



BSI Standards Publication

Small craft — Hull construction and scantlings

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

National foreword

This British Standard is the UK implementation of EN ISO 12215-5:2019. It is identical to ISO 12215-5:2019. It supersedes BS EN ISO 12215-5:2018, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee GME/33, Small craft.

A list of organizations represented on this committee can be obtained on request to its committee manager.

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English Version

**Small craft - Hull construction and scantlings - Part 5:
Design pressures for monohulls, design stresses, scantlings
determination (ISO 12215-5:2019, Corrected version
2024-03)**

Petits navires - Construction de coques et
échantillonnage - Partie 5: Pressions de conception
pour monocoques, contraintes de conception,
détermination de l'échantillonnage (ISO 12215-5:2019,
Version corrigée 2024-03)

Kleine Wasserfahrzeuge - Rumpfbauweise und
Dimensionierung - Teil 5: Entwurfsdrücke für
Einrumpffahrzeuge, Entwurfsspannungen, Ermittlung
der Dimensionierung (ISO 12215-5:2019, korrigierte
Fassung 2024-03)

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EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

European foreword

This document (EN ISO 12215-5:2019) has been prepared by Technical Committee ISO/TC 188 "Small craft" in collaboration with CCMC.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by December 2019, and conflicting national standards shall be withdrawn at the latest by June 2021.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN ISO 12215-5:2018.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of EU Directive(s).

For relationship with EU Directive(s), see informative Annex ZA, which is an integral part of this document.

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Endorsement notice

The text of ISO 12215-5:2019, Corrected version 2024-03 has been approved by CEN as EN ISO 12215-5:2019 without any modification.

Annex ZA (informative)

Relationship between this European Standard and the essential requirements of Directive 2013/53/EU aimed to be covered

This European Standard has been prepared under a Commission's standardization request M/542/C(2015) 8736 final to provide one voluntary means of conforming to essential requirements of Directive 2013/53/EU.

Once this standard is cited in the Official Journal of the European Union under that Directive, compliance with the normative clauses of this standard given in Table ZA.1 confers, within the limits of the scope of this standard, a presumption of conformity with the corresponding essential requirements of that Directive, and associated EFTA regulations.

Table ZA.1 — Correspondence between this European Standard and Annex I of Directive 2013/53/EU

Essential Requirements of Directive 2013/53/EU	Clause(s)/sub-clause(s) of this EN	Remarks/Notes
Annex I, Part A, 2.5 – Owner's Manual	13 except 13.4 A.7.4	A.7.4 provides advice to builders and designers to clearly explain the need to monitor cracking in panels and possible failure.
Annex I, Part A, 3.1 - Structure	All clauses except Clause 12 and Annex J	This document provides a means of demonstrating conformity with this requirement for recreational craft as defined in Article 3(2) of Directive 2013/53/EU to 24m hull length (L_H) only. (Hull length means the length of the hull measured in accordance with ISO 8666.) Workboats (craft for professional use as defined in Table J.1 of this document) are not within the scope of RCD 2013/53/EU, Article 2.1. This document considers all parts of the craft that are assumed to be watertight or weathertight when assessing stability, freeboard and buoyancy in accordance with ISO 12217.

WARNING 1 — Presumption of conformity stays valid only as long as a reference to this European Standard is maintained in the list published in the Official Journal of the European Union. Users of this standard should consult frequently the latest list published in the Official Journal of the European Union.

WARNING 2 — Other Union legislation may be applicable to the product(s) falling within the scope of this standard.

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Foreword

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

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

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

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

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: [Foreword - Supplementary information](#)

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

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

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

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

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

- clarification of the scope and of many definitions, dimensions, and assessment;
- definition of a theoretical hull/deck limit height Z_{SDT} in [Table 3](#);
- renaming of n_{GC} into k_{DYN} in [Table 7](#);
- lowering of the values of k_L in the aft part of the craft in [Table 8](#);
- deletion of k_{AR} min, to better consider large panels, mainly sandwiches, in [Table 9](#);
- improvement of the values of k_{SUP} in [Table 10](#);
- modification of design pressures for motor and sailing craft in [Tables 12](#) & [13](#);
- modification of design stresses introducing k_{BB} and k_{AM} factors in [Tables 15](#) to [17](#);
- incorporation of requirements for work boats in [Table 2](#), [Clause 12](#) and [Annex J](#);
- possibility to use a wider range of assessment methods detailed in [Table 18](#);
- move of the previous assessment method (now called "simplified") in [Annex A](#);

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

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

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

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

This corrected version of ISO 12215-1:2019 incorporates the following corrections:

- errors in formulae, text and values in [Clause 7](#), [Clause 9](#), [D.1.2](#), [H.3.3](#), [H.4](#), and [Tables 12, 17, A.3, A.4, A.5, A.7, A.8, A.12, A.13, B.1, B.2, C.5, E.1, I.1](#) and [K.1](#) have been corrected;
- the formulae in [Table 13](#) have been corrected.

Introduction

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

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

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

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

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

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

Small craft — Hull construction and scantlings —

Part 5:

Design pressures for monohulls, design stresses, scantlings determination

1 Scope

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

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

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

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

- recreational craft, including recreational charter vessels;
- small commercial craft and workboats, see [Clause 12](#) and [Annex J](#).

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

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

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

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

This document covers small craft built from the following materials:

- fibre-reinforced plastics, either in single skin or sandwich construction;
- aluminium or steel alloys;
- glued wood or plywood (single skin or sandwich), excluding traditional wood construction;
- non-reinforced plastics for craft with a hull length less than 6 m (see [Annex D](#)).

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

2 Normative references

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

ISO 8666:2016, *Small craft — Principal data*

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

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

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

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

3 Terms and definitions

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

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

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1 design categories

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

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

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

3.2 loaded displacement

m_{LDC}

mass of water displaced by the craft, including all appendages, when in fully loaded ready for use condition

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

3.3 sailing craft

craft for which the primary means of propulsion is wind power

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

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

3.4 second moment of area second moment

I

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

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

Note 2 to entry: It is expressed in mm⁴ or cm⁴.

3.5 section modulus

SM
for a homogeneous material, second moment of area divided by the distance to any point from the neutral axis at which the bending stress is calculated, expressed in mm³ or cm³

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

3.6 craft speed

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

3.7 displacement craft

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

3.8 displacement mode

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

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

3.9 planing craft

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

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

3.10 planing mode

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

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

3.11 non-walking area

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

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

4 Symbols

Unless specified otherwise, the symbols shown in [Table 1](#) are used in this document.

Table 1 — Data, factors, parameters

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

Table 1 (continued)

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

Table 1 (continued)

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

5 General

5.1 Materials

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

5.2 Overall procedure for scantlings determination

[Table 2](#) describes the overall procedure of this document for scantlings determination, by steps.

Table 2 — Overall procedure for scantlings determination

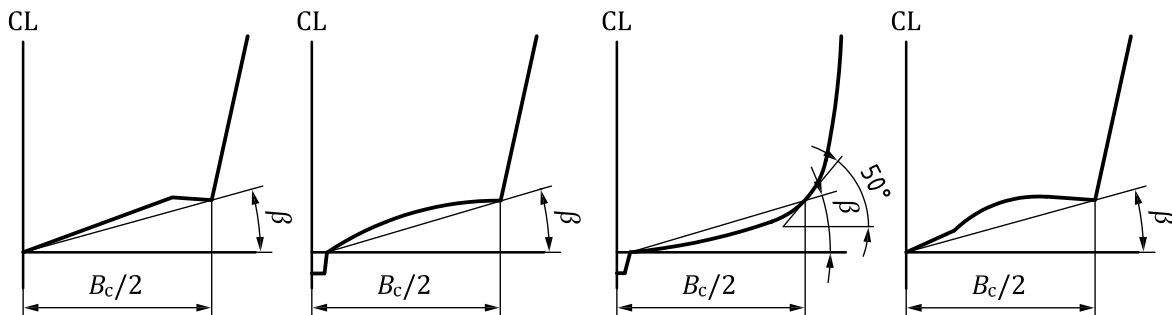
Step N°	Subject	Clause N°
1	Determination of main dimensions, data and areas	6
2	Determination of dimensions of panels and stiffeners	7
3	Determination of pressure adjustment factors	8
4	Determination of design pressures	9
5	Determination of mechanical properties and design stresses (Table 17)	10
6	The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

6 Main dimensions, data and areas

6.1 Dimensions and data

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

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


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

6.2 Areas

6.2.1 General

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

The coordinates x and Z are measured from the aft end of flotation as shown in [Figure 2](#).

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

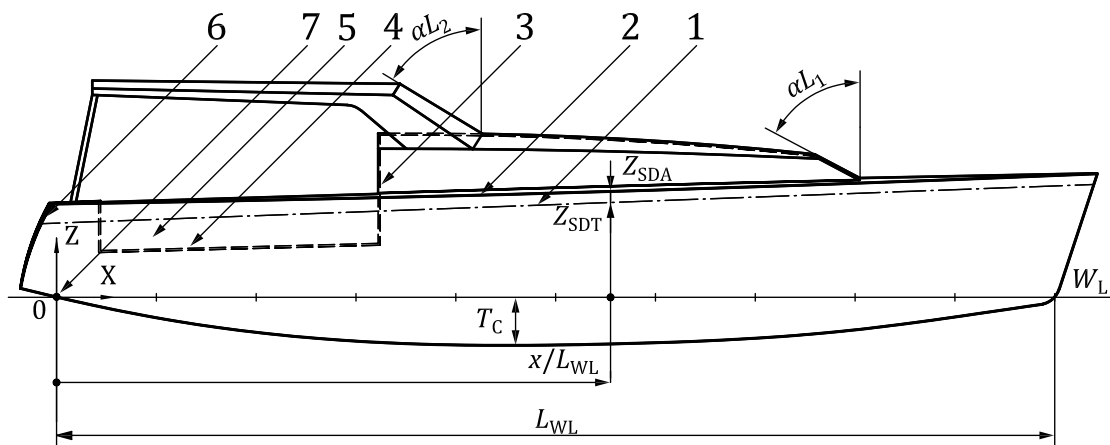
Table 3 — Height Z_{SDT} of theoretical hull deck limit according to L_{WL} and x/L_{WL}

$Z_{SDT} = (0,0286 \times L_{WL} + 0,115) \times \frac{x}{L_{WL}} + 0,0571 \times L_{WL} + 0,229 \text{ (m)}$											
For information, pre-calculated values of Z_{SDT} are given below-for three values of x/L_{WL} .											
L_{WL} (m)		6	8	10	12	14	16	18	20	22	24
		Values of Z_{SDT} (m)									
x/L_{WL}	0,00	0,57	0,69	0,80	0,91	1,03	1,14	1,26	1,37	1,49	1,60
	0,50	0,71	0,86	1,00	1,14	1,29	1,43	1,57	1,71	1,86	2,00
	1,00	0,86	1,03	1,20	1,37	1,54	1,72	1,89	2,06	2,23	2,40

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

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

Hull bottom or side, including transom and deck ^a		
Area	Sailing craft and motor craft in displacement mode	Planing craft in planing mode
Hull bottom and transom bottom	Part of the hull outer shell located below waterline (W_L)	Part of the hull outer shell up to chine for local $\beta \leq 30$ if chine below W_L Part of the hull outer shell up to W_L for local $\beta > 30$ and if chine above W_L . Transom below W_L is excluded and subject to transom side pressure
Hull side and transom side	Part of the hull shell located between bottom and local height Z_{SDT} .	
Deck and cockpit bottom	Lower horizontal or near horizontal area of the craft structure located above hull side. If there are several deck levels, it is the lower one at the considered section. Where $Z_{SDA} \leq Z_{SDT}$ it is subject to side/transom pressure, otherwise it is subject to deck pressure (see Tables 12 & 13)	
Cockpit sides & superstructures		
Area	Walking area	Non-walking area (see 3.10)
See Table 10 that details the areas and their reduction factor k_{SUP} .		
^a This definition applies even if this area is not considered part of the working deck by ISO 15085 as long as it is exposed to the weather. The inner decks are not considered in this document as they are not exposed to weather.		



Key

- | | | | |
|---|--|---|---|
| 1 | theoretical hull deck limit Z_{SDT} above W_L | 5 | cockpit side |
| 2 | actual hull deck limit Z_{SDA} above W_L | 6 | transom (below & above Z_{SDA}) |
| 3 | protected aft side of superstructure (see Table 10) | 7 | origin of coordinates x, y, z at aft of waterline |
| 4 | cockpit bottom | | |

Figure 2 — Sketch showing areas

NOTE [Figure 2](#) shows the case where $Z_{SDA} > Z_{SDT}$ but the opposite case is obviously possible.

7 Dimensions of panels and stiffeners

7.1 General

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

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

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

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

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

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

- The plating is strong enough to keep its shape and transmit the shear force and bending moment resulting from the pressure load to its supports: the secondary stiffeners.
- The secondary stiffeners (where installed), are strong enough to keep their shape and transmit the shear force and bending moment from the plating to their supports: the primary stiffeners.
- The primary stiffeners (where installed), are strong enough (usually much stiffer and stronger than the secondary) to keep their shape and transmit the shear force and bending moment from the secondary stiffeners to the rest of the structure.

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

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

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

7.2 Rectangular grid of panels and stiffeners

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

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

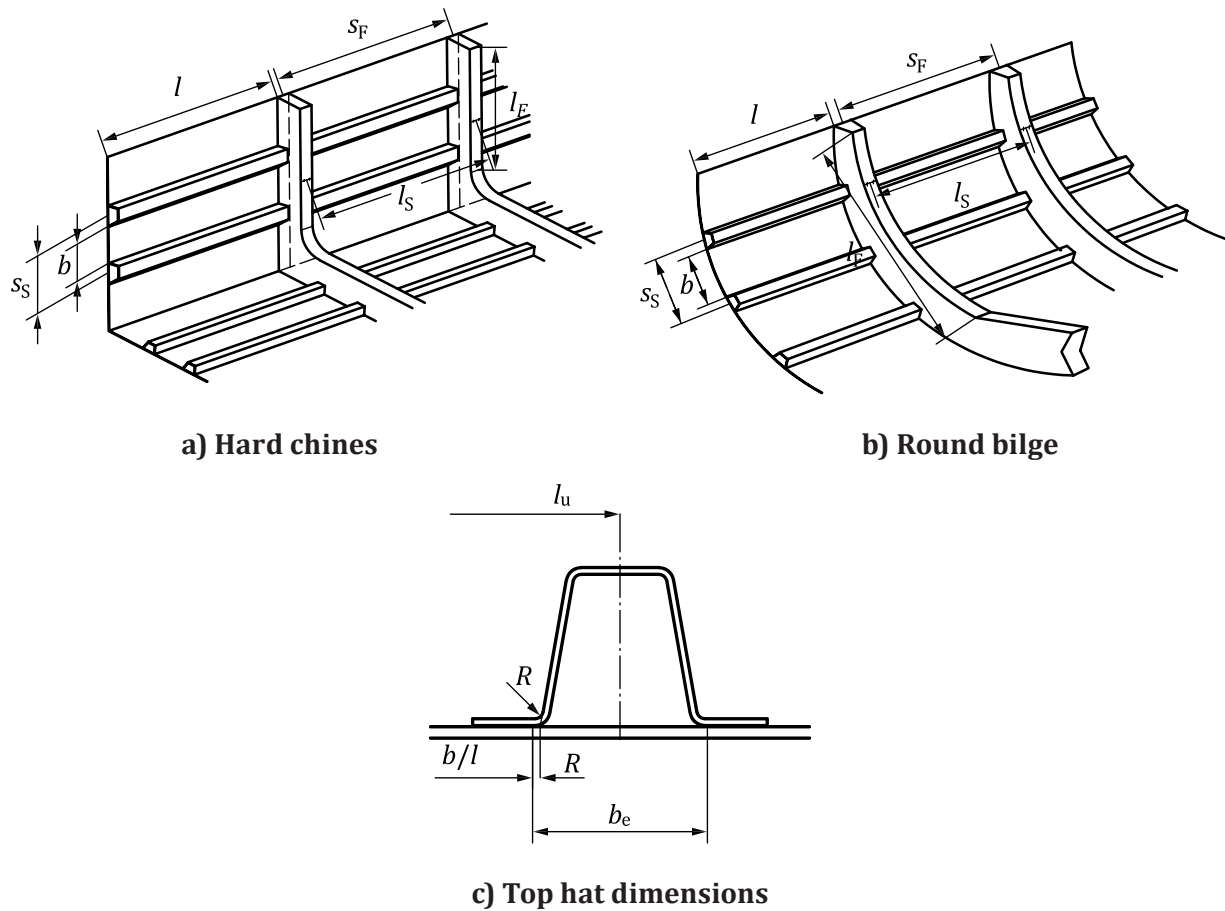


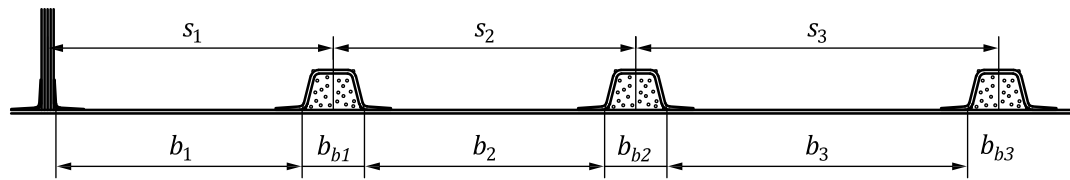
Figure 3 — Sketch explaining the dimensions in [Clause 7](#)

Table 5 — Dimensions of panels and stiffeners

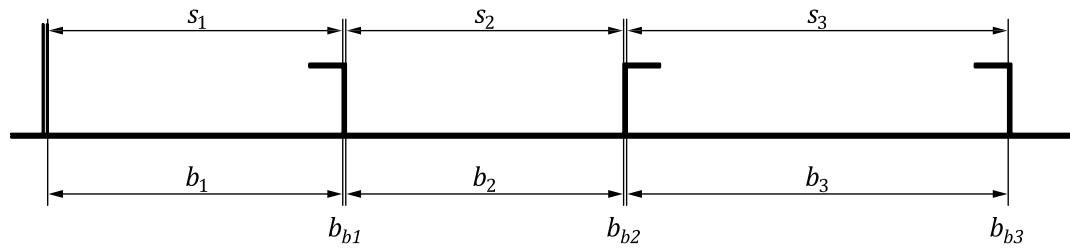
Variable	Units	Definition
b and l	mm	Respectively the small and large unsupported ^a dimensions of a panel
s and l_u	mm	Respectively the small and large unsupported dimensions for stiffeners, measured at mid support width (in Figure 3 , index 'u' is replaced by F for frame and s for stringers). For top hat or composite stiffeners l_u is usually greater than l as $l_u = l + b_e$ [see Figure 3 c]
For top hats, the dimensions b and l may be taken up to the intersection of the extension of the closest (inner) web with the plating minus one cove radius R , see Figure 3 c . Subclause A.12.1 and Figure A.9 show examples on how to consider stiffeners not perpendicular to the plating. If 3 consecutive stiffeners are not equally spaced, s shall be taken as their average.		
^a The supports are the support boundaries where the reaction to the plating pressure forces apply. This is normally the closest distance between loaded webs i.e. the closer side of top hats as in Figure 3 c , 4 a) or the single metallic flange axis as in Figure 4 b).		

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

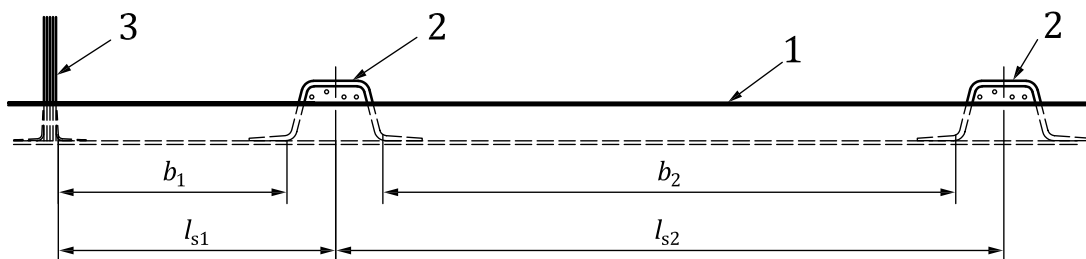
Where there are no definite stiffeners, hard chines or round bilges having the required dimensions and strength may be considered as “natural” stiffeners. [Clause A.5](#) gives methods of analysis of such stiffeners.



a) Bulkhead and transversal top-hat stiffeners



b) L-shaped stiffeners in metallic construction



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

Key

- 1 stringer (length l_{s1} or l_{s2})
- 2 top-hat frame
- 3 bulkhead

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

7.3 Non-rectangular panels

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

7.3.1 Trapezoidal or triangular panels

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

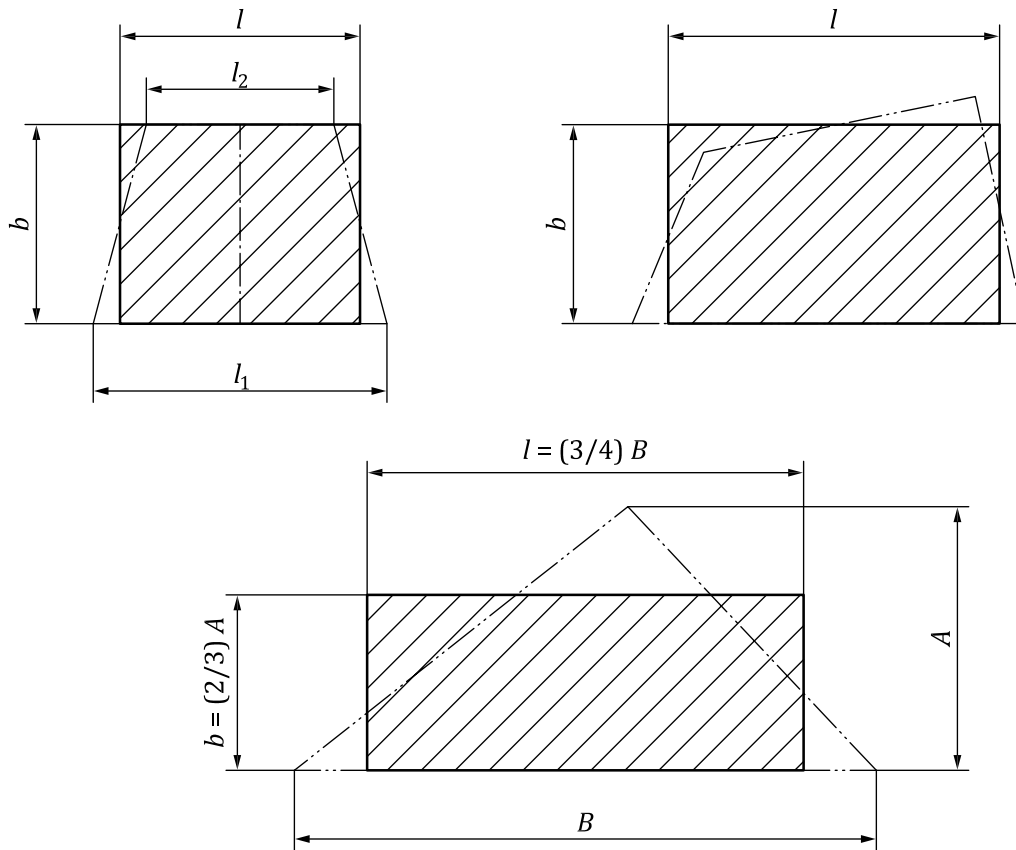
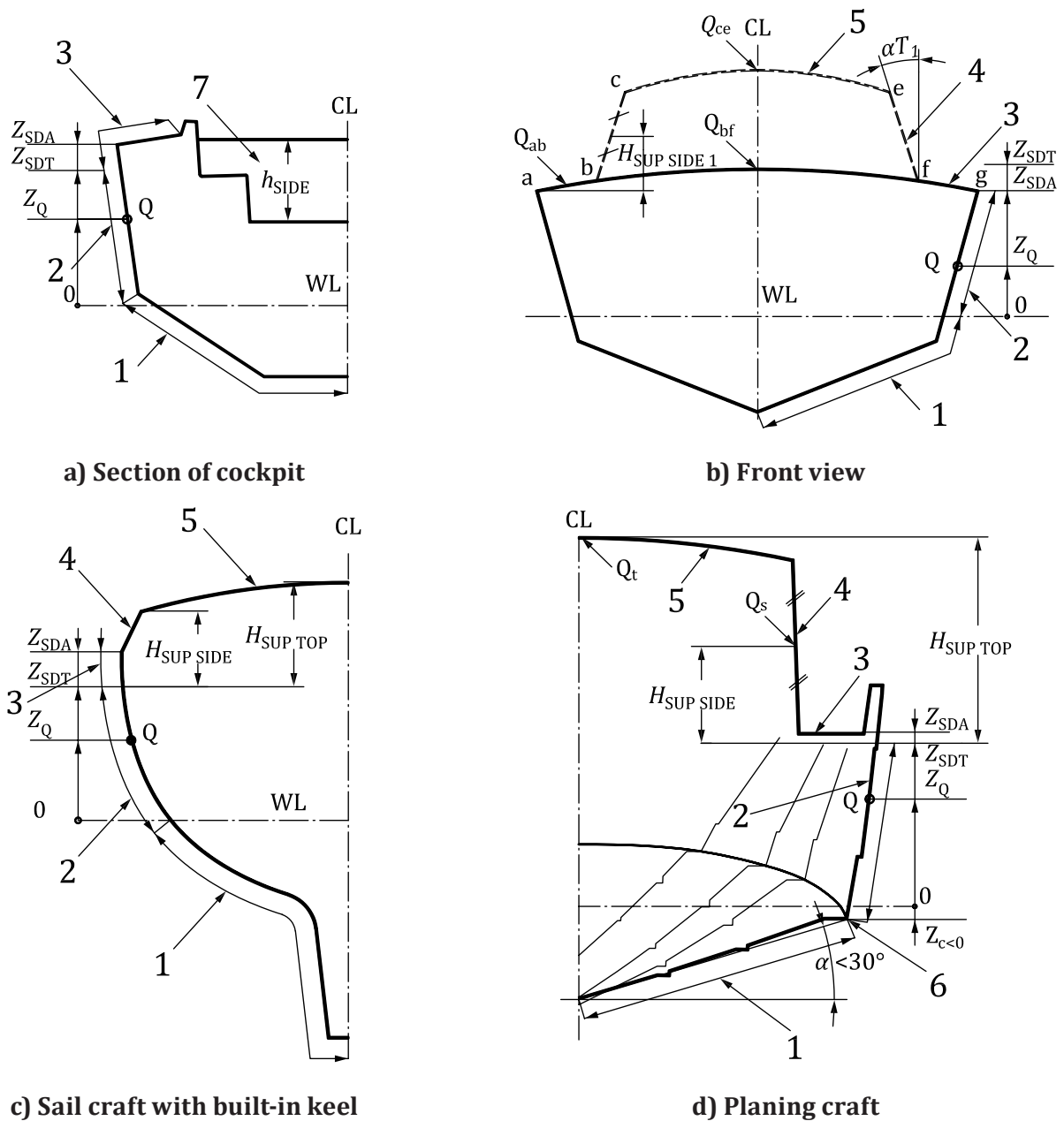


Figure 5 — Examples of equivalent rectangular panels with a trapeze or a triangle

7.3.2 Other shapes

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

7.4 Pressure on a panel or a stiffener



Key

- | | | | |
|---|---------------------------|---|--|
| 1 | bottom area | 5 | superstructures top area |
| 2 | side area | 6 | chine below W_L at section x and $\beta \leq 30^\circ$ |
| 3 | deck area | 7 | closed cockpit |
| 4 | superstructures side area | | |

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

Figure 6 shows typical craft sections at mid-waterline.

- a) Section in way of a closed cockpit on a hard chined displacement motor craft with local actual deck height Z_{SDA} greater than theoretical value Z_{SDT} and therefore the part of the topsides above Z_{SDT} is considered subject to deck pressure. According to Table 12, the side pressure is interpolated between 0,8 times the bottom pressure and deck pressure up to Z_{SDT} and is equal to deck pressure above Z_{SDT} . The value of h_{SIDE} for the cockpit aft panel, according to Table 10 for side of closed cockpit, is measured

from the cockpit bottom up to the middle of panel. Similar method for vertical bottom and back support of seats (non-walking area) and horizontal seat area (walking area).

- b) Hard chined displacement motor craft. The actual deck level is lower than the theoretical height: $Z_{SDA} < Z_{SDT}$, the topsides are fully in side area and the actual pressure on the deck is increased as required in [Table 12](#) or [13](#). The coachroof side transverse angle α_{T1} make it a non-walking area (see [3.10](#)). The side pressure at point Z_Q is calculated according to [Table 12](#). For side deck, the pressure for panel a-b is calculated at point Q_{ab} , and for panel b-f, it shall be calculated at Q_{bf} at mid-panel and top of camber, same for point Q_{ce} at top of coachroof.
- c) Sailing craft with faired connection between bottom and keel, and the bottom area goes down to the keel and or tuck. See [A.13](#) and ISO 12215-9 for either keel reinforcement or thicker plating in way of keel). As $Z_{SDA} > Z_{SDT}$ the value of H_{SUP} for coachroof top is measured from Z_{SDT} .
- d) Hard-chined planing craft. As the angle of chine (deadrise), calculated according to [Figure 1](#), is $\beta \leq 30^\circ$, the bottom area goes up to the chine. Other forward sections have a deadrise angle $\beta > 30^\circ$ and the bottom front area is considered up to flotation (the chine is anyway above waterline). Z_C is the height of the chine measured from waterline, and as in that section $Z_C < 0$ as it is below waterline, and in [Table 12](#) $Z_Q - Z_C = Z_Q + \text{absolute value of } Z_C$, same logic for $Z_{SDT} - Z_C$. The deck height Z_{SDA} is slightly higher than Z_{SDT} so the upper part of the topsides and outer bulwark are subject to deck pressure. The inner part of the bulwark is subject to cockpit side pressure. The side and top of coachroof are calculated at points Q_s and Q_t (only if the top on coachroof has no intermediate stiffener).

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

8 Pressure adjusting factors

8.1 General

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

8.2 Design category factor k_{DC}

The design category factor is defined in [Table 6](#).

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

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

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

8.3 Dynamic load factor k_{DYN}

- For planing craft running in planing mode, the dynamic load factor k_{DYN} , used in the bottom pressure and k_L determination shall be taken as the lesser of k_{DYN1} and k_{DYN2} , as defined in [Table 7](#).
- For sailing and motor craft in displacement mode k_{DYN} is not used for pressure determination, but is used for the determination of k_L in [Table 8](#) and [Figure 7](#) using the values for $k_{DYN} = 3$.

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

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

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

8.4 Longitudinal pressure distribution factor k_L

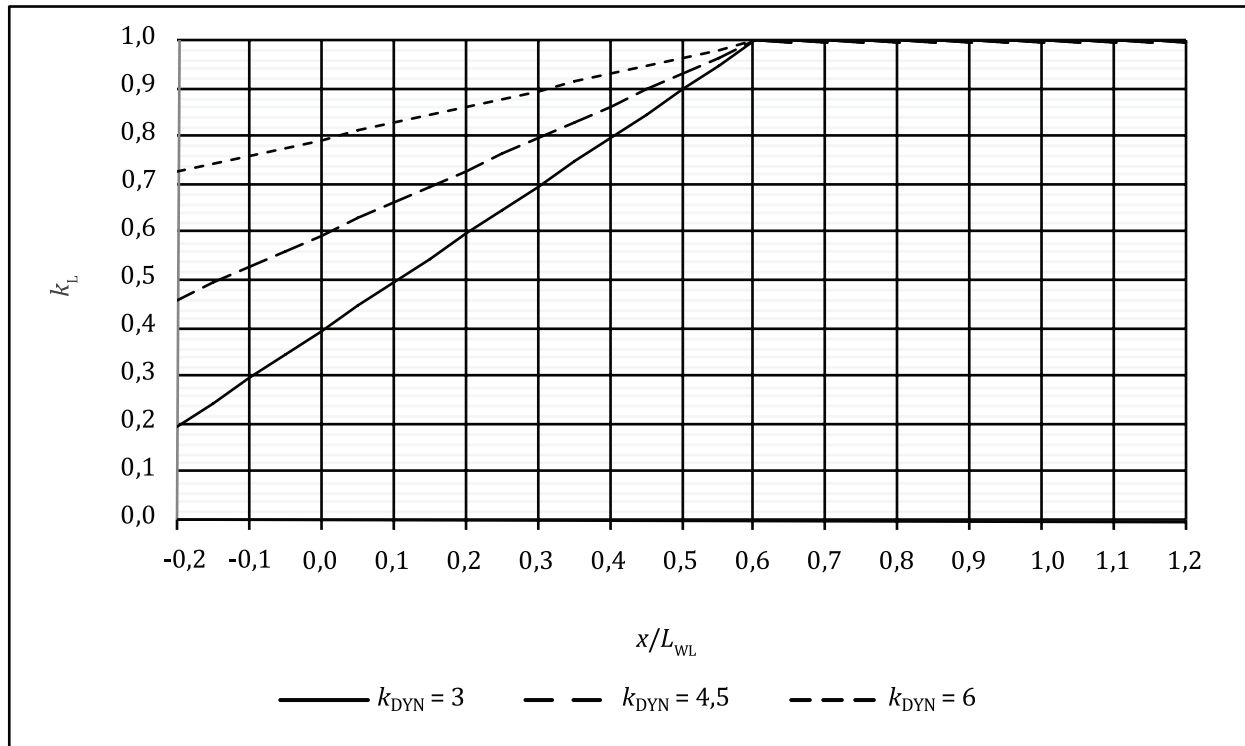
The longitudinal pressure distribution factor k_L defined in [Table 8](#), considers the variation of pressure loads according to the lengthwise position on the craft. [Figure 7](#) shows tabulated values of [Table 8](#).

Table 8 — Values of longitudinal pressure distribution factor k_L

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

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

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

Figure 7 — Longitudinal pressure distribution factor k_L

8.5 Area pressure reduction factor k_{AR}

The area pressure reduction factor k_{AR} is given in [Table 9](#).

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

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

8.6 Superstructures and deckhouse pressure reduction factor k_{SUP}

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

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

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

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

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

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

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

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

^b Panel on non-walking areas.

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

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

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

Table 11 — Values of k_{SLS}

Design category	Value of k_{SLS} for light and stable sailing craft
C & D	$k_{SLS} = 1$
A & B	$k_{SLS} = 1$ where $m_{LDC} > 5 L_{WL}^3$ otherwise
	$k_{SLS} = \left(\frac{10 GZ_{MAX < 60} \times L_{WL}^{0,5}}{m_{LDC}^{0,33}} \right)^{0,5}$ but not taken < 1

Where $GZ_{MAX < 60}$, in (m) is the maximum righting moment lever taken at a heel angle $\leq 60^\circ$, with all stability-increasing devices such as canting keels or water ballast at their most effective position, in fully loaded condition. If the maximum righting lever occurs at a heel angle $> 60^\circ$, the value at 60° shall be taken. The crew shall be considered in upwind hiking position in the calculation of the above $GZ_{MAX < 60}$.

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

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

9 Design pressures

9.1 Design pressure for motor craft

[Table 12](#) defines the design pressures for motor craft.

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

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

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

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

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

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

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

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

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

CAUTION — k_{AR} and therefore pressures are different for plating and stiffeners, see [Table 9](#).

Motor craft bottom in displacement mode P_{BMD}	$P_{BMD \text{ BASE}} = 2,4 m_{LDC}^{0,33} + 20$ $P_{BMD} = \max(P_{BMD \text{ BASE}} \times k_{AR} \times k_{DC} \times k_L; P_{BM \text{ MIN}})$ with $P_{BM \text{ MIN PLT}} = \max\left[\left(0,45 \times m_{LDC}^{0,33} + 0,9 L_{WL} \times k_{DC}\right) \times k_L; 10 T_C; 7\right]$ for plating, and $P_{BM \text{ MIN STF}} = \max(0,85 P_{BM \text{ MIN PLT}}; 7)$ for stiffeners
Motor craft bottom in planing mode P_{BMP}	$P_{BMP \text{ BASE}} = \frac{0,1 m_{LDC}}{L_{WL} \times B_C} \times \left(1 + k_{DC}^{0,5} \times k_{DYN}\right)$ $P_{BMP} = \max(P_{BMP \text{ BASE}} \times k_{AR} \times k_L; P_{BM \text{ MIN}})$, with $P_{BM \text{ MIN PLT}}$ and $P_{BM \text{ MIN STF}}$ are the same as for displacement.
Motor craft deck and cockpit bottom P_{DM} same for displacement & planing	$P_{DM \text{ BASE}} = 0,31 m_{LDC}^{0,33} + 12$ $P_{DM} = \left[0,8 P_{BMD \text{ BASE}} - (0,8 P_{BMD \text{ BASE}} - P_{DM \text{ BASE}}) \times \min\left(\frac{Z_Q}{Z_{SDT}}; 1\right)\right] \times k_{AR} \times k_{DC} \times k_L$ Not taken <5 for walking area or <3,5 for non-walking area, both for plating and stiffeners
Motor craft side in displacement mode P_{SMD}	$P_{SMD} = \left[0,8 P_{BMD \text{ BASE}} - (0,8 P_{BMD \text{ BASE}} - P_{DM \text{ BASE}}) \times \min\left(\frac{Z_Q}{Z_{SDT}}; 1\right)\right] \times k_{AR} \times k_{DC} \times k_L$ $P_{SMD \text{ MIN PLT}} = \max\left[0,8 P_{BM \text{ MIN PLT}} - (0,8 P_{BM \text{ MIN PLT}} - 5) \times \frac{Z_Q}{Z_{SDT}}; 0,9 L_{WL} \times k_{DC}; 5\right]$ for plating, and $P_{SMD \text{ MIN STF}} = \max(0,85 P_{SMD \text{ MIN PLT}}; 5)$ for stiffeners
Motor craft side in planing mode P_{SMP}	$P_{SMP} = \left[0,25 P_{BMP \text{ BASE}} - (0,25 P_{BMP \text{ BASE}} - P_{DM \text{ BASE}}) \times \min\left(\frac{Z_Q - Z_C}{Z_{SDT} - Z_C}; 1\right)\right] \times k_{AR} \times k_{DC} \times k_L$ $P_{SMP \text{ MIN PLT}} = \max\left[0,25 P_{BM \text{ MIN PLT}} - (0,25 P_{BM \text{ MIN PLT}} - 5) \times \min\left(\frac{Z_Q - Z_C}{Z_{SDT} - Z_C}; 1\right); 0,9 L_{WL} \times k_{DC}; 5\right]$ for plating, and $P_{SMP \text{ MIN STF}} = \max(0,85 P_{SMP \text{ MIN PLT}}; 5)$ for stiffeners
Motor craft superstructures and cockpit side P_{SUPM}	$P_{SUPM} = \left[0,8 P_{BMD \text{ BASE}} - (0,8 P_{BMD \text{ BASE}} - P_{DM \text{ BASE}}) \times \min\left(\frac{Z_{SDA}}{Z_{SDT}}; 1\right)\right] \times k_{AR} \times k_{DC} \times k_L \times k_{SUP}$ Not taken <5 for walking area or <3,5 for non-walking area, both for plating and stiffeners With k_{SUP} taken from Table 10 according to area
Z_Q is the height of point Q at mid-panel or stiffener above waterline (L_{WL} or chine see Figure 6), Z_C is the height of the chine above waterline, and Z_{SDA} and Z_{SDT} are respectively the height of actual and theoretical hull deck limit above waterline (see Table 4 & Figure 6), all values considered at distance x from aft of L_{WL}. For cockpit bottom Z_Q need not be taken less than Z_{SDA}.	
NOTE 1 The base pressure for planing craft in planing mode contains the k_{DC}, factor but at the power 0,5 because the pressure is more governed by impact loads due to speed than sea conditions.	

9.2 Design pressure for sailing craft

[Table 13](#) defines the design pressures for sailing craft.

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

CAUTION — k_{AR} and therefore pressures are different for plating and stiffeners, see [Table 9](#).

Sailing craft bottom P_{BS}	$P_{BS\ BASE} = (2m_{LDC}^{0,33} + 18) \times k_{SLS}$
	$P_{BS} = \max(P_{BS\ BASE} \times k_{AR} \times k_{DC} \times k_L; P_{BS\ MIN})$ with
	$P_{BS\ MIN\ PLT} = \max\left[\left(0,3 \times m_{LDC}^{0,33} + 0,66 L_{WL} \times k_{DC}\right) \times k_L; 10 T_C; 7\right]$ for plating
	$P_{BS\ MIN\ STF} = \max(0,85 P_{BS\ MIN\ PLT}; 7)$ for stiffeners
Sailing craft deck and cockpit bottom P_{DS}	$P_{DS\ BASE} = 0,5 m_{LDC}^{0,33} + 12$
	$P_{DS} = \left[P_{BS\ BASE} - (P_{BS\ BASE} - P_{DS\ BASE}) \times \min\left(\frac{Z_Q}{Z_{SDT}}; 1\right) \right] \times k_{AR} \times k_{DC} \times k_L$ Not taken <5 for walking area or <3,5 for non-walking area, both for plating and stiffeners
Sailing craft side P_{SS}	$P_{SS} = \left[P_{BS\ BASE} - (P_{BS\ BASE} - P_{DS\ BASE}) \times \min\left(\frac{Z_Q}{Z_{SDT}}; 1\right) \right] \times k_{AR} \times k_{DC} \times k_L$
	$P_{SS\ MIN\ PLT} = \max\left[P_{BS\ MIN\ PLT} - \frac{Z_Q}{Z_{SDT}} (P_{BS\ MIN\ PLT} - 5); 5 \right]$ for plating
	$P_{SS\ MIN\ STF} = \max(0,85 P_{SS\ MIN\ PLT}; 5)$ for stiffeners
Sailing craft super-structures and cockpit side P_{SUPS}	$P_{SUPS} = \left[P_{BS\ BASE} - (P_{BS\ BASE} - P_{DS\ BASE}) \times \min\left(\frac{Z_{SDA}}{Z_{SDT}}; 1\right) \right] \times k_{AR} \times k_{DC} \times k_L \times k_{SUP}$ not taken <5 for walking area or <3,5 for non-walking area, both for plating and stiffeners With k_{SUP} taken from Table 10 according to area

Z_Q is the height of point Q at mid-panel or stiffener above waterline (W_L or chine see [Figure 6](#)), Z_{SDA} and Z_{SDT} are respectively the height of actual and theoretical hull deck limit above waterline (see [Table 4](#) & [Figure 6](#)), All values considered at distance x from aft of L_{WL} . For cockpit bottom Z_Q need not be taken less than Z_{SDA} .

9.3 Watertight bulkheads and integral tank boundaries design pressure

9.3.1 General

[Table 14](#) defines the design pressures for watertight bulkheads and integral tanks.

Table 14 — Design pressures for watertight bulkheads and integral tanks

Type of watertight partition	Design pressure (kN/m ²)
Watertight bulkhead	$P_{WB} = 7 h_B$
Integral tank	$P_{WB} = 10 h_B$

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

- for plating, the distance from a point 2/3 of the depth of the panel below the top of bulkhead;
- for vertical stiffeners, the distance from a point 2/3 of the depth of the stiffener below top of bulkhead;
- for horizontal stiffeners, the height measured from the stiffener to the top of bulkhead.

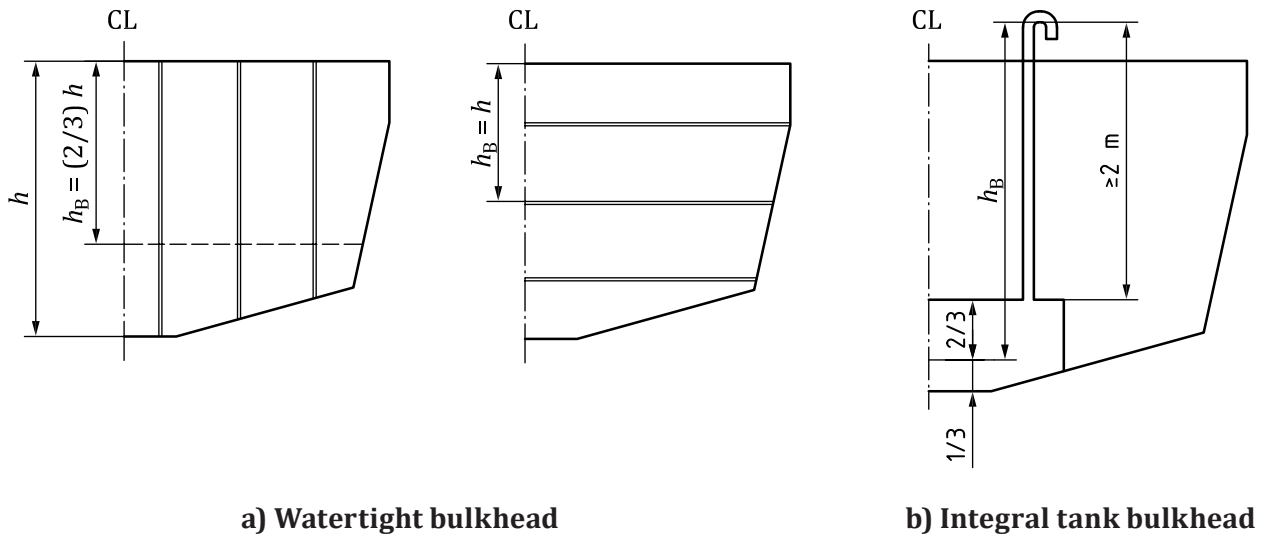


Figure 8 — Watertight and integral tanks bulkheads

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

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

9.3.2 Integral tanks wash plates

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

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

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

9.3.3 Collision bulkheads

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

9.3.4 Non-watertight or partial bulkheads

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

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

9.3.5 Centreboards of lifting keel wells

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

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

9.3.6 Transmission of pillar loads

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

9.3.7 Loads from outboard engines

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

10 Mechanical properties and design stresses

10.1 Boat building quality factor k_{BB}

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

- building environment (e.g. temperature, hygrometry, etc. during storage and building);
- building process (e.g. preparation process prior to building such as dusting, degreasing, priming, etc.);
- type of material (e.g. proper combination of material, etc.);
- etc.

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

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

Table 15 — Values of k_{BB} factor

Built quality	Builder characteristics	Value of k_{BB}	
		Hand laid	Infused, pre-preg or similar
TESTED	Mechanical properties of the laminates are produced ^a , as built, based on test of the mechanical characteristics (modulus, breaking strains, etc.) ^b . Monitoring records, material batch traceability, frequency (once a year as a minimum) and test procedures are drawn up into a quality procedure, such as ISO 9001 or equivalent.	1 on Tested value	1 on Tested value
HIGH	Fibre mass content monitoring, obtained either from sample thickness with theoretical approach, either burning process; for range of representative layups. Monitoring records, material batch traceability, frequency (once a year as a minimum) and test procedures are drawn up into a quality procedure, such as ISO 9001 or equivalent.	0,95 of calculation/ Table value	1 of Calculation/ Table value
LOW	No measurements or checking on fibre mass content. Volume content is taken from Table C.7 , according to relevant building process (minimum value where there is a range)	0,75 of calculation/ Table value	0,80 of calculation/ Table value
^a Not based on UD layers only.			
^b Tests are based, for stresses on 90 % of mean values or mean value minus 2 standard deviations, whichever the smaller, and mean value for modulus, see Item 2 of Table C.1 .			

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

10.2 Assessment method factor k_{AM}

The assessment method factor k_{AM} is defined in [Table 16](#).

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

Table 16 — Assessment method factor k_{AM}

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

10.3 Design stresses according to material and calculation method

The design stresses are defined in [Table 17](#).

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

Material	Structural element	Direct stress σ_d N/mm ²	Shear stress τ_d N/mm ²	
FRP	Single skin plating simplified method	$\sigma_d = 0,5 \sigma_{uf} \times k_{BB} \times k_{AM}$	$\tau_d = 0,5 \tau_u \times k_{BB} \times k_{AM}$	
	Stiffeners ^a	$\sigma_{do} = 0,5 \sigma_{ut} \times k_{BB} \times k_{AM}$	$\tau_d = 0,5 \tau_u \times k_{BB} \times k_{AM}$	
	Sandwich outer skin	$\sigma_d = 0,5 \sigma_{ut} \times k_{BB} \times k_{AM}$	$\tau_d = 0,5 \tau_u \times k_{BB} \times k_{AM}$	
	Sandwich inner skin ^{a,b}	$\sigma_{di} = \min[0,5 \sigma_{uc} ; 0,3(E_c \times E_{CO} \times G_{CO})^{0,33}] \times k_{BB} \times k_{AM}$	$\tau_d = 0,5 \tau_u \times k_{BB} \times k_{AM}$	
	Sandwich core or bulking material Use minimum or σ_{uco} or τ_{uco} core value given by core manufacturer/ provider in directions <i>b</i> and <i>l</i> , where relevant (see Table A.4)	Core compressive stress perpendicular to faces		Core shear stress
		End grain balsa	$\sigma_{dcco} = 0,5 \sigma_{ucco} \times k_{AM}^c$	$\tau_{dco} = 0,5 \tau_{uco} \times k_{AM}^c$
		Elongation at break $\leq 35\%$	$\sigma_{dcco} = 0,55 \sigma_{ucco} \times k_{AM}^d$	$\tau_{dco} = 0,55 \tau_{uco} \times k_{AM}^d$
		Elongation at break $> 35\%$ ^d	$\sigma_{dcco} = 0,65 \sigma_{ucco} \times k_{AM}^d$	$\tau_{dco} = 0,65 \tau_{uco} \times k_{AM}^d$
		Honeycomb	$\sigma_{dcco} = 0,5 \sigma_{ucco} \times k_{AM}^e$	$\tau_{dco} = 0,5 \tau_{uco} \times k_{AM}^e$
Aluminium alloy	Plating	$\sigma_d = \min(0,6 \sigma_{uw} ; 0,9 \sigma_{yw})$	$\tau_d = 0,58 \sigma_d$	
	Stiffeners	$\sigma_d = 0,7 \sigma_{uw}^f$	$\tau_d = 0,58 \sigma_d$	
Steel	Plating	$\sigma_d = \min(0,6 \sigma_u ; 0,9 \sigma_y)$	$\tau_d = 0,58 \sigma_d$	
	Stiffeners	$\sigma_d = 0,8 \sigma_y$	$\tau_d = 0,58 \sigma_d$	
Laminated wood & plywood	Plating	$\sigma_d = 0,5 \sigma_{uf} \times k_{AM}^g$	$\tau_d = 0,5 \tau_u \times k_{AM}$	
	Stiffener	$\sigma_d = 0,45 \sigma_{uf} \times k_{AM}^g$	$\tau_d = 0,45 \tau_u \times k_{AM}$	
Plywood on edge	Stiffener	$\sigma_d = 0,45 \sigma_{uf} \times k_{AM}^g$	$\tau_d = 0,45 \tau_u \times k_{AM}$	
Solid stock wood	Stiffener	$\sigma_d = 0,4 \sigma_{uf} \times k_{AM}^g$	$\tau_d = 0,4 \tau_u \times k_{AM}$	

CAUTION — k_{BB} is a boatbuilding quality factor and only concerns FRP, see [Annex C](#).

Mechanical properties for core (σ_{co} , τ_{co} , E_{co} & G_{co}) shall be taken from "minimal" manufacturer/provider value.

The requirement for inner skin considers wrinkling effects, even if not formally stated.

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

^b E_c is the compressive *E* modulus of inner skin in direction *b*, $0/90^\circ$ plane axis of panel E_{CO} is the compressive *E* modulus of core perpendicular to skins, G_{CO} is the core shear modulus in the direction parallel to load.

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

^d According to core material type.

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

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

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

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

11 Methods for structural analysis and scantlings determination

11.1 The six available methods

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

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

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

CAUTION — For FRP, the thickness required from [Table A.5](#), or wherever such thickness appears in this document shall not be measured, but translated into a mass of dry fibre reinforcement w_f (kg/m²) using the fibre content in volume ϕ or in mass ψ according to [Tables C.2](#) or [C.7](#), and compared to the actual reinforcement mass.

11.2 Method 1: "Simplified" method

The "Simplified" method is only valid for:

- Single skin or sandwich GRP (glass reinforced plastics) with the same properties in directions b and l and made from the fiberglass plies listed in [Tables C.5](#) to [C.10](#);
- metals and wood (plywood or laminated wood, see [Annex F](#)).

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

- design pressure defined in [Tables 12](#) to [14](#);
- design stresses defined in [Table 15](#) to [17](#) and in [Annex B](#) for metals, [Annex C](#) for GRP, and [Annex F](#) for wood/plywood laminates;

- for sandwich specific requirements according to [Table A.6](#) for stresses in skins and [Table A.7](#) for core strength.

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

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

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

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

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

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

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

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

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

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

11.5 Method 4: "Direct test method"

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

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

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

11.6 Method 5: "FEM" Finite Element Method

11.6.1 General considerations

This method, mainly applicable to "developed" FRP construction, recognizes that structural components are best analysed using 3-D numerical procedures, now easily accessible. It uses [Tables 12](#) & [13](#) for the design pressure and [Table 17](#) for the design stress or strain. The mechanical properties of the materials shall be derived from the relevant Annex ([Annex B](#), [C](#), or [F](#)).

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

- 1) apply a unit pressure to the analysed elements, taking care how the model is “held” and ensure that results of outside forces and moments is nil;
- 2) calculate the stresses σ_i in each analysed element due to the unit pressure;
- 3) check on significant elements that $\sigma_i \times P_d \leq \sigma_d$, where P_d is the design pressure, determined for each panel with all the relevant factors. See Note for an alternative calculation.

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

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

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

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

11.6.2 General guidance for assessment by 3-D numerical procedures

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

11.6.3 Boundary assumptions and load application

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

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

11.6.4 Model idealisation

Models may be of beam-element, plate or brick type. Where beam elements are adopted, effective plating dimensions shall, unless otherwise documented, be obtained from [A.12.5](#) or from published effective breadth formulas. Closed sections having significant torsional stiffness should have this parameter calculated using accepted methods, e.g. Bredt-Batho theory.

When using plate-based models, sufficient elements shall be used between frames to replicate local bending effects.

Unless a non-linear analysis is used, analysts should make sure that buckling modes of failure are precluded. This can normally be accounted for by respecting the allowable slenderness ratios for beams and flanges as outlined in [A.12.6](#).

11.7 Method 6: Alternative test: Drop test

The drop test, specified in [Table 2](#) and [Annex D](#), only applies to craft with $L_H < 6$ m. For this size of craft, the related double curvature and/or monocoque effects and robustness cannot be fully taken into account by the methods in [11.2](#) to [11.6](#). The drop test method offers an alternative particularly applicable to craft made of non-reinforced plastics, where thickness and dimensions are not easy to measure, and where the large deflections may not be dealt with by the theory applied in this document.