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Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

For national standards, comments will be reviewed by the relevant UK national committee and the resulting standards published as a British Standard.

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Please indicate whether you consider the UK should submit a negative (with supporting technical reasons) or positive vote on this draft. Please indicate if you are aware of any reason why this draft standard should not be published as a British Standard.

Submission of Comments

- **Annotated drafts are not acceptable and will be rejected.**
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Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/ Figure/Table/Note	Type of comment	Comment (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	



DRAFT International Standard

ISO/DIS 12215-9

Small craft — Hull construction and scantlings —

Part 9: Sailing craft appendages

*Petits navires — Construction de coques et échantillonnage —
Partie 9: Appendices des bateaux à voiles*

ICS: 47.080

ISO/TC 188

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This document is circulated as received from the committee secretariat.

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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).

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

This document was prepared by Technical Committee ISO/TC 188, *Small craft*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 464, *Small Craft*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 12215-9:2012), which has been technically revised.

The main changes are as follows:

- Editorial changes throughout to improve format, language, consistency, clarity, interpretation, readability, acknowledgement of current practice and compliance with this part of the standard
- The addition of consideration of canting keel actuator and keel support structure to [Table 3](#)
- Compliance: [Annex A](#) shall be completed in all instances. Wording has been clarified.
- The addition of qualified backing plate diameter and thickness treatment in the case of reduced hull thickness in [Table D.2](#)
- A specific caution about bolt proximity to welds in [Clause D.4.7](#)
- Re-assessment of [Annex F Simplified fatigue strength](#) assessment, doubling the operational life to 16 million stress cycles and associated MSF calculation

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

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

Introduction

This document recognises the importance of adequate scantlings, construction practice and condition assessment for sailing craft appendages, principally the ballast keel.

The loss of a ballast keel leading to craft capsizes is one of the major casualty hazards on sailing craft and therefore the structural effectiveness of all elements of the keel and its connection to the craft is paramount.

This document specifies the design loads and their associated stress factors. The user (e.g, the designer or builder) then has a choice of two options to assess the structural arrangement:

- a) Use of computational methods which allow the structure to be modelled three-dimensionally. Methods include finite element analysis, matrix displacement or framework methods, **following which [Annex A](#) shall be completed for compliance**. General guidance is provided on modelling assumptions within [Clause 8](#) of this document.

or

- b) Use of simplified two-dimensional stress formulae. These are presented in [Annexes B](#) to [F](#) and, if this option is chosen, use of all applicable Annexes will be necessary to fulfil the requirements of this document, **following which [Annex A](#) shall be completed for compliance**.

This document has been developed in consideration of current practice and sound engineering principles. The design loads and criteria of this document may be used with the scantling determination formulae of this document or using equivalent engineering methods as indicated in a) above.

This document reflects current practice, provided the craft is correctly handled in accordance with good seamanship, is well designed and built¹⁾, maintained, equipped and operated at a speed appropriate to the prevailing sea state. Inspection of all appendages after grounding is essential.

Racing craft are not the principal focus of ISO 12215. In particular, users are strongly cautioned against attempting to design scantlings for racing craft such that scantlings only just comply.

Annex J of ISO 12215-5:2019 provides additional requirements for commercial craft and workboats. The principles of these requirements may also be considered applicable to craft that engage in racing, where their usage conditions warrant an independent maintenance and survey program set up by a qualified organization. This is further discussed in [Clause 9](#) of this document.

1) Compliance with this document will not ensure a satisfactory design in all cases nor absolve the user, such as the designer or builder, of their design responsibilities, with whom such responsibilities are entirely vested.

Small craft — Hull construction and scantlings —

Part 9: Sailing craft appendages

1 Scope

This document defines the loads and specifies the scantlings of sailing craft appendages on monohull sailing craft with a length of hull (L_H) measured according to ISO 8666 or a load line length (see NOTE 1 in Clause 1 of ISO 12215-5) of up to 24 m. It gives:

- design stresses,
- the structural components to be assessed,
- load cases and design loads for keel, centreboard and their attachments,
- computational methods and modelling guidance, and
- the means for compliance with its provisions.

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. Dated versions are intended where this part makes direct reference to a section in that dated part of ISO 12215.

ISO 898-1, *Mechanical properties of fasteners made of carbon steel and alloy steel — Part 1: Bolts, screws and studs with specified property classes — Coarse thread and fine pitch thread*

ISO 3506-1, *Fasteners — Mechanical properties of corrosion-resistant stainless steel fasteners — Part 1: Bolts, screws and studs with specified grades and property classes*

ISO 8666, *Small craft — Principal data*

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

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

ISO 12215-6:2008, *Small craft — Hull construction and scantlings — Part 6: Structural arrangements and details*

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

3 Terms and definitions

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

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

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

— IEC Electropedia: available at <https://www.electropedia.org/>

3.1 design category

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 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.

3.4 mass of keel

m_{KEEL}
mass of the ballast keel, i.e. keel fin plus bulb, where fitted, and, for twin or multiple keels, of a single keel

Note 1 to entry: The mass of keel is expressed in kg.

4 Symbols

For the purposes of this document, unless specifically otherwise defined, the symbols given in [Table 1](#) apply.

Table 1 — Nomenclature

Symbol	Unit	Designation/meaning of symbol	Ref/Subclause
A_{CB}	m ²	Area of fully deployed centreboard	7.7.1
A_S	m ²	Reference sail area (mainsail + fore triangle + wing mast) as per ISO 12217-2	7.7.1
a	m	Distance along keel centreline, from centre of gravity (CG) of keel to keel junction with hull or tuck	7.2
b_f	mm	Overall breadth of the appendage aerofoil section	E.1
c	m	Distance along keel centreline from keel junction to floor mid-height	7.2
c_a	m	Average value of c for several floors	7.5.1
e	m	Proportion of the total side force taken by the centreboard	7.7.1
F_i	N	Design force with i according to load case	7
g	m/s ²	Acceleration of gravity = 9,81 m/s ²	7
h_{CE}	m	Height of centre of area of A_S	7.7.1
h_K	m	Height of keel between its bottom and hull connection	7.5.1
h_{F4}	m	Height of application of force F_4 (load case 4)	7.5.1
I_L	cm ⁴	Longitudinal second moment appendage aerofoil section	E.2.2
k_{DC}	–	Design category coefficient	5 , Table 2
k_f	–	Appendage section shape factor	Table E.1

Table 1 (continued)

Symbol	Unit	Designation/meaning of symbol	Ref/Subclause
k_{f1}	–	Appendage section shape factor	Table E.1
k_{LC}	–	Load case coefficient	5, Table 3
k_{LD}	–	Length displacement coefficient	7.7.1
k_{MAT}	–	Material coefficient	5, Table 2
L_f	mm	Chord length of appendage aerofoil section	E.1
L_{WL}	m	Length of waterline in m_{LDC} conditions	7.7.1
m_{LDC}	kg	See definition 3.2	3.2, 7
m_{KEEL}	kg	See definition 3.4	3.4, 7.4
M_{IJ}	N·m	Design bending moment, with index I and J according to load case	7
SM_L	cm ³	Appendage aerofoil shape longitudinal section modulus	E.2.2
st_i	N/mm ²	Stress, which can be σ or τ , and where i can be LIM, d, u, y, yw or yu	5
t_f	mm	Wall thickness of hollow appendage aerofoil section	E.1
α	deg.	Angle of attack of centreboard	7.7.1
ε_R	%	Elongation at break	Table B.2
θ	deg.	Angle between keel axis and centreline for canting keels	7.3.1

5 Design stresses

The maximum stress shall be calculated for each relevant structural component and load case.

The design stress, st_d , is the relevant limit stress multiplied by various stress coefficients:

$$st_d = st_{LIM} \times k_{MAT} \times k_{LC} \times k_{DC} \text{ in N/mm}^2 \quad (1)$$

where

st_{LIM} is the limit stress, with st representing either σ , the direct stress, or τ , the shear stress, and index LIM is as follows:

- for metal in the unwelded state or well clear of the heat affected zone (HAZ), $\min(st_y; 0,5 \times st_u)$ where index y is the yield strength and index u is the ultimate strength, i.e. σ_y, σ_u for direct stress, τ_y, τ_u for shear stress and σ_{by}, σ_{bu} for bearing stress;
- for metal within the HAZ, $\min(st_{yw}; 0,5 \times st_{uw})$ where index y is the yield strength and index u is the ultimate strength, i.e. σ_{yw}, σ_{uw} for direct stress, τ_{yw}, τ_{uw} for shear stress and for $\sigma_{byw}, \sigma_{buw}$ bearing stress;
- for wood and fibre-reinforced polymer (FRP), the ultimate strength in tensile σ_{tu} , compressive σ_{cu} , flexural σ_{fu} , bearing, σ_{bu} or shear stress τ_u ;

k_{MAT} is the material coefficient as defined in [Table 2](#), with the design stress adjusted according to the material;

k_{LC} is the load case coefficient as defined in [Table 3](#), with the design stress adjusted according to the load case;

k_{DC} is the design category coefficient as defined in [Table 2](#), with allowance for an increase in design stress for lower design categories.

[Table 2](#) gives details on these variables.

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The values of st_{LIM} — i.e. $\sigma_y, \sigma_u, \tau_u$ for unwelded metals, $\sigma_{yw}, \sigma_{uw}, \tau_{yw}, \tau_{uw}$ for welded metals in a HAZ, or $\sigma_{tu}, \sigma_{cu}, \sigma_{fu}, \sigma_{bu}$ or τ_u for wood and FRP — shall be taken

- in accordance with ISO 12215-5:2019, i.e. according to tests or default values specified in its [Annex C](#) for FRP, its [Annex E](#) for sandwich core, and its [Annex F](#) for laminated wood and plywood,
- in accordance with [Annex B](#) for the listed metals, including, where relevant, ISO 3506-1 for stainless steel fasteners and ISO 898-1 for carbon steel or alloy steel fasteners, and
- for other metals, either from a recognized standard or from tests made in accordance with the relevant International Standard.

Table 2 — Design stresses and stress coefficients

Variable	Material/designation	Value
st_{LIM}	Metals, unwelded or well clear of HAZ ^a	$\min.(st_y; 0,5 \times st_u)_{b,c}$
	Metals, within HAZ, in welded condition ^a	$\min.(st_{yw}; 0,5 \times st_{uw})_{b,c}$
	Wood or FRP as dictated by sense of applied stress	$\sigma_{uc}, \sigma_{ut}, \sigma_{uf}, \sigma_{ub}$ and τ_u as relevant ^c
k_{MAT}	Stress factor	
	Metals with elongation at break, $\epsilon_R \% \geq 7$	0,75
	Metals with elongation at break, $\epsilon_R \% < 7$	$\min.(0,062 5\epsilon_R + 0,312 5; 0,75)_{d}$
	Wood and FRP	0,33
k_{LC}	Stress factor (see Table 3)	
k_{DC}	Stress factor	
	Craft of design categories A and B	1,00
	Craft of design categories C and D	1,25

^a Generally, the heat-affected zone is considered as being 50 mm from the weld (see [F.3.4.3](#)).

^b For metals, $\tau = 0,58 \times \sigma$.

^c Bearing stress depends on material type (Ref [\[8\]](#) gives $\sigma_{ub}/\sigma_{uc} = 2,8$ for Glass CSM and 0,91 for roving), metal regulation usually gives 2,4 to 3 for bolts (but with restrictions: far from edges, min. bolt spacing, min. thickness/bolt d). Values derived from tests are recommended.

^d The factor gives 0,75 for $\epsilon_R \geq 7 \%$, and 0,375 for $\epsilon_R = 1 \%$ and linear interpolation in between. Values of ϵ_R are given in [Table B.2](#).

Table 3 — Value of k_{LC} stress factor according to load case

Load case	Keels and appendages — Load case description	Subclause	Value of k_{LC}
1	Keel bolt ^a	7.2	0,67
	Other elements of fixed keel—metal	—	0,8
	Other elements of fixed keel—FRP ^b	—	0,9
2	Canting keel—metal	7.3	0,8
	Canting keel—FRP	7.3	0,9
	Canting keel—metallic actuator/metallic actuator and keel support structure	7.3	0,8
	Canting keel—FRP actuator/FRP actuator and keel support structure	7.3	0,9
3	Keel vertical pounding	7.4	1

^a Load case 1 treats bolts differently from other structural components. The design stress of bolts is lower than that of other structural components in recognition of stress concentration effects in bolts, according to long-standing practice.

^b Caution: The requirements of this document are based on strength criteria. In some cases, such as keel fins constructed of lower modulus materials, the need to limit deflections and/or increase natural frequencies may require a substantial increase in scantlings above those requirements. Such cases are outside the scope of this document.

Table 3 (continued)

Load case	Keels and appendages — Load case description	Subclause	Value of k_{LC}
4	Keel longitudinal impact	7.5	1
5	Dinghy capsize recovery (strength of centre/dagger board)	7.6	1,34
6	Centre/dagger board upwind	7.7	1,0
^a Load case 1 treats bolts differently from other structural components. The design stress of bolts is lower than that of other structural components in recognition of stress concentration effects in bolts, according to long-standing practice. ^b Caution: The requirements of this document are based on strength criteria. In some cases, such as keel fins constructed of lower modulus materials, the need to limit deflections and/or increase natural frequencies may require a substantial increase in scantlings above those requirements. Such cases are outside the scope of this document.			

6 Structural components to be assessed

CAUTION — Keel loss can be attributed to insufficient thickness of bottom plating in the keel region. In particular, connecting bolts or inadequately assessed load paths between connecting bolts and the corresponding structure and bolts located too far from the relevant stiffener are causative. It is strongly recommended that the provisions of [D.5](#) and [Table D.2](#) be followed and, in particular, for bolts located too far from a stiffener, those provisions of [Table D.2](#), item 3. Keel loss can also be attributed to insufficient fatigue strength of keel fins. In such cases, the provisions in [Annex F](#) should be followed.

The following shall be considered when assessing or designing the structure covered by this document.

- Keel-to-hull connection (bolts, wedge connection, stub keel, etc.) — see [Figures 1](#), [C.3](#), [C.4](#) and [D.1](#).
- Bottom shell plating in respect of the keel bolts and transition arrangements beyond the keel bolting zone into the hull structure. Keels should not be bolted to a hull bottom of sandwich construction. The structural arrangement shall ensure that all loads — keel compression loads, bolt preload, etc. — are safely transferred. Note that the terms “pre-stress” and “preload” are used interchangeably.
- Backing plates (usually rectangular steel plates installed on the hull plating inner surface that spread load)/steel washers (annular, placed under securing nuts or bolt heads).
- Floors, girders and associated supporting structure.
- Keel boxes, canting keel actuators and support structure.
- Fins, centreboards, dagger boards of aerofoil cross-section (note: hydrofoils are not considered).

Assessment should be conducted either by numerical methods in accordance with [Clause 8](#) or the established practice methods given in [Clause 9](#).

7 Load cases

7.1 General

7.1.1 Status of design load cases

CAUTION — For load cases 1 and 2 — where keels have a large sweep angle, the centre of gravity (CG) of the bulb/fin can be located a significant distance aft or forward of the fin or bolt group longitudinal centre at the root. This will induce a torsional moment in addition to the bending moment. In such cases, it will be necessary to combine direct stresses owing to bending with shear stresses due to the torsion. The resulting von Mises equivalent stress shall not exceed the design stress given in [Formula \(1\)](#), also noting [Clause 7.8](#). See also [Clause 7.8.1](#).

The design stress shall be assessed for each load case using [Formula \(1\)](#), together with the design stress coefficients given in [Table 2](#) and [Table 3](#), as follows:

- [7.2](#) defines the *fixed keel 90° knockdown* load case 1 and corresponding force, F_1 , and design bending moment, M_1 , at 90° heel, for the keel at its root/bolt level and floor neutral axis, respectively; it shall be used for fixed keels, either vertical or angled as in the case of twin keel craft, and axially lifting or swing ballast keels;
- [7.3](#) defines *canted keel* load case 2 and the corresponding force, F_2 , and design bending moment, M_2 , at 30° steady heel plus a dynamic overload factor; it shall only be used for canting keels;
- [7.4](#) defines *vertical pounding* load case 3 and design vertical force, F_3 ;
- [7.5](#) defines *longitudinal impact* load case 4 and design horizontal force, F_4 , that considers a longitudinal impact with a fixed or submerged object or marine life;
- [7.6](#) defines *dinghy capsize recovery* load case 5 and the design vertical force, F_5 , in 90° knockdown, applied on the tip of a centreboard for dinghy capsize recovery;
- [7.7](#) defines *centreboard/dagger board* load case 6 and the transverse horizontal force, F_6 , applied to centreboard or dagger board used while sailing upwind;
- [7.8](#) considers other load cases, particularly where specific designs cause combined stresses.

7.1.2 Limitation of load cases

This document is based on the presumption that load magnitudes are set at such a high level of severity that the number of expected occurrences during the lifetime of the craft will be low. Hence, all load cases are considered to be static and used in conjunction with static design stresses according to [Tables 2](#) and [3](#).

For keels of welded construction, compliance with the static load cases cannot guarantee that fatigue failure due to cyclic loading will not occur. In such cases, an explicit fatigue life assessment and inspection regime shall be considered (see [Annexes A](#) and [F](#)). It is of the utmost importance that the response of structures experiencing cyclic loading is less than the fatigue strength. Fatigue analysis is required when the stresses are high in magnitude and when structures feature welds that required detailed design and documentation.

Keel configurations resembling the types shown in [Figure C.4](#) require case-by-case consideration.

In addition, the load cases consider that, for bolted connections, the methods for assessing keel bolts are based on the presumption of a broadly uniform distribution of diameter and spacing along the fin root or keel flange (see [D.4](#) for details).

7.2 Load case 1 — Fixed keel at 90° knockdown

This case corresponds to a 90° knockdown case (heeled at 90°) (see [Figure 1](#)), which is usually the most severe transverse bending load for fixed ballast keels:

$$F_1 = m_{\text{KEEL}} \times g \quad (2)$$

expressed in N as the vertical force, at 90° knockdown, exerted by gravity at the keel CG

$$M_{1.1} = F_1 \times a \quad (3)$$

expressed in N·m as the keel heeling design moment at the keel junction

$$M_{1.2} = F_1 \times (a + c) \quad (4)$$

expressed in N·m, keel heeling moment at floor mid height

where

- a is the distance, in m, along the keel centreline, from the keel CG to the keel's junction with the hull or stub;
- c is the distance, in m, along the keel centreline from the keel junction to the floor at mid-height;
- g is the acceleration due to gravity, taken as 9,81 m/s² and used throughout this document.

The craft's structure, keel connection and stiffeners shall be able to withstand this force and moments.

For craft fitted with a fin and stub [see [Figure 1 b](#)], it may be necessary to consider a range of values of c to establish the most highly stressed point.

[Annex C](#) provides information on how to calculate the shear force and bending moment on each floor when these are analysed as independent beams.

NOTE For single fixed keels, when considered parallel to the centreline these bending moments correspond to a heel angle of 90° knock-down. For fixed twin keels [see [Figure 1 c](#)], the cosine of angle ϕ from the horizontal when the craft is knocked down is not considered, as the keels will be parallel to the waterline at some point before or after the craft reaches 90° of heel.

7.3 Load case 2 — Canted keel steady load at 30° heel with dynamic overload factor

7.3.1 General

This case only applies to canting keels [see [Figure 1 d](#)]. It corresponds to a steady heel at 30° that can be experienced as a long-term load, with an additional dynamic overload factor which represents the additional fluctuating load experienced as the craft responds to the seaway.

Load case 2 represents the normal sailing condition for a craft with canted keel, but is augmented by a 40 % dynamic overload factor²⁾ to allow for unusual combinations of rigid body motions and accelerations, and is thereby considered to constitute an infrequently occurring case. Fatigue will still need to be considered, noting [Clause 7.1.2](#):

$$F_2 = 1,4 \times m_{\text{KEEL}} \times g \quad (5)$$

expressed in N as the vertical force exerted by gravity at the keel CG

$$M_{2,1} = F_2 \times a \times \sin(30^\circ + \theta) \quad (6)$$

expressed in N×m as the canting keel design heeling moment at the keel junction

where θ is the maximum canting angle from axial (vertical) plane and shall not be taken as greater than 60° or less than 30°.

NOTE 1 The lower limit of 30° ensures a load at least 22 % greater than load case 1.

NOTE 2 Very thin fins of a canting keel, especially those of FRP construction, often require “flutter” (vibration) analysis, but this is considered outside the scope of this document (see [Clause 7.1.2](#) and [Annex F](#)).

For calculation of floors, the keel design heeling moment of supporting structure floors is

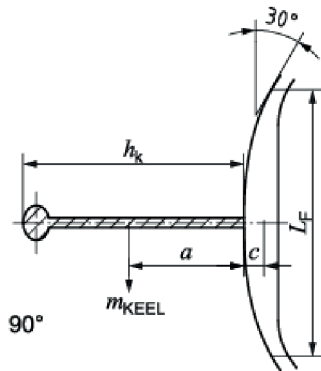
$$M_{2,2} = F_2 \times [a \times \sin(30^\circ + \theta) + 0,5c] \quad (7)$$

expressed in N as the design bending moment of canting keel floors.

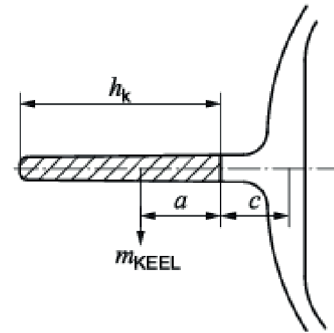
The craft structure, keel connection and stiffeners shall be able to withstand this force and moments.

2) The dynamic overload factor for normal sailing conditions is in the order of 15–20 % but may be higher.

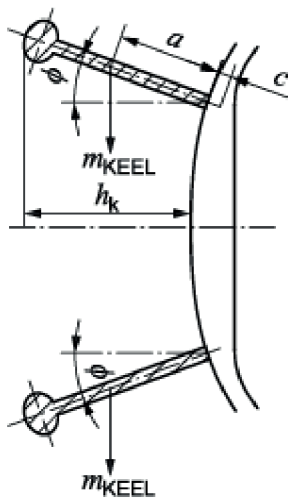
[Annex C](#) provides information on how to calculate the shear force and bending moment on each of the two “wet-box” bulkheads when these can be analysed as independent beams.



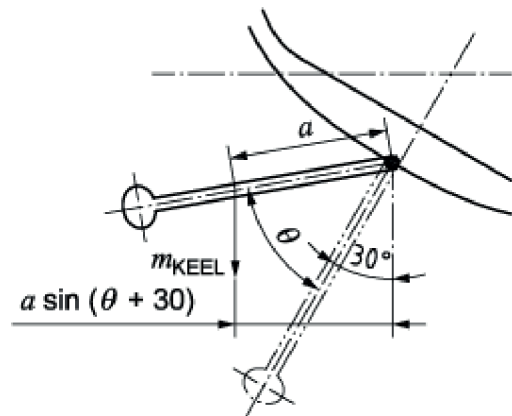
a) Craft with axial keel heeled at 90°



b) Craft with axial keel with stub keel



c) Craft with twin keels heeled at 90°



d) Craft with canting keel heeled at 30°

Figure 1 — Sketch of fixed axial keel, twin keels and laterally canting keel

7.3.2 Specific requirements for canting keel structure

The canting keel system shall be fitted with a box that is watertight.

Structural elements shall be provided to support the loads from the canting keel, in case of leakage or a defect in the orientation rams or system, and to protect the surrounding structure, such as stops, actuators and locking pins.

7.4 Load case 3 — Keelboat vertical pounding

This case considers a vertical impact load in relation to the events of dry-docking or purely vertical and upwards grounding:

$$F_3 = g(m_{LDC} - m_{KEEL}) \quad (8)$$

expressed in N as the vertical pounding force exerted at keel bottom with the craft upright.

The bending moment is not specifically given here as it depends of the floor and keel arrangement (number, length, stiffness, end fixity, etc.). [Annex C](#) gives information on how to calculate the shear force and bending moment on each floor when these may be analysed as independent beams.

The craft structure, keel connection and stiffeners shall be able to withstand a vertical force, F_3 , exerted at the ballast keel bottom, passing through the keel CG, without exceeding the grounding design stresses defined in [Clause 5](#).

For twin or multiple keels, 100 % of F_3 is considered to be applied on the bottom of each keel and its structure and attachment, as the grounding could happen on one keel. This will induce a bending moment for such keels that shall be taken into account (see [7.8.2](#)).

Canting keels are also to be considered in the “neutral” (cant angle of zero) position.

For lifting keels, this requirement applies to the worst case of deployed or retracted condition.

In the deployed condition, the lifting/deploying device shall

- either be able to support load F_3 without surpassing the design stress, or
- retract without damaging the actuating system until the retracted condition is attained.

7.5 Load case 4 — Keelboat longitudinal impact

7.5.1 Value of longitudinal impact and bending moment

The craft structure and keel connection shall be able to withstand, without exceeding design stresses, a longitudinal and horizontal force, F_4 exerted at the bottom of the leading edge of the keel and which does not need to be taken lower than $0,2L_{WL}$ below the loaded waterline.

CAUTION — The moments given in the following formulae are *not* the bending moments in the various floors; see [Annex C](#).

$$F_4 = 1,2 \times g \times (m_{LDC} - m_{KEEL}) \quad (9)$$

expressed in N as the longitudinal and horizontal impact force

$$M_{4,1} = F_4 \times h_{F4} \quad (10)$$

expressed in N×m as the combined bending moment at the keel connection (root) from both longitudinal and lateral horizontal impact forces.

$$M_{4,2} = F_4 \times (h_{F4} + c_a) \quad (11)$$

expressed in N×m as the combined bending moment at floor mid-height from both longitudinal and transverse impact forces.

where

$h_{F4} = \min(h_k; 0,2L_{WL})$, expressed in m, is the lesser of

- the height of the keel, h_k measured parallel to the axial plane of the craft, between its bottom and its connection to the hull or skeg (see [Figure 1](#)), and
- $0,2L_{WL}$, measured from the loaded waterline;

c_a is the average vertical distance, in m, of the c values from the keel junction to the mid-height of the loaded floor.

For canting keels, h_k is measured with the keel oriented so as to have the maximal draft, with the craft upright.

For twin or multiple keels, F_4 is considered to be applied on each keel at the level of h_{F_4} , as defined above, because the impact can be on only one keel when heeled.

For lifting keels, h_k is measured with the keel fully deployed. The device shall resist F_4 in the worst case of deployed or retracted condition.

In the deployed condition, the lifting/deploying device shall either

- be able to support F_4 without surpassing the design stress, or
- retract without damaging the actuating system until the retracted condition is attained.

The centreboards and lifting keels that are not required by ISO 12217 to be locked in the deployed condition need not be considered for the application of F_4 .

NOTE For tilting centreboards, the lifting rope or ram usually acts as a breaking-pin. For dagger boards, the well or a crash box acts as the device supporting F_4 .

7.6 Load case 5 — Centreboard on capsize recoverable dinghies

On capsize recoverable sailing craft, as defined in ISO 12217, and where the capsize recovery method, according to that International Standard, uses the centreboard as a lever, this centreboard shall be assessed using the more demanding of either F_5 , calculated using [Formula \(12\)](#), or F_6 as defined in [7.7](#):

$$F_5 = 80 \times 9,81 \times n_{PR} \quad (12)$$

expressed in N as the vertical force at the tip of the deployed centreboard on a knocked-down dinghy

where n_{PR} is the minimal required number of persons for recovering from capsize according to ISO 12217.

NOTE This requirement represents the case where the crew weight is pushed down on the tip of the centreboard to right the craft. The mass of 80 kg corresponds to a wet crew member.

In either case, the greatest bending stress generally occurs at the point where the centreboard enters the hull. The centreboard shall be taken as fully deployed.

7.7 Load case 6 — Centreboard or dagger board upwind

7.7.1 Non-ballasted centreboards

The design force, F_6 , exerted at the geometric centroid of a non-ballasted (typically $0,5 \times \text{span}$) fully deployed centreboard shall be the greater of

$$F_{6.1} = 136 \times (0,075\alpha) \times A_{CB} \times V^2 \quad (13)$$

expressed in N as the design force due to lift at angle of attack, α , or

$$F_{6.2} = e \frac{M_{RUP}}{h_{CE}} \quad (14)$$

expressed in N as the design force balancing the force on sails when sailing upwind

where

α is the design angle, in degrees, of attack of the aerofoil, which shall not be taken as less than 5° ;

- A_{CB} is the average centreboard planform area (mean chord $\times$ span beyond hull), in m^2 , in the fully deployed condition, where relevant;
- V is the maximum speed of the craft, in knots, in the minimum operation condition, m_{MOC} (see ISO 12217), and where, if this speed is not known, it may be taken as
- $$V = 2,5 \times L_{WL}^{0,5} \times \left(\frac{k_{LD}}{6,15} \right)$$
- where
- $$k_{LD} = \frac{L_{WL}}{\left(\frac{m_{LDC}}{1\,025} \right)^{0,33}}$$
- but shall not be taken as less than 6,15;
- e is the proportion of the total side force carried by the centreboard or dagger board, depending on the contribution from the keel, rudder and canoe body for balancing the force from sails, and which, in the absence of better data, may be taken as 0,6;
- M_{RUP} expressed in N·m, is the righting moment when the craft is sailing upwind, which shall be taken as the moment at 30° heel unless otherwise documented;
- h_{CE} expressed in m, is the height of the centre of the area of the nominal sail area, A_S , above the waterline when the craft is upright, as used in F_{KR} of STIX (stability index) according to ISO 12217-2.

The coefficient, 0,075, given in [Formula \(13\)](#) is valid for centreboards with a symmetrical aerofoil section but may not be valid for non-symmetrical profiles, which usually achieve greater lifting force.

If the centreboard is not designed to support the forces defined by [Formulae \(13\)](#) and [\(14\)](#) at maximum speed V , as defined above, a warning shall be included in the owner's manual.

7.7.2 Ballasted centreboards

Ballasted centreboards shall also be analysed according to all the relevant load cases specified in [Clause 7](#), with the more demanding requirement being applied.

7.8 Other load cases

7.8.1 General

This document should not be regarded as a complete structural design procedure. Load cases 1 to 6 are intended to correspond to those loads which normally govern keel attachment scantlings for most conventional keel configurations. Consequently, it should not be taken that compliance with this document will ensure a satisfactory design in all cases, or that such compliance will absolve the user e.g. the designer or builder of their respective design responsibilities.

The following sets out general guidance for areas where the user may wish to exercise judgement beyond the scope of this document and offers simple methods for checking the applicability of [Annexes B](#) to [F](#).

7.8.2 Combined bending and torsion (knockdown case)

For load cases 1 and 2, with large keel sweep angle and/or bulb CG positioned well aft or forward, the CG of the bulb/fin may be located a significant distance aft or forward of the fin or bolt group longitudinal centre at the keel root. See CAUTION in [Clause 7.1.1](#).

The presence of torsion significantly complicates the simplified independent beam approach used to assess floor strength in [Annex C](#) (for example, see [Table C.1](#)). For users undertaking 3D structural analysis, it is recommended that the keel be modelled as a stiff member/framework and the ballast force applied at its correct vertical and fore and aft locations. This is considered to be good practice as point loads should generally be applied well away from the area of interest in finite element analysis (FEA). See [Clause 8.2.3](#).

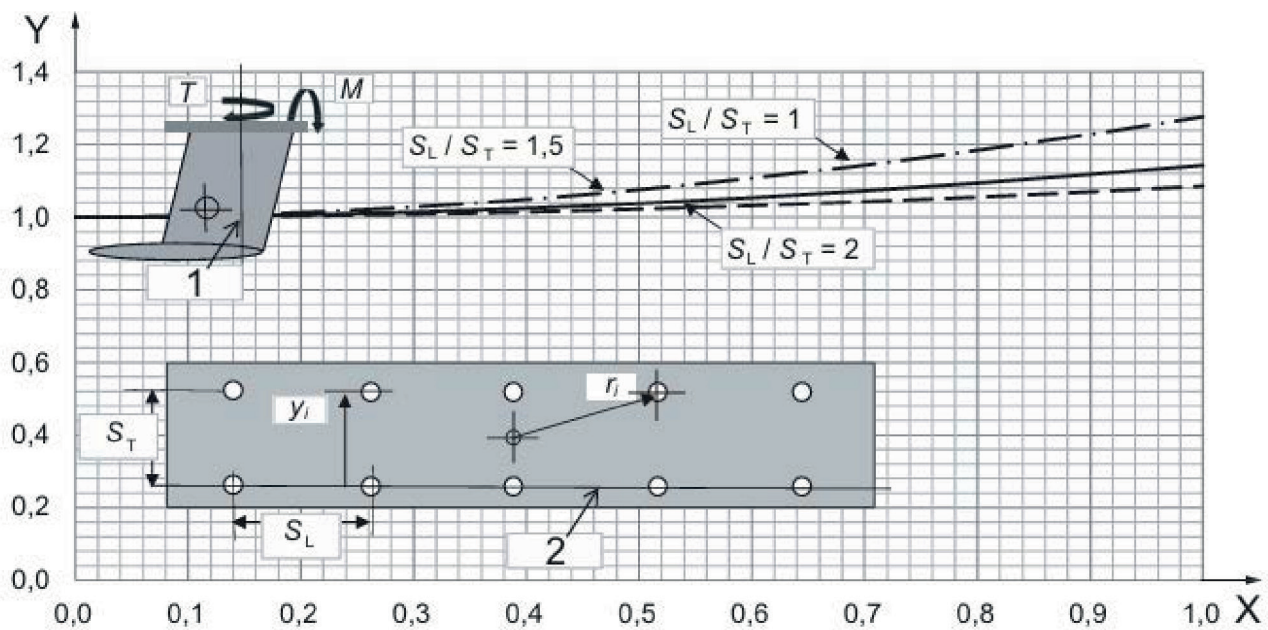
The effect of torsion on the bolt stress can be determined, assuming the reference axis is:

- for the torque, T , a vertical line passing through the CG of bolt group areas (see Key item 1 in [Figure 2](#));
- for the bending moment, M , a horizontal line defined by the hinge bearing axis (see Key item 2 in [Figure 2](#) and Key item 1 in [Figure D.1](#)), and using formulae of the form:

$$\sigma_{max} = \frac{M \times y_{imax}}{\sum_{i=1}^n [a_i \times y_i^2]} \quad (15)$$

$$\tau_{max} = \frac{T \times r_{imax}}{\sum_{i=1}^n [a_i \times r_i^2]} \quad (16)$$

[Figure 2](#) indicates a relationship between the applied torque and bending moment ($M_{1,1}$) for a set of $n = 10$ bolts (of identical area a_i), set up in a uniform “keel-flange” style arrangement.



Key

- X torque/transverse bending moment ratio
- Y von mises stress/stress due to bending moment ratio
- 1 torque reference axis (bolt group centroid)
- 2 bending moment reference axis

Figure 2 — Effect of torque on bolt stress under load case 1

It can be seen that the torque increases the von Mises equivalent stress by a factor of, typically (10–20) % for moderate fore and aft offset. The force is the same as for case 1, i.e. $m_{KEEL} \times g$, so that the ratio torque/transverse bending moment is equal to the fore and aft torque offset from the bolt group centroid divided by a , as defined in [Clause 7.2](#)). This increase is a function of the ratio S_L/S_T , the longitudinal and transverse spacing of bolts, respectively.

This implies that in cases of moderate torque/moment ratio, the effect may be allowed for by ensuring that the bolt stress compliance factor is not less than approximately 1,2 when $M_{1,1}$ is acting alone.

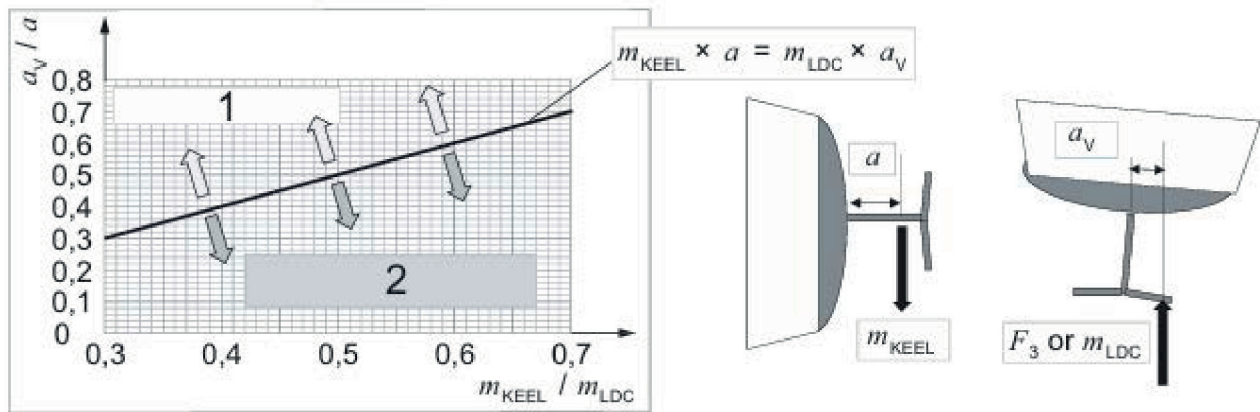
It should be noted that the structure in way of keel bolts (see [Annex D](#)) only considers a vertical force and the additional transverse bearing force induced by torsion is neglected. This should be borne in mind in cases of minimum compliance with the requirements of [Annex D](#), and design revisions undertaken as needed.

7.8.3 Combined bending moment and vertical load (load case 3)

Load case 3 assumes that the craft impacts such that the vertical force passes through the vessel's centreline. This induces no bending moment at the keel root and the formulae in [Table C.1](#) will be valid. However, it is possible that the craft could dropped onto the seabed or hard standing at an angle, β . This would induce a moment of $m_{LDC} \times S_{KEEL} \times \sin \beta$ (where S_{KEEL} is the keel span). Assuming a (see [Clause 7.2](#)) is $0,6 S_{KEEL}$ and $m_{KEEL} / m_{LDC} = 0,5$, an angle β greater than 20° could mean that load case 1 no longer gives the worse transverse bending.

A keel with large wings could also give rise to the same effect at much smaller angles. For users employing 3D structural analysis methods, it is recommended that the keel be modelled as a stiff member/framework and that the vertical force (F_3 or m_{LDC}) be applied at its correct vertical and transverse location. With suitable design discretion, it may also be possible to combine load cases 1 and 3 (see [Table C.1](#)).

Provided the transverse offset (a_v) is less than $m_{KEEL} / m_{LDC} \times a$ (see [Figure 3](#)), load case 1 will normally generate the larger transverse moment. This neglects the moment due to the vertical force (as per [Table C.1](#)) so resulting compliance factors close to unity (1.0) will require re-design. A value of a_v equal to the distance between the centreline of craft to furthest transverse dimension (as in [Figure 3](#)) may be a suitable starting point.



Key

- 1 area where load case 3 (vertical pounding) governs
- 2 area where load case 1 governs

Figure 3 — Simplified method for initial assessment of the effect of transverse offset of vertical load

7.8.4 Other combined load cases

As design responsibility is entirely vested in the user e.g the designer or builder exercising design responsibility, some users may wish to combine load cases given in this document which have been presented separately. For example it is possible that a canting keel craft might hit a floating object such that load cases 2 and 4 act simultaneously. Such cases are outside the scope of this document, as the combined load cases may not be used with the allowable stresses given in [Clause 5](#).

8 Computational methods

8.1 General

This document recognizes that some structural components within its scope are best analysed using 3D numerical procedures (e.g. box keels, girder and floor grillage frames), using defined load cases and associated stress factors/factors of safety. The stress assessment is left to the discretion of the user, subject to the criteria given in [Clause 8.2](#).

In order to assist users designing conventional keel structures, [Annexes B](#) to [F](#) contain a series of simplified strength assessment methods which may be considered established practice for conventional keel configurations.

8.2 General guidance for assessment by 3D numerical procedures

IMPORTANT — It is good design practice to compare scantlings derived from this subclause with those derived from [subclause 8.3](#). A technical explanation shall be provided by the user e.g. the designer in cases where 3D numerical procedures give significantly lower scantlings than the assessment specified in [8.3](#).

Reference can also be made to Clause 11.6 of ISO 12215-5:2019.

8.2.1 3D numerical procedures

The term “3D numerical procedures” is intended to indicate any structural assessment method that is not limited to simple geometries. In most cases, the term will correspond to **finite element analysis**.

8.2.2 Material properties

Irrespective of the numerical method, the design stresses of any material shall be taken as stated in [Clause 5](#).

8.2.3 Boundary assumptions

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

8.2.4 Load application

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

8.2.5 Model idealization

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

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 ensure that buckling modes of failure are precluded. This can normally be accounted for by respecting the allowable slenderness ratios for beams and flanges as outlined in ISO 12215-5.

Non-linear analysis is required for accurate analysis of bolted structures using contact algorithms.

8.3 Assessment by strength of materials/non-computational-based methods

The methods outlined in [Annexes C](#) and [D](#) contain a series of standard beam/plate theory-based methods and other simplified procedures. Many of these derive from established practice and have been validated by long-term use. In general, the methods are considered to be conservative. The methods will work well for one- and two-dimensional structures of isotropic material construction.

9 Compliance

Compliance with this document may be claimed if:

- a) The user documents that the requirements of [Clauses 5 to 7](#) and [Annex A](#) have been met, that this [Clause 9](#) has been adhered to, including the Notes below as applicable, as well as any of the established practices given in [Annexes B to F](#) that are relevant. However, where one of [Annexes B to F](#) or a part thereof is not used, the user shall justify and explain the choice of the alternative scantling assessment methods that have been used, in accordance with [Clause 8](#), to meet these requirements and record these details when completing [Annex A](#). Such documentation evidences the claim.

or

- b) The user documents that the requirements of [Clauses 5 to 7](#), [Annex A](#) and [Annexes B to F](#) (established practice) have been met, that this [Clause 9](#) has been adhered to, including the Notes below as applicable, *in their entirety*. Such documentation evidences the claim.
- [Annex A](#), an application declaration by the user showing how this document has been used, is normative. It shall be completed for compliance in the case of either a) or b) described above;
 - [Annex B](#) shall be used for metals and fastener/bolt material choice, and provides established practice for fastener/bolt tightening and welded keels;
 - [Annex C](#) gives established practice for structural arrangements in respect of the ballast keel;
 - [Annex D](#) gives established practice for calculating keel fin strength (fixed or canting) and fixed ballast keels connected by fasteners/bolts;
 - [Annex E](#) gives information on the geometric properties of typical appendage shapes (second moment, section modulus, etc.);
 - [Annex F](#) gives information on simplified fatigue stress assessment.

NOTE 1 The scantling requirements of this document correspond to the minimum strength requirements for sailing craft operated in a safe and responsible manner with due regard for the operating conditions. No sailing craft can be designed to survive the most extreme load cases, such as very severe grounding, collisions or extreme sea states. Minimum compliance implies that the craft will be able to cope with heavy seas and moderate impact loads while minimising structural damage. Users e.g. builders or designers should not systematically seek minimum compliance as variability in construction, use and maintenance would lead to *de facto* non-compliance. Initial and ongoing scheduled condition surveys by an independent qualified organisation, especially after grounding, are strongly recommended and are further described below.

NOTE 2 Scantlings derived from this document are primarily intended to apply to recreational craft, including commercial charter vessels. As stated in the Introduction, Annex J of ISO 12215-5:2019 provides additional requirements for commercial craft and workboats, which may be considered applicable to racing craft where their usage conditions also warrant a maintenance and survey program set up by an independent qualified organization.

NOTE 3 Re-occurring inspection and survey is just as important as new-build inspection and survey procedures, as it would identify any metallic corrosion that has developed, in consideration of not only the damage but the possibility of chemical degradation of any metal alloys employed. At the same time, cracks from weld fatigue may be revealed.

The design of ongoing inspection procedures should be done by a suitably qualified independent organization, on a case-by-case basis. For example, appropriate non-destructive technologies (NDT) may be stipulated. For a cast or solid milled or forged keel, a visual inspection assisted by dye penetrant may be sufficient once coatings are removed at the most critical areas, dictated on a case-by-case basis. A welded keel may require different methods such as ultrasound or x-ray.

Re-inspection frequency may be better determined on a distance-sailed basis, as opposed to a time basis such as three-yearly, as determined by the independent organization designing and conducting the inspection regime.

Annex A

(normative)

Application declaration

The following declaration shall be completed by the user (e.g. the designer or builder). It shall be included as part of the scantling report, so that third parties may readily determine the extent to which the user has applied this document.

Relevant Clause/Annex of ISO 12215-9		Applied		Notes
5	Design stresses	Yes []	No []	"No" means non-compliance with these clauses and, consequently, ISO 12215-9.
6	Structural components to be assessed	Yes []	No []	
7	Load cases	Yes []	No []	
8	Computational methods	Annexes B–F -based []		Enter "[X]" for all of B–F below (grey section).
		Alternative methods []		Enter "[X]" for none of B–F below (grey section).
		Mix of Annexes <i>and</i> alternative methods []		Enter "[X]" in the case of selected Annexes (grey section), listing those used here: _____
9	Compliance claimed	Yes []	No []	"No" means non-compliance with ISO 12215-9.
B	Information on metals for appendages and fasteners and <i>established practice</i> for fastening and welding	Clauses used: All [] None [] Selected []		If "All [X]", no further details need be supplied. If "None [X]", supply full description of alternative methods, including background and validation. If "Selected [X]", supply full description of alternative methods, including background and validation for those areas NOT covered by the Annexes B–F clauses used. NOTE In this context, "supply" means technical documentation appropriate to the application of the standard, e.g. notified body or plan review submission. Provide details on additional pages, as needed.
C	Established practice structural arrangement for ballast keel	Clauses used: All [] None [] Selected []		
D	Established practice calculation of keel fin strength (fixed or canting) and fixed ballast keel connected by bolts	Clauses used: All [] None [] Selected []		
E	Geometrical properties of some typical appendage aerofoil shapes	Clauses used: All [] None [] Selected []		
F	Simplified fatigue strength assessment (Required for welded keels)	Clauses used: All [] None [] Selected []		