕ	ψ	t/w	t	E	G	tE	tG	ε_{ut}	ε_{uc}	ε_{uf}	γ_u	σ_{ut}	σ_{uc}	σ_{uf}	τ_u
2		kg/m²	Vol	Mass	1/(ϕ*ρ$_f$)	mm	N/mm²		N/mm		-------------	%	----------------		----	N/mm²	-------	
3	2 Mat 300	0,6	0,167	0.300	2,34	1,40	8 267	2 943	11 602	4 130	1,35	1,70	1,88	2,00	112	141	155	59
4																		
5	1 Mat 300	0,30	0,167	0.300	2,34	0,70	8 267	2 943	5 801	2 065	1,35	1,70	1,88	2,00	112	141	155	59
6	1 Roving 800	0,80	0,300	0.478	1,30	1,04	14 698	2 156	15 310	2 246	1,55	1,40	1,84	1,70	228	206	270	37
7	1 Rovimat 800/300	1,10	0,246	0.411	1,58	1,74	**12 109**	**2 473**	21 112	4 311	**1,35**	**1,40**	**1,84**	**1,70**	**163**	**170**	**223**	**42**
8																		
9	2 Mat 300	0,60	0,167	0,300	2,34	1,40	8 267	2 943	11 602	4 130	1,35	1,70	1,88	2,00	112	141	155	59
10	1 Rovimat 800/300	1,10	0,246	0,411	1,58	1,74	12 109	2 473	21 112	4 311	1,35	1,40	1,84	1,70	163	170	223	42
11	Total	1,70	0,211	0,363	1,85	3,15	**10 396**	**2 682**	32 714	8 441	**1,35**	**1,40**	**1,84**	**1,70**	**140**	**146**	**191**	**46**
12																		
13	2 Mat 300	0,60	0,167	0,300	2,34	1,40	8 267	2 943	11 602	4 130	1,35	1,70	1,88	2,00	112	141	155	59
14	2 Rovimat 800/300	2,20	0,246	0,411	1,58	3,49	12 109	2 473	42 223	8 622	1,35	1,40	1,84	1,70	163	170	223	42
15	Total	2,80	0,224	0,381	1,75	4,89	**11 007**	**2 608**	53 825	12 752	**1,35**	**1,40**	**1,84**	**1,70**	**149**	**154**	**203**	**44**
16																		
17	2 Mat 300	0,60	0,167	0,300	2,34	1,40	8 267	2 943	11 602	4 130	1,35	1,70	1,88	2,00	112	141	155	59
18	3 Rovimat 800/300	3,30	0,246	0,423	1,58	5,23	12 109	2 473	63 335	12 933	1,35	1.40	1,84	1,70	163	170	223	42
19	Total	3,90	0,230	0,389	1,70	6,63	**11 297**	**2 572**	74 937	17 063	**1,35**	**1,40**	**1,84**	**1,70**	**153**	**158**	**208**	**44**

Row 3 of Table C.11 gives the calculations for 2 Mat 300, Row 7 for a Rovimat 800/300, and rows 11, 15, and 19 give respectively the properties for 2M 300+ 1, 2 and 3 Rovimat. (Yellow cells are data, blue cells are calculation results, green cells are important results for E, G, ε and σ). Green cells for ultimate stress (tensile/compressive/flexural) are obtained by multiplying final E (green) by the min of the ε_S of the plies. Same for shear stress but using G, γ and τ. The last row shows that the design stress of the two types of layers, Mat or Rovimat differ either by −18 % for mat and +18 % for Rovimat. The global allowable bending moment for these various single skin laminates could also be calculated according to Table H.2. See examples in Annex H.

CAUTION — For ease of calculation, k_{BB} and k_{AM} have been taken as 1 and the glass contents in mass ψ is arbitrarily taken from Table C.7. For actual calculation, all these data shall be determined according to Clause 10 and the stresses according to Table 17.

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Annex D
(normative)

Drop test for craft <6 m

D.1 Theoretical background

D.1.1 Theory of drop test

The impact pressure of a craft running in waves can be approximately estimated as the impact pressure acting on a two-dimensional wedge model penetrating the water.

On the other hand, impact pressure on a craft that falls free into the water can be approximately estimated as the impact pressure on the same model. For this approach *Wagner's Theory* is used.

D.1.2 Wave conditions

The following parameters are taken into consideration:

— wave height H_W;

— wave length l_W;

— wave slope H_W/l_W;

— wave length to craft length ratio l_W/L_{WL};

— wave height to craft length ratio H_W/L_{WL}.

As the impact acceleration on a running craft should be the maximum value, the following assumptions are made for the above parameters:

d) H_W/l_W = 1/20

e) l_W/L_{WL} = 2

f) H_W/L_{WL} = 0,1

D.1.3 Relative impact speed

For the estimated relative impact speed in waves, the following parameters are taken into consideration:

— vertical factor of wave motion;

— vertical factor by pitching;

— vertical factor of advance speed with bow inclination to waves;

— trim angle of 4°.

Taking into account that a craft at high speed is for some time airborne, it is assumed that the craft falls from the wave crest to the wave bottom.

The relative impact speed in a drop test can be calculated by using Wagner's formula for the craft's motion. From these parameters, the response can be determined.

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D.1.4 Verification of “drop height”

Drop tests have been carried out using the impact load as measured on the same craft in running condition in waves. These data have been compiled in a graph which allows determining the appropriate drop height for a certain craft at a given speed under defined wave conditions, as described under D.1.2.

D.1.5 Safety margin

In the main body of this document, the safety margin is included in the design stresses for the material. In the drop test, the safety margin is incorporated in the maximum impact load, assuming that all craft are at some time airborne, because the stipulated wave conditions are assumed to cover all the actual conditions.

D.1.6 Fatigue

As the method of scantling determination in the main body of this part of ISO 12215 does not address fatigue, it seems justified to use the same approach in the drop test. In both cases the one-time impact is considered to give adequate answers for the long-term durability of the craft.

D.2 Test and compliance

D.2.1 General

This test is considered applicable to craft with a hull length of <6 m, of single skin or sandwich construction, where the internal face of the plating and the internal stiffeners can be inspected after the craft has been subject to the drop test.

D.2.2 Test procedure

The craft is lifted to a predetermined height H_Z, as determined from Figure D.1, in relation to the speed/length ratio $V/\sqrt{L_{WL}}$.

The following conditions shall be fulfilled:

— the craft is in loaded displacement condition, m_{LDC}; the mass of the maximum recommended number of persons and of vulnerable equipment and outfit may be replaced by a mass with the same distribution within the craft;

— the keel shall be approximately parallel to the water surface;

— the wave height in the test premises shall not exceed 100 mm.

— The craft is released, dropping into the water.

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D.2.3 Inspection and pass/fail requirements

The craft is then taken on land and the bottom and side structure of the hull, deck and internal stiffeners are inspected. The craft is deemed to pass the test if:

— on FRP craft, laminate or gel coat: cracks and the possible debonding/failure of the internal structure;

— on other material: cracks on the internal or external face of the plating and failure of the internal structure.

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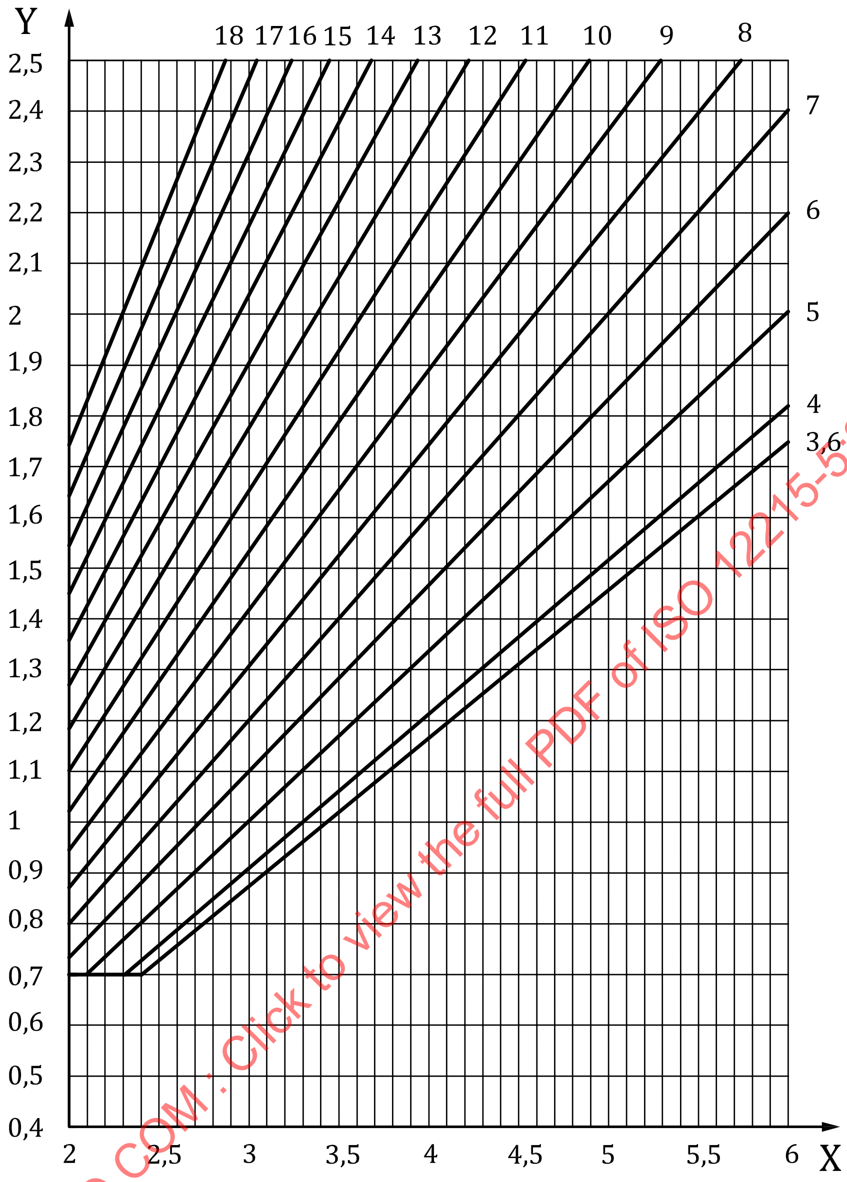

Key

X L_{WL}, m

Y H_Z, m

NOTE The numbers at the end of each straight line correspond to the speed/length ratio $V/\sqrt{L_{WL}}$ of the line.

Figure D.1 — Determination of drop test height

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Annex E
(normative)

Sandwich calculations

E.1 Sandwich formulas

E.1.1 General

The core is considered ineffective in carrying any bending moment and is only capable of transmitting shear force. Table E.1 gives the general formula, approached values, and values for symmetric sandwich.

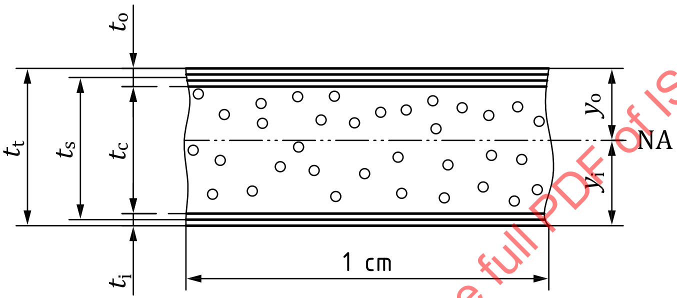

Figure E.1 — Sandwich schematic sketch

Table E.1 — Sandwich formulas (See Figure E.1)

General formulas		
$t_t = t_c + t_o + t_i$	mm	total thickness of sandwich
$t_s = t_c + \frac{(t_o + t_i)}{2}$	mm	distance between mid-thickness (centroids) of skins
$y_o = \frac{t_i \times t_s}{t_i + t_o} + \frac{t_o}{2}$	mm	distance of the furthest side of outer skin from NA
$y_i = \frac{t_o \times t_s}{t_i + t_o} + \frac{t_i}{2}$	mm	distance of the furthest side of inner skin from NA
$I = \left(\frac{t_o \times t_i \times t_s{}^2}{t_o + t_i} + \frac{t_o^3 + t_i^3}{12} \right) 10^{-3}$	cm⁴/cm	second moment of area per centimetre width
$SM_o = \frac{10 \times I}{y_o}$	cm³/cm	section modulus of the outer skin
$SM_i = \frac{10 \times I}{y_i}$	cm³/cm	section modulus of the inner skin
where		
t_o and t_i	mm	thickness of the outer and inner skins of the sandwich r;
t_c	mm	thickness of the core.

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Table E.1 *(continued)*

Approached values - Only valid if skins made of the same material and layup and $t_i = \geq 0{,}7\ t_o$		
$SM_o = \frac{t_c \times t_o}{100}$ and $SM_o = \frac{t_c \times t_i}{100}$	cm³/cm	approached section modulus of the outer and inner skin
$I = \frac{t_o \times t_i \times t_s^2}{1\,000(t_o + t_i)}$	cm⁴/cm	approached second moment
Symmetric sandwich - where $t = t_o = t_i$		
$SM = \frac{t_c \times t}{100}$	cm³/cm	approached section modulus
$I = \frac{t \times t_s^2}{2\,000}$	cm⁴/cm	approached second moment

E.2 Sandwich pre-calculated tables and figures

The section moduli *SM* (cm^3/cm) are given in Table E.2 and Figure E.2.

The second moments *I* (cm^4/cm) are given in Table E.3 and Figure E.3.

Table E.2 — Values of approximated section moduli (cm^3/cm) of symmetrical sandwiches

Core thickness	**Thickness of each skin** *t* (mm)							
t_c	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
12	0,12	0,24	0,36	0,48	0,60			
16	0,16	0,32	0,48	0,64	0,80	0,96		
20	0,20	0,40	0,60	0,80	1,00	1,20	1,40	1,60
24	0,24	0,48	0,72	0,96	1,20	1,44	1,68	1,92
28	0,28	0,56	0,84	1,12	1,40	1,68	1,96	2,24
32	0,32	0,64	0,96	1,28	1,60	1,92	2,24	2,56
36	0,36	0,72	1,08	1,44	1,80	2,16	2,52	2,88
40	0,40	0,80	1,20	1,60	2,00	2,40	2,80	3,20

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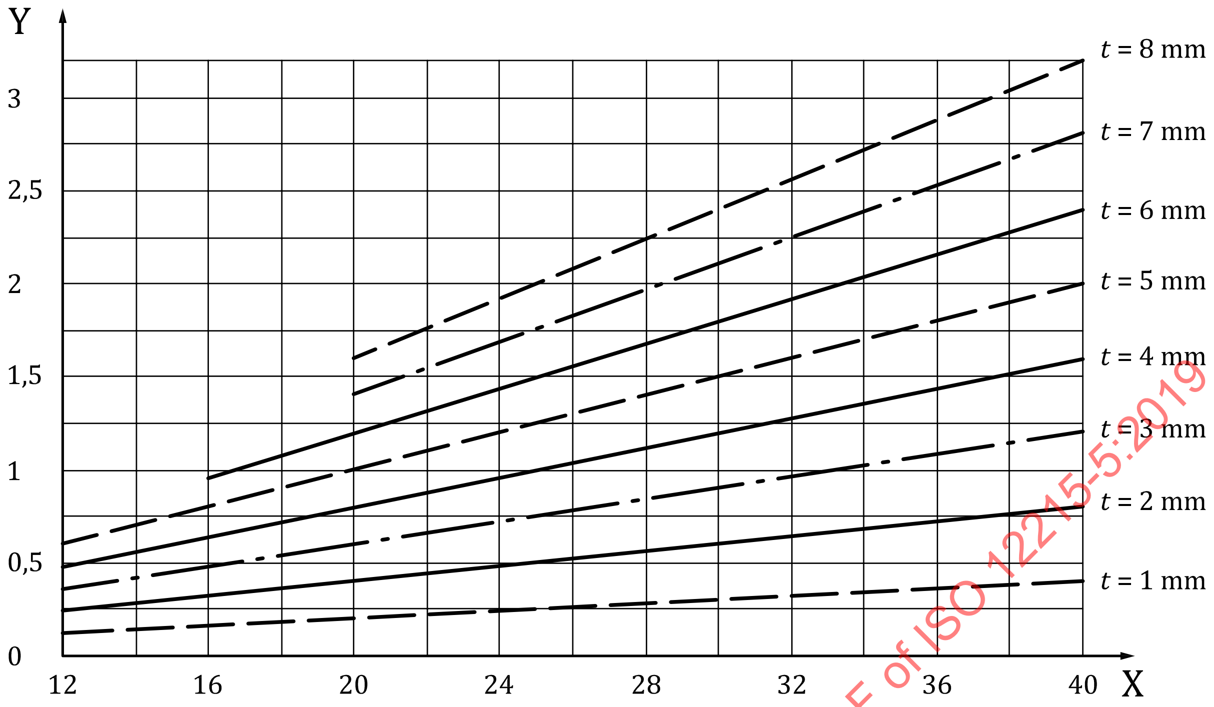

Key

X t_c, mm

Y *SM*, cm^3/cm

Figure E.2 — Graph of approximated section moduli (cm^3/cm) of symmetrical sandwiches

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Table E.3 — Values of approximated second moment *I* (cm^4/cm) of symmetrical sandwiches

Core thickness t_c (mm)	Thickness of each skin *t* (mm)							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
12	0,08	0,20	0,34	0,51	0,72			
16	0,14	0,32	0,54	0,80	1,10	1,45		
20	0,22	0,48	0,79	1,15	1,56	2,03	2,55	3,14
24	0,31	0,68	1,09	1,57	2,10	2,70	3,36	4,10
28	0,42	0,90	1,44	2,05	2,72	3,47	4,29	5,18
32	0,54	1,16	1,84	2,59	3,42	4,33	5,32	6,40
36	0,68	1,44	2,28	3,20	4,20	5,29	6,47	7,74
40	0,84	1,76	2,77	3,87	5,06	6,35	7,73	9,22

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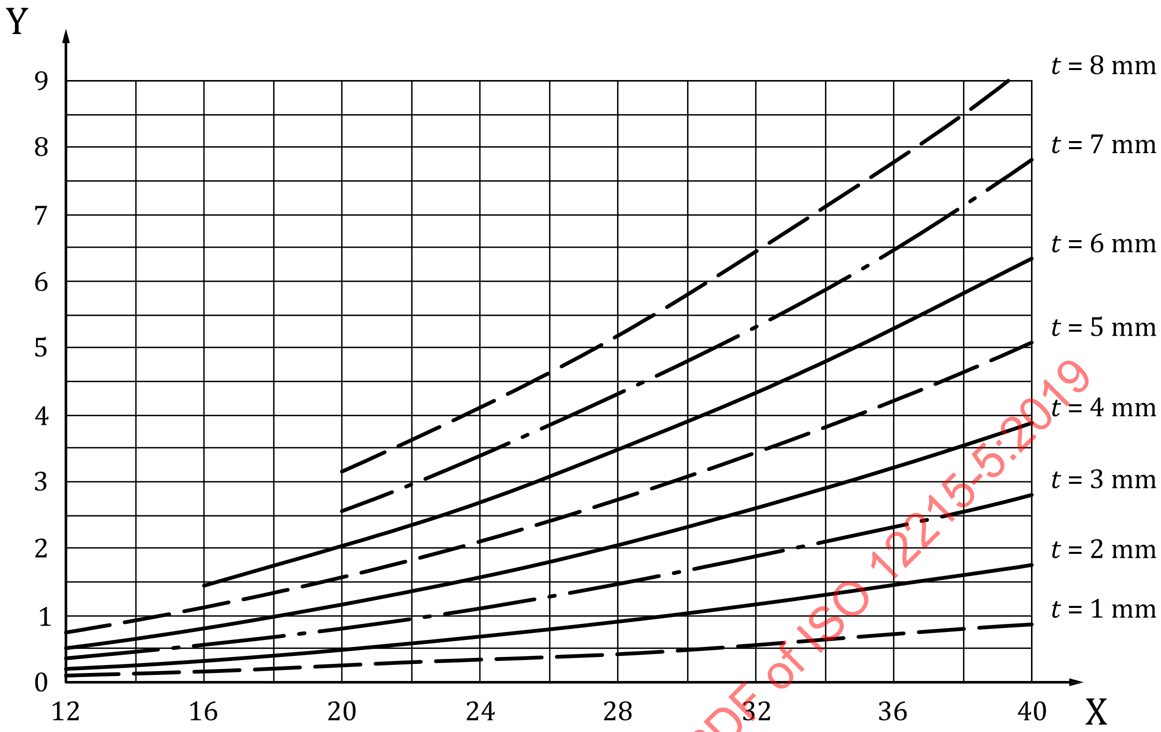

Key

X t_c, mm

Y I, cm^4/cm

Figure E.3 — Graph of approximated second moment I (cm^4/cm) of symmetrical sandwiches

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Annex F
(normative)

Wood/plywood laminate properties and calculations

F.1 Wood laminates

F.1.1 General

This Annex applies to three types of laminated wood construction – plywood (F.1.2), moulded veneer (F.1.3) and strip planking (F.1.4).

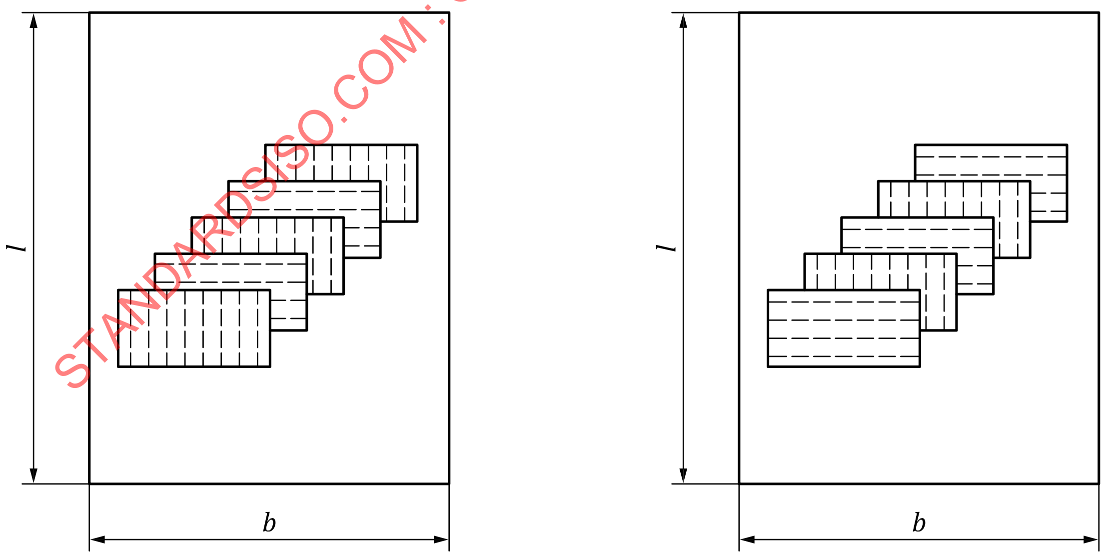
In each case the wood plies shall be bonded by a structural adhesive, and at the construction stage the wood shall be effectively encapsulated to stabilize the long-term moisture content.

Lightweight sheathings of 0,2 kg/m^2 to 0,3 kg/m^2 fibreglass are usually employed. A lower mass of sheathing is considered too light, heavier sheathing is unnecessary unless considered as part of the working material and analysed under Annex H. A construction with a wood core and composite skins which differ from the content of A.10.3 is not included in this annex (see Annex H, assuming a structurally effective core, i.e. not as a sandwich construction).

NOTE *b* is the direction parallel to the short dimension of the panel.

F.1.2 Plywood

Plywood is made of prefabricated laminated plies (minimum 5) alternately orientated at 0/90° and generally arranged such that the outer face grain is either parallel or perpendicular to the sides of the panel. See Figure F.1.



a) Outer face perpendicular with *b* direction **b) Outer face parallel with *b* direction**

NOTE The example shows a plywood with 5 plies.

Figure F.1 — Plywood sheet-ply orientation

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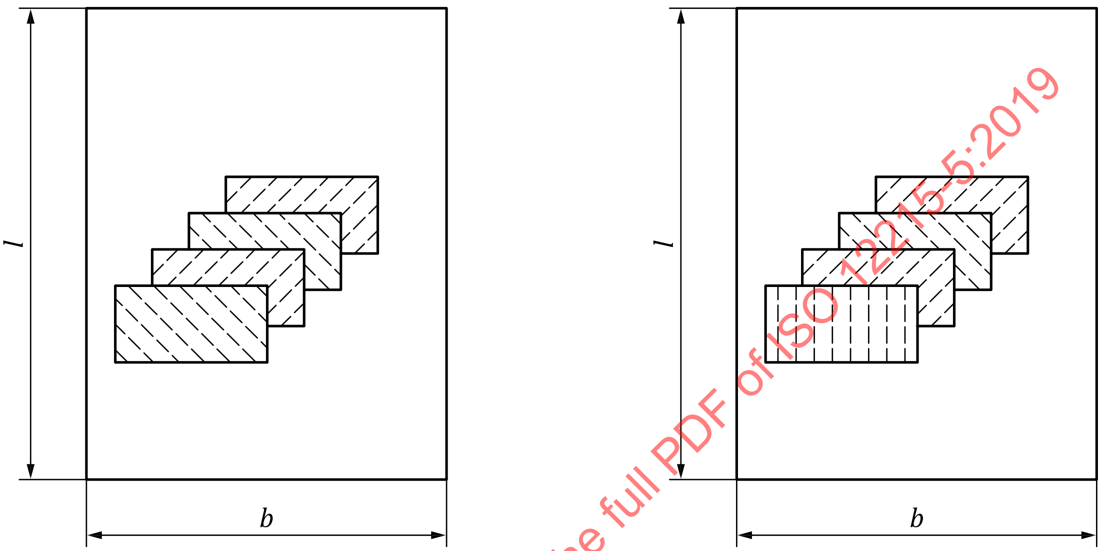
CAUTION — Builders shall be aware that plywood is stiffer and stronger in the direction of the outer face grain and shall accordingly take that the orientation of the plywood sheets is according to design and structural calculation (See Table A.5 and the following Tables).

F.1.3 Moulded in-situ veneers

Cold moulded in situ is made of thin veneers, orientated at ±45° to the panel sides, comprising at least 3 plies. The outer ply may run parallel or perpendicular to the panel sides. See Figure F.2.



a) All veneers run at ±45° with *b* direction

b) Veneers run at ±45° with *b* direction, except final veneer

NOTE The example shows 4 veneers.

Figure F.2 — Moulded veneer orientation

NOTE Cold-moulded in this document means 3 or so thin veneers on closely spaced (say 200 - 300 mm) stringers NOT thick laminated monocoque shell which relies on shell behaviour for strength/stiffness. The latter is outside this Annex because it may not be analysed with simple formulas.

F.1.4 Strip planking

Strip planking is made of narrow planks glued edgewise, may be butt jointed, generally run fore and aft and are supported by transverse frames. Strip planking combined with ± 45° veneers where the hull is strip-planked and finished off with a number of thin veneers are also included.

For all but strip plank with 1 mm (0,8 kg/m^2) glass skins inside and outside, the thickness requirement from Table A.5 refers to the total thickness of wood (strip plank and veneers), exclusive of any lightweight sheathing. See Figure F.3.

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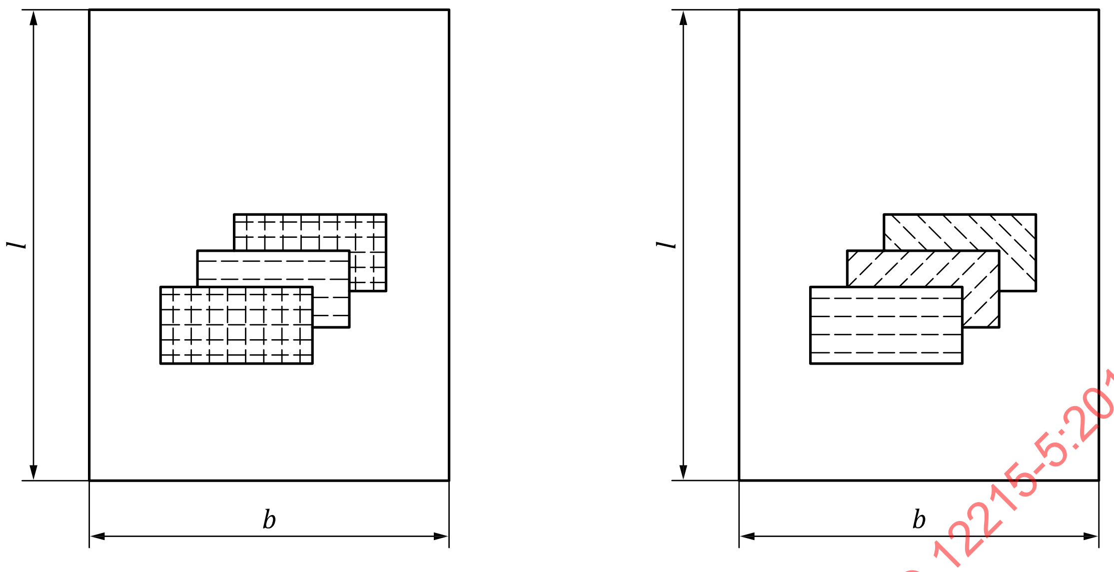

a) 1 mm (0,8 kg/m[2]) glass sheathing inside and outside of strip planking

b) Two ±45° veneers on thick strip planking

Figure F.3 — Strip planking with heavy fibre sheathing or veneers

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F.2 Wood laminate mechanical properties

F.2.1 Tested properties

Where the mechanical properties used for the scantlings determination are derived from tests, these tests shall be conducted in accordance with the applicable or appropriate International Standard. Where an International Standard does not exist, a national standard may be used instead.

The mechanical properties obtained from tests on small, clear, straight-grained samples using the same ply sequence as the as-used material. σ_{uf} used in the calculations shall be 80 % of the mean ultimate strength or mean ultimate strength minus two standard deviations, whichever is the lower. For plywood, as the building process is more industrial the 80 % above may be replaced by 90 %.

F.2.2 Non-tested properties

σ_{uf} shall be obtained

— from manufacturers' data, which correspond to guaranteed minimum values;

— using 90 % of typical manufacturers' data for plywood;

— from laminate stack analysis where the method has been verified against previous test data (see Annex H), and where the input mechanical properties of each solid wood ply are to be taken as not >80 % of the average of typical values;

— using the formulas given in Table F.2, tabulated in Tables F.4 and F.5, which supply prediction formulas for the three types of construction covered and mechanical wood properties taken from Table F.1;

— using the formulas given in Table F.3, tabulated in Table F.6, which supply prediction formulas for plywood on edge.

The mechanical properties of non-tested plain woods to be used in the scantlings calculation shall be obtained from Table F.1. The values presented in Table F.1 correspond to 80 % of the mean values

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obtained from tests on small, essentially defect-free samples. These values shall be used in Table 17 with the design stress factors given in Table 16.

The mechanical properties of non-tested wood panels: plywood ±45° cold-moulded veneers, and strip planking shall be obtained from Table F.2 and are computed for typical cases in Tables F.3 and F.4.

When plywood or cold-moulded wood is used in webs (webs of stiffeners, webs of large beams like multihull cross arms), it is very important to know the allowable shear stress. The in-plane (on edge) shear strength of plywood or cold-moulded panels where the plies are oriented ±45° from the main directions of the panel is greater than at 0/90° and can be derived from Table F.3.

Table F.1 — Mechanical properties of typical wood species

Wood species		**Density**	σ_{uf} // grain	σ_{cu} // grain	τ_u // grain	≈E // grain
Softwood		ρ				
Common name	Scientific name	kg/m³	N/mm²	N/mm²	N/mm²	N/mm²
Fir, Douglas	*Pseudotsuga menziesii*	520	74	41	8,9	10 140
Larch, European	*Larix decidua*	545	74	37	9,8	10 630
Pine, Yellow	*Pinus strobus*	433	64	34	7,5	8 440
Cedar, Western Red	*Thuja plicata*	368	52	28	6,8	7 180
Redwood, Baltic	*Pinus sylvestris*	481	67	36	9,1	9 380
Spruce, European	*Picea abies*	400	52	28	7,6	7 800
Spruce, Sitka	*Picea stitchensis*	384	53	29	6,9	7 490
Other woods		ρ	0,137 ρ	0,075 ρ	0,018 ρ	
Softwood – Elastic modulus // grain		E (N/mm²) = 19,5 ρ				
Hardwood		**Density** ρ	σ_{uf} // grain	σ_{cu} // grain	τ_u // grain	≈E // grain
Common name	Scientific name	N/mm²	N/mm²	N/mm²	N/mm²	N/mm²
Aspen, European	*Populus tremula*	460	55	34	6	8 050
Afrormosia	*Pericopsis elata*	737	108	57	14	12 900
Afzelia	*Afzelia* sp.	817	100	63	14	14 300
Agba	*Gossweilerodendron balsamiferum*	497	65	35	9	8 700
Ekki (azobe)	*Lophira alata*	1 037	142	72	19	18 150
Okoume Gaboon	*Aucoumea klaineana*	440	60	28	8	9 200
Iroko	*Chlorophora excelsa*	657	72	44	11	11 500
Jarrah	*Eucalptus marginata*	865	94	51	14	15 140
Kapur	*Dryobalanops beccarii*	705	93	53	10	12 340
Karri	*Eucalyptus diversicolor*	914	111	60	14	16 000
Keruing	*Dipterocarpus caudiferus*	641	88	48	10	11 220
Mahogany, African	*Khaya anthotheca*	514	67	36	10	9 000
Mahogany, American	*Swietenia marcrophylla*	497	67	36	10	8 700
Makore	*Tieghemella heckelii*	609	81	43	11	10 660
Meranti, light red	*Shorea dasyphylla*	481	70	40	8	8 420
Oak, European	*Quercus* spp.	689	77	41	11	12 060
Opepe	*Nauclea diderrichii*	753	96	58	14	13 180
Sapele	*Entandrophragma cylindricum*	673	89	47	14	11 780
Teak	*Tectona grandis*	641	84	48	12	8 050

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Table F.1 *(continued)*

Utile (Sipo)	*Entandrophragma utile*	641	83	48	14	12 900
Other woods		ρ	0,130 ρ	0,071 ρ	0,018 ρ	
Hardwood – Elastic modulus // grain		E (N/mm^2) = 17,5 ρ				

Table F.2 — Ultimate flexural strengths and flexural moduli for laminated wood panels

Specifications	Ultimate flexural strength σ_{uf} N/mm^2	Flexural modulus[c] E_f N/mm^2
Plywood		
Parallel to face grain[a]	$\left(\frac{\rho_{PW}}{1\,000}\right)^{0,5}\left(68-2N_{ply}+0,03N_{ply}^{2}\right)$	$\left(\frac{\rho_{PW}}{1\,000}\right)^{0,75}\left(11\,400-580N_{ply}+16N_{ply}^{2}\right)$
Perpendicular to face grain[b]	$\left(\frac{\rho_{PW}}{1\,000}\right)^{0,5}\left(11+6,5N_{ply}-0,28N_{ply}^{2}\right)$	$\left(\frac{\rho_{PW}}{1\,000}\right)^{0,75}\left(1\,320N_{ply}-55N_{ply}^{2}-1200\right)$
ρ_{PW} is the specific mass (density in kg/m^3/1 000) of the plywood in question. This value shall be obtained by measurement of actual samples. This value shall include the presence of glue lines and may exceed the density of the base wood by 10 % or more. N_{ply} is the number of plies, presumed to be an odd number between 5 and 15.		
±45° cold-moulded veneers		
All plies at ±45° to short panel side (valid in both short and long panel directions)	0,3 σ_{uf} of parent wood	0,2 E_f of parent wood
Final ply running at 90° to the short panel side		
In short panel direction	(0,01 N_{ply} + 0,17) σ_f of parent wood	(0,006 N_{ply} + 0,14) E_f of parent wood
In long panel direction	Not relevant for panel[d]	0,35 E_f of parent wood

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Table F.2 *(continued)*

Specifications	Ultimate flexural strength σ_{uf} N/mm²	Flexural modulus[c] E_f N/mm²
Strip planking		
The grain of the strip plank is presumed to run parallel to the short panel side.	$1,6\ (\sigma_L/\sigma_S)^{0,5} \times \sigma_{uf}$ of strip plank wood[e]	$(\sigma_L/\sigma_S) \times E_f$ of strip plank[f]
[a] The parallel to the face grain value shall be used in Table A.5 for laminated wood of plywood, when the face grain runs parallel to the short dimension of the panel. [b] The perpendicular to the face grain value shall be used Table A.5 for laminated wood of plywood, when the face grain runs at 90° to the short dimension of the panel. [c] The flexural modulus is to be used when calculating the effective extent of attached plating for stiffener assessments. [d] If the final ply runs parallel to the short panel side, analysis should be carried using Annex H. However, the formula for all plies at ±45° to short panel side may be used as a conservative estimate. [e] (σ_L/σ_S) is the ratio of the strength of the panel in the long panel direction to that in the short panel direction. It shall not be taken >0,39. [f] For purposes of calculating the effective extent of attached plating for stiffener assessments, the flexural modulus perpendicular to the grain of the strip plank, may be taken as (σ_L/σ_S) × flexural modulus of strip plank.		
Typical σ_L/σ_S values For strip plank with a very light sheathing: 0,07 For strip plank with 1 mm + sheathing, inside and out: 0,14 For strip plank with ±45° veneers, where the veneer thickness <50 % of the strip plank thickness: 0,20 NOTE These figures for σ_L/σ_S and the use of the strip plank flexural strength are intended to be conservative. Better estimates may be obtained by testing or using the method of Annex H.		
Flexural moduli of parent (solid) wood may be obtained from Softwood: $E_f = 19{,}5\ \rho$, Hardwood: $E_f = 17{,}5\ \rho$		

Table F.2 gives data for a plywood or cold-moulded panel (bending like a hull panel under external pressure).

Tables F.4 and F.5 give pre-calculated values from Table F.2.

Table F.3 gives data for plywood on edge (bending like a bulkhead or a frame under external pressure).

Table F.6 gives pre-calculated values from Table F.3.

CAUTION — Plywood with thin plies and full ply continuity usually have better mechanical properties than documented here, and the users may use specific minimum values declared by the plywood manufacturer. The same applies to non-balanced plywood, designed for rudders, centreboards, etc. that have increased mechanical properties in the direction of greater bending stress.

Table F.3 — Mechanical properties for plywood on edge

Variable	Unit	Formula
E //	N/mm²	$17{,}5 \times (0{,}1 + 0{,}9 \times k_N) \times (\rho_{PW} - 100)$
$E \perp$	N/mm²	$17{,}5 \times (1 - 0{,}9 \times k_N) \times (\rho_{PW} - 100)$
σ_U //	N/mm²	$0{,}007\ 5 \times E$ //
$\sigma_U \perp$	N/mm²	$0{,}007\ 5 \times E \perp$
G	N/mm²	$1{,}2\ \rho_{PW}$
τ	N/mm²	$0{,}02\ \rho_{PW}$

Table F.3 *(continued)*

Variable	Unit	Formula
E // or $E \perp$ at angle θ	N/mm²	E // or $E \perp \left(1-\dfrac{\theta}{38}+\dfrac{\theta^2}{3\,400}\right)$ for $0 \le \theta < 90°$
σ_U //or $\sigma_U \perp$ at angle θ	N/mm²	σ_U //or $\sigma_U \perp \left(1-\dfrac{\theta}{57}+\dfrac{\theta^2}{5\,100}\right)$ for $0 \le \theta < 90°$
τ at angle θ	N/mm²	$\tau \times \left(1+\dfrac{\theta}{250}+\dfrac{\theta^2}{4\,000}\right)$ for $0 \le \theta < 45°$
where $k_N = 0{,}5\left(1+\dfrac{1}{N_{ply}}\right)$ and ρ_{PW} is the plywood actual density (kg/m³). This assumes an odd number of equal thickness plies. Where the two outer plies are thinner (perhaps due to sanding) than the other plies, k_N shall be taken as 0,5.		

Table F.4 — Pre-calculated values of plywood properties according to Table F.2

Density kg/m³	**Number of plies**	σ_{uf} // N/mm²	$\sigma_{uf} \perp$ N/mm²	E_f // N/mm²	$E_f \perp$ N/mm²
400	5	37	23	4 476	2 024
	7	35	27	4 086	2 688
	9	33	30	3 760	3 141
	11	31	31	3 499	3 352
450	5	39	24	4 890	2 211
	7	37	29	4 464	2 937
	9	35	31	4 108	3 420
	11	33	33	3 822	3 662
500	5	42	26	5 292	2 393
	7	39	30	4 831	3 178
	9	37	33	4 445	3 701
	11	35	34	4 146	3 963
550	5	44	27	5 684	2 571
	7	41	32	5 189	3 414
	9	39	35	4 775	3 976
	11	37	36	4 443	4 257
600	5	46	28	6 067	2 744
	7	43	33	5 538	3 644
	9	41	36	5 097	4 244
	11	38	38	4 742	4 544

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Table F.5 — Pre-calculated values of cold-moulded ±45° veneers according to Table F.2

Wood common name	Number of plies	σ_f short direction N/mm²	σ_f long direction N/mm²	E_f short direction N/mm²	E_f long direction N/mm²
All plies at ±45° to short panel side					
Western red cedar	any	16	16	1 435	1 435
Mahogany, African	any	20	20	1 796	1 796
Final ply at 90° to short panel side					
Western red cedar	3	10	NR	1 144	2 512
	4	11	NR	1 177	2 512
	5	11	NR	1 220	2 512
Mahogany, African	3	14	NR	1 418	3 142
	4	14	NR	1 472	3 142
	5	15	NR	1 526	3 142

Table F.6 — Pre-calculated values of plywood on edge according to Table F.3

Density kg/m³	Number of plies	k_N	σ_{uf} // N/mm²	σ_{uf} ⊥ N/mm²	E_f // N/mm²	E_f ⊥ N/mm²	$G_{0/90}$ N/mm²	$\tau_{0/90}$ N/mm²	$\tau_{+/-45}$ N/mm²
400	5	0,60	25	18	3 360	2 415	480	8,0	14,5
	7	0,57	24	19	3 225	2 550			
	9	0,56	24	20	3 150	2 625			
	11	0,55	23	20	3 102	2 673			
450	5	0,60	29	21	3 920	2 818	540	9,0	15,2
	7	0,57	28	22	3 763	2 975			
	9	0,56	28	23	3 675	3 063			
	11	0,55	27	23	3 619	3 118			
500	5	0,60	34	24	4 480	3 220	600	10,0	16,9
	7	0,57	32	26	4 300	3 400			
	9	0,56	32	26	4 200	3 500			
	11	0,55	31	27	4 146	3 564			
550	5	0,60	38	27	5 040	3 623	660	11,0	18,6
	7	0,57	36	29	4 838	3 825			
	9	0,56	35	30	4 725	3 938			
	11	0,55	35	30	4 653	4 009			
600	5	0,60	42	30	5 600	4 025	720	12,0	20,3
	7	0,57	40	32	5 375	4 250			
	9	0,56	39	33	5 250	4 375			
	11	0,55	39	33	5 170	4 455			

F.3 Laminated wood calculation examples

This clause provides examples of scantlings assessment based on the default mechanical properties of Tables F.1 and F.2, and computed values from Tables F.4 and F.5. Where alternative data sources are used, these values may be substituted in place of the default mechanical properties.

EXAMPLE 1 Design of sheet plywood

Determine plywood density (600 kg/m³) and number of plies (7).

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Determine flexural strength for the two orientations from Tables F.2 or F.4:

$\sigma_{//}$ to outer face $= \left(\dfrac{\rho_{PW}}{1\,000}\right)^{0,5} \left(68 - 2N_{ply} + 0{,}03N_{ply}^{\;2}\right) = 0{,}6^{0,5}\,(68 - 2 \times 7 + 0{,}03 \times 7^2) = 43\ \text{N/mm}^2$

$\sigma_{\perp}$ to outer face $\left(\dfrac{\rho_{PW}}{1\,000}\right)^{0,5} \left(11 + 6{,}5N_{ply} - 0{,}28N_{ply}^{\;2}\right) = 0{,}6^{0,5}\,(11 + 6{,}5 \times 7 - 0{,}28 \times 7^2) = 33\ \text{N/mm}^2$

Determine whether the outer plywood face runs parallel or perpendicular to the short panel side (perpendicular).

Use Table A.5 for laminated wood of plywood to determine the required thickness.

$$t = b \times \sqrt{\frac{P_d \times k_2}{1\,000 \times \sigma_d}} = 450\sqrt{\frac{60 \times 0{,}5}{1\,000(0{,}5 \times 33)}} = 19{,}2\ \text{mm}$$

EXAMPLE 2 Design of *in-situ* moulded veneers from Khaya (African Mahogany)

Determine veneer density (514 kg/m^3) before moulding and determine ultimate flexural strength parallel to the grain from Table F.1 using the “other woods” formula or pick off the actual wood.

From Table $\sigma_{uf//}$ to grain = 67 N/mm^2 or, from density 0,130 × 514 = 67 N/mm^2.

Determine whether the outer veneer face runs perpendicular or at 45° to the short panel side (perpendicular) and the number of plies (4).

Determine the flexural strength using Table F.2 ± 45° cold-moulded veneer.

$\sigma_{uf//}$ to short panel side = (0,01 N_{ply} + 0,17) σ_{uf} of parent wood = (0,01 × 4 + 0,17) × 67 = 14 N/mm^2.

NOTE If all veneers are at ±45°, σ // to short panel side = 0,3 σ_{uf} of parent wood = 0,3 × 67 = 20 N/mm^2.

Use Table A.5 for laminated wood of plywood to determine the required thickness.

$$t = b \times \sqrt{\frac{P_d \times k_2}{1\,000 \times \sigma_d}} = 250\sqrt{\frac{60 \times 0{,}5}{1\,000(0{,}5 \times 14)}} = 16{,}5\ \text{mm}$$

EXAMPLE 3 Design of strip plank from Western red cedar

Determine strip-plank density (368 kg/m^3) before moulding and determine ultimate flexural strength parallel to the grain from Table F.1 using the “other woods” formula or pick off the actual wood.

From Table $\sigma_{uf\,//}$ to grain = 52 N/mm^2, and from density 0,137 × 368 = 50 N/mm^2.:50 chosen

Determine whether the configuration is strip plank only or strip plank with 1 mm FRP faces or strip plank with ±45° veneers (yes).

Select σ_L/σ_s value from Table F.2 (0,2).

Calculate the ultimate flexural strength 1,6 × $(\sigma_L/\sigma_s)^{0,5}$ × σ_f of strip plank = 1,6 × 0,2^{0,5} × 50 = 36 N/mm^2.

Use Table A.5 for laminated wood of plywood to determine the required thickness.

$$t = b \times \sqrt{\frac{P_d \times k_2}{1\,000 \times \sigma_d}} = 800\sqrt{\frac{60 \times 0{,}5}{1\,000(0{,}5 \times 36)}} = 33\ \text{mm}$$

NOTE For strip plank only, the ultimate flexural strength 1,6 × $(\sigma_L/\sigma_s)^{0,5}$ × σ_{uf} of strip plank = 1,6 × 0,07^{0,5} × 50 = 21 N/mm^2 and the required thickness would be 43 mm.

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Annex G
(normative)

Geometric properties of stiffeners

G.1 General

The required geometric properties of stiffeners, as required by Table A.5 or A.8 may be determined using the following tables. Intermediate values may be derived by interpolation. Due to the variety of attached plating width, the values are given with a range. To obtain more precise values, the use of an analysis according to Clause H.4 is recommended.

G.2 Glass-reinforced plastic

G.2.1 General

Tables G.1 to G.3 give the geometric properties of three different typical types of top-hat laminates: "squat", "square" and "tall".

The stiffener laminate is mat with ψ = 0,30. The plating is also supposed to be all mat with an attached plating breath b_e which depends (see Table A.11 and Figure A.13) of the material and the aspect ratio of the panel l_u/s, plus the top-hat bottom width b_b. The former is covered by a laminate having a dry glass weight in kilograms per square metre, as given in column 6.

The section modulus *SM*, (cm^3), the shear web area, A_w (cm^2), and the second moment around neutral axis I_{NA}, (cm^4), are given in columns 8, 9 and 10 respectively.

If the stiffener spacing is less than the width of associated plating $b_e + b_b$ of column 6, the geometric properties would need to be assessed using Annex H.

To calculate top hats where the top flange includes Glass UD, or where different materials are used, one shall apply Annex H. Tables H.6 to H.8 give an example of calculation of such a stiffener.

G.2.2 "Squat" former top hats

"Squat" top hats have a top width (flange) 0,85 times the base width b_c = 0,85 b_b and a height around h = 0,7 b_b. The stiffener thickness t_w /2 = 2,34 × w_f (ψ = 0,30, see Table C.7). See Figure G.1.

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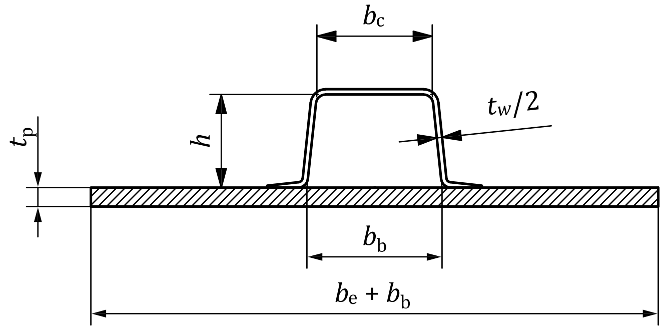

Figure G.1 — Sketch of a “squat” top hat

Table G.1 — "Squat" top hats properties

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Dimensions of former			**Plating**	**Attached plating**		**Stiffener**	**Geometric properties**		
h	b_b	b_c	t_p	b_e	$b_e + b_b$	Laminate	SM_{min}	A_w	I_{NA}
mm	mm	mm	mm	mm		kg/m^2	cm^3	cm^2	cm^4
25	36	30	4	50	86	0,600	1,5	0,7	4
			6	50	86	0,600	1,8	0,7	5
			8	50	86	0,600	2,1	0,7	6
40	60	50	4	80	140	0,600	3,8	1,1	16
			6	80	140	0,600	4,4	1,1	18
			8	80	140	0,600	4,8	1,1	20
50	75	65	4	100	175	0,900	8,2	2,1	43
			6	100	175	0,900	9,4	2,1	49
			8	100	175	0,900	10,3	2,1	54
60	90	75	4	120	210	1,200	14,0	3,4	88
			6	120	210	1,200	16,1	3,4	101
			8	120	210	1,200	17,8	3,4	112
75	100	85	6	150	250	1,200	23,2	4,2	180
			8	150	250	1,200	25,4	4,2	198
			10	150	250	1,200	27,3	4,2	213
120	175	150	8	200	375	1,800	88,3	10,2	1 096
			10	200	375	1,800	95,1	10,2	1 181
			12	200	375	1,800	100,9	10,2	1 253
The doubling of b_e in column 5 increases SM by less than12 %, average +8 %.									

NOTE This table is only fully valid if b_e (column 5) is smaller than stiffener spacing s.

G.2.3 "Square” former top hats

"Square" top hats have a top width (flange) 0,85 times the base width $b_c = 0,85\ b_b$ and a height $h = b_b$. The stiffener thickness $t_w/2 = 2,34 \times w_f$ ($\psi = 0,3$ see Table C.7). See Figure G.2.

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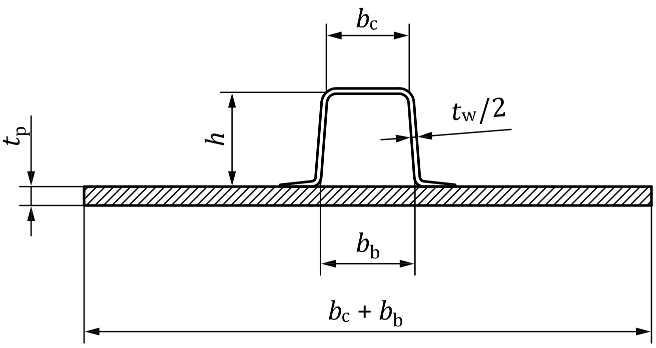

Figure G.2 — Sketch of a "square" top hat

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Table G.2 — "Square" top hats properties

1	2	3	4	5	6	7	8	9	10
Dimensions of former			**Plating**	**Attached plating**		**Stiffener**	**Geometric properties**		
h	b_b	b_c	t_p	b_e	$b_e + b_b$	Laminate	SM_{min}	A_w	I_{NA}
mm	mm	mm	mm	mm		kg/m^2	cm^3	cm^2	cm^4
			4	50	75	0,600	1,2	0,7	3
25	25	20	6	50	75	0,600	1,5	0,7	4
			8	50	75	0,600	1,7	0,7	5
			4	80	120	0,600	3,1	1,1	13
40	40	35	6	80	120	0,600	3,5	1,1	15
			8	80	120	0,600	3,9	1,1	16
			4	100	150	0,900	6,5	2,1	34
50	50	45	6	100	150	0,900	7,5	2,1	39
			8	100	150	0,900	8,3	2,1	43
			4	120	180	1,200	11,0	3,4	69
60	60	50	6	120	180	1,200	12,7	3,4	80
			8	120	180	1,200	14,0	3,4	88
			6	150	225	1,200	19,8	4,2	154
75	75	65	8	150	225	1,200	21,7	4,2	169
			10	150	225	1,200	23,3	4,2	182
			8	200	300	1,800	50,7	8,5	528
100	100	85	10	200	300	1,800	54,6	8,5	570
			12	200	300	1,800	58,1	8,5	606
The doubling of b_e in column 5 increases *SM* by less than 14 % average 9 %.									

NOTE This table is only fully valid if be (column 5) is smaller than stiffener spacings.

G.2.4 "Tall" former top hats

"Tall" top hats have a top width (flange) equal to the base width $b_c = b_b$ and a height h comprised between 2 and 3 times b_c. The stiffener thickness $t_w/2 = 2{,}34 \times w_f$ ($\psi = 0{,}3$ see Table C.7). See Figure G.3.

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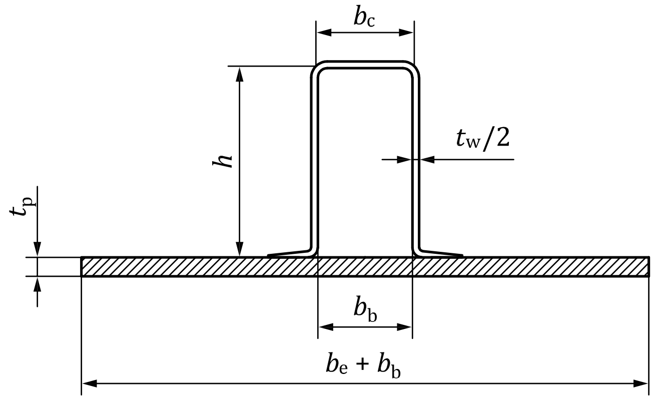

Figure G.3 — Sketch of a "tall" top hat

Table G.3 — "Tall" top hats properties

1	2	3	4	5	6	7	8	9	10
Dimensions of former			**Plating**	**Attached plating**		**Stiffener**	**Geometric properties**		
h	b_b	b_c	t_p	b_e	$b_e + b_b$	Laminate	SM_{min}	A_w	I_{NA}
mm	mm	mm	mm	mm		kg/m^2	cm^3	cm^2	cm^4
100	50	50	4	50	100	1,800	22,0	8,5	230
			6	50	100	1,800	26,0	8,5	271
			8	50	100	1,800	29,4	8,5	306
125	50	50	4	80	130	2,100	35,9	12,3	466
			6	80	130	2,100	42,0	12,3	545
			8	80	130	2,100	47,2	12,3	613
150	50	50	4	100	150	2,700	57,0	19,0	890
			6	100	150	2,700	66,1	19,0	1 033
			8	100	150	2,700	74,0	19,0	1 157
150	75	75	4	120	195	3,000	74,8	21,2	1 175
			6	120	195	3,000	87,2	21,2	1 370
			8	120	195	3,000	98,0	21,2	1 538
175	75	65	6	150	225	3,000	107,9	24,7	1 964
			8	150	225	3,000	120,7	24,7	2 197
			10	150	225	3,000	131,9	24,7	2 402
200	100	100	8	200	300	3,600	204,0	33,8	4 252
			10	200	300	3,600	222,9	33,8	4 646
			12	200	300	3,600	239,7	33,8	4 997
The doubling of b_e in column 5 increases *SM* by less than 20 % average 16 %.									

NOTE This table is only fully valid if b_e (column 5) is smaller than stiffener spacing *s*.

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G.3 Metal hull stiffeners

In commercially available extruded stiffeners, the height h_1 is usually measured from the top of plating to the top of the stiffener flange (see Figure G.4 and Table G.4). In fabricated stiffeners, the height h_2 is usually measured from the top of plating to the bottom of the stiffener flange, as these are the dimension of the commercially available plates (see Figure G.5 and Table G.5). Tables G.4 and G.5 are only fully valid if b_e is smaller than stiffener spacing.

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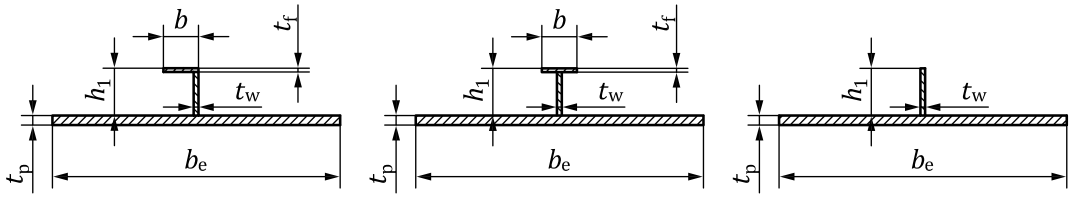

Figure G.4 — Sketch of commercially available extruded L or T and flat bar stiffeners

Table G.4 — Minimum section modulus of extruded L or T and angle and flat bar

Commercially available extruded L or T (See Figure G.4)			
Section $h_1 \times b \times t_w$ mm	**Plating** t_p mm	**Attached plating** b_e mm	SM cm^3
30 × 30 × 4	4	100	4,0
	6	100	4,3
	8	100	4,6
40 × 40 × 5	4	150	8,8
	6	150	9,3
	8	150	9,8
50 × 50 × 5	4	200	14,1
	6	200	14,9
	8	200	15,5
60 × 60 × 6	4	200	23,6
	6	200	24,8
	8	200	25,8
70 × 70 × 6	4	300	33,2
	6	300	34,7
	8	300	35,9
80 × 80 × 6	4	300	43,6
	6	300	15,4
	8	300	46,9
90 × 90 × 8	4	300	69,2
	6	300	72,6
	8	300	75,1
100 × 75 × 8	4	300	69,2
	6	300	72,6
	8	300	75,1

Flat bars			
Section $h_1 \times t$ mm	**Plating** t_p mm	**Attached plating** b_e mm	SM cm^3
30 × 4	4	100	1,3
	6	100	1,4
	8	100	1,6
40 × 4	4	150	2,2
	6	150	2,4
	8	150	2,6
50 × 5	4	200	4,2
	6	200	4,5
	8	200	4,8
60 × 5	4	200	5,9
	6	200	6,3
	8	200	6,7
60 × 6	4	300	7,2
	6	300	7,7
	8	300	8,1
70 × 7	4	300	11,1
	6	300	11,7
	8	300	12,3
80 × 7	4	300	14,2
	6	300	15,0
	8	300	15,7
90 × 8	4	300	19,9
	6	300	21,1
	8	300	22,1

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Table G.4 *(continued)*

Commercially available extruded L or T (See Figure G.4)				Flat bars			
Section $h_1 \times b \times t_w$ mm	Plating t_p mm	Attached plating b_e mm	SM cm^3	Section $h_1 \times t$ mm	Plating t_p mm	Attached plating b_e mm	SM cm^3
125 × 75 × 8	4	300	92,8	100 × 9	4	300	26,9
	6	300	97,5		6	300	28,6
	8	300	100,8		8	300	29,9
150 × 100 × 8	4	300	143,1	125 × 10	4	300	44,4
	6	300	150,5		6	300	47,7
	8	300	155,7		8	300	49,7

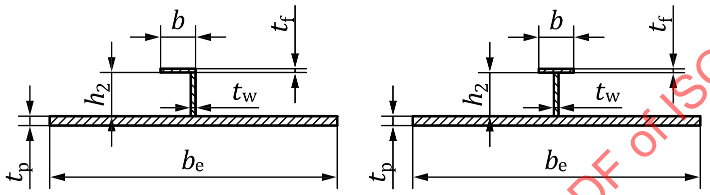

Figure G.5 — Sketch of a fabricated L or T shaped stiffeners

Table G.5 — Minimum section modulus of fabricated L or T

Fabricated L or T (See Figure G.5)			
Section $h_2 \times t_w + b \times t_f$ mm	Plating t_p mm	Attached plating b_e mm	SM cm^3
100 × 6 + 50 × 8	4	300	54,3
	6	300	56,7
	8	300	28,5
150 × 6 + 100 × 8	4	300	145,1
	6	300	151,7
	8	300	156,2
200 × 8 + 100 × 10	4	400	260,0
	6	400	273,0
	8	400	281,7
250 × 10 + 100 × 12	4	450	411,6
	6	450	434,6
	8	450	450,2
250 × 12 + 100 × 15	4	500	496,8
	6	500	525,6
	8	500	545,5

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G.4 Wood stiffeners

G.4.1 General

As the elastic modulus of the plating is usually different from the one of the stiffeners, the calculations are usually made considering the base elastic modulus E as the one of the stiffener. In that analysis the thickness of the plating is multiplied by kE_{0-90}, the ratio between in plane elastic modulus of attached plating parallel to stiffener axis/in plane elastic modulus of the stiffener (see grey cells in Table G.6).

Therefore, wood stiffeners shall be analysed according with one of the following methods:

a) the general method explained in G.4.3 and Table G.7;

b) the application of Annex H for the cases not considered in Table G.6;

c) the use of Table G.6. This method is simpler, and gives quick results for SM. The application of G.4.3 is however required if the verification of shear stress is needed.

G.4.2 Wood stiffeners pre-calculated tables

Table G.6 is calculated applying the general method explained in G.4.3 and considers 4 cases, connected to 4 typical values of kE_{0-90}: these values are:

kE_{0-90}

0 **Floating stiffener** (Top left of Table G.6) Case where the stiffener sits on top of another stiffener such that this stiffener is not directly attached to the plating. The plating is therefore non-effective. The geometric properties are those of the frame alone. The plating is attached to the stiffener but the grain of the plating is perpendicular to that of the stiffener, as is usually the case for a fore and aft strip planked craft with transverse frames, a value of kE_{0-90} equals zero may be used conservatively.

0,25 **Stiffener on ±45° Veneers** (Top right of Table G.6) This corresponds to the case of veneers at ±45° from the grain of the stiffener.

0,50 **Solid stiffener on plywood plating** (Bottom left of Table G.6).

1,00 **Stiffener and plating grain aligned** (Bottom right of Table G.6). This case corresponds to mainly transversal plating on transversal frames, or mainly longitudinal plating on stringers.

Table G.6 shall be used in conjunction with the requirements and explanations given in G.4.3. See Figure G.6.

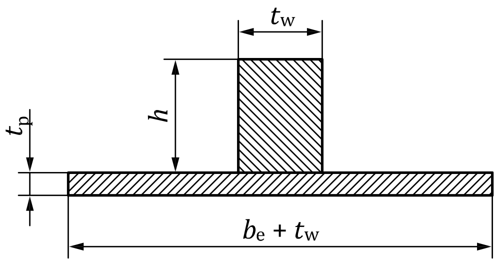

Figure G.6 — Sketch of solid wood stiffener

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Table G.6 — Properties of wood stiffeners

Floating stiffener		Stiffener on ±45° veneers			
kE_{0-90} **= 0,00**	**No attached plating**	kE_{0-90} **= 0,25**	Width of attached plating b_e (mm)		
			75	100	150
			Thickness of attached plating t_p (mm)		
			10	15	20
Section $h \times t_w$	**SM** cm^3	**Section** h x t_w	**SM min**[a] cm^3		
25 × 25	2,6	25 × 25	4,6	6,9	9,6
30 × 30	4,5	30 × 30	6,5	9,8	13,6
40 × 40	10,7	40 × 40	12	20	34
50 × 50	21	50 × 50	21	30	49
60 × 60	36	60 × 60	35	43	66
75 × 50	47	75 × 50	47	58	86
100 × 50	83	100 × 50	83	96	132
125 × 50	130	125 × 50	129	145	189
150 × 50	187	150 × 50	186	204	257
For k_{E-90} = 0,25. *SM* is is increased by 20 %for t_p = 10 & 20 mm and by 40 % for t_p = 15 if b_e is doubled (150 to 300 mm)					

Solid stiffener on plywood plating					Stiffener and plating grain aligned		
kE_{0-90} **= 0,50**	**Width of attached plating** b_e (mm)			kE_{0-90} **= 1,0**	Width of attached plating b_e (mm)		
	75	100	150		75	100	150
	Thickness of attached plating t_p (mm)				Thickness of attached plating t_p (mm)		
	10	15	20		10	15	20
Section $h \times t_w$	***SM* min**[a] cm^3			**Section** $h \times t_w$	***SM* min**[a] cm^3		
25 × 25	6,0	8,2	11	25 × 25	6,8	9,3	13
30 × 30	9,1	12	16	30 × 30	10	14	18
40 × 40	18	27	40	40 × 40	21	31	46
50 × 50	31	45	63	50 × 50	37	52	71
60 × 60	50	69	93	60 × 60	58	80	106
75 × 50	65	86	111	75 × 50	75	99	125
100 × 50	110	140	173	100 × 50	126	160	196
125 × 50	168	207	250	125 × 50	191	237	283
150 × 50	238	288	342	150 × 50	269	329	386
For k_{E-90} = 0,5 and 1, *SM* is increased by about 10 % if b_e is doubled (150 to 300 mm).							
[a] *SM* min= min (*SM* stiffener; *SM* plating) see item 4 of Table G.7.							

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G.4.3 Method to assess wood stiffeners

Assessment of flat bar stiffeners attached to plating may be carried out using the following formulae and procedures. A worked example is included to demonstrate the method. Fabricated tee-section stiffeners produced for example by gluing flange pieces either side of a plywood web or any other section may be analysed using the methods of Annex H.

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Table G.7 — Method

1-Preliminary calculations

Formula for the second moment of areas about the neutral axis NA

$$I_{NA} = A_P\left(\frac{t_P}{2}\right)^2 + A_S\left(\frac{h}{2}\right)^2 + \frac{A_P \times t_P^2}{12} + \frac{A_S \times h^2}{12} - A \times y_{NA}^2 \text{ with } y_{NA} = \frac{A_s \times \frac{h}{2} - A\frac{t_p}{2}}{A} \text{ and } A = A_P + A_S$$

This may be simplified to

$$C = \frac{A_s \times A_p}{3}\left(h^2 + 1{,}5 \times h \times t_p + t_p^2\right) + \frac{1}{12}\left[\left(A_p \times t_p\right)^2 + \left(A_s \times h\right)^2\right] \text{ (cm}^6\text{) and } I_{NA} = \frac{C}{A_p + A_s} \text{ (cm}^4\text{),}$$

where

$A_s = h \times t_w$	area of the stiffener shear web, (cm^2);
$A_p = kE_{0-90} \times t_p \times b_e$	effective area of attached plating, (cm^2);
kE_{0-90}	ratio (E in plane of attached plating parallel to stiffener axis)/(E in plane of the stiffener);
b_e	effective breadth of attached plating (cm) (See Table A.11);
t_p	plating thickness, (cm);
t_w	flat bar thickness, (cm);
h	flat bar depth, (cm).

NOTE Section moduli and second moment of area for a stiffener and attached plating are transformed into a homogeneous combination having the elastic modulus of the stiffener.

2-Required section moduli

To find the section modulus of the stiffener (at its top) the second moment of area I_{NA} is divided by y_{max}.

For the stiffener
$$y_{max} = h - y_{NA} = \frac{A \times h - A_S\frac{h}{2} + \frac{A_p \times t_p}{2}}{A} \text{ and } SM_{Stiffener} = \frac{I_{NA}}{y_{max}} = \frac{C}{A_P\left(h + \frac{t_p}{2}\right) + \frac{A_S \times h}{2}} \text{ (cm}^3\text{)}$$

with $A = A_s + A_p$ and

For the plating
$$y_{max} = t_p + y_{NA} = \frac{A \times t_p - A_S\frac{h}{2} + \frac{A_p \times t_p}{2}}{A} \text{ and } SM_{plating} = \frac{C}{A_S\left(\frac{h}{2} + t_P\right) + \frac{A_P \times t_p}{2}} \text{ (cm}^3\text{)}$$

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Table G.7 *(continued)*

3-Shear stress at stiffener/plating interface
$\tau = \frac{F_d \times A_y}{I_{NA} \times b}$ shear stress where $A_y = A_p \times \left(t_p + y_{NA}\right) = \frac{A_p \times A_S \times \left(\frac{h}{2} + \frac{t_p}{2}\right)}{A_S + A_p}$ first moment of areas, and $I_{NA} = \frac{C}{A_S + A_p}$ second moment about NA. If dimensions are in (cm), areas in (cm^2) and stresses in (N/mm^2) the shear stress at the interface is $\tau = \frac{0{,}005 \times F_d \times A_P \times A_S \times \left(h + t_p\right)}{C \times t_w}$
4-Analysis of a wooden stiffener
4.1 General
kE_{0-90} = 0,25 for ±45° veneers, and kE_{0-90} = 0,05 ≈ 0 for transverse frames on longitudinally laid strip planks. When kE_{0-90} = 0 as is the case for 'floating' frames, then $SM_{min} = \frac{t_w \times h^2}{6}$ (cm^3) Table G.6 provides calculations for minimum section modulus and second moment of area for selected stiffeners. Wood stiffener and plating combinations shall be examined for compliance at the following locations:
4.2 Stress at the extreme top of the flat bar stiffener The direct stress at the extreme top of the stiffener shall be assessed as specified in Table 17, i.e. it has to be checked against σ_d which is σ_d = 0,45 × σ_{uf} × k_{AM} for laminated and plywood on edge frames, σ_d = 0,4 × σ_{uf} × k_{AM} for solid wooden frames, with k_{AM} = 0,95 as it is the "enhanced" method. $\sigma_{stiffener} = \frac{M_d}{SM_{stiffener}}$ (N/mm^2)
4.3 Tensile stress at the extreme underside of the attached plating $\sigma_{plating} = \frac{M_d}{SM_{plating}} kE_{0-90}$ (N/mm^2) where M_d is the design bending moment, (Nm), defined in Table A.8.
4.4 Shear stress in the stiffener $\tau_{stiffener} = \frac{F_d}{A_s}$ (N/mm^2) According with Table 17, the shear stress assessment shall be based respectively on : τ_d = 0,45 × τ_u × k_{AM} for laminated wooden frames, or τ_d = 0,4 × τ_u × k_{AM} for frames made out of solid wood
4.5 Shear stress at the interface between a plating panel and its stiffener See H.4.

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Table G.8 — Worked example

Dimensions are in (cm), areas in (cm^2) and stresses in (N/mm^2).

Sitka spruce 50 × 50 stringers at s = 280 mm centres with plating of a total of 15 mm made with Khaya ±45° veneers. Stiffener span = l= 800 mm.

Effective extent of attached plating (See Table A.11) $\frac{b_e}{s} = \frac{1}{1+2,478\times 7\times \left(\frac{s}{l}\right)^2} = 0,32$

and b_e = 0,32 × 280 = 90 mm, the stiffener width must be added to this value, hence $b_e + b$ = 90 + 50 = 140 mm.

Stiffener

From Table F.1 Sitka spruce (ρ = 384). Ultimate flexural stress σ_{uf} = 53 N/mm^2

Design flexural stress: σ_{df} = 0,4 × 53 × 0,95 = 20,1 N/mm^2 with k_{AM} = 0,95 (Enhanced method)

Ultimate shear stress τ_u = 6,9 N/mm^2. Design shear stress τ_d = 0,4 × 6,9 × 0,95 = 2,6 N/mm^2

E = 19,5 × 384 = 7 488 N/mm^2 A_s = 5 × 5 = 25 cm^2.

Plating

The african Mahogany (Khaya) plating is at ±45° to short panel side. From Tables F.1 and F.2

Ultimate flexural stress σ_{uf} = 0,3 × 0,130 × 514 = 20 N/mm^2

Same as σ_{uf} = 0,3 of parent wood strength = 0,30 ×67 = 20 N/mm^2.

Design stress σ_d = 0,5 × 20,7 × 0,95 = 9,5 N/mm^2 according to Table 17 (k_{AM} = 0,95)

E = 0,2 × 17,5 × 513 = 1 800 N/mm^2 (0,2 of parent wood, from Table F.1).

Dimensions in cm, cm^2 or cm^3.

kE_{0-90} = E plating/E stiffener = 1 800/7 488 = 0,24. Close to the ,25 of Table G.6.

$A_p = kE_{0-90} \times t_p \times b_e$ = 0,24 × 14 × 1,5 = 5,05 cm^2. $A_s = h \times t_w$ = 5 × 5 = 25 cm^2

$$C = 0,333 A_s \times A_p \left(h^2 + 1,5\times h\times t_p + t_p^2\right) + 0,083\,33\left[\left(A_p\times t_p\right)^2 + \left(A_s\times h\right)^2\right].$$

C = 0,333 × 25 × 5,05 (5^2 + 1,5 × 5 × 1,5 + $1,5^2$) + 0,083 3 [$(5,04 × 1,5)^2$+ $(25 × 5)^2$] = 2 926 (cm^6)

$I_{NA} = \frac{C}{A_p + A_s}$ = 2 926 / (25 + 5,05) = 97,4 (cm^4)

$SM_{stiffener} = \frac{I_{NA}}{y_{max}} = \frac{C}{Ap\left(h+\frac{t_p}{2}\right)+\frac{A_s\times h}{2}}$ = 2 × 926 / [5,03 ×(5 + 0,75) + 25 × 5/2] = 32,0 (cm^3)

$SM_{plating} = \frac{C}{A_s\left(\frac{h}{2}+tp\right)+\frac{A_p\times t_p}{2}}$ = 2 × 926 / [25 × (5/2 + 1,5) +5,03 × 1,5/2] = 28,2 cm^3

Bending moment and shear force on the stiffener

If the design pressure is P = 28 kN/m^2 and k_{cs} = 1 (no curvature)

$F_d = k_{SF}\times P\times l_u \times 10^3$ = 0,5 × 28 × 280 × 800 × 10^{-3} = 3 136 N (See Table A.8)

k_{SF} = 0,5 according to Table A.8 for Fully fixed ends

$M_d = 0,0833\times k_{CS}\times P\times s\times l_u^2 \times 10^{-6}$ = (83,33 × 28 × 280 × 800^2) × 10^{-6} = 416 Nm (See Table A.8)

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Table G.8 *(continued)*

Required section moduli and compliance factor CF = $\sigma_d / \sigma_{actual}$
For the stiffener (flexural strength criterion) $\sigma_{a\ stiffener} = \frac{M_d}{SM_{stiffener}}$ = 416/32 = 13,1 N/mm² CF stiff = 20,1/13 = 1,55; complies. For the plating (flexural strength criterion) $\sigma_{a\ plating} = \frac{M_d}{SM_{plating}} kE_{0-90}$ = 416/28,2 ×0,24 = 3,57 N/mm² CF plating = 9,5/3,57 = 2,67; complies.
Stiffener area check for shear
$\tau_{stiffener} = F_d / A_s$ = 3 136 / (50 × 50) = 1,25 N/mm² CF shear stiffener = 2,6/1,25 = 2,09; complies. The design shear stress for plating at ±45° is about the same as the one for parent wood (and not 30 % as for stiffener), and the design shear stress (see excel file et the end of Table G.9) is 4,8 N/mm² and the compliance factor is 3,8 >> 2,1 for the stiffener. The shear on stiffener/plating interface is the limiting one.
Use of Table G.6
For kE_{0-90} = 0,25, (different from 0,24) with 50 × 50 frame Table G.6 for t_p = 15 mm gives *SM* min = 30 cm³ for b_e = 100 mm, (mm here) which is a little greater than the SM min for plating at 28,2 of this example.

Table G.9 — Continued — Excel file

Stiffener										
E	σ_{uf}	τ_{uf}	*b*	*h*	*l*		A_s	k_{AM}	σ_d	τ_d
									0,4 $\sigma_{uf} \times k_{AM}$	0,4 $\tau_u \times k_{AM}$
N/mm²	N/mm²	N/mm²	cm	cm	cm		cm²	1	N/mm²	N/mm²
7 448	53	6,9	5,00	5,00	80		25,00	0,95	20,1	2,6
Plating										
E	σ_{uf}	τ_{uf}	k_{E0-90}	t_p	s	b_e+*b*	A_p	k_{AM}	σ_d	τ_d
						0,32s+*b*			0,5 $\sigma_{uf} \times k_{AM}$	0,5 $\tau_u \times k_{AM}$
N/mm²	N/mm²	N/mm²	1	cm	cm	cm	cm²	1	N/mm²	N/mm²
1 799	20,7	10,0	0,24	1,50	28	14,0	5,05	0,95	9,8	4,8
-------------------- **General calculation results** -----------------------										
C	Ina	SM plat.	SM stiff	P	k_{SF}	Fd	k_{BM}	Md		
1	cm4	cm3	cm3	kN/m²	1	N	1	Nm		
2 926	97,4	28,2	32,0	28,0	0,5	**3 136**	0,083	**416**		
------ **Calculation results for plating ---- Calculation results for stiffeners**										
σ_a plating	CF σ	τ_a	CF τ	σ_a	CF σ	τ_a	CF τ			
$k_E{*}M_d/SM_p$	σ_d/σ_a	$F_d/100A_s$	τ_d/τ_a	M_d/SM_s	σ_d/σ_a	F_d/A_s	τ_d/τ_a			
N/mm²	1	N/mm²	1	N/mm²	1	N/mm²	1			
3,57	**2,66**	**1,25**	**3,79**	**13,1**	**1,54**	**1,25**	**2,09**			

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