INTERNATIONAL STANDARD

ISO 12215-5

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Small craft — Hull construction and scantlings —

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

Petits navires — Construction de la coque et échantillonnage —

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

Reference number
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Contents

Page

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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 12215-5 was prepared by Technical Committee ISO/TC 188, *Small craft*.

ISO 12215 consists of the following parts, under the general title *Small craft — Hull construction and scantlings*:

— *Part 1: Materials: Thermosetting resins, glass fibre reinforcement, reference laminate*

— *Part 2: Materials: Core materials for sandwich construction, embedded materials*

— *Part 3: Materials: Steel, aluminium alloys, wood, other materials*

— *Part 4: Workshop and manufacturing*

— *Part 5: Design pressures for monuhulls, design stresses, scantlings determination*

— *Part 6: Structural arrangements and details*

— *Part 7: Scantling determination of multihulls*

— *Part 8: Rudders*

— *Part 9: Sailing boats — Appendages and rig attachment*

Introduction

The reason underlying the preparation of this part of ISO 12215 is that standards and recommended practices for loads on the hull and the dimensioning of small craft differ considerably from one to another, thus limiting the general worldwide acceptability of boat scantlings. This part of ISO 12215 has been set towards the lower boundary of the range of current practice.

The objective of this part of ISO 12215 is to achieve an overall structural strength that ensures the watertight and weathertight integrity of the craft. It is intended to be a tool to assess the scantlings of a craft against lower bound practice and it is not intended to be a structural design procedure

The scantling requirements are based principally on 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. The criteria contained within may need to be supplemented by additional considerations deemed necessary by the designer of the structure.

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. The responsibility for the decision to use this part of ISO 12215 as part of the design procedure rests solely with the designer and/or manufacturer.

The design pressures given in this part of ISO 12215 are only used with the given equations.

Considering future development in technology and boat types and small craft currently outside the scope of this part of ISO 12215, provided methods supported by appropriate technology exist, consideration may be given to their use provided equivalent support for this part of ISO 12215 is achieved.

The dimensioning according to this part of ISO 12215 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.

Important notice:

1) ISO/TC 188/WG 18 believes that this part of ISO 12215 is the best that can be achieved at the time of publication. It has therefore decided to publish this document as an ISO Standard. It is anticipated that wider usage may reveal a number of issues that require modification. It is for this reason that WG 18 has asked for a revision of the document at the same time as its publication. This revision agreement will enable the group to amend this part of ISO 12215 quickly should this prove necessary.

2) In furtherance of this, this part of ISO 12215 needs to be applied with a critical mind, and users are invited to report to the TC secretariat, or national standardization body, any items that are considered to require correction, together with supporting evidence, be that theoretical or based on satisfactory, long-term service experience with actual boats operating in the appropriate design category sea states.

Small craft — Hull construction and scantlings —

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

1 Scope

This part of ISO 12215 applies to the determination of design pressures and stresses, and to the determination of the scantlings, including internal structural members of monohull small craft constructed from fibre-reinforced plastics, aluminium or steel alloys, glued wood or other suitable boat building material, with a length of hull, L_H, in accordance with ISO 8666, between 2,5 m and 24 m. It only applies to boats in the intact condition.

It only applies to craft with a maximum speed $\leqslant$ 50 knots in m_{LDC} conditions.

The assessment shall generally include all parts of the craft that are assumed watertight or weathertight when assessing stability, freeboard and buoyancy in accordance with ISO 12217 and are essential to the safety of the craft and of persons on board.

For the complete scantlings of the craft, this part of ISO 12215 is used in conjunction with Part 6, for details, Part 7 for multihulls, Part 8 for rudders and Part 9 for appendages and rig attachment.

The scantling determination of windows, portlights, deadlights, hatches and doors, is in accordance with ISO 12216. The structure supporting these elements is in accordance with this part of ISO 12215.

NOTE 1 Scantlings derived from this part of ISO 12215 are primarily intended to apply to recreational craft including recreational charter vessels and may not be suitable for performance racing craft.

NOTE 2 This part of ISO 12215 is based on the assumption that scantlings are governed solely by local loads.

NOTE 3 The scantling requirements of this part of ISO 12215 are considered to correspond to the minimum strength requirements of motor and sailing craft which are operated in a safe and responsible manner, having due cognisance of the prevailing conditions.

Pressures and stresses are normally expressed in pascals, kilopascals or megapascals. For the purposes of a better understanding for the users of this part of ISO 12215, the pressures are expressed in kilonewtons per square metre (1kN/m^2 = 1kPa) and stresses or elastic moduli are expressed in newtons per square millimetre (1 N/mm^2 = 1 MPa).

2 Normative references

The following referenced documents are indispensable for the application 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 178, *Plastics — Determination of flexural properties*

ISO 527-1, *Plastics — Determination of tensile properties — Part 1: General principles*

ISO 527-2, *Plastics — Determination of tensile properties — Part 2: Test conditions for moulding and extrusion plastics*

ISO 844, *Rigid cellular plastics — Determination of compression properties*

ISO 845, *Cellular plastics and rubbers — Determination of apparent density*

ISO 1922, *Rigid cellular plastics — Determination of shear strength*

ISO 8666:2002, *Small craft — Principal data*

ISO 12215-3, *Small craft — Hull construction and scantlings — Part 3: Materials: Steel, aluminium alloys, wood, other materials*

ISO 12215-6, *Small craft — Hull construction and scantlings — Part 6: Structural arrangements and details*

ISO 12215-7, *Small craft — Hull construction and scantlings — Part 7: Scantling determination of multihulls*

ISO 12215-9, *Small craft — Hull construction and scantlings — Part 9: Sailing boats — Appendages and rig attachment*

ISO 12216, *Small craft — Windows, portlights, hatches, deadlights and doors — Strength and watertightness requirements*

ISO 12217 (all parts), *Small craft — Stability and buoyancy assessment and categorization*

ASTM C393, *Standard Test Method for Flexural Properties of Sandwich Constructions*

3 Terms and definitions

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

3.1
design categories
sea and wind conditions for which a boat is assessed by this part of ISO 12215 to be suitable, provided the craft is correctly handled in the sense of good seamanship and operated at a speed appropriate to the prevailing sea state

3.1.1
design category A ("ocean")
category of boats considered suitable to operate in seas with significant wave heights above 4 m and wind speeds in excess of Beaufort Force 8, but excluding abnormal conditions, e.g. hurricanes

NOTE For the application of this part of ISO 12215, the calculation wave height is 7 m.

3.1.2
design category B ("offshore")
category of boats considered suitable to operate in seas with significant wave heights up to 4 m and winds of Beaufort Force 8 or less

3.1.3
design category C ("inshore")
category of boats considered suitable to operate in seas with significant wave heights up to 2 m and a typical steady wind force of Beaufort Force 6 or less

3.1.4
design category D ("sheltered waters")
category of boats considered suitable to operate in waters with significant wave heights up to and including 0,3 m with occasional waves of 0,5 m height, for example from passing vessels, and a typical steady wind force of Beaufort Force 4 or less

3.2
loaded displacement mass
m_{LDC}
mass of the craft, including all appendages, when in the fully loaded ready-for-use condition as defined in ISO 8666

3.3
sailing craft
craft for which the primary means of propulsion is wind power, having $A_S > 0{,}07(m_{LDC})^{2/3}$ where A_S is the total profile area of all sails that may be set at one time when sailing close hauled, as defined in ISO 8666 and expressed in square metres

NOTE In the rest of this part of ISO 12215, non-sailing craft are considered as motor craft.

3.4
second moment of area
I
for a homogeneous material, it is the 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, and is expressed in centimetres to the fourth or millimetres to the fourth

NOTE The second moment of area is also referred to in other documentation as the moment of inertia and for brevity as "second moment" within this part of ISO 12215.

3.5
section modulus
SM
for a homogeneous material, it is the second moment of area divided by the distance to any point from the neutral axis at which the stress is to be calculated and is expressed in cubic centimetres or cubic millimetres

NOTE The minimum section modulus is calculated to the furthest point from the neutral axis.

3.6
displacement craft
craft whose maximum speed in flat water and m_{LDC} conditions, declared by its manufacturer, is such that

$$\frac{V}{\sqrt{L_{WL}}} < 5$$

3.7
displacement mode
mode of running of a craft in the sea such that its mass is mainly supported by buoyancy forces

NOTE This is the case if the actual speed in a seaway and m_{LDC} conditions is such that its speed:length ratio makes the craft behave as a displacement craft.

3.8
planing craft
craft whose maximum speed in flat water and m_{LDC} conditions, declared by its manufacturer, is such that

$$\frac{V}{\sqrt{L_{WL}}} \geqslant 5$$

NOTE This speed:length ratio limit has been arbitrarily set up in this part of ISO 12215, but it may vary from one boat to another according to hull shape and other parameters.

3.9
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 A planing craft in calm water will run in planing mode.

NOTE 2 A planing craft may be obliged to significantly reduce its speed when the sea gets worse, running in that case in displacement mode.

4 Symbols

Unless specifically otherwise defined, the symbols shown in Table 1 are used in this part of ISO 12215.

NOTE The symbols are shown in alphabetic order, not in order of appearance.

Table 1 — Symbols, factors, parameters

Symbol	Unit	Designation/meaning of symbol	Reference/subclause concerned
Principal craft data			
A_S	m	Sail area in accordance with ISO 8666	ISO 8666
B_C	m	Chine beam	6.1
B_H	m	Beam of the hull	ISO 8666
B_{WL}	m	Beam of the fully loaded waterline at m_{LDC}	ISO 8666
D_b	m	Depth of bulkhead	11.8.1
L_H	m	Length of the hull	ISO 8666, 6.1
L_{WL}	m	Length of the fully loaded waterline at m_{LDC}	ISO 8666, 6.1
V	knots	Maximum speed at m_{LDC}	6.1
h_b	m	Load head for watertight bulkhead or integral tank	8.3
m_{LDC}	kg	Loaded displacement mass of the craft	3.2
$\beta_{0,4}$	°	Deadrise angle at 0,4 L_{WL} forward of its aft end	6.1, 7.3
Panel or stiffener dimensions			
A_D	m^2	Design area under consideration	7.5.1
b	mm	Shorter dimension of plate panel	9.1, 10
b_e	mm	Effective extent of plating connected to a stiffener	11.6
c	mm	Crown of a curved panel	10.1.3
c_u	mm	Crown of a curved stiffener	11.2.1
h	m	Height of centre of panel or mid stiffener above W_L	7.6
l	mm	Longer dimension of plate panel	9.1.2
l_u	mm	Unsupported span of stiffener or frame	9.2.2
s	mm	Stiffener or frame spacing	9.2.1
x	m	Distance of mid panel or stiffener from of aft end of L_{WL}	7.4
Z	m	Height of top of hull or deck angle above W_L	7.6
Calculation data: factor, pressures, parameters, stresses			
A_W	cm^2	Shear area cross-section	11.4.1
I	cm^4, mm^4	Second moment of area	11.4.2

Table 1 (*continued*)

Symbol	Unit	Designation/meaning of symbol	Reference/subclause concerned
k_{AR}	1	Area pressure reduction factor	7.5
$k_{AR\ MIN}$	1	Minimun value for k_{AR}	7.5
k_{AS}	1	Stiffener shear force correction in Table 21	11.7.2
k_C	1	Curvature correction factor for plating	10.1.3
k_{CS}	1	Curvature correction factor for stiffeners	11.2.1
k_{DC}	1	Design category factor	7.2
k_L	1	Longitudinal pressure distribution factor	7.4
k_R	1	Structural component and boat type factor	7.5
k_{SA}	1	Stiffener shear area factor	11.2.2
k_{SHC}	1	Shear strength aspect ratio factor	10.5.4
k_{SLS}	1	Light and stable sailboat pressure correcting factor for slamming	7.8
k_{SM}	1	Stiffener bending moment correction in Table 21	11.7.2
k_{SUP}	1	Superstructure pressure reduction factor	7.7
k_Z	1	Vertical pressure distribution factor	7.6
k_1	1	Bending stiffness factor for sandwich	10.1.1
k_2	1	Panel aspect ratio factor for bending strength	10.1.2
k_3	1	Panel aspect ratio factor for bending stiffness	10.1.2
k_4	1	Sandwich minimum skin location factor	10.5.6
k_5	1	Sandwich fibre factor	10.5.6
k_6	1	Sandwich care factor	10.5.6
k_7, k_8	1	Minimum thickness factors	10.6.2
n_{CG}	1	Dynamic load factor	7.3
$P_{BM\ MIN}$	kN/m^2	Motorcraft bottom minimum pressure (planing or displacement)	8.1.2, 8.1.3
P_{BMD}	kN/m^2	Motorcraft bottom pressure in displacement mode	8.1.2
$P_{BMD\ BASE}$	kN/m^2	Motorcraft base bottom pressure in displacement mode	8.1.2
P_{BMP}	kN/m^2	Motorcraft bottom pressure in planing mode	8.1.3
$P_{BMP\ BASE}$	kN/m^2	Motorcraft base bottom pressure in planing mode	8.1.3
P_{SMD}	kN/m^2	Motorcraft side pressure in displacement mode	8.1.4
P_{SMP}	kN/m^2	Motorcraft side pressure in planing mode	8.1.5
$P_{SM\ MIN}$	kN/m^2	Minimum motorcraft side pressure (displacement or planing mode)	8.1.4, 8.1.5
P_{DM}	kN/m^2	Motorcraft deck pressure	8.1.6
$P_{DM\ BASE}$	kN/m^2	Motorcraft deck base pressure	8.1.6
$P_{DM\ MIN}$	kN/m^2	Minimum motorcraft deck pressure	8.1.6
$P_{SUP\ M}$	kN/m^2	Motorcraft superstructure pressure	8.1.7
P_{BS}	kN/m^2	Sailing craft bottom pressure	8.2.1
$P_{BS\ BASE}$	kN/m^2	Sailing craft bottom base pressure	8.2.1
$P_{BS\ MIN}$	kN/m^2	Minimum sailing craft bottom pressure	8.2.1

Table 1 (*continued*)

Symbol	Unit	Designation/meaning of symbol	Reference/subclause concerned
P_{SS}	kN/m^2	Sailing craft side pressure	8.2.2
$P_{SS\ MIN}$	kN/m^2	Minimum sailing craft side pressure	8.2.2
P_{DS}	kN/m^2	Sailing craft deck pressure	8.2.3
$P_{DS\ BASE}$	kN/m^2	Sailing craft deck base pressure	8.2.3
$P_{DS\ MIN}$	kN/m^2	Minimum sailing craft deck pressure	8.2.3
$P_{SUP\ S}$	kN/m^2	Sailing craft superstructure pressure	8.2.4
P_{WB}	kN/m^2	Design pressure, watertight boundaries	8.3.1
P_{TB}	kN/m^2	Design pressure, integral tank boundaries	8.3.2
q	N/mm	Shear flow	H.2.1.7, H.3.2
Q	cm^3, mm^3	First moment of area	11.4.1
SM	cm^3, mm^3	Section modulus	11.4.1
σ_d	N/mm^2	Design direct stress	10
σ_u	N/mm^2	Ultimate strength (flexural, compressive, tensile)	10
τ_d	N/mm^2	Design shear stress	10.5.4, 11
τ_u	N/mm^2	Ultimate shear strength	10.5.4, 11
E	N/mm^2	Elasticity modulus (flexural, compressive, tensile)	10.5, 11
w	kg/m^2	Dry fibre reinforcement mass per square metre	10.2.2, 10.5.6
ψ	1	Glass content in mass	Annex A, Annex C
ϕ	1	Glass content in volume	Annex A, Annex C
Other variables contained in annexes are not listed in this table.			

5 General

The scantling determination shall be accomplished as follows:

— for craft with a length L_H of 2,5 m up to 24 m, in accordance with Clauses 6 to 11;

— for sailing craft with a length L_H of 2,5 m up to 9 m of design categories C and D, in accordance with Annex A for plating;

— for craft with a length L_H of 2,5 m up to 6 m and of single-skin construction, the drop test in Annex B may be used as an alternative to the main body of this part of ISO 12215.

NOTE 1 These scantling requirements are based on normal anticipated sea loads during normal usage. Compliance with these requirements does not eliminate the possibility of damage from accidental overloads, careless handling, trailing loads, chocking loads, grounding or berthing. In some instances the requirements may come out lower than fabrication requirements such as welding ability, and should therefore be increased accordingly. For craft < 6 m, in particular, robustness criteria may be the governing aspect for scantling determination, e.g. beaching, grounding, trailer and fender loads. See 10.5.6 and 10.6.

NOTE 2 Annex A is applicable mainly to small, lightweight inshore sailing boats and sailing dinghies that might otherwise find the scantlings from other sections too conservative, but is only available for plating thickness assessment.

NOTE 3 If an annex is used as an alternative to Clauses 6 to 11, the boat builder shall still refer to parts 7 (multihulls), 8 (rudders) and 9 (appendages and rig attachment) of ISO 12215, as appropriate, in addition to using the particular annex.

6 Dimensions, data and areas

6.1 Dimensions and data

All dimensions are measured, unless otherwise specified, 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.

The main dimensions are

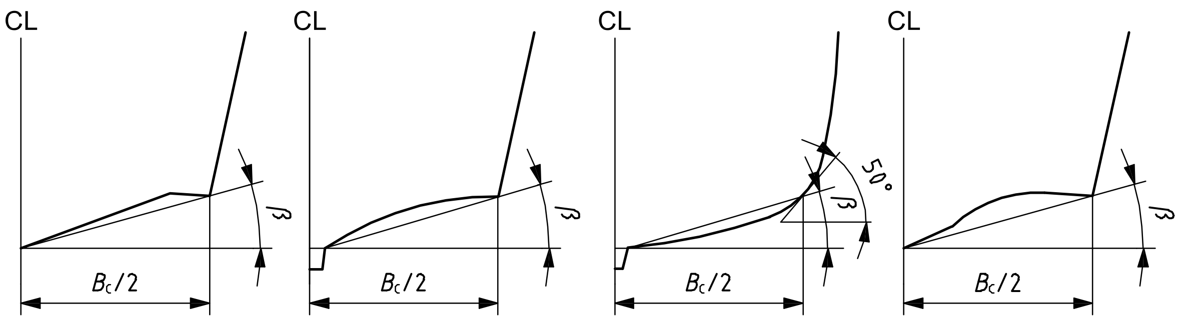
— L_H, the hull length in metres,

— L_{WL}, the length of the waterline, craft at rest in m_{LDC} conditions, in metres,

— B_C, the chine beam, measured in accordance with Figure 1, at 0,4 L_{WL} forward of its aft end, in metres,

— $\beta_{0,4}$, the deadrise angle at 0,4 L_{WL} forward of its aft end, measured according to Figure 1, not to be taken $<$ 10°, nor $>$ 30°, in degrees,

— V, for motor craft, the maximum speed in calm water declared by the manufacturer, with the craft in m_{LDC} conditions. This speed shall not be taken as $< 2{,}36\sqrt{L_{WL}}$. For sailing craft, speed does not need to be declared in knots.



NOTE For round bilge, the outer limit or chine is considered at the point where a tangent at 50° from the horizontal is tangent to the hull.

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

6.2 Areas

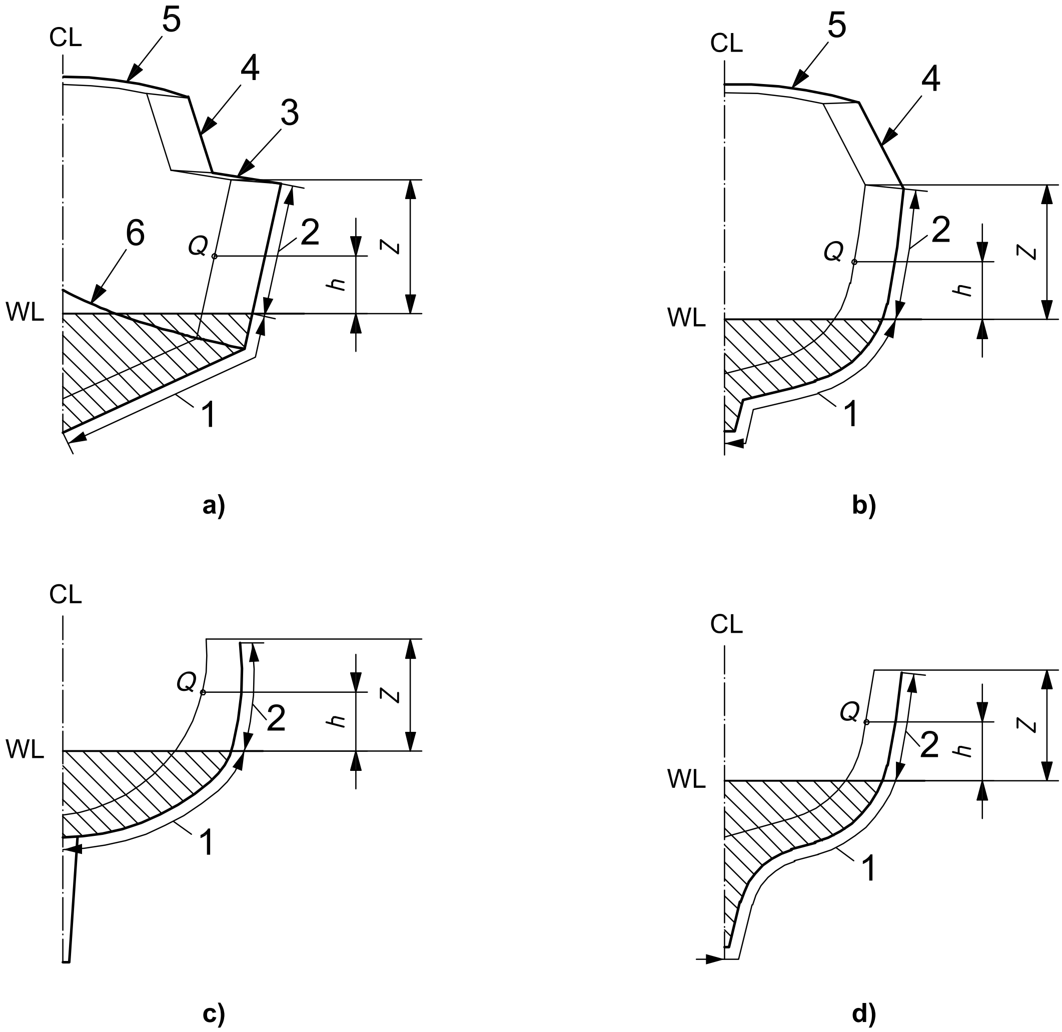
6.2.1 General

The hull, deck and superstructure are divided into various areas: bottom, side, decks and superstructures (see Figure 2).

6.2.2 Bottom areas

For all craft, bottom pressure applies up to waterline (see Figure 2).

The part of the transom following the above definition is considered as bottom.



Key

1 bottom (hatched area)
2 side
3 deck
4 superstructures
5 superstructure top
6 hard chine

Figure 2 — Definitions of areas, and panel height above waterline

6.2.3 Side areas

The extent of the side pressure area, which includes the transom, is the part of the hull not considered as belonging to the bottom area.

6.2.4 Decks and superstructures

Deck areas are parts of the deck exposed to weather and where persons are liable to walk. Cockpit bottom and top of benches and seating areas are included.

Superstructure areas include all areas above deck level. Table 4 lists the different superstructure types.

6.2.5 Panel fully in one area or across two areas

The general situation is as follows:

1) where the plate panel or stiffener is fully within a specified design area, e.g. bottom, side, deck, superstructures, etc., its design pressure shall be determined at the middle of the panel or at mid-length of the stiffener;

2) where the plate panel or stiffener extends over both bottom area and side area, its design pressure shall be determined as a constant pressure over the entire design area, calculated as a weighted average between the two pressures, as shown in the following example.

EXAMPLE For a sailboat panel that lies 30 % in the bottom area and 70 % in the side area, the average pressure is 0,3 P_b + 0,7 P_s, where P_s is obtained at the midpoint of that part of the panel which lies above the waterline.

CAUTION — According to 8.1.1, for 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)]. In that case, method 2) above shall be used.

For large panels, see also 10.1.4.

7 Pressure adjusting factors

7.1 General

Final design pressure is adjusted by a set of factors according to design, boat type, location, etc.

7.2 Design category factor k_{DC}

The design category factor k_{DC}, defined in Table 2, takes into account the variation of pressure loads due to sea with design category.

Table 2 — 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

7.3 Dynamic load factor n_{CG}

7.3.1 General

The dynamic load factor n_{CG} is considered to be close to the single amplitude acceleration measured at the craft centre of gravity at the relevant frequency for a certain period of time. This factor is the negative 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 gs where 1g is the acceleration due to gravity (9,81 m/s^2).

7.3.2 Dynamic load factor n_{CG} for planing motor craft in planing mode

The dynamic load factor for planing craft running in planing mode shall be determined from Equation (1) or Equation (2).

$$n_{CG} = 0{,}32\left(\frac{L_{WL}}{10 \times B_C} + 0{,}084\right) \times \left(50 - \beta_{0,4}\right) \times \frac{V^2 \times B_C{}^2}{m_{LDC}} \qquad (1)$$

where all data are previously defined.

NOTE 1 Equation (1) is derived from practical tests and is therefore not required to be dimensionally correct.

Where Equation (1) gives an n_{CG} value $\leqslant$ 3,0, the value given by Equation (1) shall be used.

Where Equation (1) gives an n_{CG} value > 3,0, that value or the value from Equation (2) shall be used.

$$n_{CG} = \frac{0{,}5 \times V}{m_{LDC}{}^{0{,}17}} \qquad (2)$$

In any case, n_{CG} need not be taken > 7.

NOTE 2 The limitation on n_{CG} in this paragraph is due to the limitation of speed by the crew to keep the slamming accelerations within acceptable comfort and safety limits. The crew of “super sports” or racing boats accept a harder ride than a family cruiser, but need special body support, shock damping seats or equipment to prevent injury from high gs.

7.3.3 Dynamic load factor n_{CG} for sailing craft and displacement motor craft

For sailing craft, n_{CG} is not used for pressure determination. It is only used in the calculation of k_L for which purpose the value of n_{CG} shall be taken as 3. For motor craft where n_{CG}, determined using Equation (1), is < 3,0 from Equation (1), a value of 3,0 shall still be used for calculation of k_L.

7.4 Longitudinal pressure distribution factor k_L

The longitudinal pressure distribution factor k_L takes into account the variation of pressure loads due to location on the craft. It shall be taken from Figure 3 or calculated from Equation (3).

k_L is a function of the dynamic load factor defined below for motor craft.

$$k_L = \frac{1 - 0{,}167 \times n_{CG}}{0{,}6} \frac{x}{L_{WL}} + 0{,}167 \times n_{CG} \text{ but not taken} > 1 \text{ for } \frac{x}{L_{WL}} \leqslant 0{,}6 \qquad (3)$$

$$k_L = 1 \text{ for } \frac{x}{L_{WL}} > 0{,}6$$

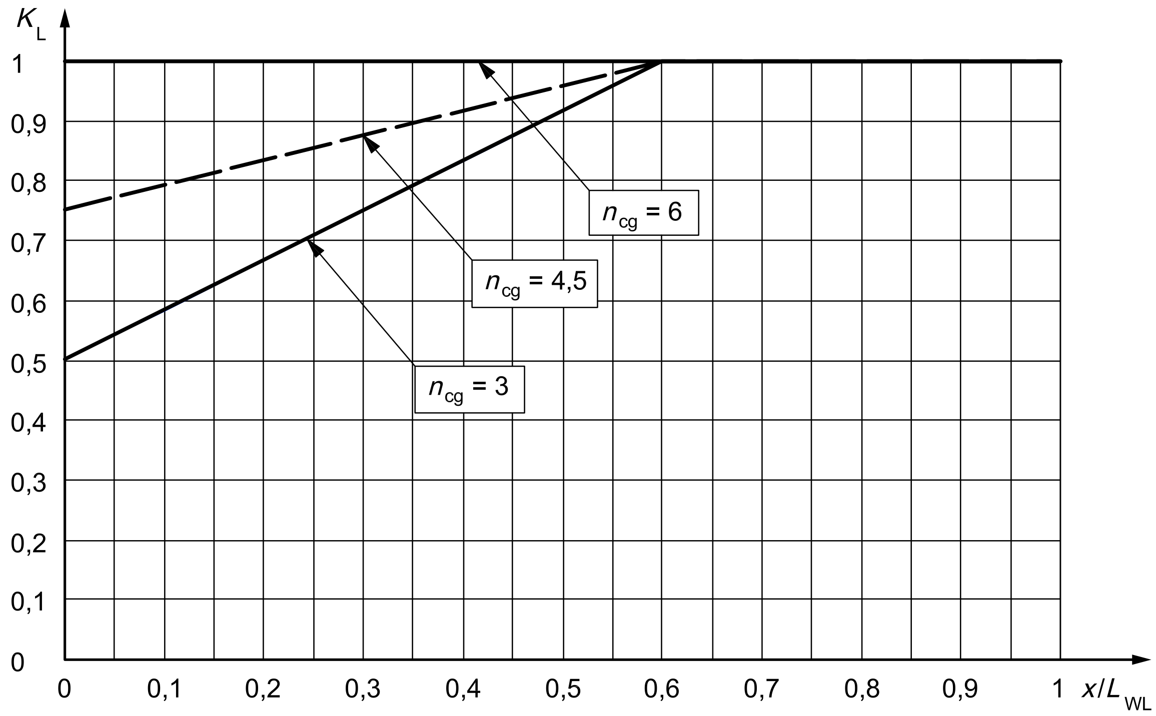
where

n_{CG} is determined in accordance with 7.3, but for the purposes of determination of k_L, n_{CG} shall not be taken < 3 nor > 6;

$\frac{x}{L_{WL}}$ is the position of the centre of the panel or middle of stiffener analysed proportional to L_{WL}, where $\frac{x}{L_{WL}} = 0$ and 1 are respectively the aft end and fore end of L_{WL}.

where x is the longitudinal position of the centre of the panel or middle of stiffener forward of aft end of L_{WL} in m_{LDC} conditions, in metres.

The overhangs fore and aft shall have the same value of k_L as their respective end of the waterline.



NOTE In the graph the only represented intermediate value of n_{CG} between 3 and 6 is 4,5; for other intermediate values, k_L shall be determined either by calculation according to Equation (3) or by interpolation in the graph.

Figure 3 — Longitudinal pressure distribution factor k_L

7.5 Area pressure reduction factor k_{AR}

7.5.1 General

The area pressure reduction factor k_{AR} takes into account the variation of pressure loads due to panel or stiffener size.

$$k_{AR} = \frac{k_R \times 0{,}1 \times m_{LDC}{}^{0{,}15}}{A_D{}^{0{,}3}} \tag{4}$$

where

k_R is the structural component and boat type factor:

$k_R = 1{,}0$ for bottom side and deck panels and stiffeners of planing motor craft operating in planing mode;

$k_R = 1{,}5 - 3 \times 10^{-4} \times b$ for bottom side and deck panels of sailing craft, displacement motor craft and planing motor craft operating in displacement mode;

$k_R = 1 - 2 \times 10^{-4} \times l_u$ for bottom side and deck stiffeners of sailing craft, displacement motor craft and planing motor craft operating in displacement mode;

m_{LDC} is the loaded displacement mass defined in 3.2, in kilograms;

A_D is the design area, in square metres:

$A_D = (l \times b) \times 10^{-6}$ for plating, but shall not be taken $> 2{,}5 \times b^2 \times 10^{-6}$;

$A_D = (l_u \times s) \times 10^{-6}$ for stiffeners but need not be taken $< 0{,}33 \times l_u{}^2 \times 10^{-6}$;

b is the shorter dimension of the panel, as defined in 9.1.1, in millimetres;

l is the longer dimension of the panel, as defined in 9.1.2, in millimetres;

s is the stiffener spacing, as defined in 9.2.1, in millimetres;

l_u is the unsupported span of a stiffener, as defined in 9.2.2, in millimetres.

7.5.2 Maximum value of k_{AR}

k_{AR} shall not be taken $>$ 1.

7.5.3 Minimum values of k_{AR}

k_{AR} shall not be taken at less than the values given in Table 3.

Table 3 — Minimum values of k_{AR}

Design category	Side and bottom single-skin panels and stiffeners Deck and superstructures sandwich and single-skin panels and stiffeners	Side and bottom sandwich panels [a]		
		$\frac{x}{L_{WL}} \leqslant 0{,}4$	$0{,}4 < \frac{x}{L_{WL}} < 0{,}6$	$\frac{x}{L_{WL}} \geqslant 0{,}6$
A	0,25 any craft hull and deck	0,4 any craft	Interpolation between values at $\frac{x}{L_{WL}} = 0{,}4$ and 0,6	0,5 sail bottom and topside 0,5 motor bottom 0,4 motor topside
B	0,25 any craft hull and deck	0,4 any craft		0,4 any craft
C & D	0,25 any craft hull and deck	0,4 any craft		

[a] Minimum k_{AR} applies to bending or shear strength and deflection requirement.

7.6 Hull side pressure reduction factor k_Z

The side pressure reduction factor k_Z interpolates the pressure of the hull side between the (bottom) pressure at waterline and deck pressure at the top edge (see Figure 2).

$$k_Z = \frac{Z - h}{Z} \tag{5}$$

where

Z is the height of top of hull or hull/deck limit above the fully loaded waterline, in metres;

h is the height of centre of panel or middle of stiffener above the fully loaded waterline, in metres.

The height of top of hull or hull/deck limit is the one at the longitudinal location under consideration.

7.7 Superstructure and deckhouse pressure reduction factor k_{SUP}

The superstructure and deckhouse pressure reduction factor k_{SUP} is defined according to location and boat type by Table 4.

Table 4 — Values of k_{SUP} for superstructures and deckhouses

Position of panel	k_{SUP} motor and sail	Application
Front	1	Any area
Side	0,67	Walking area
Side	0,5	Non-walking area
Aft end	0,5	Any area
Top, $\leqslant$ 800 mm above deck	0,5	Walking area
Top, $>$ 800 mm above deck and upper tiers	0,35	Walking area
Upper tiers [a]	Minimum deck pressure 5 kN/m^3	Non-walking area

[a] Elements not exposed to weather shall be considered as upper tiers.

7.8 Light and stable sailing craft pressure correcting factor for slamming k_{SLS}

The light and stable sailing craft pressure correcting factor k_{SLS} takes into account higher slamming pressures encountered on light and stable sailing craft when sailing upwind (i.e at an angle of up to 90° off true wind). It is defined below.

— In design category C and D: $k_{SLS} = 1$

— In design category A and B:

— $k_{SLS} = 1$ if $m_{LDC} > 5\,L_{WL}{}^3$

— $$k_{SLS} = \left(\frac{10\; GZ_{MAX<60} \times L_{WL}{}^{0,5}}{m_{LDC}{}^{0,33}} \right)^{0,5} \quad \text{if } m_{LDC} \leqslant 5\,L_{WL}{}^3 \text{ but shall not be taken} < 1 \qquad (6)$$

where $GZ_{MAX<60}$ is the maximum righting moment lever taken at a heel angle not $>$ 60°, with all stability-increasing devices such as canting keels or water ballast at their most effective position, in fully loaded condition, measured in metres.

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 $GZ_{MAX<60}$.

NOTE This factor is aimed at 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° is aimed at considering stability characteristics that may be acting on performances, i.e. at angles below 30°, and not “survival” stability at angles $>$ 60°.

8 Design pressures

8.1 Motor craft design pressure

8.1.1 General

The bottom pressure of motorcraft shall be the greater of (see NOTE 1)

— the displacement mode bottom pressure P_{BMD} defined in 8.1.2 or

— the planing mode bottom pressure P_{BMP} defined in 8.1.3.

For motorcraft of design categories A and B, the side pressure shall be the greater of (see NOTE 3)

— the displacement mode side pressure P_{SMD} defined in 8.1.4 or

— the planing mode side pressure P_{SMP} defined in 8.1.5.

For motorcraft of design categories C and D, the side pressure 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).

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

NOTE 2 Craft well into the planing mode, $\left(\frac{V}{\sqrt{L_{WL}}} \geqslant 5\right)$, will usually experience P_{BMP} values higher than P_{BMD}.

NOTE 3 In planing mode, the side pressure may be smaller than in displacement mode as, in the former case, the side pressure is interpolated between 0,25 P_{BMP} and deck pressure, whereas, in the latter case, the side pressure is interpolated between 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.

8.1.2 Motor craft bottom pressure in displacement mode P_{BMD}

The bottom design pressure for motor craft in displacement mode P_{BMD} is the greater of

$$P_{BMD} = P_{BMD\,BASE} \times k_{AR} \times k_{DC} \times k_L \text{ kN/m}^2 \text{ or} \quad (7)$$

$$P_{BM\,MIN} = 0{,}45\, m_{LDC}^{0{,}33} + (0{,}9 \times L_{WL} \times k_{DC}) \text{ kN/m}^2 \quad (8)$$

where $P_{BMD\,BASE} = 2{,}4\, m_{LDC}^{0{,}33} + 20$ kN/m^2 (9)

8.1.3 Motor craft bottom pressure in planing mode P_{BMP}

The bottom design pressure for planing motor craft P_{BMP} is the greater of

$$P_{BMP} = P_{BMP\,BASE} \times k_{AR} \times k_L \text{ kN/m}^2 \text{ or} \quad (10)$$

$$P_{BM\,MIN} = 0{,}45\, m_{LDC}^{0{,}33} + (0{,}9 \times L_{WL} \times k_{DC}) \text{ kN/m}^2 \text{ [same as Equation (8)]}$$

where $P_{\text{BMP BASE}} = \dfrac{0,1\, m_{\text{LDC}}}{L_{\text{WL}} \times B_{\text{C}}} \times \left(1 + k_{\text{DC}}{}^{0,5} \times n_{\text{CG}}\right)$ is the base bottom pressure for motorcraft, in planing mode, in kilonewtons per square metre (11)

NOTE The index of 0,5 on k_{DC} is there to reflect that, although some design category effect is present, this effect is attenuated in the planing mode. The reason is that peak planing pressure is mainly experienced in category C conditions and hence the difference between design categories is less marked than in the displacement mode.

8.1.4 Motor craft side pressure in displacement mode P_{SMD}

The side design pressure for motor craft in displacement mode P_{SMD} is the greater of

$$P_{\text{SMD}} = \left[P_{\text{DM BASE}} + k_{\text{Z}} \times \left(P_{\text{BMD BASE}} - P_{\text{DM BASE}}\right)\right] \times k_{\text{AR}} \times k_{\text{DC}} \times k_{\text{L}} \text{ kN/m}^2 \text{ or} \tag{12}$$

$$P_{\text{SM MIN}} = 0,9\, L_{\text{WL}} \times k_{\text{DC}} \text{ kN/m}^2 \tag{13}$$

For decked boats, those parts of the side above hull-deck limit (e.g. bulwark) shall be assessed using $P_{\text{SM MIN}}$.

8.1.5 Motor craft side pressure in planing mode P_{SMP}

For side areas located at or above waterline, the side design pressure P_{SMP} for motor craft in planing mode is the greater of

$$P_{\text{SMP}} = \left[P_{\text{DM BASE}} + k_{\text{Z}} \times \left(0,25 \times P_{\text{BMP BASE}} - P_{\text{DM BASE}}\right)\right] \times k_{\text{AR}} \times k_{\text{DC}} \times k_{\text{L}} \text{ kN/m}^2 \text{ or} \tag{14}$$

$P_{\text{SM MIN}} = 0,9\, L_{\text{WL}} \times k_{\text{DC}}$ kN/m² [same as Equation (13)]

For decked boats, those parts of the side above hull-deck limit (e.g. bulwark) shall be assessed using $P_{\text{SM MIN}}$.

8.1.6 Motor craft deck pressure P_{DM}

The design pressure P_{DM} for the motor craft weather deck is the greater of

$$P_{\text{DM}} = P_{\text{DM BASE}} \times k_{\text{AR}} \times k_{\text{DC}} \times k_{\text{L}} \text{ kN/m}^2 \text{ or} \tag{15}$$

$$P_{\text{DM MIN}} = 5 \text{ kN/m}^2 \tag{16}$$

where $P_{\text{DM BASE}} = 0,35\, L_{\text{WL}} + 14,6$ kN/m² (17)

8.1.7 Motor craft pressure for superstructures and deckhouses $P_{\text{SUP M}}$

The design pressure $P_{\text{SUP M}}$ for superstructures and deckhouses exposed to weather of motor craft is proportional to the deck pressure, but not to be taken less than $P_{\text{DM MIN}}$ in walking areas:

$$P_{\text{SUP M}} = P_{\text{DM BASE}} \times k_{\text{DC}} \times k_{\text{AR}} \times k_{\text{SUP}} \text{ kN/m}^2 \tag{18}$$

8.2 Sailing craft design pressure

8.2.1 Sailing craft bottom pressure

The bottom design pressure P_{BS} for sailing craft is the greater of

$$P_{BS} = P_{BS\,BASE} \times k_{AR} \times k_{DC} \times k_L \text{ kN/m}^2 \text{ or} \tag{19}$$

$$P_{BS\,MIN} = 0{,}35\ m_{LDC}{}^{0{,}33} + 1{,}4\ L_{WL} \times k_{DC} \text{ kN/m}^2 \tag{20}$$

$$\text{where } P_{BS\,BASE} = \left(2\ m_{LDC}{}^{0{,}33} + 18\right) \times k_{SLS} \text{ kN/m}^2 \tag{21}$$

8.2.2 Sailing craft side pressure P_{SS}

The side pressure for sailing craft P_{SS} is the greater of

$$P_{SS} = \left[\left(P_{DS\,BASE} + k_Z \times (P_{BS\,BASE} - P_{DS\,BASE}\right)\right] \times k_{AR} \times k_{DC} \times k_L \text{ kN/m}^2 \text{ or} \tag{22}$$

$$P_{SS\,MIN} = 1{,}4\ L_{WL} \times k_{DC} \text{ but shall not be taken} < 5 \text{ kN/m}^2 \tag{23}$$

where

$P_{BS\,BASE}$ is the base sailboat bottom pressure defined in 8.2.1;

$P_{DS\,BASE}$ is the base sailboat deck pressure defined in 8.2.3.

8.2.3 Sailing craft deck pressure P_{DS}

The design pressure for the weather deck of sailing craft P_{DS} is the greater of

$$P_{DS} = P_{DS\,BASE} \times k_{DC} \times k_{AR} \times k_L \text{ kN/m}^2 \text{ or} \tag{24}$$

$$P_{DS\,MIN} = 5 \text{ kN/m}^2 \tag{25}$$

$$\text{where } P_{DS\,BASE} = 0{,}5\ m_{LDC}{}^{0{,}33} + 12 \text{ kN/m}^2 \tag{26}$$

8.2.4 Sailing craft superstructure pressure $P_{SUP\,S}$

The design pressure $P_{SUP\,S}$ for superstructures and deckhouses exposed to weather on sailing craft is proportional to the deck pressure, but not to be taken less than $P_{DS\,MIN}$ in walking areas.

$$P_{SUP\,S} = P_{DS\,BASE} \times k_{AR} \times k_{DC} \times k_{SUP} \text{ kN/m}^2 \tag{27}$$

8.3 Watertight bulkheads and integral tank boundaries design pressure

8.3.1 Watertight bulkheads pressure P_{WB}

The design pressure P_{WB} on watertight bulkheads, where fitted, is

$$P_{WB} = 7\ h_B \text{ kN/m}^2 \tag{28}$$

where

h_B is the water head, in metres, measured as follows (see Figure 4):

— 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.

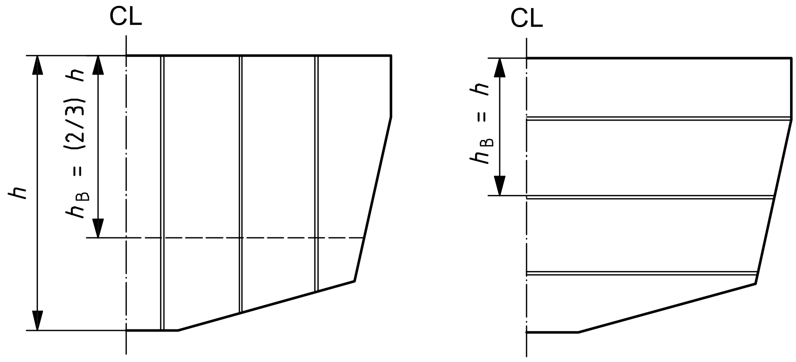


Figure 4 — Watertight bulkheads

8.3.2 Integral tank bulkheads and boundaries P_{TB}

The design pressure P_{TB} on integral tank bulkheads and boundaries is:

$$P_{TB} = 10\ h_B \text{ kN/m}^2 \tag{29}$$

where

h_B is the water head, in metres, measured as follows (see Figure 5):

— for plating, the distance from a point 2/3 of the depth of the panel below top of tank or top of overflow, whichever is the greater;

— for vertical stiffeners, the distance from a point 2/3 of the depth of the stiffener below top of tank or top of the overflow, whichever is the greater;

— for horizontal stiffeners, the height measured from the stiffener to top of tank or top of overflow, whichever is the greater.

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

For determination of the 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 has to be assessed according to the requirements of this section.

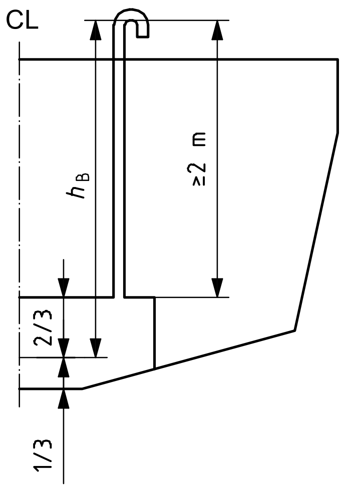


Figure 5 — Measurement of dimensions for integral tank scantling calculation

8.3.3 Wash plates

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 < 50 % 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 both minimum section modulus and second moment of area may be 50 % of that required for stiffener members of integral tanks.

8.3.4 Collision bulkheads

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

8.3.5 Non-watertight or partial bulkheads

Where a bulkhead is structural but non-watertight, the scantlings shall be as required in 11.8.

Bulkheads and partial bulkheads that are non-structural are outside the scope of this part of ISO 12215.

8.3.6 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 12215-9 for mast step analysis for sailing craft.

8.4 Design pressures for structural components where k_{AR} would be $\leqslant$ 0,25

The design pressures in 8.1 and 8.2 are intended to represent the dynamic load experienced by craft. The dynamic effect reduces as the structural component size increases. For very large structural components, the design pressure should be based on the hydrostatic pressure, since it is this load that can be reasonably taken as being distributed over the whole area of the component.

"Very large" components are defined as panels or stiffeners for which the product of the shorter and longer panel sides (panels) or the span and spacing (stiffeners) exceeds the following areas:

— for bottom structure, 30 % of the $L_{WL} \times B_{WL}$ product;

— for side structure, 30 % of the $L_{WL} \times D$ product, where D is the hull total depth;

— for deck structure, 30 % of the $L_{WL} \times B_{WL}$ product.

In such cases, irrespective of the pressure loads obtained from 8.1 and 8.2, the design pressures need not be taken greater than:

— for bottom structure, $0{,}45\ m_{LDC}^{0{,}33}$, but not < 5 kN/m²; (30)

— for side structure, $0{,}3\ m_{LDC}^{0{,}33}$, but not < 5 kN/m²; (31)

— for deck structure, 5 kN/m². (32)

9 Dimensions of panels and stiffeners

9.1 Dimensions of plating panels

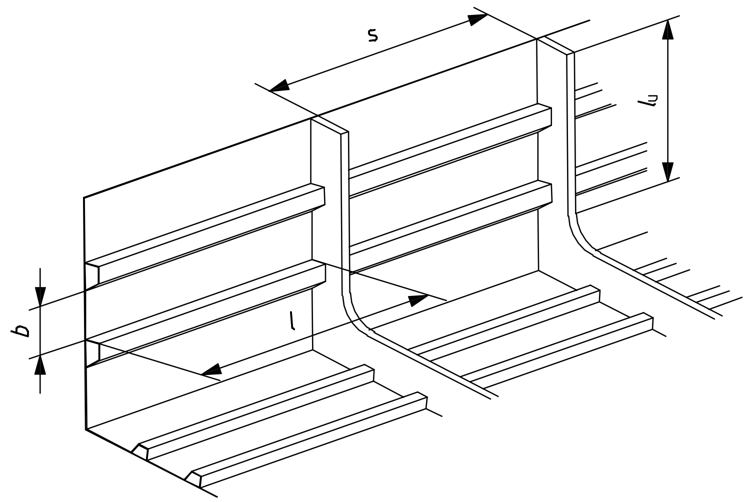


Figure 6 — Sketch explaining the dimensions in 9.1

9.1.1 Short dimension of the panel b

b is the short dimension of the panel between the two closest stiffeners, in millimetres.

In the case of top-hat stiffeners, it is the distance between the web base of a top hat and the web base of the closest top hat or stiffener [see Figure 7 a)].

If there are no definite stiffeners, or in the case of hard chine plating, see respectively 9.1.4 and 9.1.5.

9.1.2 Large dimension of the panel l

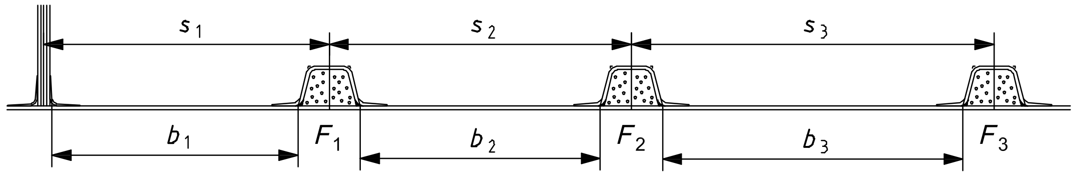
l is the large dimension of the panel between the two closest stiffeners, in millimetres.

In the case of top-hat stiffeners, it is the distance between the web base of a top hat and the web base of the closest top hat or stiffener [see Figure 7 c)].

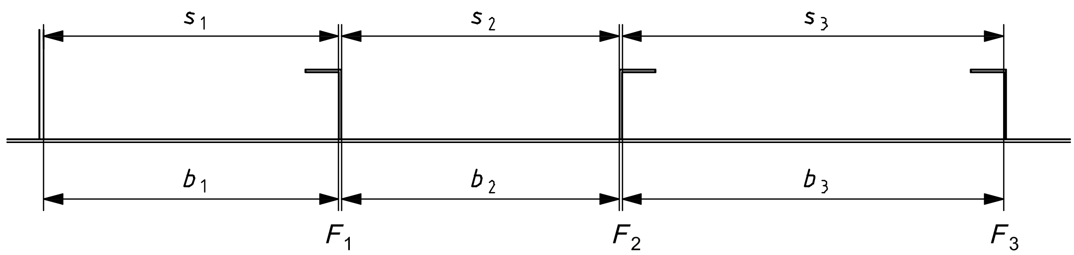
l need not be taken > $330 \times L_H$, in millimetres.

9.1.3 Non-rectangular panels

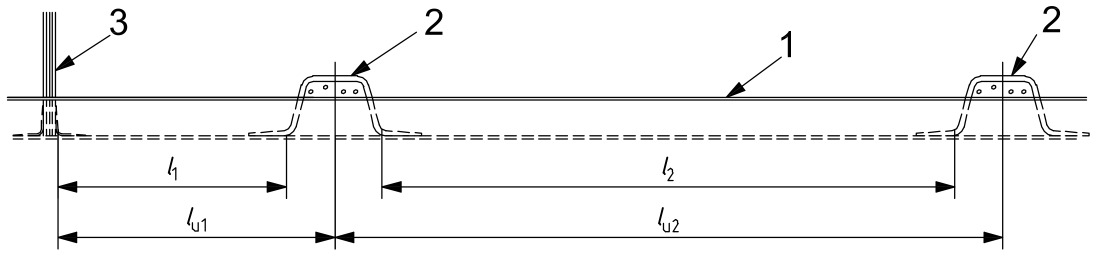
Non-rectangular panels shall be assessed using equivalent rectangular panels with dimensions $b \times l$, or $s \times l_u$. These equivalent rectangular panels shall be assessed on the basis of equal area to the actual panel. Figure 8 gives examples (hatched) of equivalent rectangular panels for a trapeze or a triangle.



a) Bulkhead and transversal top-hat stiffeners



b) L-shaped stiffeners in metallic construction



c) Continuous stringer between top-hat frames and a bulkhead. l_1 and l_2 are the unsupported lengths of the panels between stringers. l_{u1} and l_{u2} are the lengths of the stringer

Key

1 stringer

2 top-hat frame

3 bulkhead

Figure 7 — Examples of b, s, l and l_u measurements

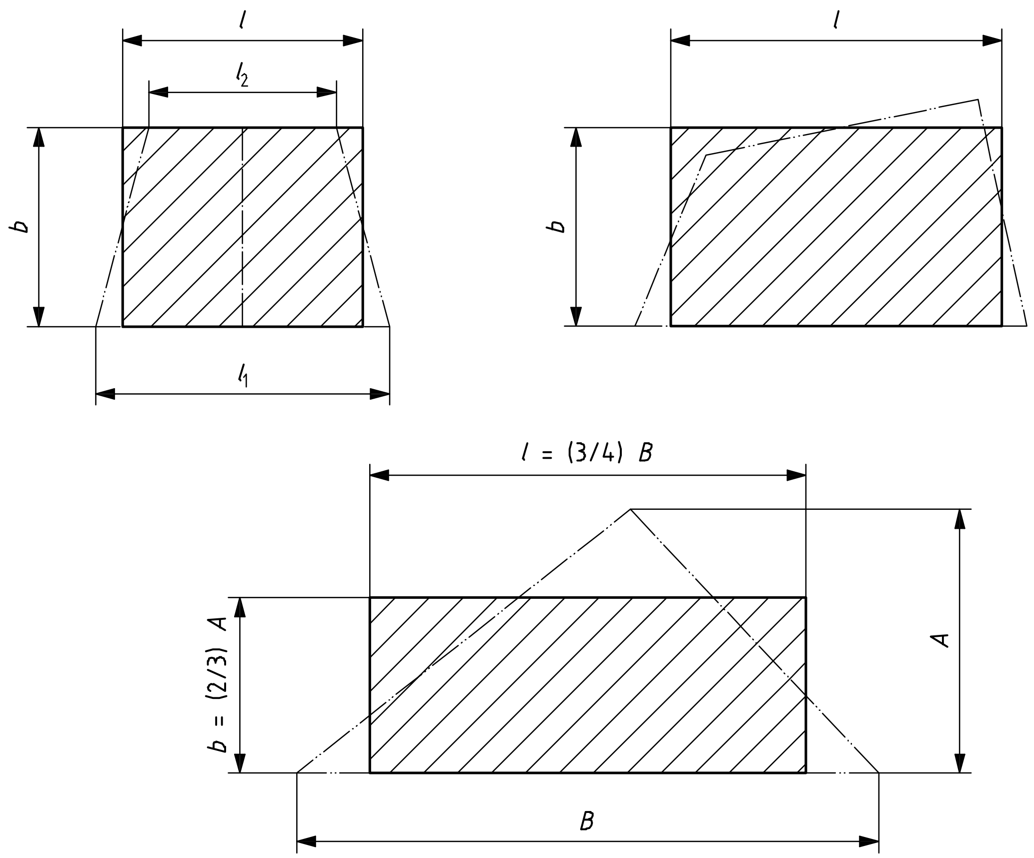


Figure 8 — Examples of equivalent rectangular panels with a trapeze or a triangle

9.1.4 Large panel assessment when there are no or few stiffeners

9.1.4.1 If there are obvious natural or dedicated stiffeners

Natural stiffeners are angled centreline, deck/hull angles, etc. There is a certain degree of interpretation, but natural stiffeners are normally the ones where the angle between two adjacent panels is $< 130°$ with a hard angle or very small radius.

Dedicated stiffeners are stringers, girders, bunk edges, frames, liners, tray mouldings, etc.

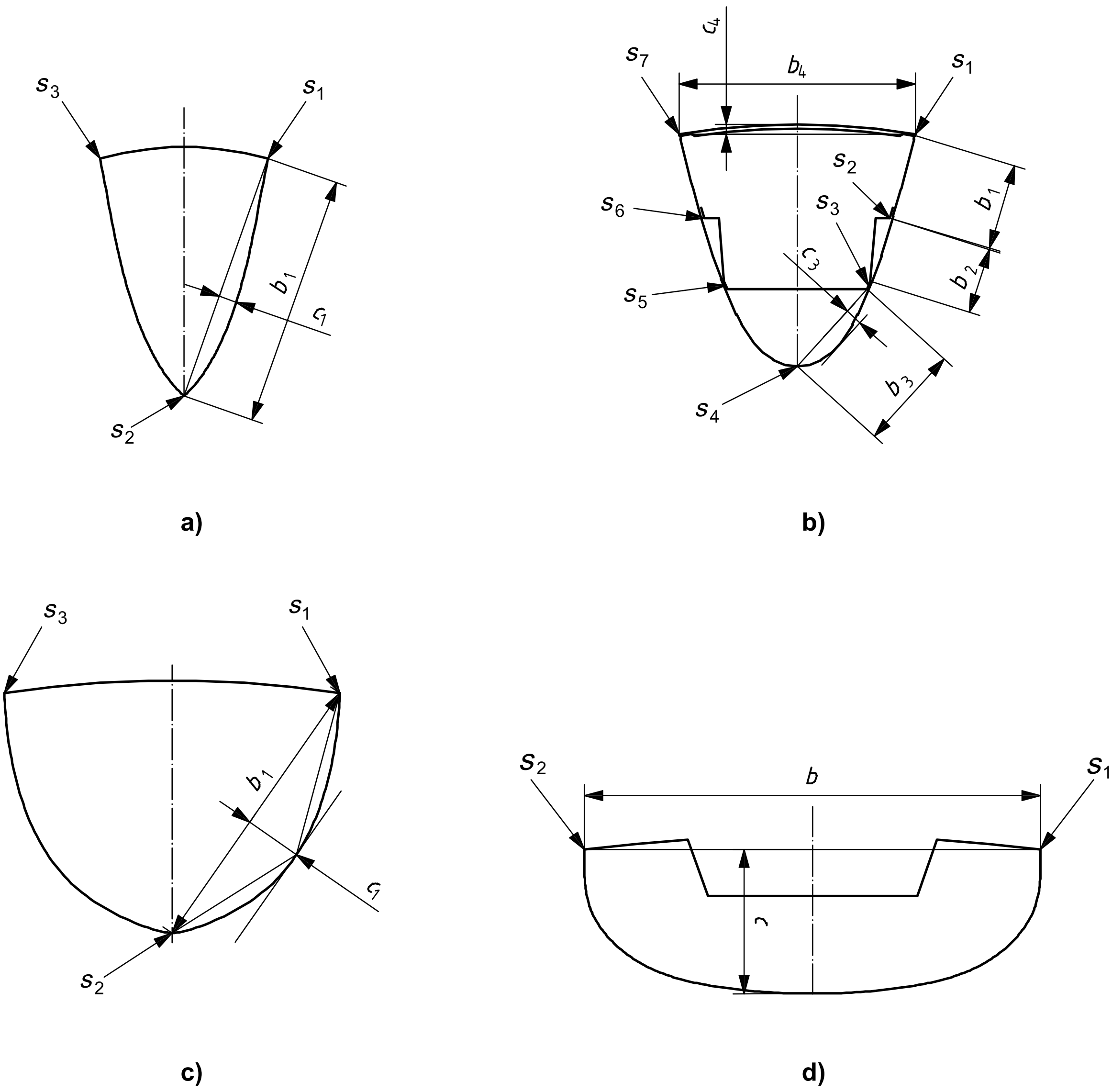
Figure 9 shows a variety of natural and dedicated stiffeners. Figures 9 a) and 9 c) show sections without dedicated natural stiffeners but with three natural stiffeners, s_1, s_2, s_3, made by the hull deck joint and the centreline. In Figure 9 d), the centreline has no chine or V and cannot be considered as a stiffener, and there are only two natural stiffeners, the hull/deck angles. Figure 9 b) shows a section where the liner adds two dedicated stiffeners each side s_2, s_3, s_5 and s_6.

9.1.4.2 Determination of the short dimension and curvature of a panel

Draw a straight line between the closest points of these stiffeners. Measure b and c, then calculate k_C according to Table 5 [see Figure 9 a), and b_1, b_2, b_3 and b_4 for the deck in Figure 9 b)].

9.1.4.3 Very wide panels

Find the minimum distance between the two closest “natural” stiffeners. In the case of Figure 9 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 crown of the panel, c, and calculate k_C according to Table 6.



Key

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

Figure 9 — Examples of panel size and curvature assessment

9.1.5 Panels between hard chines

The b dimensions are the dimensions between chines (see Figure 10).

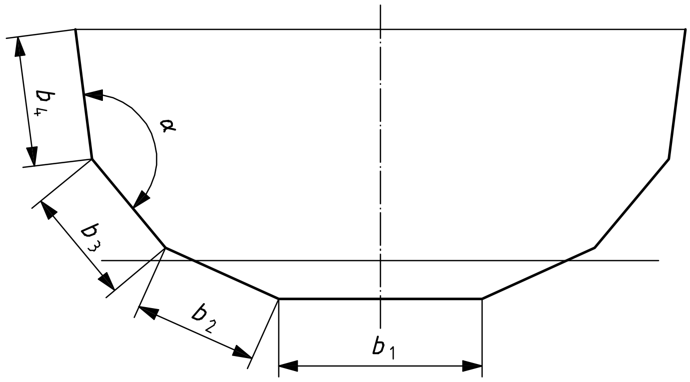


Figure 10 — Hard chine section

9.1.6 Characteristics of natural stiffeners

The above analysis is only valid if the “natural” stiffeners (round bilges, hard chines, etc.) are strong and stiff enough to be considered as proper stiffeners. This means that they shall fulfil the requirements of Clause 11 for stiffeners. The length of these natural stiffeners is their unsupported length between members such as bulkheads, floors and frames. As they are often curved, the factor k_C is usually helpful. The pressure limitation of 8.4 may also apply.

Chines with 130° $< \alpha <$ 150° are generally considered to fulfil the above requirements.

Tables G.4 and G.5 give section modulus (see 3.5) values for some round bilges and hard chines.

9.2 Dimensions of stiffeners

9.2.1 Spacing of stiffeners s

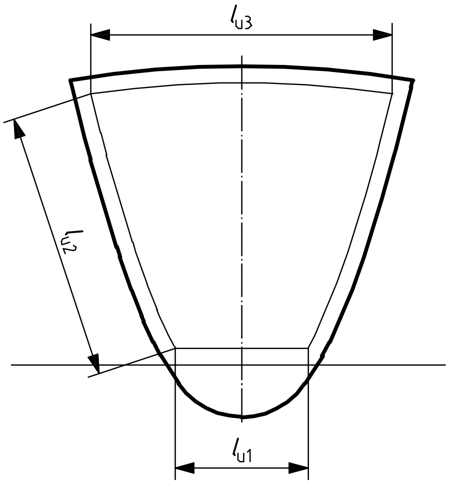
s is the spacing, in millimetres, between centrelines of stiffeners (stringers, frames, web frames, bulkheads, girders, beams, etc.). If the stiffeners are not symmetrical, s is the distance between the middle of the stiffener webs [see Figure 7 b)].

If three consecutive stiffeners do not have the same spacing, s is the mean value of their spacing [see Figures 7 a) and 7 b)].

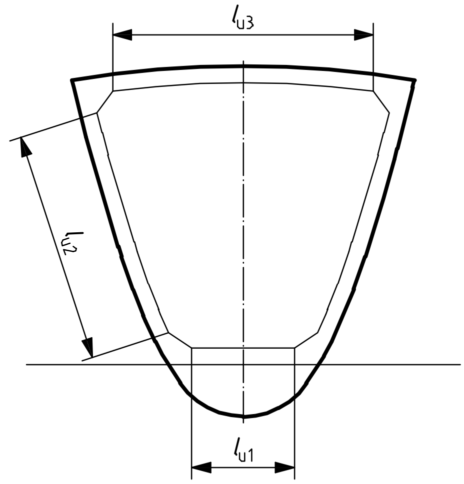
9.2.2 Long dimension of a stiffener l_u (unsupported length)

l_u is the long dimension, in millimetres, of a panel between the two closest stiffeners, it is also the unsupported length of these stiffeners. See Figure 11 for some examples of assessment. In the case of a top-hat stiffener, l_u is the distance between the centrelines of top-hats [see Figure 7 c)].

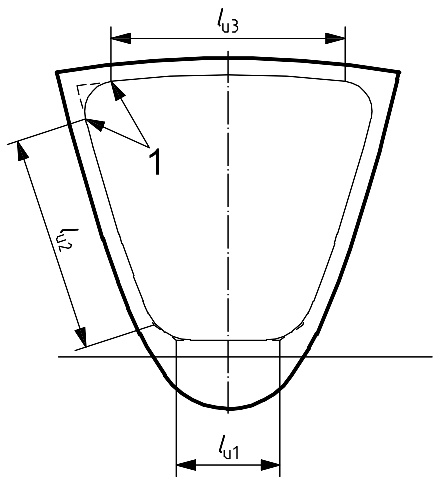
As a consequence of 8.4, l_u need not be taken $>$ 330 L_H, in millimetres.



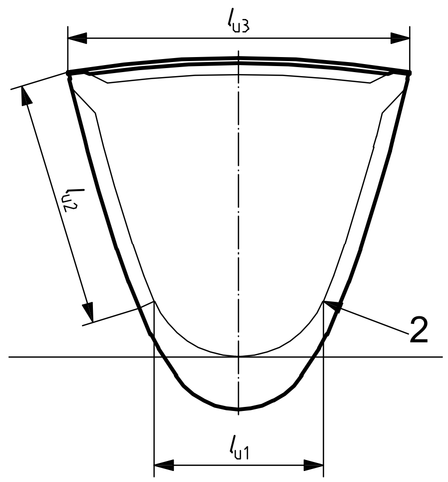
a) Continuous stiffeners l_{u1} for floor, l_{u2} for frame, l_{u3} for beam



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



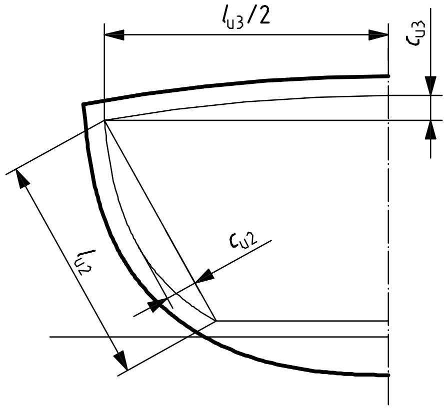
c) Brackets with tangential junctions: the ends of l_u are at the closest tangent points (Key 1)



d) Case where the frames and beams are not continuous to allow the deck to be put at a late stage of building without subsequent lamination.

NOTE The beam is fully fixed at both ends. The frame is simply supported at its top end. The limit floor/frame (Key 2) is at their tangent or junction point, i.e. a change in the stiffener height or stiffness.

Figure 11 — Examples of stiffener dimensions on a FRP craft



e) Case of curved stiffeners c_{u2} and c_{u3} are respectively the crown of the frame and the beam with respective lengths, l_{u2} and l_{u3}; these are used to assess k_{CS}.

Key

1 closest tangent point

2 tangent of connection between floor and frame

Figure 11 (*continued*)

9.2.3 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 and stiffness criteria of this part of ISO 12215.

Where it is not possible for the stiffener to achieve this or where the stiffener is not intented to reduce the panel dimensions, the panel may be analysed with the stiffener in question taken as non-effective. This will lead to a large increase in the panel size. If the resulting larger panel is able to comply with this part of ISO 12215, then the stiffener may be designated as “non-structural”.

Builders and designers are cautioned as to the meaning of this term. “Non-structural” means 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 will attract a load in proportion to its stiffness relative to the adjacent structure. This means that the 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, it is possible that this could cause cracking of the adjacent structure, which could result in further failure. It is not considered 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.

10 Plating — Scantling equations

10.1 Thickness adjustment factors for plating

10.1.1 Bending deflection factor k_1 for sandwich plating

$$k_1 = 0{,}017$$

NOTE The bending deflection factor k_1 is only used for FRP sandwich (see 10.5.3).

10.1.2 Panel aspect ratio factor for strength k_2 and for stiffness k_3

The panel aspect ratio factors for strength k_2 and for stiffness k_3 are given in Table 5.

NOTE k_3 is only used for the determination of I or EI in sandwich calculation.

Table 5 — Values of k_2 and k_3 in function of aspect ratio l/b for isotropic panels

Panel aspect ratio l/b	Factor k_2 k_2 to be taken = 0,5 for laminated wood plating	Factor k_3
$>$ 2,0	0,500	0,028
2,0	0,497	0,028
1,9	0,493	0,027
1,8	0,487	0,027
1,7	0,479	0,026
1,6	0,468	0,025
1,5	0,454	0,024
1,4	0,436	0,023
1,3	0,412	0,021
1,2	0,383	0,019
1,1	0,349	0,016
1,0	0,308	0,014
	k_2 can be evaluated by the formula below, keeping $0,308 < k_2 < 0,5$	k_3 can be evaluated by the formula below, keeping $0,014 < k_3 < 0,028$
	$k_2 = \frac{0,271(l/b)^2 + 0,910\,(l/b) - 0,554}{(l/b)^2 - 0,313\,(l/b) + 1,351}$	$k_3 = \frac{0,027\,(l/b)^2 - 0,029\,(l/b) + 0,011}{(l/b)^2 - 1,463\,(l/b) + 1,108}$

10.1.3 Curvature correction factor k_C for curved plates

The curvature correction factor k_C is given by Table 6, where c is the crown of the panel, as defined in Figure 12. k_C shall not be taken $<$ 0,5 nor $>$ 1.

NOTE k_C applies both for convex and concave curvature.

Table 6 — Curvature correction factor k_C

c/b	k_C
0 to 0,03	1,0
0,03 to 0,18	$1,1 - \frac{3,33c}{b}$
$>$ 0,18	0,5

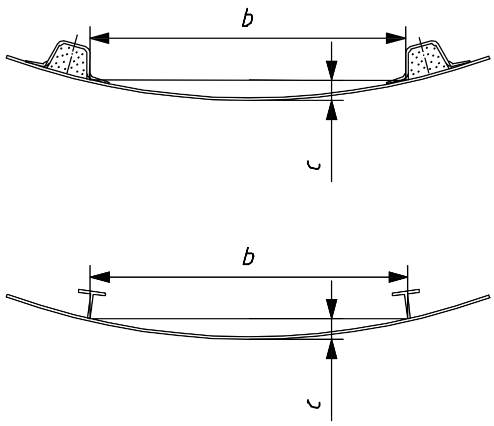


Figure 12 — Measurement of convex curvature

10.1.4 Final design pressure and panel analysis

For bottom, deck and superstructures, the design pressure is constant and shall be applied as defined in Clause 8.

Side pressure varies along the freeboard as specified in 8.1.5 or 8.2.2 for motor or sailing monohulls respectively.

In the case of large panels with variable pressure (because it is a large side panel or because it is across side and bottom), the design pressure shall be taken as an average constant pressure corresponding to the pressure at mid-panel (see also 6.2.4).

In the case of a panel having variable scantlings (single skin or sandwich of variable thickness, single skin transformed into sandwich somewhere in the panel, etc.), all scantlings shall be assessed, the weakest one being used for assessing compliance of the panel with this part of ISO 12215.

NOTE At the time of publication, this part of ISO 12215 has no provision to consider specifically variable pressure or variable scantlings. This is a statically indeterminate case, and the fixity at the ends of the panels may have any value from 0,2 to 1 according to the structural arrangements.

10.1.5 Shear force and bending moment on a panel

The shear force and bending moment on a panel do not generally need to be known as they are included in the thickness requirements of the various paragraphs. However, they sometimes need to be calculated, mostly in the case on non-homogenous or non-isotropic material (see Annex H). Their equations are

$F_\text{d} = \sqrt{k_\text{C}} \times k_\text{SHC} \times P \times b \times 10^{-3}$ is the shear force in the middle of the b dimension in N/mm (33)

$M_\text{d} = 83{,}33 \times k_\text{C}{}^2 \times 2k_2 \times P \times b^2 \times 10^{-6}$ is the bending moment in the b direction in Nmm/mm (34)

where all dimensions are previously defined except k_SHC which is defined in Table 12.

Where the panel stiffness is not similar in the two principal panel directions, Equation (34) shall be replaced by Equations (H.4) and (H.5) (see Annex H).

10.2 FRP single-skin plating

10.2.1 Design stress for FRP single-skin plating

Table 7 — Design stresses for FRP single-skin plating

Material	Structural element	Design stress σ_d N/mm^2
FRP single skin	All elements	0,5 σ_{uf}

where σ_{uf} is the minimum ultimate flexural strength, in newtons per square millimetre.

The mechanical properties of the FRP laminate shall be determined in accordance with Annex C.

10.2.2 Required thickness for FRP single-skin plating

The following equation is only valid if the mechanical properties in both directions differ by < 25 %; otherwise the panel shall be analysed in accordance with Annex H, using the shear force and bending moment given by Equations (33) and (34).

The minimum required single-skin plating thickness t is

$$t = b \times k_c \times \sqrt{\frac{P \times k_2}{1000 \times \sigma_d}} \text{ mm} \quad (35)$$

where

- b is the short dimension of the panel, according to 9.1.1, in millimetres;
- k_c is the curvature correction factor for curved panels given in Table 6;
- P is the design pressure (bottom, side, deck, etc.) of the panel in accordance with Clause 8, in kilonewtons per square metre;
- k_2 is the panel aspect ratio factor for bending strength given in Table 5;
- σ_d is the design stress for FRP plating given in Table 7, in newtons per square millimetre.

For FRP, the thickness required from Equation (35), or wherever such thickness appears in this part of ISO 12215, shall not be measured, but translated into a mass of dry fibre reinforcement w_f (in kilograms per square metre) using the fibre mass content ψ according to the methods of Annex C, and compared to the actual reinforcement mass. An example is given in Annex C. Similarly, the dry fibre mass, w_f, in the laminate of an existing boat or project shall be transformed into thickness in the same manner in order to be compared with the requirements of Equation (35).

The mechanical properties of FRP laminates are those parallel to b, where $l/b \geqslant 2{,}0$ and the lesser of the mechanical properties parallel to b or l, where $l/b < 2{,}0$.

10.2.3 Use of bulking material

10.2.3.1 General

A bulking material is a core material (thick fabric, resin-rich felt, syntactic foam, etc.) intended to increase the thickness 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 flexure.

10.2.3.2 Resin-saturated foam or felt

Bulking materials having a shear strength $>$ 3 N/mm^2 may be substituted for the central layers of a single-skin FRP laminate, providing the total thickness of the combined FRP/bulking material is increased to between 1,15 and 1,30 times the thickness t of single skin determined by Equation (35) according to the following requirements:

— if the total thickness is 1,15 t, the bulking material thickness shall be 0,33 times the total laminate thickness, i.e. a bulking thickness 0,383 t and each skin 0,383 t;

— if the total thickness is 1,30 t, the bulking material thickness shall be 0,50 times the total laminate thickness, i.e. a bulking thickness 0,65 t and each skin 0,325 t.

For a total thickness between 1,15 t and 1,30 t, bulking thickness may be interpolated.

NOTE The thickness increase is required to ensure that the bulking material FRP laminate has equivalent shear force and bending moment capabilities to the required single skin. For total thickness 1,15 t single skin, the laminate is governed by a bulk shear stress near neutral axis; for the other case, it is governed by outer bulk strength.

For bulking materials with high shear strength ($>$ 5 N/mm^2), the percentage increases given above are likely to be pessimistic and use of Annex H may be more appropriate.

10.2.3.3 Syntactic foam

Syntactic foams shall be analysed as follows:

— laminates using syntactic foams having mechanical properties that do not differ by $>$ 25 % from those of core materials listed in D.1 shall be analysed as sandwich using 10.5;

— laminates using syntactic foams having mechanical properties that do not differ by $>$ 25 % from those of bulking material defined in 10.2.3.2 shall be analysed as in 10.2.3.2;

— laminates using syntactic foams of other mechanical characteristics shall be analysed in accordance with Annex H.

10.2.3.4 Plywood “cores”

Where plywood is used as a “core”, the elastic constants are normally sufficiently large, compared with that of the FRP skins, that the plywood makes a significant contribution to the bending strength and stiffness. For this reason, plywood “cored” panels should be treated neither as bulking material nor as a conventional foam/balsa-cored sandwich. Annex H provides details on the calculation procedure to be used.

10.3 Metal plating — Aluminium alloy and steel

10.3.1 Design stress for metal plating

Table 8 — Design stresses for metal plating

Material	Structural element	design stress σ_d N/mm^2
Aluminium alloys	All elements	0,6 σ_{uw} [a] or 0,9 σ_{yw}
Steel	All elements	0,6 σ_u [a] or 0,9 σ_y
[a] The lesser value applies.		

where

for steel:	σ_y	is the minimum tensile yield strength, in newtons per square millimetre;
	σ_{ut}	is the minimum ultimate tensile strength, in newtons per square millimetre;
for welded aluminium:	σ_{yw}	is the minimum tensile yield strength, in the welded condition, in newtons per square millimetre;
	σ_{utw}	is the minimum ultimate tensile strength, in the welded condition, in newtons per square millimetre.

For aluminium adhesively bonded or mechanically fastened, σ_y and σ_{ut} are in the unwelded state.

The mechanical properties of metals shall be according to ISO 12215-3. The values of Table F.1 may also be used.

10.3.2 Required thickness for metal plating

The thickness of metal required 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.

The minimum required thickness of the plating t is

$$t = b \times k_c \times \sqrt{\frac{P \times k_2}{1\,000 \times \sigma_d}} \text{ mm} \quad (36)$$

where

- b is the short dimension of the panel, according to 9.1.1, in millimetres;
- k_c is the curvature correction factor for curved panels given in Table 6;
- P is the design pressure (bottom, side, deck, etc.) for the panel in accordance with Clause 8, in kilonewtons per square metre;
- k_2 is the panel aspect ratio factor for bending strength given in Table 5;
- σ_d is the design stress for metal plating given in Table 8.

10.4 Laminated wood or plywood single-skin plating

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

10.4.1 Design stress for laminated wood or plywood plating

Table 9 — Design stresses for laminated wood and plywood plating

Material	Structural elements	design stress σ_u N/mm^2
Laminated wood and plywood plating	All elements	$0{,}5\sigma_{uf}$

where σ_{uf} is the minimum ultimate flexural strength parallel to the short side of the panel (see Table E.2).

The mechanical properties of the wood laminate shall be determined in accordance with Annex E.

NOTE 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 Annex H, assuming a structurally effective core, i.e. not as a sandwich construction.

10.4.2 Required thickness for laminated wood or plywood plating

This section applies only to plywood construction, moulded veneer construction and strip plank wood construction as specified in Annex E.

The required thickness of the wood laminate t, excluding any lightweight sheathing, is

$$t = b \times \sqrt{\frac{P \times k_2}{1000 \times \sigma_d}} \text{ mm} \tag{37}$$

where

- b is the short dimension of the panel, according to 9.1.1, in millimetres;
- P is the design pressure (bottom, side, deck, etc.) for the panel in accordance with Clause 8, in kilonewtons per square metre;
- k_2 = 0,5, as laminated wood is too far from isotropic to benefit in that field;
- σ_d is the design stress for wood given in Table 9.

NOTE The curvature factor k_c is not relevant for wood because the mechanical properties are very low in a direction perpendicular to the grain.

10.5 FRP sandwich plating

10.5.1 General

This section applies to sandwich panels where the outer and inner skins are similar in layout, in strength and in elastic properties. The skin laminates are considered similar when the ratio of their mechanical properties is within 25 percent of each other.

If this is not the case, the sandwich shall be analysed in accordance with Annex H using Equations (33) and (34) for shear force and bending moment, and the flexural rigidity required by Equation (42). In any case, the thickness requirement from the shear load capacity of 10.5.4 shall be followed.

10.5.2 Design stress for sandwich plating

Table 10 — Design stresses for FRP sandwich plating

Material	Structural element	Design stress σ_{dt} or σ_{dc} N/mm^2
FRP sandwich	Hull, deck, superstructures, structural and watertight bulkheads and tanks	In outer skin $0{,}5\sigma_{ut}$ In inner skin $0{,}5\sigma_{uc}$; $0{,}3\sqrt[3]{E_c \times E_{co} \times G_c}$ [a]
[a] See 10.5.3 and Equation (41).		

where

for FRP sandwich: σ_{ut} is the minimum ultimate tensile strength of the skin, in newtons per square millimetre;

σ_{uc} is the minimum ultimate compressive strength of the skin, in newtons per square millimetre.

The mechanical properties of the skin shall be determined in accordance with Annex C.

10.5.3 Minimum section modulus and second moment

The required minimum section modulus about the neutral axis of a strip of sandwich panel shall not be less than the values given by Equations (38) and (39).

Minimum required section modulus of the outer skin of sandwich 1 cm wide:

$$SM_o/1\text{ cm width} = \frac{b^2 \times k_C{}^2 \times P \times k_2}{6 \times 10^5 \times \sigma_{dto}} \text{ outer skin cm}^3/\text{cm} \quad (38)$$

Minimum required section modulus of the inner skin of sandwich 1 cm wide:

$$SM_i/1\text{ cm width} = \frac{b^2 \times k_C{}^2 \times P \times k_2}{6 \times 10^5 \times \sigma_{dci}} \text{ inner skin cm}^3/\text{cm} \quad (39)$$

NOTE 1 These equations derive from the fact that for a fixed-ended panel, the maximum bending moment at supports governs and the external skin is in tension.

NOTE 2 In order to have an easily manageable number, it is customary to specify the requirements for sandwich in cubic centimetres per centimetre for section modulus, SM, and centimetres to the fourth per centimetre for second moment, I. These requirements can be converted to cubic millimetres per millimetre and millimetres to the fourth per millimetre by multiplying the values of SM and I given in this subclause by 100 and 1 000 respectively.

NOTE 3 For shear force and bending moment calculations, see H.2.1.2.

Minimum required second moment (moment of inertia) for a strip of sandwich 1 cm wide:

$$I/1\text{ cm width} = \frac{b^3 \times k_C{}^3 \times P \times k3}{12 \times 10^6 \times k_1 \times E_{io}} \text{ cm}^4/\text{cm} \quad (40)$$

where

b is the shorter dimension of the panel, according to 9.1.1, but shall not be taken $>$ 330 L_H (see 9.2.2), in millimetres;

NOTE For a sandwich the b dimension corresponds to the length of a stiffener.

k_C is the curvature correction factor for curved panels given in Table 6;

P is the pressure (bottom, side, deck, etc.) for the panel in accordance with Clause 8, in kilonewtons per square metre;

k_2 is the panel aspect ratio factor for bending strength given in Table 5;

k_3 is the panel aspect ratio factor for bending stiffness given in Table 5;

k_1 = 0,017 is the sandwich bending deflection factor;

E_{io} is the mean of the inner and outer face moduli, in newtons per square millimetre (see Annex C); this approach is suitable when the inner and outer faces are similar, i.e. differ by not $>$ 25 %.

Design tensile stress on the outer skin:

σ_{dto} is the tensile design stress of the outer skin given in Table 10, i.e. 0,5 σ_{ut}, in newtons per square millimetre

Design compressive stress on the inner skin:

σ_{dci} is the compression design stress of the inner skin which is the lesser of

0,5 σ_{uc} or

$$0{,}3\,\sqrt[3]{E_c \times E_{co} \times G_c} \quad (41)$$

where

E_c is the compressive E modulus of inner skin in 0°/90° in-plane axis of panel (see Annex C), in newtons per square millimetre,

E_{co} is the compressive E modulus of core, perpendicular to skins (see Annex D), in newtons per square millimetre;

G_c is the core shear modulus in the direction parallel to load (see Annex D), in newtons per square millimetre.

Equation (40) may also be written as

$$EI \text{ per mm width} = \frac{b^3 \times k_c{}^3 \times P \times k3}{12 \times 10^3 \times k_1} \text{ N·mm}^2\text{/mm} \quad (42)$$

This approach is better when the inner and outer faces are very different, e.g. carbon inner and carbon/aramid outer.

See Annex D for sandwich SM and I calculation.

See Annex H for more specific ply-by-ply analysis or bending moment assessment.

10.5.4 Thickness required by shear load capabilities

In order to transmit the shear load, the effective thickness of sandwich laminate t_s shall not be less than given by Equation (43):

$$t_s \geqslant \sqrt{k_C}\,\frac{k_{SHC} \times P \times b}{1\,000 \times \tau_d} \text{ mm} \quad (43)$$

where

$t_s = t_c + 0{,}5\,(t_i + t_o)$ is the distance between mid-thickness of the skins of the sandwich, in millimetres;

k_C is the curvature correction factor defined in Table 6;

t_o is the thickness of the sandwich outer skin, excluding gel coat, in millimetres;

t_i is the thickness of the sandwich inner skin, in millimetres;

t_c is the thickness of the core, in millimetres;

k_{SHC} is the shear strength aspect ratio factor, given in Table 12;

Where the elastic properties of the skins are different by > 25 % in the principal axes, k_{SHC} shall not be taken < 0,465;

P is the pressure (bottom, side, deck, etc.) for the panel in accordance with Clause 8, in kilonewtons per square metre;

b is the short dimension of the panel, according to 9.1.1, in millimetres;

τ_d is the design shear stress of the core, according to Table 11, in newtons per square millimetre.

Table 11 — Design shear strength of sandwich cores

Material	Core design shear stress τ_d (N/mm²)
End grain balsa	0,5 τ_u [a]
Core having shear elongation at break < 35 % (cross-linked PVC, etc.)	0,55 τ_u
Core having shear elongation at break > 35 % (linear PVC, SAN, etc.)	0,65 τ_u
Honeycomb cores (to be compatible with marine application)	0,5 τ_u [b]

[a] 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, τ_d may be taken as 0,55 τ_u.

[b] Use core properties in the direction of short span of the panel (b).

τ_u is the minimum ultimate core shear strength according to Annex D, in newtons per square millimetre.

Table 12 — Shear strength aspect ratio factor k_{SHC}

l/b	> 4,0	3,0	2,0	1,9	1,8	1,7	1,6	1,5	1,4	1,3	1,2	1,1	1,0
k_{SHC} [a]	0,500	0,493	0,463	0,459	0,453	0,445	0,435	0,424	0,410	0,395	0,378	0,360	0,339

[a] The values of k_{SHC} may be calculated by the equation $k_{SHC} = 0,035 + 0,394 \times \left(\frac{l}{b}\right) - 0,09 \times \left(\frac{l}{b}\right)^2$ for $l/b < 2$.

NOTE k_{SHC} corresponds to the shear force on the large side of a rectangular panel.

10.5.5 Minimum core shear strength

For bottom laminate, the value of the design shear strength of the core, as used in 10.5.4 and derived from D.1.1 or D.1.2, shall be at least in accordance with to Table 13.

Table 13 — Minimum design core shear according to craft length

L_H (m)	< 10	10 to ⩽15	15 to 24
τ_d min (N/mm²)	0,25	0,25 + 0,03 (L_H − 10)	0,40

NOTE These values of τ_d min of 0,25 and 0,40 correspond respectively to cross-linked PVC cores of 50 kg/m³ and 75 kg/m³.

10.5.6 Minimum sandwich skin fibre mass requirements

In order to reduce the risk of skin puncture or damage, the required minimal fibre mass in kilograms per square metre is given by

$$w_{os} = k_{DC} \times k_4 \times k_5 \times k_6 \times \left(0{,}1\, L_{WL} + 0{,}15\right) \text{ kg/m}^2 \quad (44)$$

$$w_{is} = 0{,}7 \times w_{os} \text{ kg/m}^2 \quad (45)$$

where

w_{os} is the fibre mass per square metre of the outer skin, in kilograms per square metre;

w_{is} is the fibre mass per square metre of the inner skin, in kilograms per square metre;

k_4 is the sandwich minimum skin location factor where

$k_4 = 1$ for hull bottom,

$k_4 = 0{,}9$ for side shell,

$k_4 = 0{,}7$ for deck,

k_5 is the sandwich minimum skin fibre type factor where

$k_5 = 1{,}0$ for E-glass reinforcement containing up to 50 % of chopped strand mat by mass,

$k_5 = 0{,}9$ for continuous glass reinforcement (i.e. bi-axials, woven roving, unidirectionals, double bias or multiaxial),

$k_5 = 0{,}7$ for continuous reinforcement using aramid or carbon or hybrids thereof,

k_6 is the sandwich minimum skin care factor where

$k_6 = 0{,}9$ for craft where the sandwich outer skin is expected to be punctured after hitting a sharp object;

$k_6 = 1$ for other craft.

If $k_6 = 0{,}9$, a statement warning that the boat may be punctured after hitting a sharp object and that this damage shall be quickly repaired shall be inserted in the owner's manual.

10.6 Single-skin plating minimum thickness

10.6.1 General

In addition to the previous requirements, minimum single-skin thickness requirements are stated below.

NOTE This part of ISO 12215 is concerned with ensuring that the craft is able to withstand the anticipated operational loads. In addition to the loads imposed by the sea, which have been converted into design pressure and required thickness in the previous part of this document, all craft must be able to resist loads due to impact with floating debris, dropped items, berthing, handling and similar loads. Bottom and side minimal thickness is mainly governed by speed and displacement. Deck minimal thickness may only be governed by length. These requirements are based on past experience on robustness.

10.6.2 Minimum thickness or mass of reinforcement for the hull

For metal or plywood $$t_{MIN} = k_5 \times \left(A + k_7 \times V + k_8 \times m_{LDC}^{0,33} \right) \text{ mm} \quad (46)$$

For FRP, minimal dry fibre weight $$w_{MIN} = 0,43 \times k_5 \times \left(A + k_7 \times V + k_8 \times m_{LDC}^{0,33} \right) \text{ kg/m}^2 \quad (47)$$

where A, k_5, k_7 and k_8 are defined in Table 14. For sailing craft V shall be taken as 2,36 $\sqrt{L_{WL}}$.

Table 14 — Minimum thickness factors

Material	Position	A	k_5	k_7	k_8
FRP	Bottom	1,5	As defined in 10.5.6	0,03	0,15
	Side/transom	1,5		0	0,15
Aluminium	Bottom	1,0	$\sqrt{(125/\sigma_y)}$	0,02	0,1
	Side/transom	1,0		0	0,1
Steel	Bottom	1,0	$\sqrt{(240/\sigma_y)}$	0,015	0,08
	Side/transom	1,0		0	0,08
Plywood	Bottom	3,0	$\sqrt{(30/\sigma_{uf})}$	0,05	0,3
	Side/transom	3,0		0	0,3

10.6.3 Minimum deck thickness

The values of minimum deck thickness shall be derived from Table 15.

Table 15 — Minimum deck thickness

Location	Deck minimum required thickness t_{MIN} mm			
	FRP	**Aluminium**	**Steel**	**Wood, plywood**
Deck	k_5 (1,45 + 0,14 L_{WL})	1,35 + 0,06 L_{WL}	1,5 + 0,07 L_{WL}	3,8 + 0,17 L_{WL}

The requirement of Table 15 is given in terms of thickness t_{MIN}. For FRP, this requirement may be translated into the fibre dry mass using Equations (C.1) to (C.3). The fibre type factor, k_5, is defined in 10.5.6.

11 Stiffening members requirements

11.1 General

Plating shall be supported by an arrangement of stiffening members (see ISO 12215-6).

The relative 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.

11.2 Properties adjustment factors for stiffeners

11.2.1 Curvature factor for stiffeners k_{CS}

The curvature factor k_{CS} shall be taken as listed in Table 16.

Table 16 — Values of curvature factor for stiffeners k_{CS}

$\frac{c_u}{l_u}$	k_{CS}
0 to 0,03	1
0,03 to 0,18	$1,1 - 3,33\ (c_u/l_u)$
$> 0,18$	0,5

where

c_u is the crown of a curved stiffener [see Figure 11 e)], in millimetres;

k_{CS} applies to convex or concave stiffeners; it shall not be taken $< 0,5$ nor > 1.

11.2.2 Stiffener shear area factor k_{SA}

The stiffener shear area factor k_{SA} shall be taken as listed in Table 17.

Table 17 — Values of shear area factor k_{SA}

Stiffener arrangements	k_{SA}
Attached to the plating	5
Other arrangements (floating)	7,5

11.3 Design stresses for stiffeners

Table 18 — Design stresses for stiffeners

Material	Tensile and compressive design stress σ_d N/mm^2	Design shear stress τ_d N/mm^2
FRP	$0,5\ \sigma_{ut}$ and $0,5\ \sigma_{uc}$ [a]	$0,5\ \tau_u$
Aluminium alloys	$0,7\ \sigma_{yw}$ [b]	$0,4\ \sigma_{yw}$ [b]
Steel	$0,8\ \sigma_y$	$0,45\ \sigma_y$
Laminated wooden frames	$0,45\ \sigma_{uf}$ [c]	$0,45\ \tau_u$
Solid stock wooden frames	$0,4\ \sigma_{uf}$ [c]	$0,4\ \tau_u$
Plywood on edge frames	$0,45\ \sigma_{uf}$ [c]	$0,45\ \tau_u$
NOTE These design stresses also apply for the attached plating of the stiffener, according to its material.		

[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.

[b] For welded stiffeners. If aluminium stiffeners are not welded, i.e. riveted, glued, etc., the non-welded properties shall be used.

[c] σ_{uf} for laminated wooded stiffeners and σ_{uf} for solid stock shall be taken from Table E.1. For plywood, σ_{uf} shall not be taken from Table E.2 but from Tables E.3 or E.6.

τ_u is the minimum ultimate in-plane shear strength of the stiffener material, in newtons per square millimetre. Other variables are as previously defined.

NOTE The stresses σ_y or σ_{yw} for metal in Table 18 are tensile stresses.

For the purpose of this part of ISO 12215, the minimum yield shear strength for aluminium and steel is taken as 0,58 σ_y for steel and 0,58 σ_{yw} for aluminium.

The mechanical properties of the materials used shall be taken from Annexes C, E or F, as relevant.

11.4 Requirements for stiffeners made with similar materials

NOTE Similar materials are those in which mechanical properties differ by < 25 % from each other.

11.4.1 For any material: minimum section modulus and shear area

The web area A_W and minimum section modulus SM of stiffening members, including the effective plating (see 11.5) of the stiffening members, shall be not less than the values given by Equations (48) and (49):

$$A_W = \frac{k_{SA} \times P \times s \times l_u}{\tau_d} 10^{-6} \text{ cm}^2 \tag{48}$$

$$SM = \frac{83{,}33 \times k_{CS} \times P \times s \times l_u^2}{\sigma_d} 10^{-9} \text{ cm}^3 \tag{49}$$

where

k_{CS} is the curvature factor for stiffeners given in Table 16;

k_{SA} is the stiffener shear area factor given in Table 17;

P is the pressure (bottom, side, deck, etc.) for the panel in accordance with Clause 8, in kilonewtons per square metre;

s is the spacing of stiffeners, as defined in 9.2.1, in millimetres;

l_u is the length of the stiffener, as defined in 9.2.2, in millimetres;

σ_d is the design stress for stiffeners given in Table 18, in newtons per square millimetre;

A_W is the shear area (cross-sectional area of stiffener shear web), in square centimetres;

NOTE For top hats this area is the total of the areas of both sides.

τ_d is the design shear stress of the shear web as defined in Table 18, in newtons per square millimetre.

The shear loads implied by Equation (49) or given by Equation (52) shall be effectively transferred to the next supporting element (primary or shell structure). See ISO 2215-6 for details.

11.4.2 Supplementary stiffness requirements for FRP

For FRP stiffeners, the second moment of area, including the effective plating, shall not be less than given by the following formula in Equation (50).

$$I = \frac{26 \times k_{CS}^{1,5} \times P \times s \times l_u^3}{k_{1S} \times E_{tc}} 10^{-11} \text{ cm}^4 \tag{50}$$

where

E_{tc} is the mean of compressive/tensile modulus of the material (see Annex C), in newtons per square millimetre;

$k_{1S} = 0{,}05$ is the deflection factor for stiffeners (allowable relative deflection y/l_u).

11.5 Requirements for stiffeners made with dissimilar materials

Dissimilar materials are those in which mechanical properties differ by $> 25\ \%$ 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 ΣEI and allowable shear load. The value of F_d (M_d) 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.

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.5 for detailed explanations.

$F_d = 5 \times P \times s \times l_u \times 10^{-4}$ is the design shear force, in newtons (51)

$M_d = 83{,}33 \times k_{CS} \times P \times s \times l_u^2 \times 10^{-9}$ is the design bending moment, in newton metres (52)

CAUTION — With different materials the section moduli and stresses shall normally be calculated for each layer: $SM_i = \dfrac{\sum E_i \times I_{iNA}}{z_{crit} \times E_i}$ and $\sigma_i = \dfrac{M_d}{SM_i}$, where z_{crit} is the critical section within a layer (usually the farthest point from the neutral axis). In many cases the "critical" layer in the "weakest" material is obvious and the calculation only needs to be performed in that case (see example in H.2.1).

An alternative method of analysis (given in the example in G.5) is to consider all materials having the same E as a "base" element (stiffener or plating), adjusting the width of all other materials according to the ratio E/E_{base}, thus avoiding the calculation of $\sum E_i I_{iNA}$. The stress for an element i shall then be calculated as $\sigma_i = \dfrac{M_d}{SM_i} \times \dfrac{E_{base}}{E_i}$ and

$$\sum (E_{TC} \times I) \geqslant \frac{26 \times k_{CS}^{1,5} \times P \times s \times l_u^3 \times 10^{-11}}{k_{1S}} \quad (53)$$

is the required stiffness of the stiffener, in newtons per square millimetre by centimetres to the fourth.

NOTE When applying Equation (53) in Annex H (see Table H.3), it is easier to calculate ΣEI in newtons per square millimetre and the factor 10^{-11} needs to be replaced by 10^{-7}.

where

M_d is the design bending moment of the stiffener, in newton metres;

F_d is the design shear load of the stiffener, in newtons;

$\sum (E_{TC} \times I)$ is the sum of the EI products of all the elements of the stiffener, in newtons per square millimetre by centimetres to the fourth;

$k_{1S} = 0{,}05$ is the deflection factor for stiffeners (allowable relative deflection y/l_u);

k_{CS} and k_{SA} are previously defined in Tables 16 and 17 respectively.

The shear load given by Equation (52) shall be effectively transferred to the next supporting element (primary or shell structure). See ISO 12215-6 for details.

11.6 Effective plating

The lower flange of stiffening members working in bending is a band of plating called "effective plating" as shown in Figure 13. The effective extent of plating b_e shall be calculated according to Table 19, but shall not be taken greater than the actual stiffener spacing.

Table 19 — Values of b_e

Material	Steel	Aluminium	FRP single skin	FRP sandwich	Wood, plywood
b_e	80 t	60 t	20 t	20 ($t_o + t_i$) [a]	15 t

[a] The attached plating is 20 times both inner and outer skins, separated by the core, which is considered ineffective, i.e E_{core} = 0.

Where the stiffener has a significant width it may be added to b_e [see Figure 13 a)].

The above equations are valid for any stiffener: stringer, frame, bulkhead, etc.

For stiffeners along an opening, the effective extent shall be taken as 50 % of the extent as given above.

In any case the mechanical properties of the attached plating shall be those parallel to the stiffener.

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". G.5 gives explanations and requirements on wooden frames and shall be used.

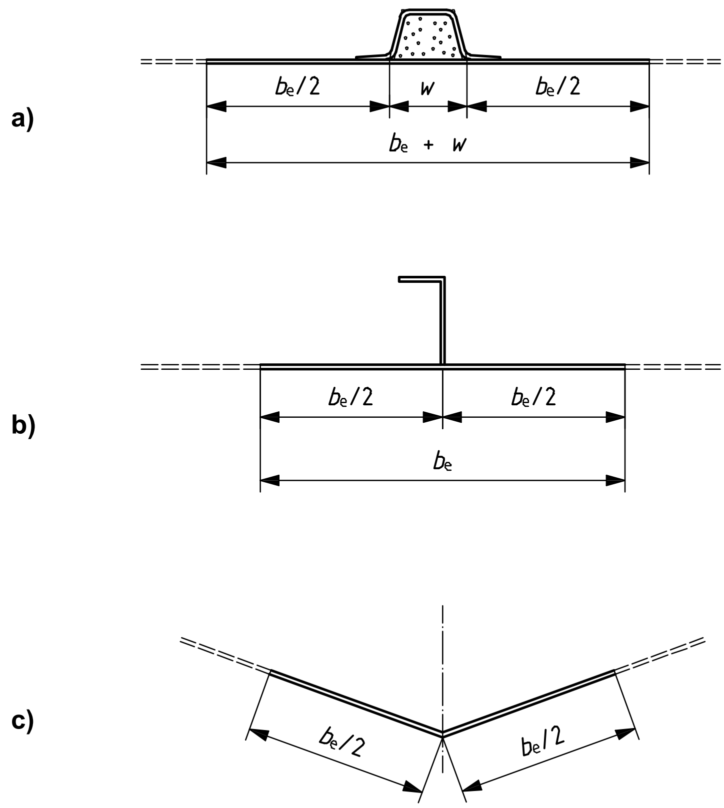


Figure 13 — Sketch showing the effective extent of plating around a stiffener (top hat, L and chine)

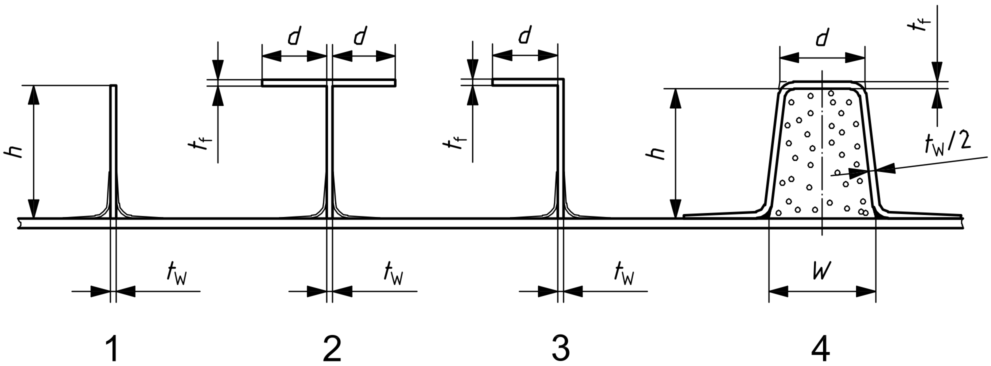
11.7 Overall dimensions of stiffeners

11.7.1 Geometry

Translation of a minimum section modulus, second moment of area, and shear web requirements into a stiffener geometry may be made using the equations and tables of Annexes C, E and F.

11.7.2 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 14 shall be taken in Table 20 if the calculated stress σ_{act} or τ_{act} is at least 80 % of respectively σ_d or τ_d given in Table 18; otherwise Table 21 shall be used. These ratios normally preclude the risk of local buckling of the stiffener.



Key

1 flat bar

2 T

3 L

4 top hat

Figure 14 — Proportions of stiffeners

The relationship between the moulding (depth) and siding (width) of conventionally proportioned wood stiffeners (laminated or solid stock) is normally such as to preclude web buckling.

The requirements below for top-hat FRP apply to structural elements that are not supported by a structurally effective core (for example a polyurethane former).

NOTE The slenderness ratios in Tables 20 and 21 are intended to provide a measure of resistance against 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 equations and comparing this with the calculated stress to ensure a margin equivalent to that implied in Tables 20 and 21. The same method can be applied where an effective core stabilizes the web laminate against buckling using engineering formulae.

Table 20 — Maximum values of h/t_w and d/t_f if actual stress σ_{act} or τ_{act} is the same as σ_d or τ_d, respectively, given in Table 18

Material	Type of profile				
	Flat bar	T- or L-shaped stiffeners		Top-hat stiffeners	
	h/t_w max	h/t_w max	d/t_f max	$h/(t_w/2)$ max	d/t_f max
GRP 35 % fibres by mass	8	30	8	30	21
Aluminium	12	40	12	40	25
Steel	15	50	15	50	40
Carbon and/or aramid laminate 0/90 40-50 % fibre by mass	13	40	13	40	35
Plywood	10	40	10	40	25

Table 21 — Maximum allowable values of h/t_w and d/t_f if actual stress σ_{act} or τ_{act} is less than the design stress, respectively σ_d or τ_d, given in Table 18

Material	Type of profile				
	Flat bar	T- or L-shaped stiffeners		Top-hat stiffeners	
	h/t_w max	h/t_w max	d/t_f max	$h/(t_w/2)$ max	d/t_f max
All materials	As in Table 20	Value of Table 20 $\times \sqrt{k_{AS}}$	As in Table 20	Value of Table 20 $\times \sqrt{k_{AS}}$	Value of Table 20 $\times \sqrt{k_{SM}}$

where

t_w is the total thickness of the solid stiffener web or solid panel bulkhead, in millimetres;

t_f is the thickness of the outstanding face bar of the stiffener flange, in millimetres;

h is the height of the stiffener web, in millimetres;

d is the width of the outstanding face bar of the stiffener flange, in millimetres;

E is the elastic compression or elastic modulus of the stiffener web or flange, in newtons per square millimetre;

σ_d is the design compressive stress of the web or flange according to Table 18, in newtons per square millimetre;

τ_d is the design shear stress of the web or flange according to Table 18, in newtons per square millimetre;

σ_{act} is the actual compressive stress in the web or flange, in newtons per square millimetre;

τ_{act} is the actual shear stress in the web or flange, in newtons per square millimetre.

$$k_{AS} = \frac{\text{Actual area of web}}{\text{Area of web required by Equation (48)}} \text{ or } \frac{\text{Actual shear force}}{F_D \text{ from Equation (51)}}$$ is the shear force correction.

NOTE 1 The second case for k_{AS} is better suited for composite stiffeners analysed by Annex H.

$$k_{SM} = \frac{\text{Actual section modulus of stiffener}}{SM \text{ required by Equation (49)}} \text{ or } \frac{\text{Actual } M_B}{M_B \text{ from Equation (52)}}$$ is the stiffener M_B correction.

NOTE 2 The second case for k_{SM} is better suited for composite stiffeners analysed by Annex H.

11.7.3 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 load given in Equation (51) or implied by Equation (48). Annex G or H or ISO 12215-6 give details of such connections.

11.8 Structural bulkheads

11.8.1 Plywood bulkheads

The thickness of unstiffened solid plywood bulkheads shall be not less than

$$t_b = 7{,}0\, D_b \text{ mm} \tag{54}$$

where D_b is the depth of the bulkhead from bottom of canoe body to deck at side, in metres.

11.8.2 Sandwich bulkheads

11.8.2.1 Core

In addition to the requirements of 11.8.2.2 and 11.8.2.3

— the core shear strength shall be in accordance with to 10.5.5 and Table 13,

— the core thickness shall be at least five times the thickness of the thinnest skin.

11.8.2.2 Sandwich bulkheads with identical plywood skins

The thickness of skins t_s and of core t_c shall be such that

$$t_s \times t_c \geqslant \frac{t_b^2}{6} \text{ mm}^2 \tag{55}$$

and

$$t_s \times \frac{t_c^2}{2} \geqslant \frac{t_b^3}{12} \text{ mm}^3 \tag{56}$$

where

t_b is the solid plywood bulkhead thickness defined by Equation (54);

t_s and t_c are as defined in 10.5.4.

11.8.2.3 Sandwich bulkheads with identical FRP skins

The thickness of skins t_s and of core t_c shall be such that

$$t_s \times t_c \geqslant \frac{t_b^2}{6}\left(\frac{25}{\sigma_d}\right) \text{ mm} \tag{57}$$

and

$$t_s \times \frac{t_c^2}{2} \geqslant \frac{t_b^3}{12}\left(\frac{4\,000}{E_{io}}\right) \text{ mm} \tag{58}$$

where

t_b is the solid plywood bulkhead thickness defined by Equation (54); σ_d and E_{io} are the values for the skins, taken from Annex C.

11.8.3 Metal bulkheads

They shall be calculated as watertight bulkheads.

11.9 Structural support for sailing craft ballast keel

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.

12 Owner's manual

12.1 General

Where relevant, the following information shall be included in the owner's manual.

12.2 Normal mode of operation

“The owner is advised that he/she is responsible for ensuring that the normal mode of operation is maintained. This will mean that the speed of the craft will need to be matched to the prevailing sea state.”

12.3 Possibility of outer skin damage

If in 10.5.6, $k_6 = 0{,}9$, the following statement shall be included in the owner's manual: “The outer skin of your boat is not design to resist local damage from hitting hard/sharp objects. If the outer skin is damaged, it shall be repaired immediately.”

Annex A
(normative)

Simplified method for scantling determination

A.1 Alternative method for sailing craft of categories C and D of $L_H < 9$ m

A.1.1 General

This method may be used as an alternative for sailing craft with a length of hull of < 9 m and of design categories C and D. Scantlings may be obtained for the construction of single-skin GRP, GRP sandwich, mild steel, aluminium alloy, plywood or strip planking.

It is only designed to provide a very simple evaluation of the plating thickness for sailing dinghies and open boats, and is not intended for cruising habitable boats.

There is no provision for stiffener calculation. Persons wanting to calculate stiffeners shall use the full method of this part of ISO 12215 both for plating and stiffeners.

A.1.2 Determination of panel laminate thickness

The required panel thickness made with the reference laminate is

$$t_r = 0{,}5 \times m_{LDC}{}^{0{,}33} \times \frac{b}{400} \times k_C \times k_{LOC} \times k_r \text{ mm} \quad \text{(A.1)}$$

where

b is the actual panel width, in millimetres;

$k_C = 1{,}1 - 3{,}3\frac{c}{b}$ where c is the hull curvature (see Figure A.1), not to be taken < 0,5 or > 1;

k_{LOC} = 1,0 for hull bottom, 0,75 for hull topsides and 0,6 for the deck;

$k_r = 0{,}54 + 0{,}23\frac{l}{b}$ where l is the longest side of the panel (in millimetres), not to be taken < 0,77 or > 1.

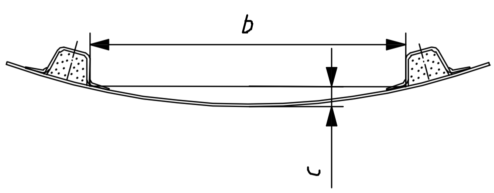


Figure A.1 — Measurement of convex curvature

This thickness value obtained is for a single-skin GRP reference laminate (E glass mat and polyester resin laminate with a glass content by mass ψ of 30 %, σ_{uf} = 134 N/mm^2, E = 5 200 N/mm^2). This thickness, in millimetres, shall be converted to fibre mass, in kilograms per square metre, by multiplying the thickness by 0,43.

For glass fibre reinforced laminates made from E glass that include woven roving, multi-axial cloths, etc., the required thickness shall be corrected according to A.2.2.

Corrections for E glass sandwich constructions or laminates using bulking material shall be obtained using A.2.3. For sandwich constructions, if the boat is handled with care during launching and recovery and is frequently inspected, and where assistance is readily available in the event of collision, the minimum skin thickness requirement of 10.5.6 for sandwich constructions does not apply for sailing craft using this method.

The thickness correction for mild steel, aluminium alloy, plywood, strip planking with lightweight glass sheathing or GRP shall be assessed using A.2.4.

A.2 Correction for other materials

A.2.1 General

For materials other than the reference material, the following corrections apply.

A.2.2 E glass-based GRP materials

A.2.2.1 Single-skin laminate

For sprayed chopped strand mat and conventional hand lay-up, no corrections are required.

For other GRP laminates the thickness required for the actual lay-up shall be obtained by multiplying the reference laminate thickness obtained from Equation (A.1) by the appropriate factor taken from Table A.1. For craft that employ complex laminate schedules where the mechanical properties deviate by $>$ 20 % from each other in the principal directions, the main core of this part of ISO 12215 shall be used in conjunction with Annex H.

For corrected thickness multiply the thickness of the reference laminate t_r obtained by Equation (A.1) by the thickness correction factor given in column 2 of Table A.1, according to the type of ply of column 1.

For corrected dry glass mass in kilograms per square metre, multiply the thickness of the reference laminate t_r obtained from Equation (A.1) by the glass mass correction factor given in column 3 of Table A.1, according to the type of ply of column 1.

A.2.2.2 Use of bulking material

Bulking materials having a shear strength $>$ 3,25 N/mm^2 may be substituted to the central layers of a single-skin FRP laminate, providing the total thickness of the combined FRP/bulking material, as obtained from Equation (A.1), is increased by the following amounts:

— 15 % when the bulking material thickness constitutes at most 33 % of the total laminate thickness;

— 30 % when the bulking material thickness constitutes at most 50 % of the total laminate thickness.

Example of bulking material: resin-rich felt or similar.

Table A.1 — Glass mass conversion factor

1	2	3
Type of ply reinforcement	**Thickness correction factor** t/t_r	**Glass mass correction factor** w/t_r
Roving mat combination	0,90	0,51
Woven roving or multi-axial	0,80	0,64

EXAMPLE If tables give $t_r = 5$ mm and a builder uses a roving mat combination, then $t = 0{,}9\ t_r = 4{,}5$ mm. The dry glass mass is $t_r\ 0{,}51 = 5 \times 0{,}51 = 2{,}55$ kg/m^2.

NOTE The glass dry mass is greater than for the reference laminate, even if the final laminate is thinner and lighter, because the amount of resin is less.

A.2.3 Correction for sandwich construction

The deck and topsides single-skin thickness may be converted to an equivalent sandwich lay-up using this method. This method shall not be employed for the bottom panels. If the bottom is of sandwich construction, the main core of this part of ISO 12215 shall be used.

The method of correction is to proceed as follows:

- the t/b value shall be determined either from Clause A.1 or A.2 as appropriate;
- the t/b value shall then be multiplied by the smallest unsupported span of the panel for the sandwich configuration, b, in millimetres (not a typical single-skin value); this gives the value of the reference thickness t_r, which is normally fairly large;
- the outer skin fibre mass w_{os}, in kilograms per square metre, shall be determined from past practice of the builder.

The next stage is the selection of a suitable core material and core depth d_c. In the simplified method, two cores are available:

- PVC type foam core of minimum density 80 kg/m^3;
- end grain balsa core of minimum density 144 kg/m^3.

Once w_{os} is chosen, the minimum value for the sandwich core depth is calculated from t_r as follows.

The selected core thickness, t_c, shall be at least equal to all the values obtained from the Equations (A.2) to (A.4) below:

$$t_{c\,min} = \frac{4\,400 \times t_r^3}{b^2} \text{ mm for end grain balsa or } t_{c\,min} = \frac{11\,000 \times t_r^3}{b^2} \text{ mm for PVC} \quad \text{(A.2)}$$

$$t_{c\,min} = \frac{0{,}266 \times t_r^{1{,}5}}{\sqrt{w_{os}}} \text{ mm} \quad \text{(A.3)}$$

$$t_{c\,min} = \frac{11 \times t_r^3}{b \times w_{os}} \text{ mm} \quad \text{(A.4)}$$

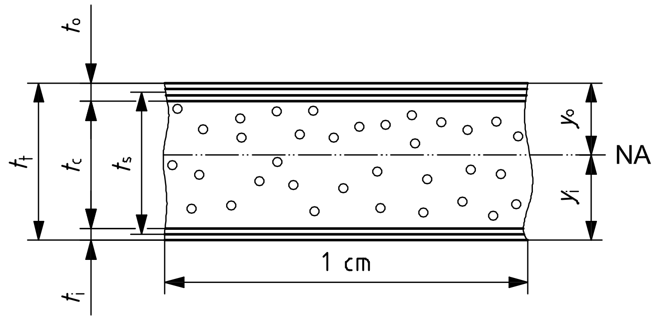


Figure A.2 — Sandwich schematic sketch

where

t_r is the thickness of reference laminate obtained from Clauses A.1 or A.2, in millimetres;

b is the smallest unsupported span of the panel, in millimetres.

These formulae are based on the assumption that the inner skin dry mass is not $<$ 70 % of the outer skin fibre dry mass in kilograms per square metre.

A.2.4 Correction for metal and wood

The thickness for actual material shall be obtained by multiplying the reference laminate thickness (as obtained in A.2.2) by the appropriate factor taken from Table A.2.

Table A.2 — Thickness correction factor for metal and wood

Material	Bottom
Aluminium alloy	0,67
Mild steel	0,56
Plywood encapsulated with resin	2,1
Strip plank with light glass sheathing	2,5

This correction gives the plate thickness requirements in millimetres and no further correction is required.

Annex B
(normative)

Drop test for boats of < 6 m

B.1 Theoretical background

B.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.

B.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:

a) $H_W/l_W = 1/20$

b) $l_W/L_{WL} = 2$

c) $H_W/L_{WL} = 0{,}1$

B.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 will for some time be airborne, it is assumed that the craft will fall 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.

B.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 will allow determining the appropriate drop height for a certain boat at a given speed under defined wave conditions, as described under B.1.2.

B.1.5 Safety margin

In the main body of this part of ISO 12215 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 will at some time be airborne, because the stipulated wave conditions are assumed to cover all the actual conditions.

B.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.

B.2 Test and compliance

B.2.1 General

This test is considered applicable to craft with a hull length of < 6 m, of single-skin 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.

B.2.2 Practical test

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

The following conditions shall be fulfilled:

— the craft is in loaded displacement mass 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 boat;

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

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

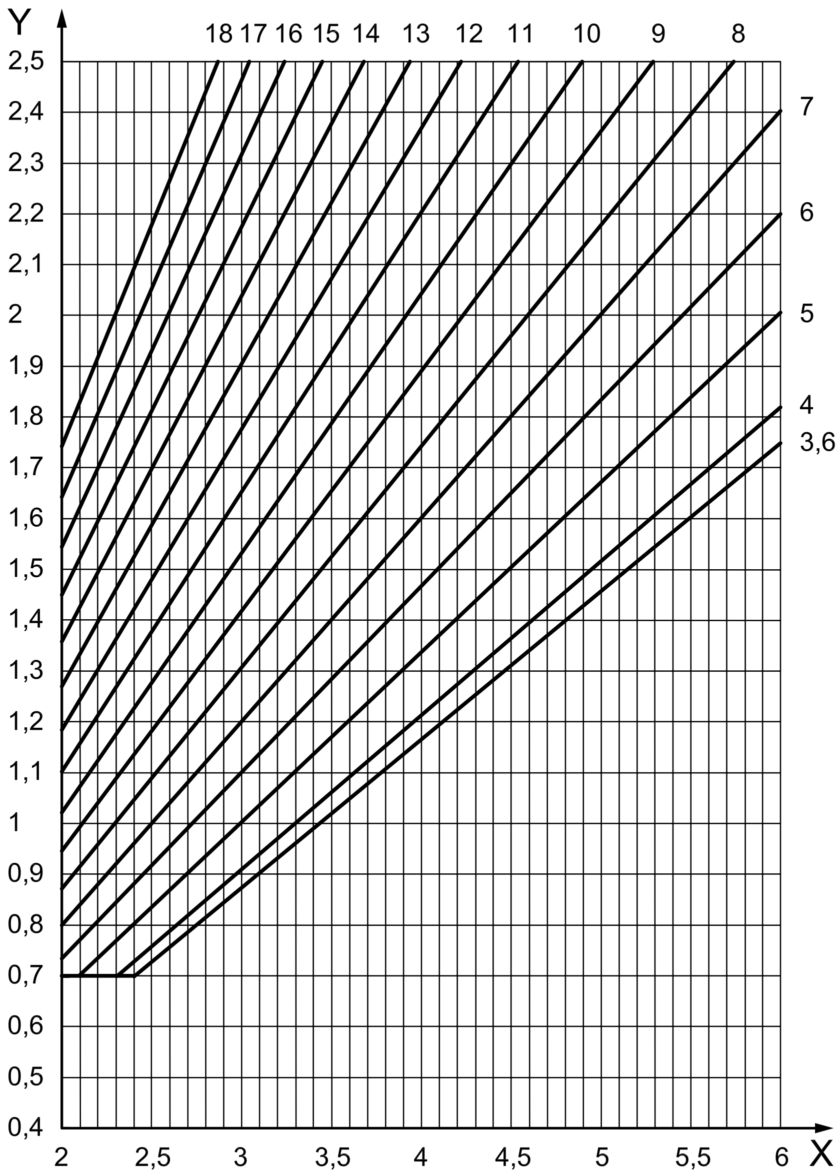
The craft is released, dropping into the water.

B.2.3 Inspection and compliance requirements

The craft is then taken on land and the bottom and side structure of the hull, deck and internal stiffeners are inspected for:

- on FRP boats, 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.

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



Key

X L_{WL}, m

Y H_Z, m

Figure B.1 — Determination of drop test height

Annex C
(normative)

FRP laminates properties and calculations

C.1 Methods for the determination of mechanical properties

C.1.1 General

Mechanical properties for use in determining scantling requirements from 8.1, 8.4, 9.1, 9.2 and Annex H shall be determined by one of three methods that depend on the mechanical property evaluation level (EL) used by the builder and defined in Table C.1.

Table C.1 — Evaluation level of mechanical property determination method

Evaluation level	Definition	Method
EL-a	Mechanical properties and fibre content by mass are determined by measurement using recognised test standards for samples that are representative of the product as manufactured.	Use measured data corrected as per C.1.1.
EL-b	Fibre content by mass is determined by measurement. Spot checks are carried out using recognised test standards for samples that are representative of the product as manufactured to ensure the product meets or exceeds the values from Tables C.4 to C.7.	Default data (Tables C.4 to C.7)
EL-c	No explicit measurements are made on fibre content and mechanical properties. Fibre content is taken from Table C.2 or other nominal values.	Default data (Tables C.4 to C.7) with multiplying factor of 0,8.

C.1.2 Evaluation level method "EL-a"

Mechanical properties and fibre mass content shall be determined experimentally and shall consist of those properties explicitly required by the scantling equations of Clauses 10 and 11 and Annex H.

The test sample shall be representative of the product as manufactured. In general, the specimen shall be manufactured under the same typical workshop conditions using the same material, fibre contents and sequence, methods of lay-up, thermal treatment and time sequence.

Tests to determine mechanical properties shall be conducted in accordance with the applicable or appropriate International Standard, e.g.

— the tensile strength and modulus shall be determined in accordance with ISO 527-1 and ISO 527-2;

— the flexural strength and modulus shall be determined in accordance with ISO 178.

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.

The mechanical properties used in the calculations shall be corrected 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.

The fibre content by mass in the laminate ψ may be determined for a specimen by ignition or ingestion of the resin or by direct measurement of the laminate, in kilograms per square metre, from the known fibre mass (see Example C.3.1).

The measured fibre content and actual fibre mass of the test samples shall be used to determine the nominal sample thickness using thickness equations. These values shall be used for converting measured failure loads and deflection into ultimate strength and modulus. Where the measured thickness deviates by > 15 % from the nominal thickness, a note to this effect shall be included in the test report.

Thickness equations

Equations for E glass

$$\frac{t}{w} = \frac{1}{3{,}072}\left(\frac{2{,}56}{\psi} - 1{,}36\right) \tag{C.1}$$

$$\psi = \frac{2{,}56}{3{,}072\frac{t}{w} + 1{,}36} \tag{C.2}$$

Tabulated values of Equation (C.1) are given in Table C.3.

Equations for high-strength carbon

$$\frac{t}{w} = \frac{1}{2{,}16}\left(\frac{1{,}8}{\psi} - 0{,}6\right) \tag{C.3}$$

$$\psi = \frac{1{,}8}{2{,}16\frac{t}{w} + 0{,}6} \tag{C.4}$$

Equations for aramid

$$\frac{t}{w} = \frac{1}{1{,}74}\left(\frac{1{,}45}{\psi} - 0{,}25\right) \tag{C.5}$$

$$\psi = \frac{1{,}45}{1{,}74\frac{t}{w} + 0{,}25} \tag{C.6}$$

where

t is the thickness, in millimetres;

w is the mass of fibre, in kilograms per square metre;

ψ is the mass content of fibre in the laminate (dry mass of fibre divided by the mass of the fibre plus resin).

Equations (C.1), (C.3) and (C.5) shall be used to find the required fibre mass that corresponds to a required thickness (as given in Clauses 10 and 11 and Annex H) at a specified fibre content by mass value. They can also be used to calculate thickness on a ply-by-ply basis or for the total laminate where ψ is the total mass of fibre divided by the total mass of the fibre plus resin. See example C.3.2.

Equations (C.2), (C.4) and (C.6) may be used to find the average mass content of a laminate for which the fibre mass and thickness are known (see H.2.1.8).

C.1.3 Evaluation level method “EL-b”

Two conditions shall be satisfied:

a) the fibre content by mass shall be established at least by direct measurement (see Example C.3.1) and with “occasional” spot checks by resin ignition or ingestion methods;

b) mechanical tests need not be carried out systematically, provided “occasional” spot-check tests on representative samples using recognised test standards and corrected as given in C.1.2 demonstrate that the builder can normally meet or exceed the values obtained from Tables C.4 to C.7.

Under these conditions, the mechanical properties may be taken from Tables C.4 to C.7 at the appropriate fibre content by mass.

The definition of “occasional” shall be such as to satisfy the builder that he is able to meet or exceed the values given in Tables C.4 to C.7 since it is his responsibility to demonstrate this. See C.1.5.

By way of guidance, as a minimum, “occasional” should include strength and modulus tests by three- or four-point bending methods for single-skin samples and sandwich beam bending tests by variable span methods.

Spot checks should always be carried out where the laminate schedule for a product is not broadly similar to a schedule for which use of data in Tables C.4 to C.7 has been validated by previous spot checks.

However, EL-b differs from EL-a in that a full set of mechanical data tests is not anticipated. It therefore follows that a builder may wish to test some critical items under EL-a while using Tables C.4 to C.7 for other non-tested properties.

C.1.4 Evaluation level method “EL-c”

The fibre content is taken from Table C.2 or from other data sources without explicit measurement of the fibre content by mass from representative samples taken from the product. Occasional spot-check tests on representative samples using recognised test standards and corrected as given in C.1.2 are rarely or never conducted. The ratio between thickness in millimetres and glass weight in kilograms per square metre is tabulated in Table C.3 for the values of ψ given in Table C.2.

Under these conditions, the mechanical properties may be taken from Tables C.4 to C.7 at the appropriate fibre content by mass, but all values so obtained shall be multiplied by a factor of 0,8.

Table C.2 — Nominal fibre content by mass

Type of ply reinforcement	Glass fibre laminate — Glass content by mass ψ		
	Open mould		Vacuum bag
	Simple surface [b]	Complex surface [b]	
Chopped strand mat (CSM) sprayed up	0,30	0,25	(0,36)
Chopped strand mat hand lay up	0,30	0,25	(0,36)
Woven roving (WR)	0,48	0,36	0,58
Roving mat combination [a]	0,46-0,18 R	0,35-0,11 R	0,56-0,22 R
Multidirectional fabric	0,50	0,38	0,60
Unidirectional fabric	0,55	0,41	0,66
Non-glass fibres (suitable for equivalent glass content by mass $>$ 0,4, i.e. not CSM)			
For carbon fibre The fibre content by mass ψ which gives the same fibre content by volume as the values above for glass may be estimated using $\psi_{\text{carbon}} = 0{,}99\ \psi_{\text{glass}}$ from the table $-$ 0,08 (see example C.3.3). Alternatively, one can take the value of Φ corresponding to ψ_{glass} in Table C.4 b) and use the same value in Table C.5.			
For aramid fibre The fibre content by mass which gives the same fibre content by volume as the values above for glass may be estimated using ψ aramid $=$ 0,95 ψ glass from the table $-$ 0,11.			

[a] R = total mass of mat (kg/m^2)/total mass of glass in laminate (mat and woven roving) (kg/m^2).

[b] A “simple” surface is a surface where resin impregnation and wetting-out is easy (e.g. large and accessible surfaces like hull and deck, cockpit bottom). A “complex” surface is a surface where resin impregnation and wetting-out is not easy (e.g. deep coamings, deep stiffeners or tray mouldings, etc.). The differentiation is up to the builder.

Table C.3 — Tabulated values of t/w in function of glass content by mass ψ

ψ	0,25	0,30	0,36	0,38	0,41	0,50	0,55	0,58	0,60	0,66
t/w [a]	2,89	2,34	1,87	1,75	1,59	1,22	1,07	0,99	0,95	0,82

[a] Ratio between thickness in millimetres and mass of dry glass in kilograms per square metre.

C.1.5 Builders’ responsibilities

Builders proceeding under any of the above evaluation level methods should recognise that responsibility for ensuring that the mechanical properties of any product meet or exceed those values used to determine the scantlings, howsoever these values were obtained (test or Tables C.4 to C.7), rests with the builder. Use of values from Tables C.4 to C.7 does not in itself make any statement about the actual built quality of the product.

In most instances, it will be in the builders’ interest to adopt level “a” or combination of levels “a” and “b”. Use of level “c” carries a considerable penalty since neither the actual fibre content by mass, nor the quality of fabrication can be quantified with any certainty.

C.2 Default mechanical properties

C.2.1 Status of default equations

The equations and values listed in Tables C.4 to C.7 are not intended to represent absolute minimums. The values are intended to be lower-bound estimates that are achievable by builders who use high-end industry standard quality material control and fabrication procedures.

The values will not be consistently achievable by builders who do not use best practice. Where there is any doubt as to the suitability of Tables C.4 to C.7, the onus is on the builder to satisfy himself that the values so obtained are achievable in practice.

The Tables are not suitable for hybrid plies, i.e. different fibres contained within a single ply. However, they may be used for a same fibre ply in a multi-fibre stack and analysed using the methods outlined in Annex H.

Tables C.4 to C.7 are mostly relevant for hand laminates or vacuum bag laminates (maybe with epoxy for carbon fibre). Oven cured pre-preg laminates, possibly in an autoclave, will show much higher strength values, but are closer to aerospace construction, and not fully within the scope of this part of ISO 12215.

C.2.2 Default values for glass-based composites

The values derived from Table C.4 a) correspond to E glass in polyester only.

Table C.4 a) — E glass fibre mechanical properties

Property	Values N/mm^2	
Hand-laminated chopped strand mat (CSM), combined mat/woven roving, woven roving (WR) and crossplied (CP) – 0/90 reinforcement [a]		
Ultimate tensile strength, σ_{ut}	$800\ \psi^2 - 80\ \psi + 37$	
Ultimate compressive strength, σ_{uc}	$150\ \psi + 72$	
Ultimate flexural strength, σ_{uf}	$502\ \psi^2 + 107$	
Ultimate in-plane shear strength, τ_u	$80\ \psi + 38$	
In-plane modulus, E	$38\ 000\ \psi - 5\ 000$	
In-plane shear modulus G	$1\ 700\ \psi + 2\ 240$	
Interlaminar (out of plane) shear strength $\tau_{u\ inter}$	$22{,}5 - 17{,}5\ \psi$	
Sprayed chopped strand mat		
Ultimate tensile strength, σ_{ut}	$150\ \psi + 25$	
Ultimate flexural strength, σ_{uf}	$300\ \psi^2 + 107$	
Other properties for sprayed CSM shall be obtained from the CSM equations above.		
Uni-directional (UD) reinforcement		
Property	**Parallel to the fibres**	**Perpendicular to the fibres**
Ultimate tensile strength, σ_{ut}	$880\ \psi^2 + 140\ \psi + 140$	42
Ultimate compressive strength, σ_{uc}	$250\ \psi + 190$	105
In-plane modulus, E	$46\ 600\ \psi^2 + 7\ 200\ \psi + 7\ 250$	$48\ 600\ \psi^2 - 39\ 000\ \psi + 12\ 500$
In-plane shear modulus, G	$14\ 380\ \psi^2 - 10\ 560\ \psi + 3\ 840$	
In-plane shear strength, τ_u	50	
Major Poisson's ratio, ν_{12}	0,3	
[a] For combined mat and woven roving, ψ may be the overall value. See Example C.3.2.		

The value for interlaminar (out of plane) shear strength of 22,5 to 17,5 ψ for CSM and WR can be used for sprayed mat and UD.

C.2.3 Comments on calculated Tables C.4 b) and C.5 b)

Tables C.4 b) and C.5 b) are displayed to help in the application of Tables C.4 a) and C.5 a). They are:

— in the upper part, calculated values of Tables C.4 a) and C.5 a), respectively for glass and carbon laminate;

— in the lower part, calculated values of Table C.7 for double bias (diagonal ± 45°) and balanced multiaxial (0/90/+45/–45) made from glass or high-strength carbon.

Double bias exhibit low values for σ and high values for τ compared with 0/90°. It is suggested that the use of pure double bias should be restricted to elements that are predominantly loaded in shear (web of high stiffeners, web of multihull crossbeams).

Table C.4 b) — GRP calculated values of Table C.4. a) and Table C.7

ψ Mass content	ϕ Volume content	Mixed mat/roving/multiaxial						Sprayed mat		UD (unidirectional)			
		σ_{ut}	σ_{uc}	σ_{uf}	τ_u	E	G	σ_{ut}	σ_{uc}	$\sigma_{ut}//$	$\sigma_{uc}//$	τ_u	E
		N/mm^2											
0,250	0,135	67	110	138	58	4 500	2 665	63	126				
0,275	0,151	76	113	145	60	5 450	2 708	66	130				
0,300	0,167	85	117	152	62	6 400	2 750	70	134				
0,325	0,184	96	121	160	64	7 350	2 793	74	139				
0,350	0,202	107	125	168	66	8 300	2 835	78	144	297	278	50	15 479
0,375	0,220	120	128	178	68	9 250	2 878			316	284	50	16 503
0,400	0,238	133	132	187	70	10 200	2 920			337	290	50	17 586
0,425	0,257	148	136	198	72	11 150	2 963			358	296	50	18 727
0,450	0,277	163	140	209	74	12 100	3 005			381	303	50	19 927
0,480	0,302	183	144	223	76	13 240	3 056			405	309	50	21 184
0,500	0,319	197	147	233	78	14 000	3 090			430	315	50	22 500
0,525	0,341	216	151	245	80	14 950	3 133			456	321	50	23 874
0,550	0,364	235	155	259	82	15 900	3 175			483	328	50	25 307
0,575	0,388	256	158	273	84	16 850	3 218			511	334	50	26 797
0,600	0,413	277	162	288	86	17 800	3 260			541	340	50	28 346

ψ Mass content	ϕ Volume content	Double bias [a] +/– 45°				Balanced quadraxial 0/45/90/–45			
		σ_{ut}	σ_{uc}	τ_u	E	σ_{ut}	σ_{uc}	τ_u	E
		N/mm^2							
0,500	0,319	95	95	140	6 300	148	147	86	10 500
0,525	0,341	95	95	144	6 728	162	151	88	11 210
0,550	0,364	95	95	148	7 155	176	155	90	11 920
0,575	0,388	95	95	151	7 583	192	158	92	12 640
0,600	0,413	95	95	155	8 010	208	162	95	13 350

[a] The data for double bias and quadraxial are only informative due to absence of extensive test data.

C.2.4 Carbon-based composites

The values derived from Tables C.5 a) and C.5 b) correspond to high-strength carbon only. High or intermediate modulus carbon is not considered. The associated resin system is assumed to be fully compatible with the fibres and provide excellent bonding and load-distribution qualities.

Carbon fibres are normally expected to be employed in the skins of sandwich panels, for which the in-plane properties (i.e. in-plane modulus, ultimate tensile and compressive strengths) are appropriate.

On occasions where an all-carbon single-skin FRP panel is to be analysed, only an approximate estimate of flexural properties may be obtained using Tables C.5 a) and C.5 b) (see C.3.4). Mechanical test of a representative laminate is strongly recommended.

Table C.5 a) — High-strength carbon fibre mechanical properties

<table>
<tr><th>Property</th><th colspan="2">Values
N/mm^2</th></tr>
<tr><td colspan="3">Hand-laminated, woven roving (WR) and crossplied (CP) — 0/90 reinforcement high-strength carbon fibre in compatible resin [a]</td></tr>
<tr><td>Ultimate tensile strength, σ_{ut} (0 or 90 direction)</td><td colspan="2">$990\ \psi - 90$</td></tr>
<tr><td>Ultimate compressive strength, σ_{uc} (0 or 90 direction)</td><td colspan="2">$610\ \psi - 55$</td></tr>
<tr><td>In-plane modulus, E (0 or 90 direction)</td><td colspan="2">$100\ 000\ \psi - 9\ 000$</td></tr>
<tr><td>Ultimate in-plane shear strength, τ_u</td><td colspan="2">$40\ \psi + 31$</td></tr>
<tr><td>In-plane shear modulus G</td><td colspan="2">5 100</td></tr>
<tr><td>Poisson's ratio</td><td colspan="2">0,05</td></tr>
<tr><td colspan="3">Unidirectional (UD) reinforcement</td></tr>
<tr><th>Property</th><th>Parallel to the fibres</th><th>Perpendicular to the fibres</th></tr>
<tr><td>Ultimate tensile strength, σ_{ut}</td><td>$2\ 000\ \psi - 200$</td><td>$50\ \psi^2 - 20\ \psi + 20$</td></tr>
<tr><td>Ultimate compressive strength, σ_{uc}</td><td>$1\ 100\ \psi - 110$</td><td>$150\ \psi^2 - 60\ \psi + 60$</td></tr>
<tr><td>In-plane modulus, E</td><td>$202\ 000\ \psi - 21\ 000$</td><td>$10\ 700\ \psi^2 - 4\ 200\ \psi + 4\ 400$</td></tr>
<tr><td>In-plane shear modulus, G</td><td colspan="2">$22\ 000\ \psi^2 - 17\ 300\ \psi + 5\ 700$</td></tr>
<tr><td>Ultimate in-plane shear strength, τ_u</td><td colspan="2">$310\ \psi^2 - 240\ \psi + 80$</td></tr>
<tr><td>Major Poisson's ratio, ν_{12}</td><td colspan="2">0,32</td></tr>
<tr><td colspan="3">Ultimate flexural strength, $\sigma_{uf} = 2,5\ \sigma_{ut} /(1 + \sigma_{ut}/\sigma_{uc})$. See example C.3.4</td></tr>
<tr><td colspan="3">[a] The mechanical properties are intended to be lower-bound values but not absolute minima. They are indicative of reasonable quality fabrication and primarily intended for preliminary design purposes. Testing in accordance with C.1 is strongly recommended.</td></tr>
</table>

Table C.5 b) — Carbon composite calculated values of Table C.5 a) and Table C.7

ψ Mass	ϕ Volume	Mixed roving and crossplies					UD carbon (high strength)							
		σ_{ut}	σ_{uc}	τ_u	E	G	σ_{ut}//	σ_{uc}//	E//	σ_{ut} perp	σ_{uc} perp	E perp	G	τ_u
Content		N/mm^2												
0,400	0,308	306	189	47	31 000	5 100	600	330	59 800	20	60	4 432	2 300	34
0,425	0,330	331	204	48	33 500	5 100	650	358	64 850	21	62	4 548	2 321	34
0,450	0,353	356	220	49	36 000	5 100	700	385	69 900	21	63	4 677	2 370	35
0,475	0,376	380	235	50	38 500	5 100	750	413	74 950	22	65	4 819	2 446	36
0,500	0,400	405	250	51	41 000	5 100	800	440	80 000	23	68	4 975	2 550	38
ψ Mass	ϕ Volume	Double bias [a] ± 45°					Balanced quadraxial 0/45/90/–45							
		σ_{ut}	σ_{uc}	τ_u	E		σ_{ut}	σ_{uc}	τ_u	E				
Content		N/mm^2												
0,400	0,308	61	57	188	7 750		184	113	118	21 700				
0,425	0,330	66	61	192	8 370		199	123	120	23 400				
0,450	0,353	71	66	196	9 000		214	132	123	25 200				
0,475	0,376	76	70	200	9 620		228	141	125	26 900				
0,500	0,400	81	75	204	10 250		243	150	128	28 700				

[a] The data for double bias and quadraxial are only informative due to absence of extensive test data.

C.2.5 Aramid-based composites

The values derived from Table C.6 correspond to aramid fibres of the type usually used in marine hull structures. The associated resin system is assumed to be fully compatible with the fibres and provide excellent bonding and load-distribution qualities.

Aramid fibres are normally expected to be used in the skins of sandwich panels, for which the in-plane properties (i.e. in-plane modulus, ultimate tensile and compressive strengths) are appropriate.

On occasions where an all-aramid single-skin FRP panel is to be analysed, only an approximate estimate of flexural properties may be obtained using Table C.6. See C.3.4.

Table C.6 — Aramid fibre mechanical properties

Property	Values N/mm^2	
Hand-laminated, woven roving (WR) and crossplied (CP) — 0/90 reinforcement aramid fibre in compatible resin [a]		
Ultimate tensile strength, σ_{ut} (0 or 90° direction)	$720\ \psi - 10$	
Ultimate compressive strength, σ_{uc} (0 or 90° direction)	$250\ \psi$	
Ultimate in-plane shear strength, τ_u	45	
In-plane modulus, E_t (0 or 90° direction)	$50\ 000\ \psi + 750$	
In-plane shear modulus G	3 400	
Poisson's ratio	0,05	
Unidirectional (UD) reinforcement		
Property	Parallel to the fibres	Perpendicular to the fibres
In-plane modulus, E	$103\ 000\ \psi - 1\ 400$	$1\ 550\ \psi + 2\ 600$
Ultimate tensile strength, σ_{ut}	$1\ 400\ \psi - 20$	$12\ \psi + 20$
Ultimate compressive strength, σ_{uc}	$340\ \psi$	$30\ \psi + 50$
In-plane shear modulus, G	$6\ 900\ \psi^2 - 2\ 250\ \psi + 1\ 800$	
Ultimate in-plane shear strength, τ_u	$100\ \psi^2 - 32\ \psi + 25$	
Major Poisson's ratio, ν_{12}	0,4	
Ultimate flexural strength, $\sigma_{uf} = 2{,}5\ \sigma_{ut}/(1 + \sigma_{ut}/\sigma_{uc})$.		

[a] The mechanical properties are intended to be lower-bound values but not absolute minima. They are indicative of reasonable quality fabrication.

C.2.6 Values for double bias or quadraxial laminates

The angles for plies 0°, +45°, 90°, –45°, etc. for multidirectional plies or laminates are the respective angles of the fibre plies from the b direction of a rectangular $l \times b$ panel (see Figure H.1).

The use of quadraxial laminates (UD balanced 0/45/90/–45) is becoming more common, particularly in sandwich laminates. The properties are usually in between those of roving and double bias.

Testing of double bias laminates is highly recommended, but in the absence of tested values, the following method can be applied for glass or carbon laminates with $0{,}5 < \psi < 0{,}6$ for GRP and $0{,}4 < \psi < 0{,}5$ for carbon laminates. Values for aramid laminates are currently not available.

Tables C.4 a) and C.5 b) incorporate the values of Table C.7.

Table C.7 — Mechanical properties of double bias or quadraxial E glass or HS carbon laminates

Mechanical property	E glass [a]	HS carbon [a]
Range of applicable ψ values	$0,5 < \psi < 0,6$	$0,4 < \psi < 0,5$
Double bias (± 45°) **laminates compared to woven roving and 0/90 reinforcements**		
Ultimate tensile strength, σ_{ut} (0 or 90°)	95 N/mm^2	0,20 σ_{ut} of woven roving or biaxial
Ultimate compressive strength, σ_{uc} (0 or 90°)	95 N/mm^2	0,30 σ_{uc} of woven roving or biaxial
Ultimate in-plane shear strength, τ_u	1,8 τ_u of woven roving or biaxial	4 τ_u of woven roving or biaxial
In-plane modulus, E_t (0 or 90° direction)	0,45 E_t of woven roving or biaxial	0,25 E_t of woven roving or biaxial
Quadraxial (0/45/90/–45) **laminates compared to woven roving and 0/90 reinforcements**		
Ultimate tensile strength, σ_{ut} (0 or 90°)	0,75 σ_{ut} of woven roving or biaxial	0,6 σ_{ut} of woven roving or biaxial
Ultimate compressive strength, σ_{uc} (0 or 90°)	1,0 σ_{uc} of woven roving or biaxial	0,6 σ_{uc} of woven roving or biaxial
Ultimate in-plane shear strength, τ_u	1,1 τ_u of woven roving or biaxial	2,5 τ_u of woven roving or biaxial
In-plane modulus, E_t (0 or 90° direction)	0,75 E_t of woven roving or biaxial	0,7 E_t of woven roving or biaxial

[a] When there is a ratio of mechanical properties, it applies for the same material (E glass or carbon HS) at the same ψ value.

C.3 Examples

C.3.1 Fibre mass by direct measurement

Procedure:

1) measure the length and width of five representative samples for which the actual fibre mass, in kilograms per square metre, is known;

2) weigh each sample with a balance that reads to an accuracy > 1 % of the sample mass;

3) divide the mass obtained at step 2, in kilograms, by the product of length and width, in metres;

4) divide the known actual fibre mass by the mass obtained at step 3.

Worked example:

Sample dimensions: 100 mm × 100 mm; mass of sample = 0,131 kg;

Mass of sample per square metre: 0,131/(0,1 × 0,1) = 13,1 kg/m^2;

Laminate schedule: 300 CSM + 4 × (450 CSM + 850 WR). Total glass = 5,5 kg/m^2;

Overall fibre content by mass: 5,5/13,1 = 0,42.

Repeat for four other samples.

C.3.2 Overall fibre content by mass by calculation

A boatbuilder builds a craft in an open mould with the following laminate for the hull bottom:

gel coat + 2 mat 225 + 3 (rov-mat 500/300) + rov 500.

The total amount of glass is 2 × 0,225 + 3 × 0,8 + 0,5 = 3,35kg/m^2.

From Table C.2: For mat $\psi_1 = 0{,}30$ (simple surface) and $w_1 = 0{,}450$ kg/m^2.

For rov-mat $R = 0{,}9/2{,}4 = 0{,}375$, therefore (simple surface), $\psi_2 = (0{,}46 - 0{,}18 \times 0{,}375) = 0{,}39$ and $w_2 = 2{,}4$ kg/m^2.

For woven roving, $\psi_3 = 0{,}48$ (simple surface) and $w_3 = 0{,}5$ kg/m^2.

The overall glass content is:

$$\psi = \frac{w_1 + w_2 + w_3}{\dfrac{w_1}{\psi_1} + \dfrac{w_2}{\psi_2} + \dfrac{w_3}{\psi_3}} = \frac{0{,}450 + 2{,}4 + 0{,}5}{\dfrac{0{,}450}{0{,}30} + \dfrac{2{,}4}{0{,}39} + \dfrac{0{,}5}{0{,}48}} = \frac{3{,}35}{8{,}7} = 0{,}39$$

From Equation (C.1), the thickness is: $t = \dfrac{w}{3{,}072}\left(\dfrac{2{,}56}{\psi} - 1{,}36\right) = \dfrac{3{,}35}{3{,}072}\left(\dfrac{2{,}56}{0{,}39} - 1{,}36\right) = 5{,}68$ mm

C.3.3 Fibre content by mass for non-glass fibre from Table C.2

Take a vacuum-bagged unidirectional. The fibre content by mass is 0,66 for glass.

For carbon, the figure giving the same fibre volume fraction would be:

ψ carbon $= 0{,}99$ ψ glass from Table C.2 $- 0{,}08 = 0{,}99 \times 0{,}66 - 0{,}08 = 0{,}57$.

C.3.4 Flexural properties of non-glass laminates

Calculate in-plane properties for the appropriate fibre content by mass.

Woven roving from Table C.2 ψ glass $= 0{,}58$.

ψ carbon $= 0{,}99$ ψ glass from Table C.2 $- 0{,}08 = 0{,}99 \times 0{,}58 - 0{,}08 = 0{,}49$.

$E = (100\,000\ \psi - 9\,000) = 40\,000$ N/mm^2 [see also Table C.5 a) for the following data].

$\sigma_{ut} = (990\ \psi - 90) = 395$ N/mm^2; $\sigma_{uc} = (610\ \psi - 55) = 244$ N/mm^2.

Estimate of flexural properties:

Ultimate flexural strength, $\sigma_{uf} = 2{,}5\ \sigma_{ut}/(1 + \sigma_{ut}/\sigma_{uc}) = 2{,}5 \times 395/(1 + 395/244) = 377$ N/mm^2.

NOTE Mechanical test of a representative laminate is strongly recommended.

C.3.5 Flexural strength of mixed spray-up CSM and WR

The flexural strength of sprayed CSM is lower than that of hand-laid CSM, typically by 12 %.

For normal hand-laid CSM/WR, the σ_{uf} formula is the same so it is only necessary to calculate the overall glass fraction.

For all sprayed CSM, the formula in Table C.4 a) shall be used, i.e. $\sigma_{uf} = 300\ \psi^2 + 107$.

For a combination of spray-up CSM and WR, in the absence of test data (the preferred method), the following approximate formula may be used:

$$\sigma_{uf} = (502 - 202\ R_{spray})\ \psi^2 + 107$$

where R_{spray} = mass of sprayed CSM glass/mass of glass.

EXAMPLE For 50 % sprayed CSM, $R_{spray} = 0{,}5$ and $\sigma_{uf} = 401\ \psi^2 + 107$.

Annex D
(normative)

Sandwich mechanical core properties and sandwich calculation

D.1 Sandwich core material mechanical properties

D.1.1 General

It is recommended to use core materials that have been tested by the builder or the core manufacturer. In that case, a test certificate according to D.1.2 shall be filed.

In other cases, the default values of D.1.3 shall be used.

D.1.2 Tested core material mechanical properties

Where the mechanical properties used for the scantling 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 test specimen shall be representative of the product as used.

The density shall be determined in accordance with ISO 845.

The shear strength shall be determined in accordance with ISO 1922.

The shear modulus shall be determined in accordance with ASTM C393.

The compressive strength and modulus of elasticity shall be determined in accordance with ISO 844.

The values shall be taken as 85 % of the mean value or this mean value minus two standard deviations, whichever is lesser, but need not be taken less than the minimum value (i.e. the lowest value obtained for all the tested samples).

D.1.3 Non-tested core material properties

Where the mechanical properties of sandwich cores have not been verified by tests, the respective properties shall be taken from Table D.1.

Mechanical properties need not be taken at less than the manufacturers' specified minimum values. However, most cores can exhibit significant variations in density and this will directly affect the mechanical properties.

NOTE The connection (glueing, lamination, etc.) between core and skins for a foam density > 120 kg/m^3 to 150 kg/m^3 may not be straightforward and may require specific procedures.

Table D.1 — Mechanical properties for sandwich core material

Core type	Density range ρ_c kg/m^3	Elongation at break %	Shear strength τ_u N/mm^2	Shear modulus G_c N/mm^2	Compressive strength σ_{uc} N/mm^2	Compressive modulus [a] E_{co} N/mm^2
End grain balsa	90-220	NR	$0{,}017\,8\ \rho_c - 0{,}34$	$0{,}868\ \rho_c - 1{,}43$	$0{,}102\ \rho_c - 5$	$30{,}7\ \rho_c - 1\,350$
Generic type — Cross-linked PVC						
Rigid PVC I	36-250	30 %	$0{,}002\,4\ \rho_c^{\ 1{,}334}$	$0{,}163\,3\ \rho_c^{\ 1{,}136}$	$0{,}001\,4\ \rho_c^{1{,}487}$	$0{,}113\,8\ \rho_c^{1{,}449}$
Rigid PVC II	33-250	20 %	$0{,}017\ \rho_c - 0{,}29$	$0{,}33\ \rho_c - 1$	$0{,}025\ \rho_c - 0{,}69$	$1{,}2\ \rho_c - 18$
Generic type — Linear PVC [b] or SAN [b]						
Linear PVC	50-140	55 %	$0{,}014\ \rho_c - 0{,}33$	$0{,}29\ \rho_c - 5{,}3$	$0{,}012\ \rho_c - 0{,}24$	$0{,}84\ \rho_c - 19$
SAN A	60-210	40 %	$0{,}017\ \rho_c - 2 \times 10^{-5}\ \rho_c^2 - 0{,}613$	$0{,}46\ \rho_c - 20$	$6{,}7\ 10^{-4}\ \rho_c^{\ 1{,}59}$	$0{,}024\ \rho_c^{1{,}75}$

[a] Modulus in the through-thickness direction. This value may not be used for balsa when calculating the bending stiffness (see H.2.1).

[b] ρ_c is the average density of the core. Typical variations in density have already been allowed for in the coefficients.

CAUTION — Some core trade designations do not always correspond to the average density. For example “type 80” may actually have an average density of 90 kg/m^3.

Table D.2 — Calculated values from Table D.1 for typical core densities

End grain balsa					Rigid PVC I					Rigid PVC II				
ρ_c	τ_u	G_c	σ_{uc}	E_{co}	ρ_c	τ_u	G_c	σ_{uc}	E_{co}	ρ_c	τ_u	G_c	σ_{uc}	E_{co}
kg/m^3	N/mm^2				kg/m^3	N/mm^2				kg/m^3	N/mm^2			
90	1,26	77	4,2	1 413	50	0,44	14	0,47	33	33	0,27	10,2	0,14	22
100	1,44	85	5,2	1 720	75	0,76	22	0,86	59	43	0,44	13,5	0,39	34
120	1,80	103	7,2	2 334	100	1,12	31	1,32	90	54	0,63	17,1	0,66	47
150	2,33	129	10,3	3 255	130	1,59	41	1,95	132	72	0,93	23,1	1,11	68
180	2,86	155	13,4	4 176	150	1,92	48	2,41	162	90	1,24	29,0	1,56	90
200	3,22	172	15,4	4 790	200	2,82	67	3,70	246	120	1,75	38,9	2,31	126
220	3,58	190	17,4	5 404	250	3,79	87	5,15	339	145	2,18	47,2	2,94	156
221	3,59	190	17,5	5 435	250	3,79	87	5,15	339	180	2,77	58,7	3,81	198

Linear PVC					SAN				
ρ_c	τ_u	G_c	σ_{uc}	E_{co}	ρ_c	τ_u	G_c	σ_{uc}	E_{co}
kg/m^3	N/mm^2				kg/m^3	N/mm^2			
60	0,51	12	0,48	31	60	0,34	8	0,45	31
70	0,65	15	0,60	40	70	0,48	12	0,58	41
80	0,79	18	0,72	48	80	0,62	17	0,71	51
100	1,07	24	0,96	65	100	0,89	26	1,01	76
140	1,63	35	1,44	99	130	1,26	40	1,54	120
					150	1,49	49	1,93	154
					200	1,99	72	3,05	255

D.2 Sandwich equations

D.2.1 General

The core is considered ineffective in carrying any bending moment and is only capable of transmitting shear force.

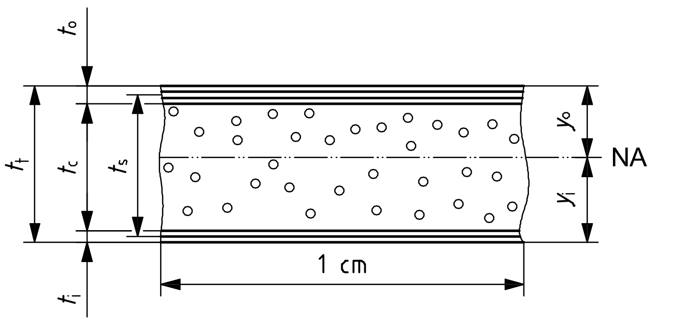


Figure D.1 — Sandwich schematic sketch

D.2.2 Equations for general sandwich sections (see Figure D.1)

$t_t = t_c + t_o + t_i$ mm total thickness of sandwich (D.1)

$t_s = t_c + \frac{(t_o + t_i)}{2}$ mm distance between mid-thickness (centroids) of skins (D.2)

$y_o = \frac{t_i \times t_s}{t_i + t_o} + \frac{t_o}{2}$ mm distance of the furthest side of outer skin from CG (D.3)

$y_i = \frac{t_o \times t_s}{t_i + t_o} + \frac{t_i}{2}$ mm distance of the furthest side of inner skin from CG (D.4)

$I = \left(\frac{t_o \times t_i \times {t_s}^2}{t_o + t_i} + \frac{t_o^3 + t_i^3}{12} \right) 10^{-3}$ cm⁴/cm second moment of area per centimetre width (D.5)

$SM_o = \frac{10 \times I}{y_o}$ cm³/cm section modulus of the outer skin per centimetre width (D.6)

$SM_i = \frac{10 \times I}{y_i}$ cm³/cm section modulus of the inner skin per centimetre width (D.7)

where

t_o and t_i are the thickness of the outer and inner skins of the sandwich respectively, in millimetres;

t_c is the core thickness, in millimetres.

D.2.3 Approximations

$SM_o = \frac{t_c \times t_o}{100}$ and $SM_i \frac{t_c \times t_i}{100}$ cm³/cm (D.8)

$I = \frac{t_o \times t_i \times {t_s}^2}{1\,000\,(t_o + t_i)}$ cm⁴/cm (D.9)

The approximations given in the above equations are only valid if the outer and inner skins are made with the same material with similar lay-ups and $t_i \geqslant 0{,}7\, t_o$.

D.2.4 Equations for symmetrical sandwich

$SM = \frac{t_c \times t}{100}$ cm³/cm (D.10)

$I = \frac{t \times {t_s}^2}{2\,000}$ cm⁴/cm (D.11)

where $t = t_o = t_i =$ skin thickness, in millimetres.

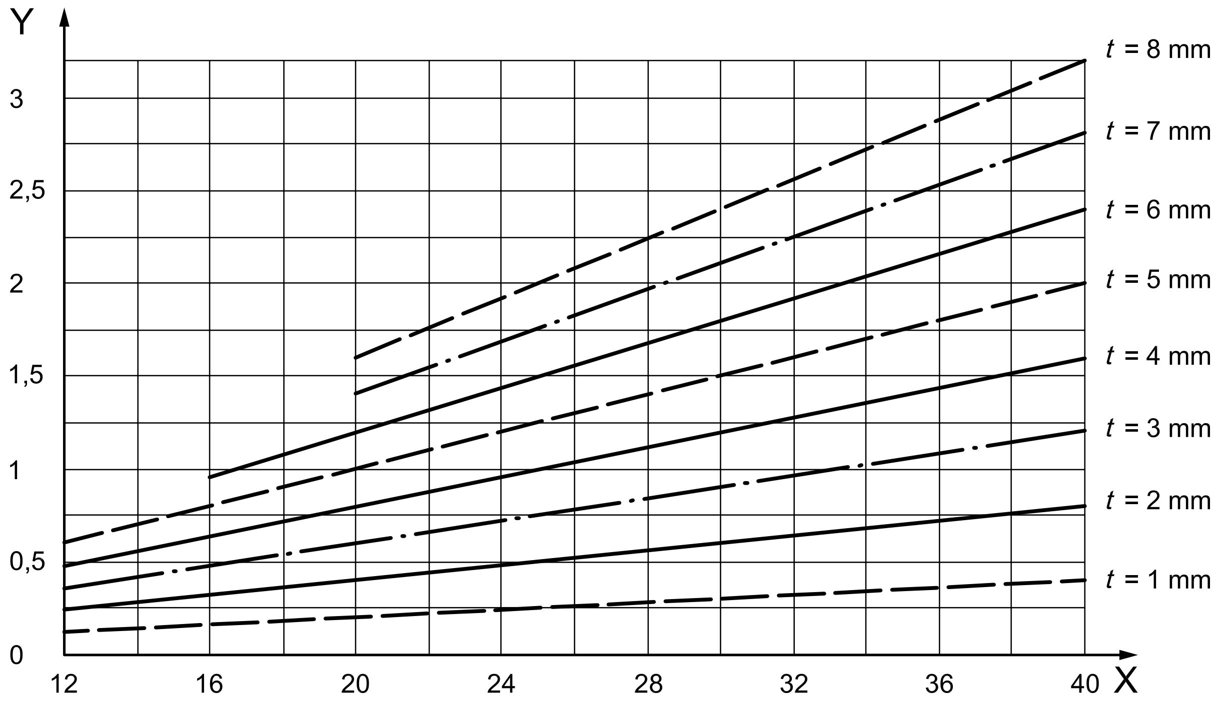
D.3 Sandwich pre-calculated tables and figures

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

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

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

Core thickness (mm)	Thickness of each skin (mm)							
	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



Key

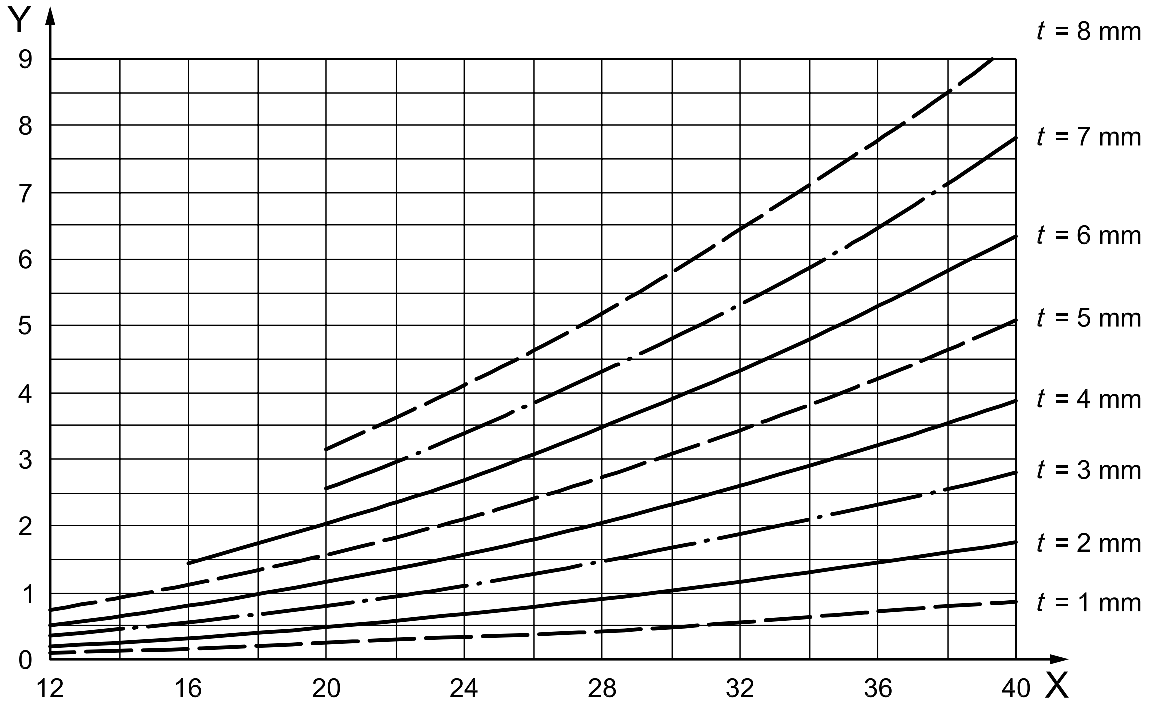
X d_c, mm

Y *SM*, cm^3/cm

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

Table D.4 — Values of approximated second moment I (cm⁴/cm) of symmetrical sandwiches

Core thickness (mm)	Thickness of each skin (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



Key

X d_c, mm

Y I, cm⁴/cm

Figure D.3 — Graph of approximated second moment I (cm⁴/cm) of symmetrical sandwiches

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Annex E
(normative)

Wood laminate properties and wood calculations

E.1 Wood laminates

E.1.1 General

This part of ISO 12215 applies to three types of laminated wood construction – plywood (E.1.2), moulded veneer (E.1.3) and strip planking (E.1.4).

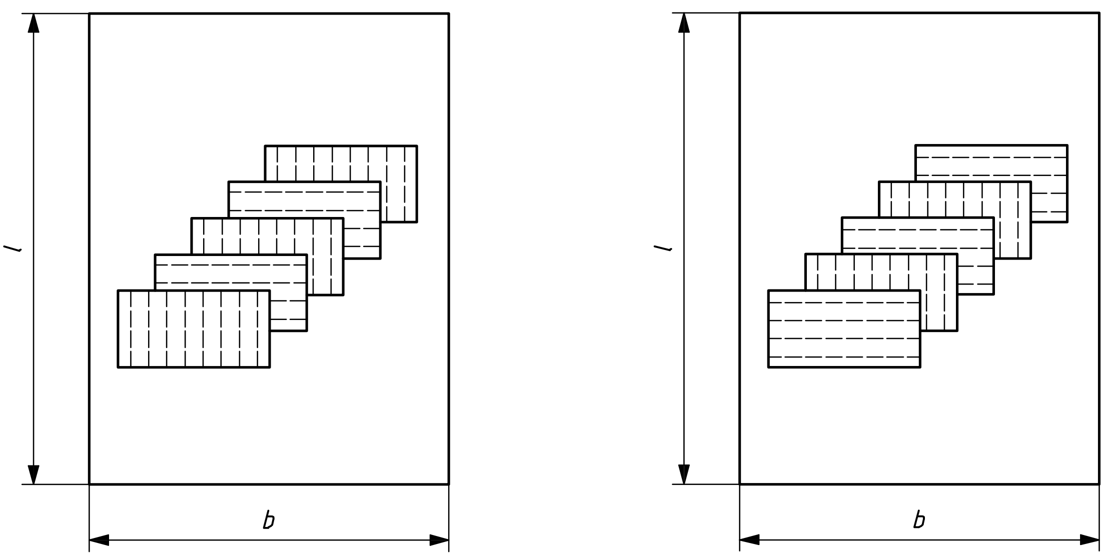
In each case the wood plies shall be bonded by a structural adhesive, and at the construction stage the wood shall be effectively encapsulated to stabilize the long-term moisture content.

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 that required in 10.4 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.

E.1.2 Plywood

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.



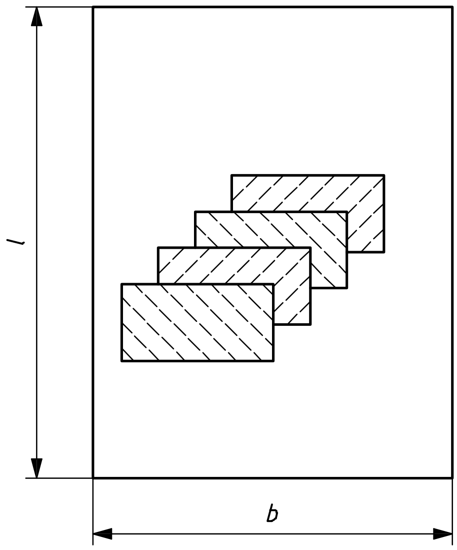
Outer face perpendicular with b direction — Outer face parallel with b direction

The example shows a plywood with 5 plies.

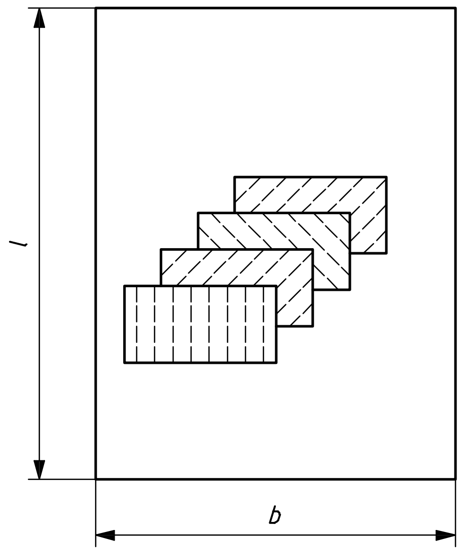
Figure E.1 — Plywood sheet-ply orientation

E.1.3 Moulded in-situ veneers

Moulded 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.



All veneers run at ± 45° with b direction



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

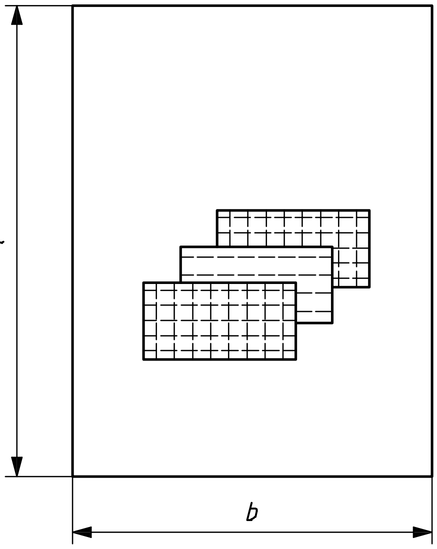
The example shows 4 veneers.

Figure E.2 — Moulded veneer orientation

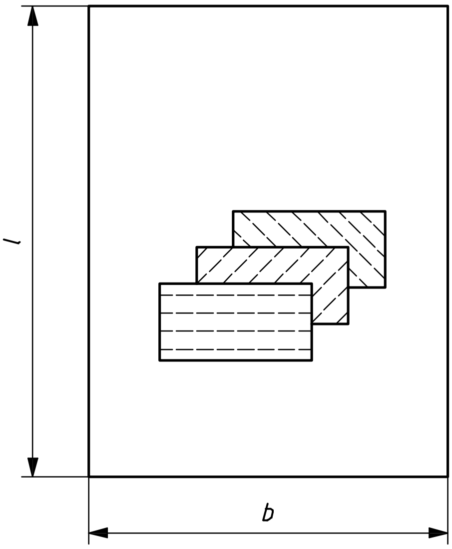
E.1.4 Strip planking

Narrow planks are 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 Equation (37) refers to the total thickness of wood (strip plank and veneers), exclusive of any lightweight sheathing.



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



Two ± 45° veneers on thick strip planking

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

E.2 Wood laminate mechanical properties

E.2.1 Tested properties

Where the mechanical properties used for the scantling 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.

E.2.2 Non-tested properties

σ_{uf} shall be obtained

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

— using 80 % 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 equations given in Table E.2, tabulated in Tables E.4 and E.5, which supply prediction equations for the three types of construction covered and mechanical wood properties taken from Table E.1;

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

The mechanical properties of non-tested plain woods to be used in the scantling calculation shall be obtained from Table E.1. The values presented in Table E.1 correspond to 80 % of the mean values obtained from tests on small, essentially defect-free samples. The values shall be used with allowable stress factors as given in Table 9.

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

CAUTION — The buckling of webs under shear may be the limiting case (see ISO 12215-7).

Table E.1 — Mechanical properties of typical wood species

Wood species		Density ρ	σ_{uf} // grain	σ_{cu} // grain	τ_u // grain
Softwood					
Common name	Scientific name	kg/m^3	N/mm^2	N/mm^2	N/mm^2
Fir, Douglas	*Pseudotsuga menziesii*	520	74	41	8,9
Larch, European	*Larix decidua*	545	74	37	9,8
Pine, Yellow	*Pinus strobus*	433	64	34	7,5
Cedar, Western Red	*Thuja plicata*	368	52	28	6,8
Redwood, Baltic	*Pinus sylvestris*	481	67	36	9,1
Spruce, European	*Picea abies*	400	52	28	7,6
Spruce, Sitka	*Picea stitchensis*	384	53	29	6,9
Other woods		ρ	0,137 ρ	0,075 ρ	0,018 ρ
Softwood – Elastic modulus // grain		E (N/mm^2) = 19,5 ρ			
Hardwood		**Density** ρ	σ_{uf} // grain	σ_{cu} // grain	τ_u // grain
Common name	Scientific name	N/mm^2	N/mm^2	N/mm^2	N/mm^2
Aspen, European	*Populus tremula*	460	55	34	6
Afrormosia	*Pericopsis elata*	737	108	57	13
Afzelia	*Afzelia* sp.	817	100	63	13
Agba	*Gossweilerodendron balsamiferum*	497	65	35	9
Ekki (azobe)	*Lophira alata*	1 037	142	72	19
Iroko	*Chlorophora excelsa*	657	72	44	11
Jarrah	*Eucalptus marginata*	865	94	51	13
Kapur	*Dryobalanops beccarii*	705	93	53	10
Karri	*Eucalyptus diversicolor*	913	111	60	13
Keruing	*Dipterocarpus caudiferus*	641	88	48	10
Mahogany, African	*Khaya anthotheca*	513	67	36	10
Mahogany, American	*Swietenia marcrophylla*	497	67	36	10
Makore	*Tieghemella heckelii*	609	81	43	11
Meranti, light red	*Shorea dasyphylla*	481	70	40	8
Oak, European	*Quercus* spp.	689	77	41	11
Opepe	*Nauclea diderrichii*	753	96	58	14
Sapele	*Entandrophragma cylindricum*	673	89	47	14
Teak	*Tectona grandis*	641	84	48	12
Utile (Sipo)	*Entandrophragma utile*	641	83	48	14
Other woods		ρ	0,130 ρ	0,071 ρ	0,018 ρ
Hardwood – Elastic modulus // grain		E (N/mm^2) = 17,5 ρ			

Table E.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]	$\left(\frac{\rho_{PW}}{1000}\right)^{0,5}\left(68 - 2\,N_{ply} + 0,03\,N_{ply}^2\right)$	$\left(\frac{\rho_{PW}}{1000}\right)^{0,75}\left(11\,400 - 580\,N_{ply} + 16\,N_{ply}^2\right)$
Perpendicular to face grain [b]	$\left(\frac{\rho_{PW}}{1000}\right)^{0,5}\left(11 + 6,5\,N_{ply} - 0,28\,N_{ply}^2\right)$	$\left(\frac{\rho_{PW}}{1000}\right)^{0,75}\left(1\,320\,N_{ply} - 55\,N_{ply}^2 - 1\,200\right)$
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	$(0,01\,N_{ply} + 0,17)\,\sigma_f$ 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
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 [e]	[f]

[a] The parallel to the face grain value shall be used in Equation (37) when the face grain runs parallel to the short dimension of the panel.

[b] The perpendicular to the face grain value shall be used in Equation (37) 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 E.2 gives data for a plywood or cold-moulded panel (bending like a hull panel under external pressure).

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

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

Tables E.6 gives pre-calculated values from Table E.3.

Table E.3 — Mechanical properties for plywood on edge

Variable	Unit	Equation
$E\,//$	N/mm^2	$17{,}5 \times (0{,}1 + 0{,}9 \times k_N) \times (\rho_{PW} - 100)$
$E\perp$	N/mm^2	$17{,}5 \times (1 - 0{,}9 \times k_N) \times (\rho_{PW} - 100)$
$\sigma_U\,//$	N/mm^2	$0{,}007\,5 \times E\,//$
$\sigma_U\perp$	N/mm^2	$0{,}007\,5 \times E\perp$
G	N/mm^2	$1{,}2\,\rho_{PW}$
τ	N/mm^2	$0{,}02\,\rho_{PW}$
$E\,//$ or $E\perp$ at angle θ	N/mm^2	$E\,//$ or $E\perp$ $(1 - \frac{\theta}{38} + \frac{\theta^2}{3\,400})$ for $0 \leqslant \theta < 90°$
$\sigma_U\,//$ or $\sigma_U\perp$ at angle θ	N/mm^2	$\sigma_U\,//$ or $\sigma_U\perp$ $(1 - \frac{\theta}{57} + \frac{\theta^2}{5\,100})$ for $0 \leqslant \theta < 90°$
τ at angle θ	N/mm^2	$\tau \times \left(1 + \frac{\theta}{250} + \frac{\theta^2}{4\,000}\right)$ for $0 \leqslant \theta < 45°$
Where $k_N = 0{,}5\left(1 + \frac{1}{N_{ply}}\right)$ and ρ_{PW} is the plywood actual density (kg/m^3). 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 E.4 — Pre-calculated values of plywood properties according to Table E.2

Density kg/m^3	Number of plies	$\sigma_{uf//}$ N/mm^2	$\sigma_{uf} \perp$ N/mm^2	$E_{f//}$ N/mm^2	$E_f \perp$ N/mm^2
400	5	37	23	4 476	2 024
	7	35	27	4 086	2 688
	9	33	30	3 760	3 131
	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	4 136	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

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

Wood common name	Number of plies	σ_f short direction N/mm^2	σ_f long direction N/mm^2	E_f short direction N/mm^2	E_f long direction N/mm^2
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	1 134	2 512
	4	11	NR	1 177	2 512
	5	11	NR	1 220	2 512
Mahogany, African	3	13	NR	1 418	3 142
	4	14	NR	1 472	3 142
	5	15	NR	1 526	3 142

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

Density kg/m^3	**Number of plies**	k_N	$\sigma_{uf//}$ N/mm^2	$\sigma_{uf\perp}$ N/mm^2	$E_{f//}$ N/mm^2	$E_{f\perp}$ N/mm^2	$G_{0/90}$ N/mm^2	$\tau_{0/90}$ N/mm^2	$\tau_{+/-45}$ N/mm^2
400	5	0,60	25	18	3 360	2 415	480	8,0	13,5
	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	4 136	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			

E.3 Laminated wood calculation examples

This clause provides examples of scantling assessment based on the default mechanical properties of Tables E.1 and E.2, and computed values from Tables E.4 and E.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/m^3) and number of plies (7).

Determine flexural strength for the two orientations from Tables E.1 or E.2:

$$\sigma_{//} \text{ to outer face} = \left(\frac{\rho_{PW}}{1000}\right)^{0,5} \left(68 - 2N_{ply} + 0,03N_{ply}^2\right) = 0,6^{0,5}\,(68 - 2 \times 7 + 0,03 \times 7^2) = 43 \text{ N/mm}^2$$

$$\sigma_{\perp} \text{ to outer face } \left(\frac{\rho_{PW}}{1000}\right)^{0,5} \left(11 + 6,5N_{ply} - 0,28N_{ply}^2\right) = 0,6^{0,5}\,(11 + 6,5 \times 7 - 0,28 \times 7^2) = 33 \text{ N/mm}^2$$

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

Use Equation (37) to determine the required thickness.

$$t = b \times \sqrt{\frac{P_d \times k_2}{1000 \times \sigma_d}} = 450 \sqrt{\frac{60 \times 0{,}5}{1\,000(0{,}5 \times 33)}} = 19{,}2 \text{ mm}$$

EXAMPLE 2 Design of *in-situ* moulded veneers

Determine veneer density (513 kg/m^3) before moulding and determine ultimate flexural strength parallel to the grain from Table E.2 using the “other woods” equation or pick off the actual wood.

For khaya, $\sigma_{uf//}$ to grain = 67 N/mm^2 or 0,130 × 513 = 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 E.1 ± 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°, $\sigma_{//}$ to short panel side = 0,3 σ_{uf} of parent wood = 0,3 × 67 = 20 N/mm^2.

Use Equation (37) to determine the required thickness.

$$t = b \times \sqrt{\frac{P_d \times k_2}{1000 \times \sigma_d}} = 250 \sqrt{\frac{60 \times 0{,}5}{1000\,(0{,}5 \times 14)}} = 16{,}5 \text{ mm}$$

EXAMPLE 3 Design of strip plank

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

For western red cedar, $\sigma_{uf\,//}$ to grain = 52 N/mm^2, and from Table E.1 (or 0,137 × 368 = 50 N/mm^2).

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 E.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 Equation (37) to determine the required thickness.

$$t = b \times \sqrt{\frac{P_d \times k_2}{1000 \times \sigma_d}} = 800 \sqrt{\frac{60 \times 0{,}5}{1000(0{,}5 \times 36)}} = 33 \text{ mm}$$

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.

Annex F
(normative)

Mechanical properties of metals

For the purpose of this part of ISO 12215, the mechanical properties displayed in Table F.1, derived from EN 13195-1 for aluminium alloys, shall be used for the metals in the table. For other metals one shall use ISO 12215-3.

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

Values in newtons per square millimetre

Design stress for plating											
Mild steel			**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)											
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
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), $\sigma_d = \min(0{,}6\sigma_{uw} \text{ or } 0{,}9\sigma_{yw})$ unwelded.

NOTE σ_u and σ_y are tensile stresses.

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

Values in newtons per square millimetre

Design stress for stiffeners										
Mild steel				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	106
E32 - AH 32				470	470	315	315	0,8	252	142
E36 - AH 36				490	490	355	355	0,8	284	160
Aluminium alloys (non-heat treatable)										
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	64
EN AW-5052	Sheet, strip, plate $3 < t < 50$	Al,Mg 2,5	H34	235	170	180	65	0,7	46	72
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	76
EN AW-5154A	Sheet, strip, plate $3 < t < 50$	Al,Mg 3,5	0/H111	215	215	85	85	0,7	60	34
EN AW-5154A	Sheet, strip, plate $3 < t < 50$	Al,Mg 3,5	H24	240	215	200	85	0,7	60	80
EN AW-5086	Sheet, strip, plate $3 < t < 50$	Al,Mg 4	0/H111	240	240	100	100	0,7	70	40
EN AW-5086	Sheet, strip, plate $3 < t < 50$	Al,Mg 4	H34	275	240	185	100	0,7	70	74
EN AW-5083	Sheet, strip, plate $t < 6$	Al,Mg 4,5 Mn 0,7	0/H111	275	275	125	125	0,7	88	50
EN AW-5083	Sheet, strip, plate $3 < t < 50$	Al,Mg 4,5 Mn 0,7	H32	305	275	215	125	0,7	88	86
AA 5059 Alustar	Sheet, strip, plate $3 < t < 50$	Al,Mg 5-6	0/H111	330	300	160	160	0,7	112	64
AA 5059 Alustar	Sheet, strip, plate $3 < t < 50$	Al,Mg 5-6	H32	370	300	270	160	0,7	112	108
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	58
EN AW-5383	Sheet, strip, plate $3 < t < 50$	Al,Mg 4,5 Mn 0,9	H32	305	290	220	145	0,7	102	88
Aluminium alloys (heat treatable)										
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	46
EN AW-6061	Closed profiles	Al,Mg1, Si Cu	T5,T6	245	165	205	115	0,7	81	46
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	46
EN AW-6005A	Closed profiles $3 < t < 50$	Al,Si,Mg (A)	T5,T6	250	165	215	115	0,7	81	46
EN AW-6082	Profiles, bars, Tubes $3 < t < 25$	Al,Si 1,Mg,Mn	T5,T6	310	170	260	115	0,7	81	46
EN AW-6082	Closed profiles	Al,Si 1,Mg,Mn	T5,T6	290	170	240	115	0,7	81	46
EN AW-6106	Profiles, bars, Tubes $3 < t < 25$	Al,Mg,Si,Mn	T6	240	240	195	195	0,7	81	78

[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), $\sigma_d = 0,7 \times \sigma_y$ unwelded and $\tau_d = 0,4 \times \sigma_y$ unwelded.

NOTE σ_u and σ_y are tensile stresses.

Annex G
(normative)

Geometric properties of stiffeners

G.1 General

The geometric properties of stiffeners may be determined using the following tables. Intermediate values may be derived by interpolation.

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 $\psi = 0{,}30$. The plating is also supposed to be all mat with an effective plating width of 20 times the plating thickness, plus the top-hat width. 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, in cubic centimetres, the shear web area, A_w in square centimetres, and the second moment around neutral axis I_{NA}, in centimetres to the fourth, are given in columns 7, 8 and 9 respectively.

If the stiffener spacing is less than the width of associated plating of column 5, 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. Table H.3 gives 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 $t_w/2 = 2{,}34 \times w_f$ ($\psi = 0{,}30$, see Table C.3).

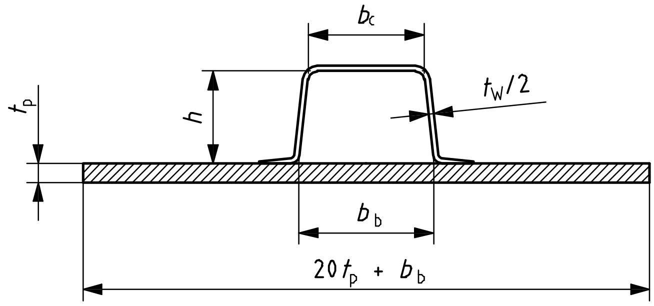


Figure G.1 — Sketch of a “squat” top hat

Table G.1 — "Squat" top-hat properties

1	2	3	4	5	6	7	8	9
Dimensions of former			Plating thickness	Associated plating	Stiffener glass mass	Geometric properties		
h	b_b	b_c	t_p	$20\ t_p + b_b$	w_f	SM_{min}	A_w	I_{NA}
mm	mm	mm	mm	mm	kg/m^2	cm^3	cm^2	cm^4
25	36	30	5	136	0,600	1,8	0,7	5
			10	236	0,600	2,7	0,7	8
			15	336	0,600	5,1	0,7	17
40	60	50	5	160	0,600	4,5	1,1	17
			10	260	0,600	5,4	1,1	24
			15	360	0,600	7,5	1,1	36
50	75	65	5	175	0,900	10,4	2,1	46
			10	275	0,900	11,8	2,1	62
			15	375	0,900	14,1	2,1	80
60	90	75	5	190	1,200	18,8	3,4	92
			10	290	1,200	21,1	3,4	127
			15	390	1,200	23,8	3,4	157
75	100	85	5	200	1,200	27,1	4,2	159
			10	300	1,200	30,1	4,2	218
			15	400	1,200	32,9	4,2	261
100	150	125	5	250	1,800	73,0	8,4	502
			10	350	1,800	81,2	8,4	715
			15	450	1,800	86,7	8,4	855
125	175	150	5	275	2,100	125,3	12,3	1 000
			10	375	2,100	139,9	12,3	1 445
			15	475	2,100	148,6	12,3	1 739
150	220	190	5	320	2,700	231,3	18,9	2 030
			10	420	2,700	259,8	18,9	2 975
			15	520	2,700	276,1	18,9	3 638

NOTE This table is only fully valid if the stiffener spacing is greater than the associated plating width (column 5).

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 $t_w/2 = 2{,}34 \times w_f$ ($\psi = 0{,}30$, see Table C.3).

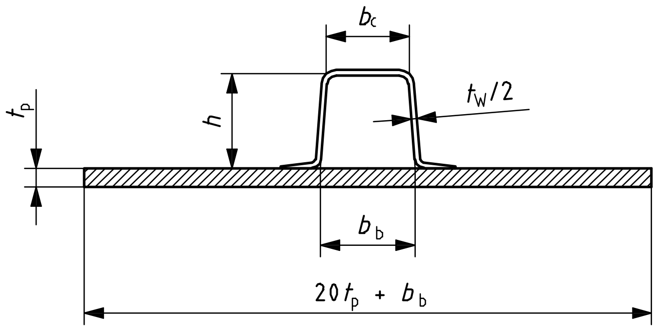


Figure G.2 — Sketch of a "square" top hat

Table G.2 — "Square" top-hat properties

1	2	3	4	5	6	7	8	9
Dimensions of former			Plating thickness	Associated plating	Stiffener glass mass	Geometric properties		
h	b_b	b_c	t_p	$20\ t_p + b_b$	w_f	SM_{min}	A_w	I_{NA}
mm	mm	mm	mm	mm	kg/m^2	cm^3	cm^2	cm^4
25	25	20	5	125	0,600	1,5	0,7	4
			10	225	0,600	2,2	0,7	7
			15	325	0,600	4,6	0,7	15
40	40	35	5	140	0,600	3,6	1,1	14
			10	240	0,600	4,4	1,1	20
			15	340	0,600	6,3	1,1	30
50	50	45	5	150	0,900	8,2	2,1	36
			10	250	0,900	9,5	2,1	50
			15	350	0,900	11,5	2,1	66
60	60	50	5	160	1,200	14,5	3,4	72
			10	260	1,200	16,6	3,4	101
			15	360	1,200	18,9	3,4	126
75	75	65	5	175	1,200	22,8	4,2	135
			10	275	1,200	25,6	4,2	187
			15	375	1,200	28,2	4,2	225
100	100	85	5	200	1,800	56,2	8,4	391
			10	300	1,800	63,7	8,4	567
			15	400	1,800	68,6	8,4	683
125	125	105	5	225	2,100	98,3	12,3	798
			10	325	2,100	111,7	12,3	1 169
			15	425	2,100	119,6	12,3	1 414
150	150	125	5	250	2,700	172,5	18,9	1 557
			10	350	2,700	198,0	18,9	2 309
			15	450	2,700	212,6	18,9	2 845

NOTE This table is only fully valid if the stiffener spacing is greater than the associated plating width (column 5).

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 two and three times b_c. The stiffener thickness $t_w/2 = 2{,}34 \times w_f$ ($\psi = 0{,}30$, see Table C.3).

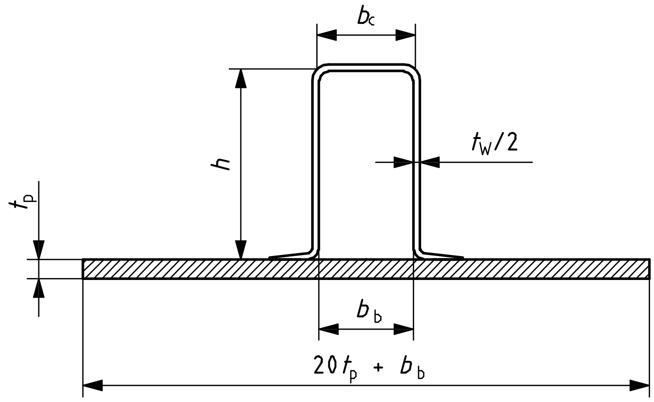


Figure G.3 — Sketch of a "tall" top hat

Table G.3 — "Tall" top-hat properties

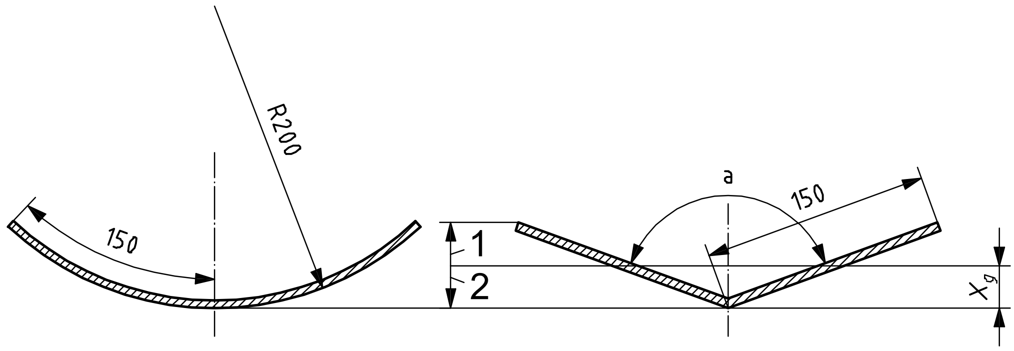
1	2	3	4	5	6	7	8	9
Dimensions of former			Plating thickness	Associated plating	Stiffener glass mass	Geometric properties		
h	b_b	b_c	t_p	$20\ t_p + b_b$	w_f	SM_{min}	A_w	I_{NA}
mm	mm	mm	mm	mm	kg/m^2	cm^3	cm^2	cm^4
100	50	50	5	150	1,800	41,3	8,4	289
			10	250	1,800	48,4	8,4	434
			15	350	1,800	52,7	8,4	529
125	50	50	5	150	2,100	64,7	12,3	532
			10	250	2,100	77,1	12,3	816
			15	350	2,100	84,1	12,3	1 006
150	50	50	5	150	2,700	103,6	18,9	960
			10	250	2,700	126,2	18,9	1 496
			15	350	2,700	139,1	18,9	1 893
150	75	75	5	175	2,700	125,5	18,9	1 140
			10	275	2,700	149,5	18,9	1 751
			15	375	2,700	163,2	18,9	2 199
175	75	65	5	175	3,000	160,5	24,5	1 675
			10	275	3,000	193,5	24,5	2 557
			15	375	3,000	213,0	24,5	3 243
200	75	75	5	175	3,600	239,4	33,6	2 713
			10	275	3,600	289,9	33,6	4 102
			15	375	3,600	322,1	33,6	5 296
200	100	100	5	200	3,600	276,9	33,6	3 081
			10	300	3,600	330,5	33,6	4 626
			15	400	3,600	364,0	33,6	5 934
250	100	100	5	200	4,200	432,8	49,0	5 836
			10	300	4,200	517,5	49,0	8 506
			15	400	4,200	576,2	49,0	11 005
300	100	100	5	200	5,100	667,6	71,5	10 571
			10	300	5,100	792,2	71,5	14 779
			15	400	5,100	890,3	71,5	19 131

NOTE This table is only fully valid if the stiffener spacing is greater than the associated plating width (column 5).

G.3 Round bilges and hard chines

These stiffeners may be made of any material (FRP, metal, plywood, etc.).

Dimensions in millimetres



Key

1 v top

2 v bott

Figure G.4 — Sketch of round bilge and hard chine stiffeners

Table G.4 — Round bilge 150 mm × 150 mm

Circular arcs 150 mm × 150 mm × t_p			
Plating thickness mm	**Arc ext. radius** mm	I cm^4	SM cm^3
5	300	19,6	7,3
	200	42,2	11,0
	150	69,0	14,4
6	300	23,5	8,8
	200	50,6	13,3
	150	82,8	17,2
7	300	27,4	10,3
	200	59,1	15,5
	150	96,5	20,1
8	300	31,3	11,8
	200	67,5	17,7
	150	110,3	23,0

Table G.5 — Hard chine 150 mm × 150 mm

Angles 150 mm × 150 mm × t_p								
Plating thickness t_p mm	**Angle** °	S cm²	I cm⁴	Xg **from outside apex** cm	V **top** cm	V **bottom** cm	V **max.** cm	SM cm³
5	120	15,11	72,3	4,0	4,0	4,1	4,1	17,8
5	140	15,09	33,8	2,9	2,8	2,9	2,9	11,9
5	160	15,04	8,9	1,6	1,6	1,6	1,6	5,5
6	120	18,13	86,7	4,0	4,0	4,1	4,1	21,4
6	140	18,11	40,6	2,9	2,8	2,9	2,9	14,2
6	160	18,05	10,6	1,6	1,6	1,6	1,6	6,6
7	120	21,15	121,4	4,0	4,0	4,1	4,1	29,9
7	140	21,13	47,3	2,9	2,8	2,9	2,9	16,6
7	160	21,06	12,4	1,6	1,6	1,6	1,6	7,7
8	120	24,18	194,3	4,0	4,0	4,1	4,1	47,9
8	140	24,14	54,1	2,9	2,8	2,9	2,9	19,0
8	160	24,06	14,2	1,61	1,55	1,61	1,61	8,8

G.4 Metal hull stiffeners

NOTE 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.5 and Table G.6).

Dimensions in millimetres

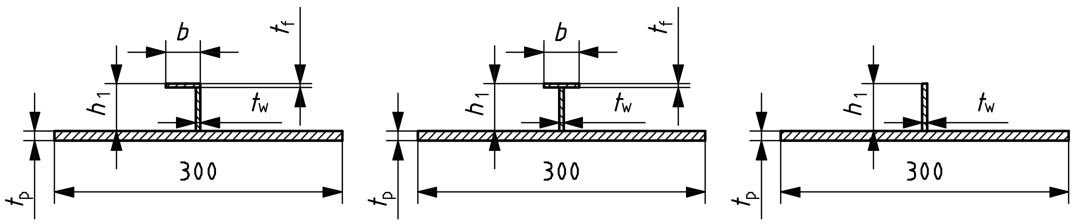


Figure G.5 — Sketch of commercially available extruded L or T and flat bar stiffeners

Table G.6 — Minimum section modulus of extruded L or T and angle and flat bar

Commercially available extruded L or T (see Figure G.5)				**Flat bars**			
Section $h_1 \times b \times t$	**Thickness of attached plating**			**Section** $h_1 \times t$	**Thickness of attached plating**		
	4 mm	6 mm	8 mm		4 mm	6 mm	8 mm
30 × 30 × 4	4,2	4,6	5,0	30 × 4	1,4	1,6	1,9
40 × 40 × 5	9,1	9,6	10,2	40 × 4	2,3	2,5	2,8
50 × 50 × 5	14,4	15,1	15,8	50 × 5	4,3	4,6	5,0
60 × 60 × 6	24,2	25,4	26,3	60 × 5	6,1	6,4	6,8
70 × 70 × 6	33,2	34,7	35,9	60 × 6	7,2	7,7	8,1
80 × 80 × 6	43,6	45,4	46,9	70 × 7	11,1	11,7	12,3
90 × 90 × 8	69,2	72,6	75,2	80 × 7	14,2	15,0	15,7
100 × 75 × 8	69,2	72,6	75,1	90 × 8	19,9	21,1	22,1
125 × 75 × 8	92,8	97,5	100,8	100 × 9	26,9	28,6	29,9
150 × 100 × 8	143,1	150,5	155,7	125 × 10	44,4	47,4	49,7

NOTE In fabricated stiffeners, the height h_2 is usually measured from the top of the plating to the bottom of the stiffener flange, as these are the dimensions of the commercially available plates (see Figure G.6 and Table G.7).

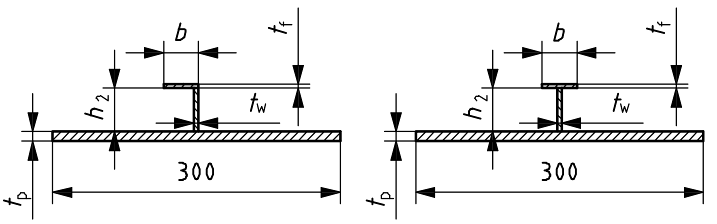


Figure G.6 — Sketch of a fabricated L or T shaped stiffeners

Table G.7 — Minimum section modulus and second moment of fabricated T, flat bar, or L

Fabricated L or T (see Figure G.6)				**Second moment of area**		
Section $h_2 \times t_w + b \times t_f$	**Thickness of attached plating**			The scantlings of steel and aluminium sections are normally decided to meet the section modulus requirements.		
	4 mm	6 mm	8 mm			
100 × 6 + 50 × 8	54,3	56,7	58,5	The second moment may be estimated with I cm$^4 = k\,Z^n$ where Z is the section modulus (cm^3) from the tables.		
150 × 6 + 100 × 8	145,1	151,7	156,2			
200 × 8 + 100 × 10	251,1	265,1	274,7	Stiffener type	k	n
250 × 10 + 100 × 12	389,5	413,5	430,7	Angle bar (L) or T	1,7	1,35
300 × 12 + 100 × 15	584,9	622,0	650,0	Flat bar	2,6	1,40

NOTE Tables G.6 and G.7 – According to Table 19, the effective plating is 80 t_p for steel and 60 t_p for aluminium respectively. For simplification, the tables are calculated for a 300 mm wide effective plating, which will give, in theory, very slightly optimistic or pessimistic results according to the case. The 300 mm value is also a practical upper limit for stiffener spacing.

G.5 Wood stiffeners

G.5.1 General

As stated in 11.5, wood stiffeners shall usually be considered as made of “different” materials, i.e. as having mechanical properties that differ by $>$ 25 %.

As the elastic modulus of the plating is usually different from that of the stiffeners, the calculations are usually made taking the base elastic modulus as 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 G.5.3.1).

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

a) the general method explained in G.5.3;

b) the application of Annex H for the cases not considered in G.5.3;

c) the use of Tables G.8 and G.9. This method is simpler, and gives quick results for SM. The application of G.5.3 will however be required if the verification of shear stress is needed.

G.5.2 Wood stiffeners pre-calculated tables

Tables G.8 and G.9 are pre-calculated tables applying the general method explained in G.5.3 and consider 4 cases, connected to 4 typical values of KE_{0-90}. These values are:

0 **floating stiffener** (left of Table G.8): this considers the case where the stiffener in question 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.

Where 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 boat with transverse frames, a value of KE_{0-90} equals zero may be used conservatively.

0,25 **stiffener on ± 45° veneers** (right of Table G.8): this corresponds to the case of veneers at ± 45° from the grain of the stiffener.

0,50 **solid stiffener on plywood plating** (left of Table G.9).

1,00 **stiffener and plating grain aligned** (right of Table G.9): this case corresponds to mainly transversal plating on transversal frames, or mainly longitudinal plating on stringers.

Tables G.8 and G.9 shall be used in conjunction with the requirements and explanations given in G.5.4.

Table G.8 — Properties of wood stiffeners (1)

Floating stiffener					Stiffener on ± 45° veneers				
KE_{0-90}	0,00				KE_{0-90}	0,25			
Section $h \times t_w$	**Geometric properties**	**Thickness of attached plating** t_p			**Section** $h \times t_w$	**Geometric properties**	**Thickness of attached plating** t_p		
		10 mm	20 mm	30 mm			10 mm	20 mm	30 mm
25 × 25	SM_{min} (cm³)	2,6	2,6	2,6	25 × 25	SM_{min} (cm³)	5,8	11,0	19,2
	I (cm⁴)	3,3	3,3	3,3		I (cm⁴)	11,5	31,5	68,4
30 × 30	SM_{min} (cm³)	4,5	4,5	4,5	30 × 30	SM_{min} (cm³)	8,8	15,6	24,8
	I (cm⁴)	6,7	6,7	6,7		I (cm⁴)	19,1	48,6	96,0
40 × 40	SM_{min} (cm³)	10,7	10,7	10,7	40 × 40	SM_{min} (cm³)	17,3	28,5	41,1
	I (cm⁴)	21,3	21,3	21,3		I (cm⁴)	44,6	101,2	180
50 × 50	SM_{min} (cm³)	20,8	20,8	20,8	50 × 50	SM_{min} (cm³)	30,0	46,7	64,0
	I (cm⁴)	52,1	52,1	52,1		I (cm⁴)	90,0	184	307
60 × 60	SM_{min} (cm³)	36,0	36,0	36,0	60 × 60	SM_{min} (cm³)	47,8	70,6	93,9
	I (cm⁴)	108	108	108		I (cm⁴)	165	306	486
75 × 50	SM_{min} (cm³)	47	47	47	75 × 50	SM_{min} (cm³)	60	86	111
	I (cm⁴)	176	176	176		I (cm⁴)	256	451	691
100 × 50	SM_{min} (cm³)	83	83	83	100 × 50	SM_{min} (cm³)	101	136	170
	I (cm⁴)	417	417	417		I (cm⁴)	555	889	1 293
125 × 50	SM_{min} (cm³)	130	130	130	125 × 50	SM_{min} (cm³)	152	196	240
	I (cm⁴)	814	814	814		I (cm⁴)	1 025	1 538	2 155
150 × 50	SM_{min} (cm³)	187	187	187	150 × 50	SM_{min} (cm³)	213	268	322
	I (cm⁴)	1 406	1 406	1 406		I (cm⁴)	1 707	2 437	3 317
200 × 75	SM_{min} (cm³)	500	500	500	200 × 75	SM_{min} (cm³)	539	626	716
	I (cm⁴)	5 000	5 000	5 000		I (cm⁴)	5 598	7 023	8 669
250 × 75	SM_{min} (cm³)	781	781	781	250 × 75	SM_{min} (cm³)	830	938	1 052
	I (cm⁴)	9 765	9 765	9 765		I (cm⁴)	10 689	12 878	15 396
300 × 75	SM_{min} (cm³)	1 125	1 125	1 125	300 × 75	SM_{min} (cm³)	1 183	1 313	1 451
	I (cm⁴)	16 874	16 874	16 874		I (cm⁴)	18 193	21 311	24 890
200 × 100	SM_{min} (cm³)	667	667	667	200 × 100	SM_{min} (cm³)	711	807	901
	I (cm⁴)	6 666	6 666	6 666		I (cm⁴)	7 335	8 873	10 511
250 × 100	SM_{min} (cm³)	1 500	1 500	1 500	250 × 100	SM_{min} (cm³)	1 565	1 707	1 847
	I (cm⁴)	22 499	22 499	22 499		I (cm⁴)	23 971	27 306	30 784
300 × 100	SM_{min} (cm³)	1 500	1 500	1 500	300 × 100	SM_{min} (cm³)	1 565	1 707	1 847
	I (cm⁴)	22 499	22 499	22 499		I (cm⁴)	23 971	27 306	30 784

NOTE Tables G.8 and G.9 assume that the maximum spacing of stiffeners (centre to centre) is never > 450 mm where the spacing exceeds this value; the above SM and I values will be conservative.

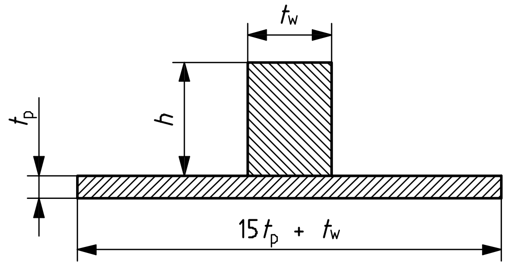


Figure G.7 — Sketch of solid wood stiffener

Table G.9 — Properties of wood stiffeners (2)

Solid stiffener on plywood plating					Stiffener and plating grain aligned				
KE_{0-90}	0,50				KE_{0-90}	1,00			
Section $h \times t_w$	**Geometric properties**	**Thickness of attached plating** t_p			**Section** $h \times t_w$	**Geometric properties**	**Thickness of attached plating** t_p		
		10 mm	20 mm	30 mm			10 mm	20 mm	30 mm
25 × 25	SM_{min} (cm^3)	6,7	13,0	25,8	25 × 25	SM_{min} (cm^3)	7,4	16,3	38,6
	I (cm^4)	15,1	40,6	97,1		I (cm^4)	18,8	53,8	149,7
30 × 30	SM_{min} (cm^3)	10,2	17,9	31,1	30 × 30	SM_{min} (cm^3)	11,4	21,1	42,7
	I (cm^4)	25,5	61,9	128,8		I (cm^4)	32,2	78,2	183,9
40 × 40	SM_{min} (cm^3)	20,3	32,3	47,7	40 × 40	SM_{min} (cm^3)	23,0	36,3	58,1
	I (cm^4)	59,4	130,6	230,4		I (cm^4)	77,2	160,6	298
50 × 50	SM_{min} (cm^3)	34,9	53,4	72,8	50 × 50	SM_{min} (cm^3)	40,1	59,3	83,5
	I (cm^4)	117,2	242,4	394,6		I (cm^4)	153,7	301	491
60 × 60	SM_{min} (cm^3)	55,0	81,6	106,8	60 × 60	SM_{min} (cm^3)	63,5	91,1	119,8
	I (cm^4)	208	408	634		I (cm^4)	272	516	785
75 × 50	SM_{min} (cm^3)	69	99	125	75 × 50	SM_{min} (cm^3)	79	110	138
	I (cm^4)	319	596	891		I (cm^4)	413	750	1 086
100 × 50	SM_{min} (cm^3)	113	157	192	100 × 50	SM_{min} (cm^3)	129	175	211
	I (cm^4)	670	1 169	1 681		I (cm^4)	850	1 490	2 059
125 × 50	SM_{min} (cm^3)	168	226	274	125 × 50	SM_{min} (cm^3)	191	255	301
	I (cm^4)	1 207	2 005	2 814		I (cm^4)	1 506	2 573	3 481
150 × 50	SM_{min} (cm^3)	234	308	368	150 × 50	SM_{min} (cm^3)	263	349	407
	I (cm^4)	1 972	3 142	4 334		I (cm^4)	2 418	4 045	5 413
200 × 75	SM_{min} (cm^3)	573	708	826	200 × 75	SM_{min} (cm^3)	630	810	939
	I (cm^4)	6 155	8 642	11 207		I (cm^4)	7 159	11 075	14 498
250 × 75	SM_{min} (cm^3)	873	1 049	1 206	250 × 75	SM_{min} (cm^3)	947	1 195	1 375
	I (cm^4)	11 560	15 473	19 544		I (cm^4)	13 162	19 554	25 250
300 × 75	SM_{min} (cm^3)	1 236	1 453	1 652	300 × 75	SM_{min} (cm^3)	1 328	1 647	1 885
	I (cm^4)	19 449	25 115	31 061		I (cm^4)	21 790	31 299	39 947
200 × 100	SM_{min} (cm^3)	750	905	1 038	200 × 100	SM_{min} (cm^3)	817	1 035	1 191
	I (cm^4)	7 964	10 713	13 391		I (cm^4)	9 118	13 607	17 427
250 × 100	SM_{min} (cm^3)	1 625	1 869	2 083	250 × 100	SM_{min} (cm^3)	1 732	2 107	2 383
	I (cm^4)	25 383	31 548	37 551		I (cm^4)	28 045	38 694	47 948
300 × 100	SM_{min} (cm^3)	1 625	1 869	2 083	300 × 100	SM_{min} (cm^3)	1 732	2 107	2 383
	I (cm^4)	25 383	31 548	37 551		I (cm^4)	28 045	38 694	47 948

NOTE Tables G.8 and G.9 assume that the maximum spacing of stiffeners (centre to centre) is never > 450 mm where the spacing exceeds this value; the above SM and I values will be conservative.

G.5.3 General method for assessing wood stiffeners

G.5.3.1 General

Assessment of flat bar stiffeners attached to plating may be carried out using the following equations and procedures. A worked example is included to demonstrate the method.

Fabricated tee-section stiffeners produced for example by glueing flange pieces either side of a plywood web or any other section may be analysed using the methods in Annex H.

G.5.3.2 Preliminary calculations

The second moment of area about the neutral axis is obtained as follow:

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

NOTE 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.

This may be simplified to

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

$$I_{NA} = \frac{C}{A_p + A_s} \text{cm}^4 \quad \text{(G.2)}$$

where

$A_s = h \times t_w$ is the area of the stiffener shear web, in square centimetres;

$A_p = KE_{0-90} \times t_p \times b_e$ is the effective area of attached plating, in square centimetres;

KE_{0-90} is the ratio between in-plane elastic modulus of attached plating parallel to stiffener axis divided by the in-plane elastic modulus of the stiffener;

b_e is the effective extent of plating, in centimetres;

t_p is the plating thickness, in centimetres;

t_w is the flat bar thickness, in centimetres;

h is the flat bar depth, in centimetres.

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.

G.5.3.3 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 $y_{max} = h - y_{NA} = \dfrac{A \times h - A_S \dfrac{h}{2} + \dfrac{A_p \times t_p}{2}}{A}$ and

where $A = A_S + A_p$

$$SM_{stiffener} = \frac{I_{NA}}{y_{max}} = \frac{C}{A_p\left(h + \dfrac{t_p}{2}\right) + \dfrac{A_s \times h}{2}} \text{ cm}^3 \qquad \text{(G.3)}$$

For the plating $y_{max} = t_p + y_{NA} = \dfrac{A \times t_p - A_S \dfrac{h}{2} + \dfrac{A_p \times t_p}{2}}{A}$ and

$$SM_{plating} = \frac{C}{A_S\left(\dfrac{h}{2} + t_p\right) + \dfrac{A_p \times t_p}{2}} \text{ cm}^3 \qquad \text{(G.4)}$$

G.5.3.4 Shear stress at stiffener/plating interface

$$\tau = \frac{F_d \times A_y}{I_{NA} \times b} \text{ is the shear stress at the interface N/mm}^2 \qquad \text{(G.5)}$$

where $A_y = A_p \times \left(t_p + y_{NA}\right) = \dfrac{A_p \times A_S \times \left(\dfrac{h}{2} + \dfrac{t_p}{2}\right)}{A_S + A_p}$ is the first moment of areas and $I_{NA} = \dfrac{C}{A_S + A_p}$.

If the dimensions are in centimetres or square centimetres and the stresses in newtons per square millimetres,

$$\tau = \frac{0{,}005 \times F_d \times A_p \times A_S \times \left(h + t_p\right)}{C \times t_w} \text{ N/mm}^2 \text{ is the shear stress at the interface} \qquad \text{(G.6)}$$

G.5.4 Analysis of wooden stiffeners

G.5.4.1 General

KE_{0-90} = 0,2 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

$$SM_{min} = \frac{t_w \times h^2}{6} \text{ cm}^3 \qquad \text{(G.7)}$$

Tables G.8 and G.9 provide 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 locations given in G.5.4.2 to G.5.4.5.

G.5.4.2 Stress at the extreme top of the flat bar stiffener

$$\sigma_{\text{stiffener}} = \frac{M_{\text{d}}}{SM_{\text{stiffener}}} \text{ N/mm}^2 \quad \text{(G.8)}$$

The direct stress at the extreme top of the stiffener shall be assessed as specified in Table 18, i.e. it shall be checked against σ_d which is 0,45 σ_{uf} for laminated frames, 0,4 σ_{uf} for solid wooden frames and 0,45 σ_{uf} for plywood on edge frames respectively.

G.5.4.3 Stress at the extreme underside of the attached plating

$$\sigma_{\text{plating}} = \frac{M_{\text{d}}}{SM_{\text{plating}}} KE_{0-90} \text{ N/mm}^2 \quad \text{(G.9)}$$

where M_d is the design bending moment, in newton metres, defined in Clause 11, Equation (52).

G.5.4.4 Shear stress in the stiffener

$$\tau_{\text{stiffener}} = \frac{F_{\text{d}}}{A_{\text{S}}} \text{ N/mm}^2 \quad \text{(G.10)}$$

According to Table 18, the shear stress assessment shall be based respectively on $\tau_d = 0{,}45\ \tau_u$ for laminated wooden frames, or $\tau_d = 0{,}4\ \tau_u$ for frames made out of solid wood.

G.5.4.5 Shear stress at the interface between panel and stiffener

See ISO 12215-6.

G.5.5 Worked example

G.5.5.1 General

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

Effective extent of attached plating $b_e = 15 \times t = 15 \times 15 = 225$ mm; the stiffener width shall be added to this figure; therefore $b_e = 225 + 50 = 275$ mm.

G.5.5.2 Stiffener

From Table E.1 Sitka spruce ($\rho = 384$). Ultimate flexural strength $\sigma_{uf} = 53$ N/mm^2. Ultimate shear strength $\tau_u = 6{,}9$ N/mm^2. $E = 19{,}5 \times 384 = 7\ 488$ N/mm^2 $A_S = 5 \times 5 = 25$ cm^2.

G.5.5.3 Plating

The plating is at ± 45° to short panel side. From Tables E.1 and E.2 $\sigma_{uf} = 0{,}3 \times 0{,}130 \times 513 = 20$ N/mm^2 (same as $\sigma_{uf} = 0{,}3$ of parent wood strength = $0{,}30 \times 67 = 20$ N/mm^2).

$E = 0{,}2 \times 17{,}5 \times 513 = 1\ 800$ N/mm^2 (0,2 of parent wood, from Table E.1).

Dimensions are in centimetres, square centimetres or cubic centimetres.

$KE_{0-90} = 1\ 800/7\ 488 = 0{,}24$ $A_p = 27{,}5 \times 1{,}5 \times 0{,}24 = 9{,}9$ cm^2

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

$$C = 0{,}333 \times 25 \times 9{,}9\ (5^2 + 1{,}5 \times 5 \times 1{,}5 \times 1{,}5^2) + 0{,}083\,3\ [(9{,}9 \times 1{,}5)^2 + (25 \times 5)^2] = 4\,497\ \text{cm}^6$$

$$I_{NA} = \frac{C}{A_p + A_S} = 4\,497/(25 + 9{,}9) = 128{,}8\ \text{cm}^4$$

$$SM_{\text{stiffener}} = \frac{C}{A_p\left(h + \frac{t_p}{2}\right) + A_S\frac{h}{2}} = \frac{4\,497}{\left[9{,}9 \times (5 + 0{,}75) + 25 \times 5/2\right]} = 37{,}7\ \text{cm}^3$$

$$SM_{\text{plating}} = \frac{C}{A_S\left(\frac{h}{2} + t_p\right) + A_p\frac{t_p}{2}} = \frac{4\,497}{\left[25 \times (5/2 + 1{,}5) + 9{,}9 \times 1{,}5/2\right]} = 41{,}9\ \text{cm}^3$$

G.5.5.4 Bending moment and shear force

If the design pressure is $P = 28$ kN/m^2.

$$M_d = 83{,}33 \times k_{CS} \times P \times s \times l_u^2 \times 10^{-9} = (83{,}33 \times 28 \times 280 \times 800^2) \times 10^{-9} = 418\ \text{Nm}$$

$$F_d = k_{SA} \times P \times s \times l_u \times 10^{-4} = 5 \times 28 \times 280 \times 800 \times 10^{-4} = 3\,136\ \text{N}$$

$H_{SA} = 5$ because the frame is attached to plating (see 11.1).

G.5.5.5 Required section moduli

For the stiffener (flexural strength criterion)

Required $SM_{\text{stiffener}} = M_d/(0{,}4 \times 53) = 418/21{,}2 = 19{,}7$ cm^3: OK as actual $SM = 37{,}7$ cm^3.

For the plating (flexural strength criterion) $\sigma_{\text{plating}} = \dfrac{M_d}{SM_{\text{plating}}} KE_{0-90}$

Required $SM_{\text{plating}} = M_d/\sigma_{\text{d plating}} \times KE_{0-90} = 418/(0{,}45 \times 20) \times 0{,}24 = 11$ cm^3: OK as actual $SM = 41{,}9$ cm^3.

G.5.5.6 Stiffener area check for shear

$\tau_{\text{stiffener}} = F_d/A_S = 3\,136/(50 \times 50) = 1{,}25$ N/mm^2 $< \tau_d = 0{,}4\ \tau_u = 0{,}4 \times 6{,}9 = 2{,}76$ N/mm^2 (Table E.1): OK.

G.5.5.7 Use of Tables G.8 and G.9

For $KE_{0-90} = 0{,}25$, the 50×50 frame properties could have been read from Table G.8 by interpolation between 10 mm and 20 mm plate thickness. Since $t_p = 15$ mm, $SM_{\min} = (30{,}0 + 46{,}7)/2 = 38{,}3$ cm^3, and $I_{NA} = (90 + 184)/2 = 134$ cm^4, which are close to the values obtained in G.5.5.3.

Annex H
(normative)

Laminate stack analysis

H.1 General

H.1.1 Application

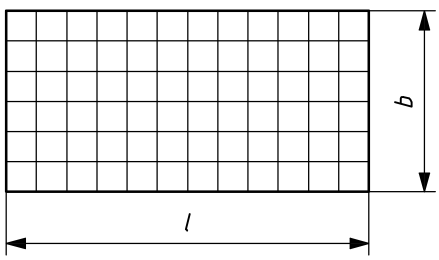
This annex is intended to be used to analyse laminate stacks for cases were the laminate schedule is complex and cannot be regarded as quasi-isotropic, or to analyse a stiffener, either made of dissimilar material or not, given in Annex G. Flexural properties are likely to be unavailable for these kinds of laminate schedule and hence equations for homogeneous single skin, sandwich or stiffener may not be appropriate. In addition, this annex allows the strength to be checked in the two principal panel directions. This is an important consideration when the fibres are biased in the short panel direction, which is the normal approach to minimize the panel mass.

The method outlined in this annex may be applied to single skin (all fibre-reinforced plies), sandwich panels with low stiffness cores (for example PVC or end grain balsa) and sandwich panels with high stiffness cores (for example cedar planking or resin-soaked bulking materials). This method is also applicable for stiffeners made of different materials (e.g. mat/roving top-hat stiffeners with UD layers on the top).

The method is **strictly** limited to laminate schedules which are largely composed of 0/90° orientations with respect to the panel sides and are nearly symmetrical about the mid-plane. Where this is not the case, significant coupling may occur between in-plane direct and shear forces, between bending and torsion and between in-plane and out-of-plane forces. Such laminate schedules are best analysed using the classical laminate theory (CLT). Validated CLT software (commercially available or developed in-house) may be used in place of this annex.

In either case, the panel is assumed to be fully fixed (clamped) around the perimeter and subjected to the pressure loads as specified in the main body of this part of ISO 12215.

H.1.2 Strip or panel analysis



Key

b short dimension of panel

l long dimension of panel

Figure H.1 — Schematic panel view

If the aspect ratio of a panel l/b is > 2, the panel may be analysed only in a direction parallel to the short direction b, as a strip (see H.2); otherwise it shall be analysed in the two principal directions b and l (see H.3).

H.2 Strip analysis

H.2.1 Calculation of the parameters for a multilayer laminate (see Table H.2)

H.2.1.1 General

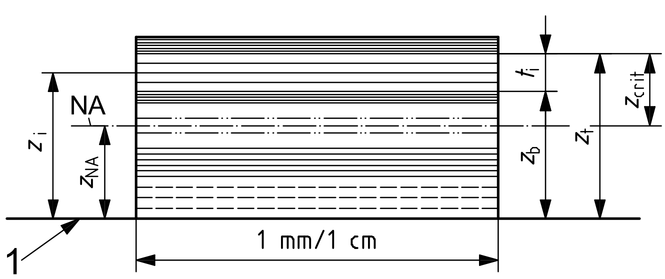
The method described here corresponds to the analysis of a laminate strip, i.e. only held in the short direction. See H.3 for a two-dimensional panel.

Table H.2 shows an example of a tabular form spreadsheet used to calculate most of the necessary parameters for the analysis of a multilayer laminate, provided the conditions of H.1.1 are fulfilled.

Data cells are lightly shaded, intermediate results are not highlighted, important results are shaded dark and in bold characters.

The table itself has 29 calculated columns. Column number n is indicated at the top of the column. Where possible, the content of the cells of column n are indicated (n) below the title cell. For example = (8)·(9) means that the cells of the column are the product of the corresponding cells of columns (8) and (9). The unit of the variable is also specified.

Caution: The calculations in the following paragraph correspond to a flat strip ($l/b \geqslant 4$) and no curvature, therefore $k_c = 1$, $k_{SHC} = 0{,}5$, $k_2 = 0{,}5$ in Equations (33) and (34). If one wishes to analyse a plate ($l/b < 2$), with eventual curvature, the shear force and bending moments at the top of Table H.2 shall be corrected according with the new values of Equations (33) and (349. All cells from columns (21) to (29) are, of course, modified accordingly.



Key

1 baseline (usually outer surface, excluding gel coat)

Figure H.2 — Schematic section of a laminate strip

H.2.1.2 Shear force and bending moment

The first two cells of the top row of Table H.2 are data cells that give the effective pressure (after all reductions are considered) from Clause 8 and the strip unsupported length b. The strip is 1 mm wide.

The third and fourth cells of the top row are calculated and give the design shear force $F_d = 5 \times P \times b \times 10^{-4}$, in newtons per millimetre, and the bending moment $M = 83{,}33 \times P \times b^2 \times 10^{-6}$, in newton millimetres per millimetre, as given in Equations (33) and (34).

NOTE In the shear force equation, for a strip $l / b \geqslant 2$, $k_{SHC} = 0{,}5$ and $k_C = 1$ (no curvature). In the bending moment equation 2 $k_2 = 1$ (panel aspect ratio $\geqslant 2$).

H.2.1.3 Ply thickness and mechanical properties

Columns (1) and (2) give ply number and definition.

Columns (3) to (5) are inputs for dry fibre: column (3) gives the fibre mass, in kilograms per square metre, column (4), the fibre type (glass, carbon or aramid) and column (5) the glass content in mass ψ according to Clause C.1.

Columns (6) and (7) give, for each ply, the values of E (in-plane modulus), respectively σ_{ut} or σ_{uc}, (whether the ply is loaded in tensile or compression, plies in compression highlighted grey, see column 23). These data may be taken, either from Table C.4 to C.6 or from proprietary data.

Column (8) gives the interlaminar (out-of-plane) ultimate shear strength, τ_u [see H.2.1.6 and Equation (H.1)].

Column (9) gives the ratio between ultimate and design stress from Table 7, and columns (10) and (11) give the calculated values of σ_{di} and τ_{di}.

NOTE The strength data are tensile or compressive values as this is the way thin plies behave in bending theory. The flexural properties E_f or σ_f are the results of the ISO 3-point bending test that measures apparent overall values of E and σ and not the values in each ply (see H.2.1.5).

Column (12) gives the thickness of each ply, calculated using Equations C.1 to C.3 from fibre weight w and fibre content ψ.

H.2.1.4 Bending stiffness EI

Column (13) gives the product $E \times$ thickness $= E_i \times t_i$ for each ply, i.e. the product of the cells of column (6) multiplied by the ones of column (12).

Column (14) gives distance zg_i of the ply centroid (mid-thickness of each ply) from the base line, which is considered as the outer side of the laminate; zg_i is $t_i/2 +$ the sum of the t_i of the previous plies.

Columns (15) to (17) give respectively $E_i \times t_i \times zg_i$, product of the cells of columns (13) × (14), and $E_i \times t_i \times zg_i^2$, product of the cells of columns (14) × (15), and $\frac{E_i \times t_i^3}{12}$, the second moment of each ply around its centroid.

The height of the neutral axis above the base

$$z_{NA} = \frac{\sum E_i \times t_i \times zg_i}{\sum E_i \times t_i}$$

displayed at the bottom of column (14), is the result of the division of [sum of the cells of column (15)/sum of column (13)].

Column (18) gives $(E_i \times I_i) = (E_i \times t_i^3/12) + (E_i \times t_i \times zg_i^2)$ calculated around the base, i.e. the outer ply (z base = 0). This is the sum of the second moments of area (inertia) of each ply around its centroid plus, according to the parallel axis theorem, the area multiplied by the square of the distance to the base. The bottom cell (shaded grey and bold) gives the overall EI_{BASE}.

The bottom cell of column (19) (not connected to the column cells) gives the EI value around the neutral axis, $EI_{NA} = EI_{BASE} - z_{NA}^2 \times \Sigma$ column (13), still according to the parallel axis theorem; EI_{NA} is usually called D rigidity in laminate theory.

In column (19) the cells calculate the "critical" section of each ply, i.e. the one farthest from the neutral axis. If $z_i \leqslant z_{NA}$, then $z_{crit} = z_i - z_{NA} - \frac{t_i}{2}$, otherwise $z_{crit\,i} = z - z_{NA} + \frac{t_i}{2}$.

NOTE For the sandwich, it is customary to present I and SM in cm^4/cm and cm^3/cm, so the corresponding results of Table H.1 need to be respectively divided by 1 000 and 100.

H.2.1.5 Bending stress analysis

In column (20), the section moduli are calculated for each layer

$$SM_{\text{i}} = -\frac{EI_{\text{NA}}}{z_{\text{crit}} \times E_{\text{i}}},$$

in column (21), the stresses $\sigma_{\text{i}} = \frac{M}{SM_{\text{i}}}$, and column (22) calculates the compliance factor, C_{F}, for each ply.

In general the compliance factor

$$C_{\text{F}} = \frac{\sigma_{\text{d}}}{\sigma_{\text{i}}} \text{ or } C_{\text{F}} = \frac{\tau_{\text{d}}}{\tau_{\text{i}}}$$

is the ratio between the design stress and the stress calculated under design pressure. A compliance factor greater than one means that the structure is stronger than required, and a compliance factor smaller than one means that the structure is not sufficient.

Where there are several layers, the compliance factor of each layer is

$$C_{\text{Fi}} = \frac{\sigma_{\text{d}}}{\sigma_{\text{i}}}$$

The weakest layer is the one whose absolute value of C_{Fi} is the smallest. The calculation is made to have σ positive in the outer side (as the outer face of the plating works in tension when fully fixed, i.e. the deflection curve has a horizontal tangent at the stiffener level, as shown in the figure at the top of Table H.2), and negative in the inside.

In Table H.2 negative values of stress correspond to compression and positive values to tension, as indicated in column (23).The entry in column (7) shall be checked to ensure that the strength (compressive or tensile) corresponds to the one indicated in column (23).

H.2.1.6 Precision on stresses

Important remark: for most composites, the flexural strength [as used in Equation (35)] will exceed both the tensile and compressive strengths, sometimes by a factor as large as two. For example, an all-CSM lay-up $\psi = 0{,}3$ could be based [see Table C.4 b)] on a flexural strength of typically 152 N/mm^2 using Equation (35), but would be limited to ultimate tensile or compressive strengths of 85 N/mm^2 or 117 N/mm^2 respectively using the method of Annex H. Consequently, analysis using Annex H will be conservative for single-skin laminates in many instances.

For sandwich panels, this consideration does not apply as the skins experience tensile or compressive stresses, and not flexural ones. The same is true for stiffeners.

For angled plies (i.e. those at other than 0 or 90° to the panel sides), the stresses from the preceding equations in H.2.1.5 do not correspond to the local ply co-ordinate system. These stresses shall be compared with the angled ply strengths in the panel co-ordinate system. A better approach is to transform stresses into the local ply system and compare with ply system strength (see H.2.1.11). Use of the classical lamination theory is recommended for panels which are governed by the behaviour of angle plies. In such cases, the ply strength shall be assessed using the Tsai-Wu failure criterion. The Tsai-Wu summation may not exceed the allowable stress factor squared, i.e. 0,25 for hull and deck.

H.2.1.7 Shear stress analysis

Columns (24) to (29) deal with shear stress analysis.

The shear flow q is defined as

$$q = F \frac{Q \times E}{E \times I_{\text{NA}}}$$

where Q is the first moment of area, i.e. E, times area from a layer to the closest outer side of a plate or laminate.

The first moment or area which is $Q_x = \int y \, \mathrm{d}A$ in textbooks is in our case , $Q = \sum E_{\text{i}} \times t_{\text{i}} \times (z_{\text{i}} - z_{\text{NA}})$, the summation being made from the closest limit (outer or inner) of the laminate to the analysed (i) ply. From layer 1 to our layer, one shall first calculate, for the first ply, $Q_1 = E_1 \times t_1 \times (z_1 - z_{\text{NA}})$, then, for the second ply, $Q_2 = Q_1 + E_2 \times t_2 \times (z_2 - z_{\text{NA}})$, etc. The concept of shear flow is not very useful for a laminate with 1 mm width, but it is very useful for stiffeners (see below) where the width varies significantly.

Remark: The shear stress analysed here is the interlaminar shear stress. This is the shear stress that is trying to slide one ply over another, and is distinct from the in-plane shear strength given in Tables C.4 to C.6, which is concerned with shear distortion within a given ply. The interlaminar shear strength is greatly influenced by the resin, and is usually much lower than the in-plane (intralaminar) shear strength. For polyester-based laminates, the interlaminar shear strength τ_{IL} is approximately given by

$$\tau_{\text{IL}} = 22{,}5 - 17{,}5\,\psi \text{ N/mm}^2 \quad \text{(H.1)}$$

In the example given in Table H.2, one can see that this interlaminar shear stress is usually not critical in a single-skin laminate, but is definitely critical for loaded cores (see H.2.1.8).

H.2.1.8 Core stress

H.2.1.8.1 Core only taking shear load

In sandwich theory the core is assumed to carry only shear loads and no bending loads. As the E value of the core is very low, using a table similar to Table H.2 will usually show that the bending load in the core stays within acceptable limits.

The shear stress in the core is implied by Equation (43) or by dividing the shear force of Equation (33) by t_{s}, the distance between skins centroids. However, for honeycomb cores, the shear stress shall be checked in both principal panel directions.

Alternatively, Equation (43) may be used with the lesser of the two honeycomb shear strengths. This is normally conservative.

H.2.1.8.2 Core effective in bending

Where using core carrying bending loads, like bulking material, and not only shear load as in sandwich theory, using Table H.2 will usually give correct values to check that both bending and shear loads in the core stay within limits. If wood or plywood core with the grain parallel to the skins (unlike balsa core) is used, Table H.2 shall be used.

Alternatively, for resin-rich material, the method given in 10.2.3 may be applied.

H.2.1.9 Example shown

Table H.2 shows a typical mat/roving laminate, with data taken from Tables C.3 and C.4.

As expected, the tensile stress at the outer ply is the critical one, with a compliance factor of 1,04 (1 is the minimum acceptable). The shear stress at the interface of plies 4 and 5 (at 0,28 mm from the maximum which is at NA) has a compliance factor of 7, so interlaminar shear stress is usually not a problem in single-skin laminates.

As explained in H.2.1.6, the analysis of Annex H for single-skin is usually pessimistic. In Table H.2, one can see that for the example stack analysis, the thickness is 6,2 mm and the average ψ is 0,384. From this value, Table C.4 a) would give a σ_{uf} of 181 N/mm^2 and a σ_{df} of 90,5 N/mm^2. With the given values of P and b, the required thickness by Equation (35) would be 4,8 mm, and the analysis of Table H.2 is pessimistic in thickness by 32 %.

H.2.1.10 General topics

The bending theory considers that the strain ε grows linearly from the neutral axis to the outer limit of the laminate. On each layer, the stress is $E_i \times \varepsilon_i$. If a layer has a high E, for example a longitudinal UD, it will be more highly stressed than a “soft” layer.

At the same time, when assessing the position of the neutral axis, the high E value for a UD will “attract” the neutral axis, as it is the centroid of all the layers having a width, not of 1 mm but of E (in millimetres), a stiff layer having more influence than a flexible one.

Another important factor is the elongation at break ε_{ui}. The ultimate stress is $\sigma_{ui} = E_i \times \varepsilon_{ui}$; and Table H.1 gives a rough comparison of the tensile elongation at break, ε_{uit}, for various materials. The values are indicative because the stress/strain curve is not, except maybe for carbon UD, a straight line.

Table H.1 — Comparative values of elongation at break ε_{uit}

Material characteristic	GRP mat/rov	GRP UD	Carbon UD	Plywood
	$\psi = 0,35$	$\psi = 0,50$	$\psi = 0,50$	ρ 500/7plies
E	8 300	22 500	80 000	4 830
σ_{ut}	107	430	800	39
ε_{ut}	1,29 %	1,91 %	1,00 %	0,81 %

From Table H.1, one can see that:

— when laminating glass and carbon unidirectionally together, the 1 % elongation at break of carbon is the limiting one (specially if the carbon is in the outer ply), and that glass will not be used fully because, at 1 % elongation, a glass UD works only at 50 % of its potential;

— when laminating mat/roving glass over a plywood core, one “mixes” plywood that breaks at 0,81 % elongation with glass that breaks at one and half times that value.

H.2.1.11 Fibres not parallel to panel sides

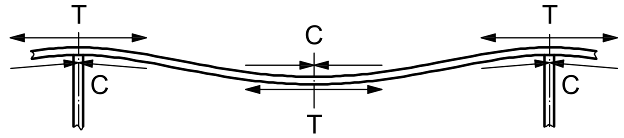
For cases where the fibres are orientated at some angle θ to the short panel side, the elastic modulus may be obtained from the following equations:

$$\frac{1}{E_b} = \frac{1}{E_1}\cos^4\theta + \left[\frac{1}{G_{12}} - \frac{2\nu_{12}}{E_1}\right]\sin^2\theta \times \cos^2\theta + \frac{1}{E_2}\sin^4\theta \quad \text{(H.2)}$$

$$\frac{1}{E_l} = \frac{1}{E_2}\cos^4\theta + \left[\frac{1}{G_{12}} - \frac{2\nu_{12}}{E_1}\right]\sin^2\theta \times \cos^2\theta + \frac{1}{E_1}\sin^4\theta \quad \text{(H.3)}$$

Table H.2 — Laminate stack analysis

Design pressure P kN/m^2	Panel short dimension b mm	Design shear force F_d/mm N/mm	Design bending Mt M_d Nmm/mm
26,0	400	5,2	347



Laminate calculation for a 1 mm wide strip laminate

1	2	3	4	5	6	7	8	9	10	11
Ply No.	Definition	Fibre Dry mass kg/m^2	type *	Content ψ	Modulus E_{ti} N/mm^2	σ_t/c_u N/mm^2	Interlaminar $\tau_{u\ interlam}$ N/mm^2	$\sigma_{tcd}/\sigma_{tcu}$ τ_d/τ_u *	σ_{tcd} N/mm^2	τ_d N/mm^2
		Input	G, C, A	C.1	Table C.5			Table 7	= (7)·(9)	= (8)·(9)
1 outer	Mat 300	0,300	G	0,30	6 400	85	17	0,5	42,5	8,6
2	Mat 300	0,300	G	0,30	6 400	85	17	0,5	42,5	8,6
3	Rov 500	0,500	G	0,48	13 240	183	14	0,5	91,5	7,1
4	Mat 450	0,450	G	0,30	6 400	85	17	0,5	42,5	8,6
5	Rov 800	0,800	G	0,48	13 240	144	14	0,5	111,3	7,1
6	Mat 450	0,450	G	0,30	6 400	117	17	0,5	76,1	8,6
7	Rov 800	0,800	G	0,48	13 240	144	14	0,5	111,3	7,1
Total		3,600		**0,384**	**9 387**					
		Sum Col		Average	Average					

1	12	13	14	15	16	17	18	19	20	21
Ply No.	Thickness t_i mm	$E_i \times t_i$ N/mm	Dist. zg_i from outside mm	$E_i \times t_i \times zg_i$ N	$E_i \times t_i \times zg_i^2$ Nmm	$E_i \times t_i \times {}^3/12$ Nmm	$(EI)_i$ From base Nmm^2	z_{crit} from z_{NA} mm	SM_i mm^3/mm	σ_i N/mm^2
	Eq. C.1 to C.3	= (6)·(12)	Calc	= (13)·(14)	= (14)·(15)	= (13)·(12)^3/12	= (17) + (18)	Calc	Calc	Calc
1 outer	0,701	4 483	0,35	1 570	550	183,3	733	−3,38	8,47	40,9
2	0,701	4 483	1,05	4 711	4 950	183,3	5 134	−2,68	10,69	32,4
3	0,647	8 562	1,72	14 765	25 460	298,4	25 759	−1,98	6,99	49,6
4	1,051	6 725	2,57	17 304	44 526	618,8	45 145	−1,33	21,49	16,1
5	1,035	13 700	3,62	49 537	179 119	1 222,3	180 341	0,75	−18,38	−18,9
6	1,051	6 725	4,66	31 329	145 952	618,8	146 571	1,80	−15,87	−21,8
7	1,035	13 700	5,70	78 107	445 321	1 222,3	446 543	2,84	−4,88	−71,1
Total	**6,219**	**58 378**	**3,38**	**197 324**	**845 879**		**850 226**	**183 255**		
	Sum Col	Sum Col	Z_{NA}	Sum Col	Sum Col		EI_{Base}	EI_{NA}		

1	22	23	24	25	26	27	28	29	
Ply No.	Compliance factor σ_d/σ_i *		Shear stress analysis Location of τ	Z calc from NA mm	First mt Q $\Sigma E_i \cdot t_i$ $(z_i - z_{NA})$ Nmm	Shear flow q N/mm	τ_i average N/mm^2	Compliance factor τ_d/τ_i *	
	=(10)/(21)			mm	calc	= F·(26)/EI_{NA}	= (27)/1	= (11)/(27)	
1 outer	**1,04**	Tens	1-2 interface	2,68	13 584	0,4	0,4	22,4	σ_t maximum outer ply
2	1,31	Tens	2-3 interface	1,98	24 027	0,7	0,7	12,7	
3	1,85	Tens	3-4 interface	1,33	38 203	1,1	1,1	6,5	
4	2,63	Tens	4-5 interface	0,28	43 630	1,2	**1,2**	**7,0**	τ is maximum at NA
5	−3,82	Comp	5-6 interface	−0,75	40 400	1,1	1,1	6,1	
6	−2,68	Comp	6-7 interface	−1,80	31 801	0,9	0,9	9,6	
7	−1,01	Comp	underside of 7	−2,84	0	0,0	0,0		τ = 0 top and bottom

Allowable design bending Mt according to this table	360	[(Nmm/mm) = Design bending Mt × minimum compliance factor for σ]		
Required thickness according to Equation (35) and σ_f according to average ψ =		4,79	mm	
Average ψ = [bottom of columm 5, using Equation (C.2)]	0,384	Value of σ_{df} according to Table C.4 a)	90,5	N/mm^2
The method of Annex H for the example of single-skin laminate gives a thickness requirement pessimistic by				32 %

The 1-2 system refers to the fibre principal direction.

The EI is then obtained in each direction using a tabular calculation, as shown in Table H.3.

For double bias plies, Table C.7 may be used instead of the above formulae.

NOTE For a unidirectional ply, E_1 refers to the parallel to the fibres' direction and E_2 to the perpendicular to the fibres' direction. For woven roving or biaxial cloths, $E_1 = E_2 = E$ in warp or weft, (0/90) directions. G_{12} is the in-plane shear modulus. ν_{12} is the major Poisson's ratio. All these data may be found in Tables C.4 to C.6. For E-glass WR/biaxials, ν_{12} may be taken as 0,25. For chopped strand mat, this calculation is not required as CSM is regarded as isotropic.

H.2.1.12 Orthotropic panel calculations

For an orthotropic panel fully fixed at its perimeter, the analysis shall be made in the two principal dimensions, as in Table H.2.

$M_{\text{db}} = k_{\text{C}}^2 \times \beta_b \times P \times b^2 \times 10^{-3}$ Nmm/mm is the maximum design bending moment in the b direction (H.4)

$M_{\text{d}l} = \beta_l \times P \times b^2 \times 10^{-3}$ Nmm/mm is the maximum design bending moment in the l direction (H.5)

$\frac{y}{b} = \frac{\alpha \times P \times b^3}{1\,000 \times EI_{\text{NA}b}} \leqslant k_1$ mm/mm is the maximum relative deflection (H.6)

Table H.3 — Value of factors α, β_b, β_l according to EAR

Effective aspect ratio EAR	α	β_b	β_l
$\frac{l}{b}\left(\frac{EI_{\text{NA}b}}{EI_{\text{NA}l}}\right)^{0,25}$	$\frac{0,002\,37}{1+\frac{1,056}{EAR^5}}$	$\frac{0,083\,3}{1+\frac{0,623}{EAR^6}}$	$\frac{0,057 EAR^{-0,1}\sqrt{EI_{\text{NA}l}/EI_{\text{NA}b}}}{1+\frac{0,111}{EAR^7}}$

where

b is the short dimension of the panel, according to 9.1.1, in millimetres;

l is the long dimension of the panel, according to 9.1.2, in millimetres;

P is the design pressure for the panel according to Clause 8, in kilonewtons per square metre;

EI_{NA} is the bending stiffness respectively in b or l direction, in newton millimetres.

Equations (H.4) to (H.6) can be used to check that the bending moments in both directions, and deflection requirements are fulfilled.

H.3 Method for stiffeners

H.3.1 General

The method outlined in H.2 and Table H.2 may be applied to stiffeners, but the calculation table needs to be amended as the width is not 1 mm, but variable. Also, the first moment is $Q = \Sigma EA(z_{\text{i}} - z_{\text{NA}})$ and the shear flow $q = \frac{F_d \times Q}{EI_{\text{NA}}}$

For the calculation of the shear force and bending moment the span l_{u} and stiffener spacing s need to be entered. The calculations are made according to Equations (51) for F_{d} and (52) for M_{d}.

The entries are the same but each part of the stiffener needs to have its depth and width entered. For the web, one shall take care to enter the total of the two sides of the web.

When applied to stiffeners, the thickness of Table H.2 shall be replaced by the area A_i of the ply or component. It shall be noted that whereas for a panel EI is per unit width, for a stiffener and its attached plating, the EI value is calculated for the whole stiffener and its attached plating.

The effective extent of attached plating, and the required values of design bending moment, shear force and required flexural rigidity EI shall be used as laid out in Clause 11.

Caution: The calculations in the following paragraph correspond to a flat stiffener with no curvature, therefore $k_{CS} = 1$, in Equation (52). If one wishes to analyse a curved stiffener, the design bending moment at the top of Table H.4 shall be corrected according with the new values of Equation (52). All cells from columns (17) to (25) are, of course, modified accordingly**.**

H.3.2 Worked example

A GRP stiffener with its associated plating is shown in Figure H.3 and analysed using Table H.4. This is a classical top-hat stiffener, the plating and stiffener being made out of mat/roving laminate with $\psi = 0,35$; an extra UD glass cap $\psi = 0,50$ is added on top [all mechanical properties from Table C.4 a) or b)]. The value of $h/(t_w/2) = 100/4 = 25$ is checked at the bottom of columns 7 to 9 and is lower than the limit of 30 given in Table 20.

The details of calculation are not explained because they are similar to the ones in H.2. The values of P, l_u, and s were chosen to induce stresses close to the limit. The minimal safety factor cells are highlighted dark and bold.

One can see that the layer closest to the limit for σ is not the outer ply of UD, but the outer ply of the flange, due to higher apparent strain in UD than in mat/roving in Table C.5 (see H.2.1.10).

The highest value of the shear stress in the table is at the neutral axis of the stiffener web (including attached plating), i.e. at 36,5 mm above baseline. To have a value at neutral axis, the web has been split into two parts, managing to have the height of top of web 1 level with the neutral axis. (the best is to first split the web in two equal parts, then put the limit at NA when this NA is found by the table).

The first moment is calculated by computing $Q = \Sigma EA(z_i - z_{NA})$, above NA, from the top of the stiffener to the section in question, and below NA, from the outer plating to the section in question.

In the example the compliance factor on σ is 1,07 ($\sigma = 50$ N/mm^2 on top of normal flange) and the compliance factor on τ is 1,04 at the neutral axis.

Remark: The shear stress given by Table H.3 is everywhere the interlaminar stress (horizontal surfaces, perpendicular to the shear force), except in the web where it is intralaminar (in-plane) as the area is vertical, i.e. parallel to the shear force F_d.

The bottom part of Table H.4 calculates the shear flow and shear stress within the laminated or glued joint between the top hat and the plating. One can see that the design shear stress within this joint is 20 % of ultimate (safety factor of 5) and the compliance factor is 1,3. This subject is treated in details in ISO 12215-6.

Dimensions in millimetres

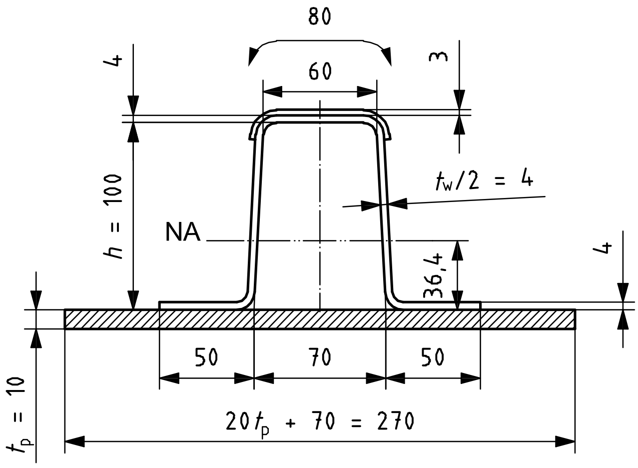


Figure H.3 — Top hat

Table H.4 — Top hat worked example

Design pressure P kN/m²	**Stiffener span** l_u mm	**Stiffener spacing** s mm	**Shear coefficient** k_{sa} *	**Design shear force** F_d N	**Design bending moment** M_d Nm	Nmm		
55,0	1 400	700	5,00	26 950	6 286	6,29E+06		
1	2	3	4	5	6	7	8	9
Element	Depth h mm	Width b mm	Modulus E_t N/mm²	σ_{tu} or s_{cu} N/mm² Annex C	τ_u N/mm²	σ_{td}/σ_{fu} τ_d/τ_u * Table 7	σ_{td} N/mm² = (5)·(7)	τ_d N/mm² = (6)·(7)
UD extra flange	3	80	22 500	430,0	13,8	0,5	215	6,9
Normal flange = web	4	60	8 300	107,0	16,4	0,5	53,5	8,2
Web above NA (2*tw/2)	67,5	8	8 300	107,0	66,0	0,5	53,5	33,0
Web below NA (2*tw/2)	**32,5**	8	8 300	125,0	66,0	0,5	62,5	33,0
Bonding flangle = web	4	100	8 300	125,0	16,4	0,5	62,5	8,2
Attached plating	10	270	8 300	125,0	16,4	0,5	62,5	8,2
Total	121		9 078					
Web1+Web2	100	**Height of top of web1 =**		**36,5**		$h/(t_w/^2)$ **see Table 20**		**25,0**
1	10	11	12	13	14	15	16	17
Element	Area $A = b \times h$ mm² = (2)·(3)	$E \times A$ N = (4)·(10)	Dist/outside zg_i mm calc	$E \times A \times z_i$ Nmm = (11)·(12)	$E \times A \times z_i^2$ Nmm² = (12)·(13)	$E \times b \times h^3/12$ Nmm² = (3)(4)·(2)³/12	Around base $(EI)_i$ Nmm² (14)+(15)	$z_{crit}\sigma$ from NA mm Calc
UD extra flange	240	5,40E+06	119,5	6,45E+08	7,71E+10	4,05E+06	7,71,E+10	84,45
Normal flange = web	240	1,99E+06	116,0	2,31E+08	2,68E+10	2,66E+06	2,68,E+10	81,45
Web above NA	540	4,48E+06	80,3	3,60E+08	2,89E+10	1,70E+09	3,06,E+10	77,45
Web below NA	260	2,16E+06	30,3	6,53E+07	1,97E+09	1,90E+08	2,16,E+09	−22,55
Bonding flange = web	400	3,32E+06	12,0	3,98E+07	4,78E+08	4,43E+06	4,83,E+08	−26,55
Attached plating	2 700	2,24E+07	5,0	1,12E+08	5,60E+08	1,87E+08	7,47,E+08	−36,55
Total	4 380	3,98E+07		1,45E+09	1,36E+11	2,09E+09	**1,38,E+11**	**8,48,E+10**
	***Z* Neutral axis z_{NA} =**		**36,5**	mm			***EI***	***EI*$_{NA}$**
	18	19	20	21	22	23	24	25
Element	Section moduli SM_i cm³ Calc	Direct stresses σ_i N/mm² Calc	Compliance factor σ_d/σ_i * = (8)/(19)	Location of τ *	First moment Q_i $\Sigma EA(z_i - z_{NA})$ Nmm calc	Shear flow q $F_d\ Q_i/EI_{NA}$ N/mm = F_d (22)/EI_{NA}	Shear stresses τ_i ave N/mm² = (23)/(3)	Compliance factor τ_d/τ_i * = (9)/(24)
Bott UD extra flange	44,6	140,9	1,53	Bott UD-flange	4,48E+08	142,4	1,8	3,86
Top of flange = web	125,4	**50,1**	**1,07**	Top of web	6,06E+08	192,7	3,2	2,55
Bott web above NA	131,9	47,7	1,12	Neutral axis	8,02E+08	255,0	**31,9**	**1,04**
Bott web below NA	− 453,0	− 13,9	− 4,50	Bott of web	7,88E+08	250,7	31,3	1,05
Bott bonding flange	− 384,7	− 16,3	− 3,83	Bott flange/ top plating	7,07E+08	224,8	2,2	3,64
Bott of plating	− 279,5	− 22,5	− 2,78	Bott of plating	0	0,0	0,0	
	Min Compl factor on σ =		**1,07**			Min Compl factor on τ =		**1,04**
Analysis of the bond between top hat bottom flange and plating (see ISO 12215-6)								
	τ_u N/mm²	τ_d/τ_u *	τ_d N/mm²	Location of τ *	Q_i = $\Sigma EA(z_i - z_{NA})$ Nmm	Shear flow q N/mm	Shear stresses N/mm²	Compliance factor *
Bonding flange	15	5	3	Bott flange/ top plating	7,07E+08	224,8	2,248	1,3

NOTE Data are highlighted light and significant results dark and bold characters; Calculation results are not highlighted.

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