INTERNATIONAL STANDARD

ISO 12215-9

First edition
2012-06-15

Small craft — Hull construction and scantlings —

Part 9: **Sailing craft appendages**

Petits navires — Construction de la coque et échantillonnage —

Partie 9: Appendices des bateaux à voiles

Reference number
ISO 12215-9:2012(E)

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Published in Switzerland

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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.

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

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

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

ISO 12215-9 was prepared by Technical Committee ISO/TC 188, *Small craft*.

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

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

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

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

— *Part 4: Workshop and manufacturing*

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

— *Part 6: Structural arrangements and details*

— *Part 7: Scantling determination of multihulls*

— *Part 8: Rudders*

— *Part 9: Sailing craft appendages*

Introduction

The reason underlying the preparation of this part of ISO 12215 is that standards and recommended practices for loads on the hull and the dimensioning of small craft differ considerably, thus limiting the general worldwide acceptability of craft.

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

This part of ISO 12215 specifies the design loads and their associated stress factors. The user then has a choice between one or the other of the following available options for assessing the structural arrangement.

a) Use of advanced engineering methods which allow the structure to be modelled as three-dimensional: suitable methods include finite element analysis and subsets thereof such as matrix displacement or framework methods. General guidance is provided on modelling assumptions within this part of ISO 12215.

b) Use of simplified, generally two-dimensional, “strength of materials”-based stress equations: These are presented in Annexes B to F and, if this option is chosen, use of the equations will be necessary to fulfil the requirements of this part of ISO 12215.

This part of ISO 12215 has been developed applying present practice and sound engineering principles. The design loads and criteria of this part of ISO 12215 may be used with the scantling determination equations of this part of ISO 12215 or using equivalent engineering methods as indicated in a), above.

The dimensioning according to this part of ISO 12215 is regarded as reflecting current practice, provided the craft is correctly handled in the sense of good seamanship and equipped and operated at a speed appropriate to the prevailing sea state.

During the latter stages of the development of the ISO 12215 series, and after publication of key parts, a number of authorities adopted this International Standard for the assessment of high-performance racing yachts. While, in theory, a category A blue-water cruising yacht could experience the same loads as a competitive racing yacht, the latter has not been the principal focus of ISO 12215. Consequently, designers are strongly cautioned against attempting to design high-performance racing craft such that nearly all structural components only just comply.

Small craft — Hull construction and scantlings —

Part 9:
Sailing craft appendages

1 Scope

This part of ISO 12215 defines the loads and specifies the scantlings of sailing craft appendages on monohull sailing craft with a length of hull, L_H, of up to 24 m, measured according to ISO 8666. 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.

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, *Mechanical properties of corrosion-resistant stainless steel fasteners — Part 1: Bolts, screws and studs*

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 12215-5:2008, *Small craft — Hull construction and scantlings — Part 5: Design pressures for monohulls, design stress, 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.

3.1
design category
sea and wind conditions for which a craft is assessed to be suitable, provided the craft is correctly handled in the sense of good seamanship and operated at a speed appropriate to the prevailing sea state

3.1.1
design category A
"ocean category"
category of craft considered suitable to operate in seas with significant wave heights above 4 m and wind speeds in excess of Beaufort Force 8, but excluding abnormal conditions such as hurricanes

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

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

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

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

NOTE 1 The displacement includes all possible options (generator, air conditioning, etc.).

NOTE 2 The loaded displacement mass is expressed in kilograms.

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

NOTE 1 For the headsails, A_S considers the area of the fore triangle.

NOTE 2 The area of the wing-mast(s) is included in A_S.

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 The mass of keel is expressed in kilograms.

4 Symbols

For the purposes of this document, unless specifically otherwise defined, the symbols given in Table 1 apply.

Table 1 — Symbols, coefficients, parameters in the main core of ISO 12215-9

Symbol	Unit	Designation/meaning of symbol	(Sub)clause/table concerned
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
c	m	Distance along keel centreline from keel junction to floor mid-height	7
c_a	m	Average value of c for several floors	7.5
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	7.5.2
h_{F4}	m	Height of application of force F_4 (load case 4)	7.5.2
k_{DC}	1	Design category coefficient	5, Table 2
k_{LC}	1	Load case coefficient	5, Table 3
k_{LD}	1	Length displacement coefficient	7.7.1
k_{MAT}	1	Material coefficient	5, Table 2
L_{WL}	m	Length of waterline in m_{LDC} conditions	7.5.2, 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
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
α	deg.	Angle of attack of centreboard foil	7.7
ε_R	%	Elongation at break	Table 2
θ	deg.	Angle between keel axis and centreline for canting keels	7.3

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:

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

where

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

- for metal in unwelded state or well clear of 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 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 due to less severe dynamic loadings than in higher design categories.

Table 2 gives details on these variables.

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 heat-affected zone (HAZ), or σ_{tu}, σ_{cu}, σ_{fu}, σ_{bu} or τ_u for wood and FRP — shall be taken

- in accordance with ISO 12215-5:2008, i.e. according to tests or default values specified in its Annex C for FRP, its Annex D for sandwich core, and its Annex E 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]	$\min.\left(st_y; 0{,}5 \times st_u\right)$ [b,c]
	Metals, within HAZ, in welded condition[a]	$\min.\left(st_{yw}; 0{,}5 \times st_{uw}\right)$ [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, ε_R % ≥ 7	0,75
	Metals with elongation at break, ε_R % <7	min.(0,0625ε_R + 0,3125;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 also the Note in F.3.4.3).

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

c Bearing stress depends on material type (Ref [8] gives σ_{ub}/σ_{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 ε_R ≥ 7%, and 0,375 for ε_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	—	0,9
3	Keel vertical pounding	7.4	1
4	Keelboat 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 materials components. The design stress of bolts is lower than that of other structural components so as to recognize stress concentration effects in bolts and accord with long-standing design practice.

b The requirements of this part of ISO 12215 are strength-criteria based. 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 part of ISO 12215.

6 Structural components to be assessed

CAUTION — Keel loss has been found on several occasions to be attributable to insufficient thickness of bottom plating in respect of the keel, in particularly, connecting bolts or inadequate load paths between connecting bolts and the corresponding structure, including bolts located too far from the relevant stiffener. 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 of Table D.2, item 3.

The following shall be considered when assessing or designing the structure covered by this part of ISO 12215.

— 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 bolt zone into the hull structure: in the case of bolted keels on a hull bottom of sandwich construction, the general practice outlined in Annex D is to have a single skin construction for keel and bolts. If this is not the case, the structural arrangement shall ensure that all loads — keel compression loads, bolt preload, etc. — are safely transferred, using proper core material, inserts, etc. The risk of water permeating the sandwich core via the bolt holes shall be seriously considered.

— Backing plates/washers, where relevant.

— Floors, girders and associated supporting structure.

— Keel boxes.

— Fins, foils, centreboards, dagger boards.

Wherever possible, assessment should be conducted by numerical methods in accordance with Clause 8. Alternatively the “established practice” methods given Clause 9 shall be used.

Where calculation procedures do not exist, assessment should be conducted by a combination of semi-empirical methods and the established practice 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 (see references in the list below) **— where keels have a large rake 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 bending about the fore and aft axis, equal to the weight of the fin/bulb multiplied by the horizontal distance between the fin/bulb longitudinal centre of gravity (LCG) and root/bolt group LCG. In such cases, it will be necessary to combine direct stresses owing to bending with shear stresses due to the torque. The resulting von Mises equivalent stress shall not exceed the design stress given in Equation (1).** See also 7.8.1.

The design stress shall be assessed for each load case using Equation (1), together with the design stress coefficients given in Tables 2 and 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/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, considering a longitudinal impact with a fixed or floating object or animal;

— 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 bring combined stresses.

NOTE On ballast keels, any buoyancy or lifting forces (as the craft is considered to have stopped) which have been exerted have been neglected for simplification, making all calculations slightly conservative.

7.1.2 Limitation of load cases

This part of ISO 12215 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” in the sense that they are used in conjunction with static design stresses according to Tables 2 and 3.

This presumes a certain relationship between static strength and fatigue strength, which is generally preserved for unwelded metals of modest static strength and low stress concentration effects. However, for welded structures and poor detail design/fabrication, compliance with the “static” load cases cannot guarantee that fatigue failure will not occur. In such cases, an explicit fatigue life assessment or inspection regime shall be considered. See Annex F.

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 newtons (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 newton metres (N·m) as the keel heeling design moment at the keel junction

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

expressed in newton metres (N·m), keel heeling moment at floor mid height

where

a is the distance, in metres (m), along the keel centreline, from the keel CG to the keel's junction with the hull or tuck;

c is the distance, in metres (m), along the keel centreline from the keel junction to the floor at mid-height;

g is the acceleration of gravity, taken as 9,81 m/s^2 and used throughout this part of ISO 12215.

For craft fitted with a fin and tuck [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 gives 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 in upwind passages, with an additional dynamic overload factor which represents the additional fluctuating load experienced as the craft progresses in an adverse seaway.

Load case 2 represents the normal upwind sailing condition for a craft with canted keel, but is augmented by a 40 % dynamic overload factor[1)] to allow for unusual combinations of rigid body motions and accelerations, and is thereby considered to constitute an infrequently occurring case, i.e. fatigue is not expected to be an issue required to be considered, except for welded metals relevant to 7.1.2:

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

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

$$M_{2.1} = F_2 \times a \times \sin(30° + \theta) \quad (6)$$

expressed in newton metres (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 30º.

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

NOTE 2 Very thin fins of canting keel, especially those of FRP construction, may need a “flutter” (vibration) analysis, but this is considered outside the scope of this part of ISO 12215 (see 7.1.2).

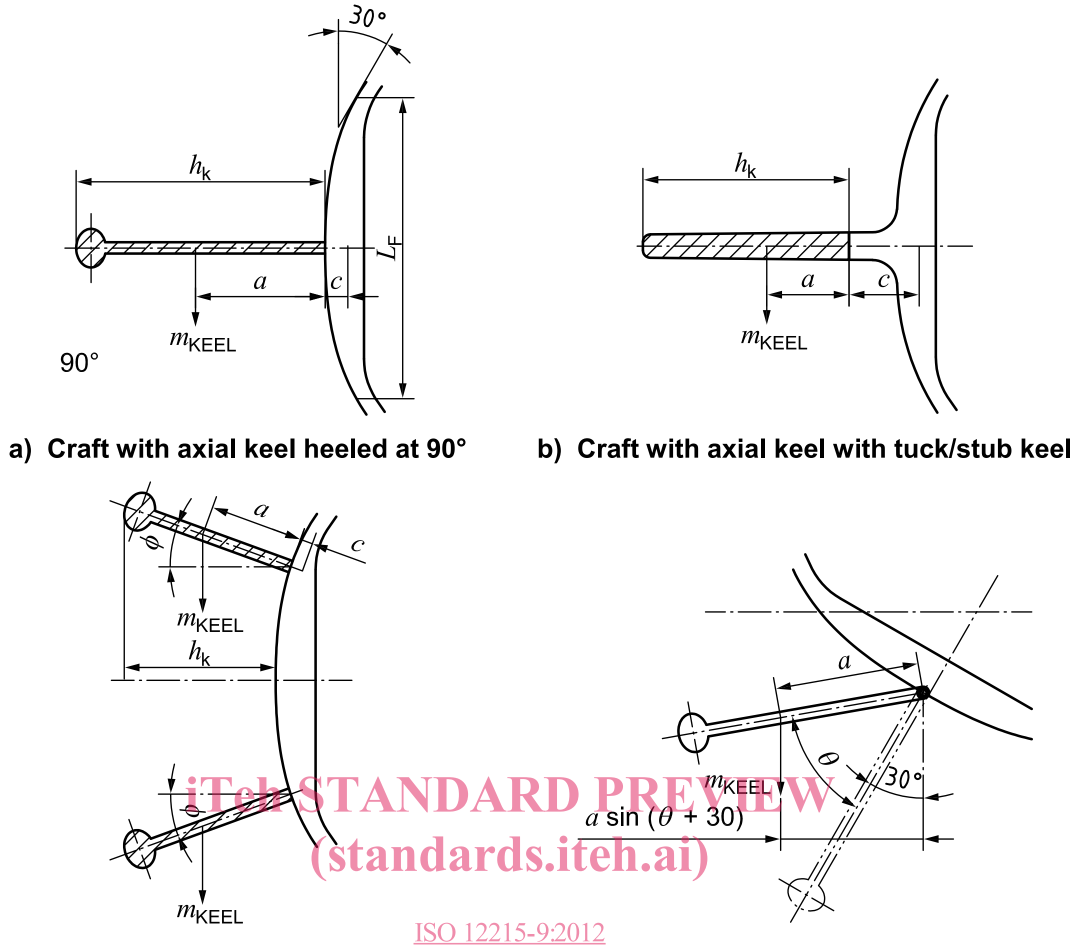
For calculation of floors, the keel design heeling moment of supporting structure floors is

$$M_{2.2} = F_2 \times \left[a \times \sin(30° + \theta) + 0{,}5\, c \right] \quad (7)$$

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

Annex C gives 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.

1) The dynamic overload factor for normal sailing conditions is in the order of 15–20 %.



a) Craft with axial keel heeled at 90°

b) Craft with axial keel with tuck/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 at least up to $0{,}01L_{WL}$ above the deepest load waterline, in order to ensure water tightness in case of leakage or loss of keel. This water tightness may be achieved by flexible elements, e.g. bellows.

Structural elements shall be provided to support the efforts from the canting keel head, in case of leakage or a defect in the orientation rams or system, and to protect the surrounding structure, e.g. stops, locking pin, etc.

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:

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

expressed in newtons (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.