# Section 2

# Hull Structures

## A. General, Definitions

### 1. Notations

#### 1.1 Restricted service ranges

For determining the scantlings of the longitudinal and transverse structures of yachts intended to operate within one of the restricted service ranges **M**, **K(50)**, **K(20)**, and **W** according to Section 1, A.7., the design loads may be reduced as specified in the particular case.

#### 1.2 Strengthening for navigation in ice

For yachts with 24 m ≤ **L** ≤ 48 m additional requirements have to be agreed upon with GL in each individual case.

For yachts with **L** > 48 m reference is made to the GL Rules Part 1 – Seagoing Ships, Chapter 1 – Hull Structures, Section 15.

#### 1.3 Further notations

Further Class Notations are given in Part 0 – Classification and Surveys.

### 2. Equivalence

Yachts deviating from the GL Rules for Construction and Classification in their type, equipment or in some other parts may be classed, provided that their structures or equipment is found to be equivalent to GL's requirements for the respective class.

### 3. Ambient conditions

The ambient conditions including inclinations and movements of the yacht, its environment as well as vibrations and noise to be experienced are described in Section 1, A.8. and A.9.

### 4. Accessibility

All parts of the hull shall be accessible for survey and maintenance, as far as feasible.

### 5. Stability

The requirements for stability of yachts are defined in Section 3, D.

### 6. Definitions

#### 6.1 General

Unless noted otherwise, the dimensions according to 6.2 and 6.3 are to be inserted in [m] into the formulae stated in the following.

#### 6.2 Principal dimensions

##### 6.2.1 Length L

The length **L** of the yacht is the distance on the waterline at full displacement, from the fore side of the stem to the centre of the rudder stock. **L** is not to be less than 96 % and need not to be greater than 97 % of the extreme length of the full displacement waterline. In yachts with unusual stern and bow arrangement, the length **L** will be specially considered.

##### 6.2.2 Length $L_c$ (according to LLC 66, MARPOL 73/78, IBC-Code and IGC-Code)

The length $\mathbf{L_c}$ is to be taken as 96 % of the total length on a waterline at 85 % of the least moulded depth $H_c$ , measured from the top of the keel, or as the length from the foreside of the stem to the axis of the rudder stock on that waterline, if that be greater. In yachts designed with a rake of keel the waterline on which this length is measured shall be parallel to the design waterline.

For the definition of the least moulded depth $H_c$ see **LLC 66**, Annex I, Chapter I, Regulation 3(5).

##### 6.2.3 Length $L^*$ (according to SOLAS 74, Chapter II-1, Reg. 2)

The length $\mathbf{L^*}$ of the yacht is the length measured between perpendiculars taken at the extremities of the deepest subdivision loadline.

##### 6.2.4 Subdivision length $L_s$

Reference is made to the definition in **SOLAS 74**, Chapter II-1, Reg.25 – 2.2.1.

##### 6.2.5 Forward perpendicular FP

The forward perpendicular coincides with the foreside of the stem on the waterline on which the respective length **L**, $\mathbf{L_c}$, $\mathbf{L^*}$ is measured.

#### 6.2.6 Aft perpendicular AP

The aft perpendicular coincides with a point at the distance **L** aft of **FP**.

#### 6.2.7 Breadth B

The breadth **B** is the greatest moulded breadth of the yacht.

***Note***

*The moulded breadth depends on the construction material of the hull:*

– *steel and aluminium hull:*
  *referring to inner edge of the shell*

– *all other materials:*
  *referring to outer edge of the shell*

*The term "moulded" applies for other dimensions accordingly.*

#### 6.2.8 Depth H

The depth **H** is the vertical distance, at the middle of the length **L**, from the base line to top of the deck beam at side on the uppermost continuous deck.

In way of effective superstructures, the depth is to be measured up to the superstructure deck for determining the yacht's scantlings.

#### 6.2.9 Draught T

The draught **T** is the vertical distance, at the middle of the length **L,** from base line to full displacement waterline.

#### 6.2.10 Hull draught $T_H$

The hull draught $\mathbf{T_H}$ is the maximum draught of the canoe body of the yacht.

### 6.3 Frame spacing a

The frame spacing **a** will be measured from moulding edge to moulding edge of frames.

### 6.4 Block coefficient $C_B$

Moulded block coefficient at full displacement draught **T**, based on the rule length **L:**

$$C_B = \frac{\nabla}{\mathbf{L} \cdot \mathbf{B} \cdot \mathbf{T}}$$

$\nabla$ = moulded volume up to the full displacement waterline [m³]

### 6.5 Yacht's speed $v_0$

The yacht's speed $v_0$ [kn] is the expected maximum ahead speed of the yacht in calm water, at the full displacement waterline.

### 6.6 Moulded displacement Δ

The moulded displacement Δ is the weight of the yacht [t] at draught **T.**

### 6.7 Definition of decks

#### 6.7.1 Bulkhead deck

Bulkhead deck is the deck up to which the watertight bulkheads are carried.

#### 6.7.2 Freeboard deck

Freeboard deck is the deck upon which the freeboard calculation is based.

#### 6.7.3 Strength deck

Strength deck is the deck or the parts of a deck which form the upper flange of the effective longitudinal structure.

#### 6.7.4 Weather deck

All free decks and parts of deck exposed to the sea are defined as weather decks.

#### 6.7.5 Shelter deck

Decks which are not accessible to guests and which are not subject to sea pressure. Crew can access such deck with care and taking account of the admissible load, which is to be clearly indicated.

#### 6.7.6 Accommodation deck

Accommodation deck is a deck which is not exposed to the sea and serves as a basis for usual crew or guest accommodation.

#### 6.7.7 Superstructure deck

The superstructure decks situated immediately above the uppermost continuous deck are termed forecastle deck, bridge deck and poop deck.

### 6.8 Coordinate system

For the description of the yacht's geometry the fixed, right-handed coordinate system 0, x, y, z as defined in Fig. 2.1 is introduced. The origin of the system is situated at the aft perpendicular, at centreline and on the moulded baseline at the yacht's keel. The x-axis points in longitudinal direction of the yacht positive forward, the y-axis positive to port and the z-axis positive upwards. Angular motions are considered positive in a clockwise direction about the three axes.

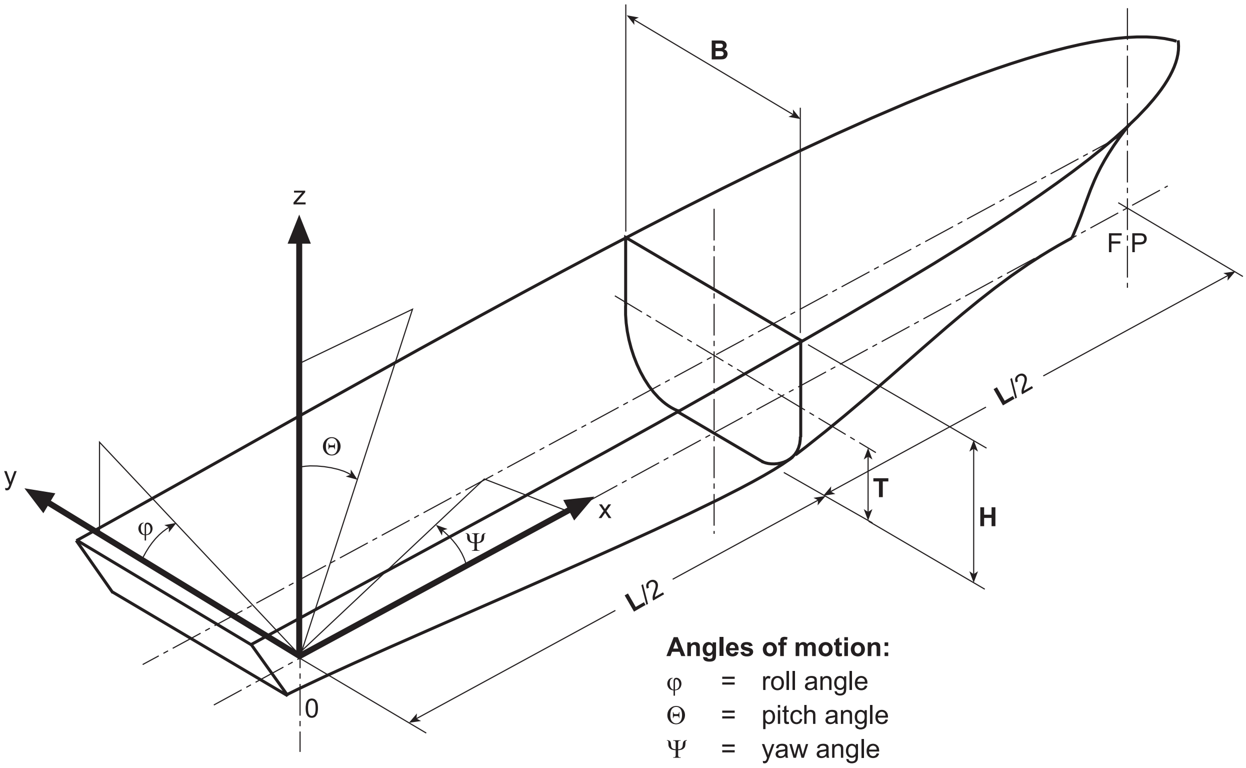



**Fig. 2.1 Coordinate system and angles of motion**

## 7. Computer programs

### 7.1 General

**7.1.1** In order to increase the flexibility in the structural design of yachts, GL also accepts direct calculations with computer programs. The aim of such analyses should be the proof of equivalence of a design with the rule requirements.

**7.1.2** Direct calculations may also be used to optimise a design; in this case only the final results are to be submitted for examination.

### 7.2 General programs

**7.2.1** The choice of computer programs according to the "State of the Art" is free. The programs may be checked by GL through comparative calculations with predefined test examples. A generally valid approval for a computer program is, however, not given by GL. GL reserve the right to refuse computer programs.

**7.2.2** Direct calculations may be applied regarding:

– global strength

– longitudinal strength

– beams and grillages

– strength of structural details

**7.2.3** For such calculations, the structural model, boundary conditions and load cases are to be agreed upon with GL.

Calculation documents are to be submitted including input and output. During the examination it may prove necessary that GL perform independent comparative calculations.

## 8. Workmanship

### 8.1 Requirements to be complied with by the manufacturer

**8.1.1** Every manufacturing plant participating in a yacht project must be provided with suitable equipment and facilities to enable proper handling of the materials, manufacturing processes, structural components, etc. GL reserve the right to inspect the plant accordingly or to restrict the scope of manufacture to the potential available at the plant.

The manufacturing plant must have at its disposal sufficiently qualified personnel. GL must be advised of the names and areas of responsibility of all supervisory and control personnel. GL reserve the right to require proof of relevant qualification.

**8.1.2** The shipyard or manufacturing plant and its subcontractors must get approval from GL for the type of work provided for the manufacture and installation of yachts. Approval can only be awarded if the conditions defined in detail in the GL Rules II –Materials and Welding are fulfilled.

**8.1.3** The fabrication sites, stores and their operational equipment shall comply also with the requirements of the relevant Safety Authorities and Professional Associations. The shipyard or manufacturing plant is alone responsible for compliance.

### 8.2 Quality control

**8.2.1** It is recommended that the shipyard operates a quality assurance system, like ISO 9001 or equivalent.

**8.2.2** As far as required and expedient, the manufacturer's personnel has to examine all structural components both during the manufacture and on completion, to ensure that they are complete, that the dimensions are correct and that workmanship is satisfactory and meets the standard of good shipbuilding practice.

**8.2.3** Upon inspection and corrections by the manufacturing plant, the structural components are to be shown to the GL Surveyor for inspection, in suitable sections, normally in unpainted condition and enabling proper access for inspection.

**8.2.4** The Surveyor may reject components that have not been adequately checked by the plant and may demand their re-submission upon successful completion of such checks and corrections by the plant.

## 9. Structural details

### 9.1 Details in manufacturing documents

**9.1.1** All significant details concerning quality and functional ability of the components concerned shall be entered in the manufacturing documents (workshop drawings, etc.). This includes not only scantlings but, where relevant, such items as surface conditions (e.g. finishing of flame cutting edges and weld seams), and special methods of manufacture involved as well as inspection and acceptance requirements and, where relevant, permissible tolerances.

For details of welded joints see the GL Rules II - Materials and Welding, Part 3 – Welding, Chapter 2 – Design, Fabrication and Inspection of Welded Joints, Annex A (Steel) and B (Aluminium).

For details of adhesive joints see the GL Rules II – Materials and Welding, Part 2 – Non-metallic Materials, Chapter 1 – Fibre Reinforced Plastics and Adhesive.

**9.1.2** If, due to missing or insufficient details in the manufacturing documents, the quality or functional ability of the component cannot be guaranteed or is doubtful, GL may require appropriate improvements. This includes the provision of supplementary or additional parts (for example reinforcements) even if these were not required at the time of plan approval or if - as a result of insufficient detailing - such requirement was not obvious.

### 9.2 Cut-outs, plate edges

**9.2.1** The free edges (cut surfaces) of cut-outs, hatch corners, etc. are to be properly prepared and are to be free from notches. As a general rule, cutting drag lines, etc. must not be welded out, but are to be smoothly ground. All edges should be broken or in cases of highly stressed parts, should be rounded off.

**9.2.2** Free edges on flame or machine cut plates or flanges are not to be sharp cornered and are to be finished off as laid down in 9.2.1. This also applies to cutting drag lines, etc., in particular to the upper edge of shear strake and analogously to weld joints, changes in sectional areas or similar discontinuities.

### 9.3 Cold forming

**9.3.1** For cold forming (bending, flanging, beading) of plates the minimum average bending radius should not fall short of 3 times the plate thickness t. For the welding of cold formed areas special requirements have to be agreed.

**9.3.2** In order to prevent cracking, flame cutting flash or sheering burrs must be removed before cold forming. After cold forming all structural components and, in particular, the ends of bends (plate edges) are to be examined for cracks. Except in cases where edge cracks are negligible, all cracked components are to be rejected. Repair welding is not permissible.

### 9.4 Assembly, alignment

**9.4.1** The use of excessive force is to be avoided during the assembly of individual structural components or during the erection of sub-assemblies. As far as possible, major distortions of individual structural components should be corrected before further assembly.

**9.4.2** Girders, beams, stiffeners, frames, etc. that are interrupted by bulkheads, decks, etc. must be accurately aligned. In the case of critical components, control drillings are to be made where necessary, which are then to be welded up again on completion.

**9.4.3** After completion of welding, straightening and aligning must be carried out in such a manner that the material properties will not be influenced significantly. In case of doubt, GL may require a procedure test or a working test to be carried out.

### 9.5 Combination of different materials

**9.5.1** Preventive measures are to be taken to avoid contact corrosion associated with combination of dissimilar metals with different potentials in an electrolyte environment, such as sea water.

**9.5.2** The selection of different materials has to take into account the fact that also combination of composite materials, like fibre reinforced plastics, sandwich constructions, etc. and wood with each other or also with metals may lead to contact corrosion.

**9.5.3** In addition to selecting appropriate materials, steps such as suitable insulation, an effective coating and the application of cathodic protection can be taken in order to prevent contact corrosion.

**9.5.4** The selected solutions for protection have to be presented to GL for approval.

### 10. Corrosion protection

B.6. is to be observed.

## B. Materials, Corrosion Protection and Joining Technology

### 1. General

All materials to be used for the structural members mentioned in these Rules are to be in accordance with the GL Rules II – Materials and Welding, Part 1 – 3. Materials the properties of which deviate from these rule requirements may only be used upon special approval by GL.

### 2. Steel materials and welding

### 2.1 Normal strength hull structural steel

Normal strength hull structural steel is a hull structural steel with a minimum nominal upper yield point $R_{eH}$ of 235 N/mm² and a tensile strength $R_m$ of 400 – 520 N/mm².

**2.1.1** The material factor k in the formulae of C., D., G., J. in the following is to be taken 1,0 for normal strength hull structural steel.

**2.1.2** Normal strength hull structural steel is grouped into the grades GL–A, GL–B, GL–D, GL–E, which differ from each other in their toughness properties. For the application of the individual grades for the hull structural members see 2.3.

**2.1.3** If for special structures the use of steels with yield properties less than 235 N/mm² has been accepted, the material factor k is to be determined by:

$$k = \frac{235}{R_{eH}}$$

### 2.2 Higher strength hull structural steels

Higher strength hull structural steel is a hull structural steel, the yield and tensile properties of which exceed those of normal strength hull structural steel. For three groups of higher strength hull structural steels the nominal upper yield stress $R_{eH}$ has been fixed at 315, 355 and 390 N/mm² respectively. Where higher strength hull structural steel is used, for scantling purposes the values in Table 2.1 are to be used for the material factor k mentioned in C., D., G., J. of the following:

**Table 2.1 Material factors for higher strength hull structural steel**

| $R_{eH}$ [N/mm²] | k |
|---|---|
| 315 | 0,78 |
| 355 | 0,72 |
| 390 | 0,66 |

For higher strength hull structural steel with other nominal yield stresses, the material factor k may be determined by the following formula:

$$k = \frac{295}{R_{eH} + 60}$$

***Note***

*Especially when higher strength hull structural steels are used, limitation of permissible stresses due to buckling and fatigue strength criteria may be required.*

**2.2.1** Higher strength hull structural steel is grouped into the following grades, which differ from each other in their toughness properties:

GL–A 32/36/40

GL–D 32/36/40

GL–E 32/36/40

GL–F 32/36/40

In Table 2.2 the grades of the higher strength steels are marked by the letter "H".

**2.2.2** Where structural members are completely or partly made from higher strength hull structural steel, a suitable notation will be entered into the yacht's certificate.

**2.2.3** In the drawings submitted for approval it is to be shown which structural members are made of higher strength hull structural steel. These drawings are to be placed on board in case any repairs are to be carried out.

### 2.3 Material selection for the hull

#### 2.3.1 Material classes

For the material selection for hull structural members material classes as given in Table 2.2 are defined.

#### 2.3.2 Material selection for longitudinal structural members

Materials of the various structural members are not to be of lower grades than those obtained from the Table 2.3. Depending on the categories of structural members (**Secondary**, **Primary** and **Special**) for structural members not specifically mentioned in Table 2.3, grade A/AH material may generally be used. Single plate strakes within 0,4 **L** amidships for which class III or E/EH material is required are to have a breadth b = 800 + 5 **L**, max. 1 800 mm.

**Table 2.2 Material classes**

| **Thickness t [mm]** [1] | | **> 15** | **> 20** | **> 25** | **> 30** | **> 40** | **> 60** |
|---|---|---|---|---|---|---|---|
| **Material class** | **≤ 15** | **≤ 20** | **≤ 25** | **≤ 30** | **≤ 40** | **≤ 60** | **≤ 100** |
| I | A/AH | A/AH | A/AH | A/AH | B/AH | D/DH | E/EH |
| II | A/AH | A/AH | B/AH | D/DH | D/DH | E/EH | E/EH |
| III | A/AH | B/AH | D/DH | E/EH | E/EH | E/EH | E/EH |

[1] Actual thickness of the structural member.

**Table 2.3 Material class or grade for longitudinal structural members**

| **Structural member category** | **Material class or grade** | |
|---|---|---|
| | **Within 0,4 L amidships** | **Outside 0,4 L amidships** |
| **Secondary:**<br>Lower strake of longitudinal bulkhead<br>Deck plating exposed to weather, in general<br>Side plating | I | A/AH |
| **Primary:**<br>Bottom plating, including keel plate<br>Strength deck plating [1]<br>Continuous longitudinal members<br>Upper strake in longitudinal bulkhead<br>Vertical strake | II | A/AH |
| **Special:**<br>Shear strake at strength deck<br>Stringer plate in strength deck<br>Deck strake at longitudinal bulkhead<br>Bilge strake [2] | III | II<br>(I outside 0,6 **L**) |

[1] Class III or grade E/EH to be applied in positions where high local stresses may occur.

[2] May be of class II in ships with a double bottom over the full breadth and with length less than 150 metres.

### 2.3.3 Material selection for local structural members

**2.3.3.1** The material selection for local structural members, which are not part of the longitudinal hull structure, may in general be effected according to Table 2.4.

**Table 2.4 Material class for local structural members**

| Structural member | Material class |
|---|---|
| Face plates and webs of girder systems | II [1] |
| Rudder body [2], rudder horn, sole piece, stern frame, propeller brackets | II |

[1] Class I material sufficient, where rolled sections are used or the parts are machine cut from normalized plates
[2] see 2.3.3.2

**2.3.3.2** Rudder body plates, which are subjected to stress concentrations (e.g. in way of lower support of semi-spade rudders), are to be of class III material.

**2.3.3.3** Members not specifically mentioned, may be of class I material.

For topplates of machinery foundations located outside 0,6 **L** amidships, grade A normal strength hull structural steel may also be used for thicknesses above 40 mm.

### 2.3.4 Structural members which are stressed in direction of their thickness

**2.3.4.1** Rolled materials, which are significantly stressed in direction of their thickness, are recommended to be examined for doublings and non-metallic inclusions by ultrasonic testing.

**2.3.4.2** In case of high local stresses in the thickness direction, e.g. due to shrinkage stresses in single bevel or double bevel T-joints with a large volume of weld metal, steels with guaranteed material properties in the thickness direction according to the GL Rules II – Materials and Welding, Part 1 – Metallic Materials, Chapter 2 – Steel and Iron Materials, Section 1, I. are to be used in order to avoid lamellar tearing.

### 2.4 Forged steel and cast steel

Forged steel and cast steel for stem, stern frame, rudder post, etc. is to comply with the GL Rules II – Materials and Welding, Part 1 – Metallic Materials. The tensile strength of forged steel and of cast steel is not to be less than 400 N/mm².

### 2.5 Austenitic steels

**2.5.1** Stainless steels with a pitting resistance equivalent W (W = % Cr + 3,3 · % Mo) exceeding 25 are suitable for sea water without special corrosion protection, see Table 2.5.

**Table 2.5 Designation and mechanical properties of austenitic stainless steels (in welded condition)**

| Material number | Designation according to EN 10088 | Sweden SS | USA AISI / SAE | Tensile strength $R_m$ [N/mm²] | Yield strength $R_{p0,2}$ [N/mm²] | Pitting resistance equivalent W |
|---|---|---|---|---|---|---|
| 1.4306 | X2CrNi19-11 | 2333 | 340 L | 500 – 650 | 200 | 18 |
| 1.4404 | X2CrNiMo17-12-2 | 2348 | 316 L | 520 – 670 | 220 | 23 |
| 1.4435 | X2CrNiMo18-14-3 | 2353 | 316 L [1] | 520 – 670 | 220 | 25 |
| 1.4438 | X2CrNiMo18-16-4 | 2367 | 317 L | 520 – 720 | 220 | 27 |
| 1.4439 | X3CrNiMoN17-13-5 | — | — | 580 – 780 | 270 | 33 |
| 1.4541 | X6CrNiTi18-10 | 2337 | 321 | 500 – 700 | 200 | 17 |
| 1.4462 | X2CrNiMoN22-5-3 | 2324 | 329 | 640 – 840 | 460 | 31 |
| 1.4571 | X6CrNiMoTi17-12-2 | 2350 | 316 Ti | 520 – 670 | 220 | 24 |

[1] valid for Mo > 2,5 %

**2.5.2** Where austenitic steels are applied having a ratio

$$\frac{R_{p0,2}}{R_m} \leq 0{,}5$$

on special approval the 1 % proof stress $R_{p1,0}$ may be used for scantling purposes instead of the 0,2 % proof stress $R_{p0,2}$.

### 2.6 Welding

The following information summarizes some principle aspects to be considered for the design of Yachts. Detailed requirements are contained in the GL Rules II – Materials and Welding, Part 3 – Welding.

#### 2.6.1 Information contained in manufacturing documents

**2.6.1.1** The shapes and dimensions of welds and, where proof by calculation is supplied, the requirements applicable to welded joints (the weld quality grade, detail category) are to be stated in drawings and other manufacturing documents (parts lists, welding and inspection schedules). In special cases, e.g. where special materials are concerned, the documents shall also state the welding method, the welding consumables used, heat input and control, the weld build-up and any post-weld treatment which may be required.

**2.6.1.2** Symbols and signs used to identify welded joints shall be explained if they depart from the symbols and definitions contained in the relevant standards (e.g. DIN standards). Where the weld preparation (together with approved methods of welding) conforms both to normal shipbuilding practice and to these Rules and recognized standards, where applicable, no special description is needed.

#### 2.6.2 Materials, weldability

**2.6.2.1** Only base materials of proven weldability may be used for welded structures. Any approval conditions of the steel or of the procedure qualification tests and the steelmaker's recommendations are to be observed.

**2.6.2.2** For normal strength hull structural steels grades A, B, D and E which have been tested by GL, weldability is considered to have been proven. No measures beyond those laid down in these welding rules need therefore to be taken.

**2.6.2.3** Higher strength hull structural steels grade AH/DH/EH/FH which have been approved by GL in accordance with the relevant requirements of Rules for Materials and Welding, have had their weldability examined and, provided their handling is in accordance with normal shipbuilding practice, may be considered to be proven.

**2.6.2.4** High strength (quenched and tempered) fine grain structural steels, low temperature steels, stainless and other (alloyed) structural steels require special approval by GL. Proof of weldability of the respective steel is to be presented in connection with the welding procedure and welding consumables.

**2.6.2.5** Cast steel and forged parts require testing by GL. The carbon content of components for welded structures must not exceed 0,23 % C (piece analysis not exceeding 0,25 % C).

**2.6.2.6** Welding consumables used are to be suitable for the parent metal to be welded and are to be approved by GL. Where filler materials having tensile properties deviating (downwards) from the parent metal are used (upon special agreement by GL) this fact must be taken into account when dimensioning the weld joints.

#### 2.6.3 Manufacture and testing

**2.6.3.1** The manufacture of welded structural components may only be carried out in workshops or plants that have been approved by GL. The requirements that have to be observed in connection with the fabrication of welded joints are laid down in II – Materials and Welding, Part 3 – Welding.

**2.6.3.2** The weld quality grade of welded joints without proof by calculation (see 2.6.1.1) depends on the significance of the welded joint for the total structure and on its location in the structural element (location relative to the main stress direction) and on its stressing. For details concerning the type, scope and manner of testing, see Rules II – Materials and Welding, Part 3 – Welding, Chapter 3 – Welding in the Various Fields of Application, Section 1, I.

#### 2.6.4 General design principles

**2.6.4.1** During the design stage welded joints are to be planned such as to be accessible during fabrication, to be located in the best possible position for welding and to permit the proper welding sequence to be followed.

**2.6.4.2** Both the welded joints and the sequence of welding involved are to be so planned as to enable residual welding stresses to be kept to a minimum in order that no excessive deformation occurs. Welded joints should not be over dimensioned.

**2.6.4.3** When planning welded joints, it must first be established that the type and grade of weld envisaged, such as full root weld penetration in the case of HV or DHV (K) weld seams, can in fact be perfectly executed under the conditions set by the limitations of the manufacturing process involved. If this is not the case, a simpler type of weld seam shall be selected and its possibly lower load bearing capacity taken into account when dimensioning the component.

**2.6.4.4** Highly stressed welded joints, which therefore, are generally subject to examination, are to be so designed that the most suitable method of testing for faults can be used (radiography, ultrasonic, surface crack testing methods) in order that a reliable examination may be carried out.

**2.6.4.5** Special characteristics peculiar to the material, such as the lower strength values of rolled material in the thickness direction or the softening of cold worked aluminium alloys as a result of welding, are factors which have to be taken into account when designing welded joints.

**2.6.4.6** In cases where different types of material are paired and operate in sea water or any other electrolytic medium, for example welded joints made between unalloyed carbon steels and stainless steels in the wear-resistant cladding in rudder nozzles or in the cladding of rudder shafts, the resulting differences in potential greatly increase the susceptibility to corrosion and must therefore be given special attention. Where possible, such welds are to be positioned in locations less subject to the risk of corrosion (such as the outside of tanks) or special counter-measures are to be taken (such as the provision of a protective coating or cathodic protection).

#### 2.6.5 Design details

For design details see the GL Rules Part 1 – Seagoing Ships, Chapter 1 – Hull Structures, Section 19.

## 3. Aluminium alloys and welding

The following information is based on the GL Rules II – Materials and Welding, Part 1 – Metallic Materials, Chapter 3 – Non-Ferrous Metals, Section 1 with the aim of summarizing aspects applicable for the design of Yachts.

### 3.1 General

**3.1.1** The following requirements are applicable to products made from wrought aluminium alloys having a product thickness of 3 to 50 mm inclusive. Requirements applicable to products having thicknesses outside this range are to be specially agreed with GL.

**3.1.2** Alloys and material conditions which differ from the specified requirements given below, but which conform to national standards or the manufacturer's material specifications may be used provided that their properties and suitability for use, and also their weldability have been checked by GL and that GL has approved their use.

**3.1.3** Alloy designations and material conditions specified herein comply with the designations of the Aluminium Association. With regard to the definition of the material conditions European standard EN 515 is applicable.

### 3.2 Requirements to be met by manufacturers

Manufacturers wishing to supply products in accordance with these requirements must be approved by GL for the alloys and product forms in question.

### 3.3 General characteristics of products

**3.3.1** The products must have a smooth surface compatible with the method of manufacture and must be free of defects liable to impair further manufacturing processes or the proposed application of the products, e.g. cracks, laps, appreciable inclusions of extraneous substances and major mechanical damage.

**3.3.2** Surface defects may be repaired only by grinding provided that this is accomplished with a gentle transition to the adjacent surface of the product and that the dimensions remain within the tolerance limits. Repair by welding is not permitted. For repair purposes only tools are to be used which are exclusively applied for aluminium processing.

### 3.4 Aluminium alloys without post treatment for hardening

**3.4.1** Aluminium alloys of 5000 series in 0 condition (annealed) or in H111 condition (annealed flattened) retain their original mechanical characteristics and therefore are not subject to a drop in mechanical strength in the welded areas.

**3.4.2** These types of aluminium alloys are used for plates, strips and rolled sections and a representative list is defined in Table 2.6. This list, as well as the list of Table 2.7, is not exhaustive. Other aluminium alloys may be considered provided the specification (manufacture, chemical composition, temper, mechanical properties, welding, etc.) and the scope of application is submitted to GL and approved.

**Table 2.6 Material condition and strength properties of plates and strips made of wrought aluminium alloys** (with thickness t = 3,0 to 50 mm) [1]

| **Alloy number** | **Material condition** | **$R_{p\,0,2}$ min. [N/mm²]** | **$R_m$ [N/mm²]** | **Material factor $k_{A\ell}$** |
|---|---|---|---|---|
| GL-AW-5083 (AlMg4,5Mn0,7) | 0/H111/H112 | 125 | 275 – 350 | 1,59 – 1,34 |
| | H116 | 215 | ≥ 305 | 1,22 |
| | H32 | 215 | 305 – 380 | 1,22 – 1,07 |
| | Welded | 125 | 275 | 1,59 |
| GL-AW-5086 (ALMg4) | 0/H111/H112 | 100 | 240 – 310 | 1,87 – 1,55 |
| | H116 | 195 | ≥ 275 | 1,35 |
| | H32 | 185 | 275 – 335 | 1,38 – 1,22 |
| | Welded | 100 | 240 – 310 | 1,87 – 1,55 |
| GL-AW-5754 (AlMg3) | 0/H111/H112 | 80 | 190 – 240 | 2,35 – 1,98 |
| | Welded | 80 | 190 – 240 | |
| EN-AW-5059 (AlMgMn0,8ZnZr) | 0/H111 | ≥ 160 | ≥ 330 | 1,30 |
| | H116 | ≥ 260 | ≥ 360 | 1,02 |
| | H321 | ≥ 260 | ≥ 360 | |
| | Welded | ≥ 160 | ≥ 300 | 1,38 |

[1] The strength properties are applicable to both longitudinal and transverse specimens.

**Table 2.7 Material condition and strength properties of extruded sections, bars and pipes made of wrought aluminium alloys** (with thickness t = 3,0 to 50 mm) [1]

| **Alloy number** | **Material condition** | **$R_{p\,0,2}$ min. [N/mm²]** | **$R_m$ [N/mm²]** | **Material factor $k_{A\ell}$** |
|---|---|---|---|---|
| GL-AW-5083 (AlMg4,5Mn0,7) | 0/H111 | 110 | 270 – 350 | 1,67 – 1,38 |
| | Welded | 125 | 275 | 1,59 |
| GL-AW-5086 (AlMg4) | 0/H111 | 95 | 240 – 350 | 1,90 – 1,43 |
| | Welded | 100 | 240 | 1,87 |
| GL-AW-6005A (AlSiMg(A)) | T5/T6 | 215 | ≥ 260 | 1,34 |
| | Welded | 115 | 165 | 2,27 |
| GL-AW-6061 (AlMg1SiCu) | T5/T6 | 240 | ≥ 260 | 1,27 |
| | Welded | 115 | 155 | 2,35 |
| GL-AW-6082 (AlSi1MgMn) | T5/T6 | 260 | ≥ 310 | 1,11 |
| | Welded | 125 | 185 | 2,05 |

[1] The strength properties are applicable to both longitudinal and transverse specimens.

**3.4.3** Unless otherwise specified, the Young's modulus of aluminium alloys is equal to 70 000 N/mm² and the Poisson's ratio equal to 0,33.

### 3.5 Hardened aluminium alloys

**3.5.1** Aluminium alloys can be hardened by work hardening (Series 5000 other than condition 0 or H111) or by heat treatment (series 6000).

**3.5.2** These types of aluminium alloys are used for extruded section, bars and pipes and a representative selection is defined in Table 2.7.

### 3.6 Material selection

**3.6.1** The choice of aluminium alloys according to Table 2.7 is mainly recommendable for extrusions and where no excessive welding will be necessary. Otherwise only the mechanical characteristics of 0 or H111 conditions can be taken into account. Higher mechanical characteristics to be used must be duly justified.

**3.6.2** In case of structures subjected to low service temperatures or intended for other particular applications, the alloys to be employed are to be defined in each separate case by GL, which will state the acceptability requirements and conditions.

**3.6.3** For forgings and castings to be applied, requirements for chemical composition and mechanical properties are to be defined in each separate case by GL.

### 3.7 Welding

#### 3.7.1 General requirements

For welding of aluminium the requirements of relevant GL Rules apply. In particular, existing welding procedure qualifications may be approved by GL or GL will decide if new qualifications will become necessary. Welding shops and the employed welders have to be approved for the relevant welding procedures.

#### 3.7.2 Influence of welding on mechanical characteristics

**3.7.2.1** Aluminium alloys of series 5000 in 0 condition (annealed) or in H111 condition (annealed flattened) are not subject to a drop in mechanical strength in the welded areas. But welding heat input lowers the mechanical strength of alloys of series 5000 with other conditions and of that of series 6000, which are hardened by heat treatment.

**3.7.2.2** For heat-affected welding zones **t**he mechanical characteristics of series 5000 to be considered are, normally, those of condition 0 or H111. Higher mechanical characteristics may be taken into account, provided they are duly justified.

**3.7.2.3** For heat-affected zones **t**he mechanical characteristics of series 6000 to be considered are, normally, to be indicated by the supplier.

**3.7.2.4** The heat-affected zone may be taken to extend 25 mm on each side of the weld axis.

#### 3.7.3 Preparation for welding

Edge cutting, to be carried out in general by machining, is to be regular and without burrs or cuts.

The structural parts to be welded as well as those adjacent, even if they have been previously pickled, are to be cleaned carefully before welding, using suitable mechanical means, such as stainless steel wire brushes, so as to eliminate oxides, grease or other foreign matter which could give rise to welding defects.

#### 3.7.4 Welding processes

**3.7.4.1** In general, the welding of the hull structures is to be performed with the MIG (metal-arc inert gas) or the TIG (tungsten-arc inert gas) processes using welding consumables recognized as suitable for the base material to be used. For joints with extreme stress and execution requirements (gas and liquid tight, etc.) the TIG method is recommendable, otherwise the MIG method may be used. Welding processes and filler materials other than those mentioned are to be individually considered by GL at the time of the approval of welding procedures.

**3.7.4.2** For the authorization to use welding procedures in production, the following details are to be stated:

– grade and temper of parent and filler materials

– weld execution procedures: type of joint (e.g. butt-joint, fillet joint); edge preparation (e.g. thicknesses, bevelling, right angle edges); welding position (e.g. flat, vertical, horizontal) and other parameters (e.g. voltage, amperage, gas flow capacity)

– welding conditions (e.g. cleaning procedures of edges to be welded, protection from environmental atmosphere)

– special operating requirements for butt-joints, for example for plating: welding to be started and completed on end pieces outside the joint, back chipping, arrangements for repairs consequent to possible arc restarts

– type and extent of controls during production

**3.7.4.3** Establishing high welding speeds to reduce the transfer of thermal loads is recommended.

**3.7.4.4** Impermissible reinforcements of seams and hardened transition areas in the basic material shall be carefully removed.

### 3.7.5 Inspections

**3.7.5.1** Inspections of welded connections by GL Surveyors are, in general, those specified below, with the extent of inspection to be defined by GL on a case by case basis:

– inspection of base materials for compliance with the requirements 3.4 to 3.6 and for compliance of structures with the approved plans

– inspection of the use and application conditions of welding procedures for compliance with those approved and verification that qualified welders are employed

– visual examination of edge preparations, root chipping and execution of welds in way of structural connections

– examination of radiographs of welded joints (radiographing is to be performed, if necessary, depending on the extent of the examinations), and inspection of performance of execution of the ultrasonic or magnetic particle examinations, which may be required

– inspection of any repairs, to be performed with procedures and inspection methods at the discretion of the GL Surveyor

**3.7.5.2** The limits for imperfections in welded joints of aluminium alloys are defined in the GL Rules II - Materials and Welding, Part 3 – Welding, Chapter 3 – Welding in the Various Fields of Application.

**3.7.5.3** Irrespective of the extent of such inspections, it is the responsibility of the builder to ensure that the manufacturing procedures, processes and sequences are in compliance with relevant GL requirements, approved plans and sound working practice. For this purpose, the shipyard is to have its own quality management system.

### 3.7.6 General design principles

The following design principles shall be applied:

– transfer of welding seams to low stress areas, like the neutral axis of a girder by using extruded sections for the upper and lower flange

– location of welding seams in such a way, that the thermal load from welding will be led to a far extent to extrusion profiles with big wall thicknesses

– edge preparation, alignment of joints are to be appropriate to the type of joint and welding position, and comply with GL Rule requirements for the welding procedures adopted

– for correct execution of welded joints, sufficient accessibility is necessary, depending on the welding process adopted and the welding position

– unfavourable welding positions have to be avoided

### 3.8 Material factor

The material factor k for aluminium alloys is to be determined according to:

$$k_{Al} = \frac{635}{R_{p0,2} + R_m}$$

$R_{p0,2}$ = 0,2 % proof stress of the aluminium alloy [N/mm²]

$R_m$ = tensile strength of the aluminium alloy [N/mm²]

For welded connections the respective values in welded condition are to be taken. Where these figures are not available, the respective values for the soft-annealed condition are to be used.

***Note***

*The material factor to be used in the GL Rules Part 1 – Seagoing Ships, Chapter 5 – High Speed Craft, Section 3 is different from the above definition.*

**3.9** Conversion from steel to aluminium scantlings:

– section modulus: $W_{Al} = W_{St} \cdot k_{Al}$

– plate thickness: $t_{Al} = t_{St} \cdot \sqrt{k_{Al}}$

**3.9.1** When determining the buckling strength of structural elements subject to compression, the modulus of elasticity of aluminium must be taken into account. This applies accordingly to structural members for which limited shape imperfections are prescribed.

**3.9.2** The conversion of the scantlings of the main hull structural elements from steel into aluminium alloy is to be specially considered taking into account the smaller modulus of elasticity, as compared with steel, and the fatigue strength aspects, especially those of the welded connections.

## 4. Riveting

**4.1** The use of rivets for connecting structures shall be specially agreed with GL. Special applications are to be supported by experimental evidence or good in-service performance.

**4.2** The conditions for riveted connection acceptability are to be individually stated in each particular case, depending on the type of members to be connected and the rivet material.

**4.3** Whenever riveted connections are to be employed, a detailed plan, illustrating the process, as well as the dimensions and location of rivets and holes, together with the mechanical and metallurgical properties of the rivets, is to be submitted for approval.

**4.4** GL may, at its discretion, require tension, compression and shear tests to be carried out on specimens of riveted connections constructed under the same conditions as during actual hull construction, to be witnessed by a GL Surveyor.

**4.5** GL reserve the right to accept the results of tests performed by recognized bodies or other Classification Societies.

## 5. Welding transition joints

### 5.1 General

**5.1.1** For welded transitions of the hull structures between steel and aluminium alloys explosion-bonded steel-aluminium transition joints may be used. This use for plates or profiles is subject to GL's agreement.

**5.1.2** Any such jointing system is to be type-approved by GL.

**5.1.3** Qualifications tests for welding procedures are to be carried out for each joint configuration.

**5.1.4** A welding booklet giving preparations and various welding parameters for each type of assembly is to be submitted for review.

### 5.2 Types of explosion-bonded joints

According to the present state of technology and application, the following types of explosion-bonded joints are used:

– butt welds in the welding transition as such

– joints of platings (walls, decks), as a cruciform joint with coaming or a T-joint without coaming

– joints of stiffeners, as a cruciform joint with coaming or a T-joint without coaming

– joints of transverse walls, as cruciform joint with coaming or T-joint without coaming

### 5.3 Permissible transition stresses

For some widely used steel-aluminium transition joints the permissible stresses to be transmitted are defined in Table 2.8. Owing to the fact, that in general the connection between steel and aluminium is of lower specific strength, a larger surface is therefore required for force transmission.

### 5.4 Inadmissible heating

For all connections it has to be ensured, that the bond zone between steel and aluminium is not inadmissibly heated above a maximum temperature of 300 °C, as this would cause embrittlement implying the risk of failures.

## 6. Corrosion protection

### 6.1 General

For corrosion protection the requirements according to VI – Additional Rules and Guidelines, Part 9 – Materials and Welding, Chapter 6 – Guidelines for Corrosion Protection and Coating Systems have to be met. In addition the requirements below shall be observed. Special solutions concerning material selection, coatings, cathodic protection systems or other methods may be accepted after examination.

### 6.2 Shop primers

Shop primers are used to provide protection of the steel parts during storage, transport and work processes. Customarily, coatings with a thickness of 15 to 20 μm are applied. This should provide corrosion protection for a period of approx. 6 months.

### 6.3 Hollow spaces

Hollow spaces, such as those in closed box girders, tube supports and the like, which either can be shown to be air tight or are accepted as such from normal shipbuilding experience, need not have their internal surfaces protected. During assembling, however such hollow spaces must be kept clean and dry.

**Table 2.8 Material combination and permissible stresses**

| Type of bonding | Material combination | | Permissible tensile stress through thickness [N/mm²] | Permissible shear stress [N/mm²] |
|---|---|---|---|---|
| | Steel | Aluminium alloy | | |
| **Explosion-bonded** | All types | All types | 60 | 60 |

### 6.4 Combination of materials

Preventive measures are to be taken to avoid contact corrosion associated with the combination of dissimilar metals with different potentials in an electrolyte solution, such as seawater. In addition to selecting appropriate materials, steps such as suitable insulation, an effective coating and the application of cathodic protection can be taken in order to prevent contact corrosion.

#### 6.4.1 Heterogeneous assemblies of steel and aluminium alloys

Connections between aluminium alloy and steel parts, if any, are to be protected against corrosion by means of coatings applied by suitable procedures agreed by GL.

In any case, any direct contact between steel and aluminium alloy is to be avoided (e.g. by means of zinc or cadmium plating of the steel parts and application of a suitable coating on the corresponding light alloy parts).

### 6.5 Corrosion protection of ballast water tanks

All seawater ballast tanks having boundaries formed by the vessel's side shell (bottom, outside plating, deck) must be provided with a corrosion protection system consisting of coating and cathodic protection

### 6.6 Corrosion protection of the underwater hull

**6.6.1** Coatings based on epoxy, polyurethane and polyvinyl chloride are considered suitable.

**6.6.2** The coating manufacturer's instructions with regard to surface preparation as well as application conditions and processing must be observed.

**6.6.3** The coating system without antifouling shall:

– have a minimum dry film thickness of 250 μm
– provide cathodic protection in accordance with recognized standards
– be suitable for being cleaned underwater by mechanical means

**6.6.4** The cathodic protection can be provided by means of sacrificial anodes, or by impressed current systems. Under normal conditions for steel, a protection current density of at least 10 mA/m² must be ensured. Hulls or components made of aluminium and aluminium alloys, which are permanently immersed in seawater need to be protected by sacrificial anodes. For hull structures or components of zinc-free aluminium materials which are permanently submerged in seawater, cathodic protection with a protective potential of less than – 0,55 V by sacrificial anodes is required. A cathodic protection is especially needed, if galvanic corrosion is to be expected due to a bimetallic couple between the submerged aluminium alloy structure and other parts, e.g. propulsion components such as stainless steel propeller shafts, bronze propellers or steel hydrojets.

Therefore metallic connection between aluminium alloy structures and other metals should be avoided.

**6.6.5** In the case of impressed current systems, overprotection due to inadequately low potential is to be avoided. A screen (dielectric shield) is to be provided in the immediate vicinity of the impressed-current anodes.

### 6.7 Corrosion protection of austenitic stainless steels

Stainless steels and stainless steel castings exhibit a passive surface state in seawater. Accordingly, coating these types of steel is only recommended under special conditions. In general uncoated stainless steels are not protected by cathodic corrosion protection if they are suitable for withstanding the corrosion stress. Coated stainless steels must be cathodically protected in the submerged zone.

## 7. Fibre reinforced plastics, sandwich constructions and bonding

Refer to GL Rules II – Materials and Welding, Part 2 – Non-metallic Materials, Chapter 1 – Fibre Reinforced Plastics and Adhesive Joints.

### 7.1 Approval of materials

All materials to be used during production of components from FRP shall first be assessed and approved by GL. Approval by other organizations can be recognized following agreement by GL, provided the respective approval procedure is in accordance with GL requirements.

### 7.2 Properties of the materials

The basic properties of the different materials shall be verified by test certificate of a recognized testing body. These values shall fulfil the minimum requirements specified in the relevant GL Rules.

### 7.3 Processing and surveillance

**7.3.1** All manufacturing facilities, store rooms and their operational equipment shall fulfil the requirements of the responsible safety authorities and professional employers liability insurance associations. The manufacturer is exclusively responsible for compliance with this requirements.

**7.3.2** GL reserve the right to carry out inspections without giving prior notice. The manufacturer shall grant GL Surveyors access to all areas and shall present all documentation concerning records and tests carried out.

## 8. Cold-moulded wood and glueing

### 8.1 General

A cold-moulded wood laminate consists of at least three layers of veneer/lamellae.

### 8.2 Wood

**8.2.1** Any of the timbers suitable for boat building may be used.

**8.2.2** Timber envisaged for use in this type of construction is to be cut in such a way that the inclination of the annual rings is no less than 30°, i.e. the angle between the chord of the flattest annual ring, and the face of a lamella or strip of veneer must not be less than 30°. The fibres shall be oriented parallel to the edge of a lamella, if possible. Veneers for making plating may be sliced or sawn.

### 8.3 Glues and adhesives

Only adhesives and glues tested and approved by GL may be used. Adhesives and glues shall have passed the tests in accordance with Section 2 of DIN 68141 - "Prüfung von Leimen und Leimverbindungen für tragende Holzbauteile" (Testing of glues and adhesive combinations for load bearing wooden components). Relevant confirmation and/or test certificates are to be submitted to GL.

In accordance with current practice, mixed adhesives will hereinafter also be referred to as glues.

### 8.4 Works prerequisites and quality assurance

Companies producing wooden hulls and components cold-moulded by glueing shall be qualified for the work to be carried out as regards their workshop equipment, internal quality control, manufacturing process as well as the training and qualification of the personnel carrying out and supervising the work.

Providing the prerequisites for approval have been met, suitability will be certified for the works on application by a GL shop approval.

## 9. Wood and joining of wood materials

The following requirements are an excerpt of the GL Rules II – Materials and Welding, Part 2 – Non-metallic Materials, Chapter 2 – Wood with the aim of summarizing all aspects directly necessary for the design of Yachts.

### 9.1 General

#### 9.1.1 Timber selection according to the field of application

Only proven boatbuilding wood shall be used for all timber components exposed to water and weather, i.e. timber with good resistance to water and weather, fungal attack and insect infestation, as well as with good mechanical properties that are also suitable for the particular application. Furthermore, it shall have low swelling and shrinkage properties. For components not exposed to water or weather, and not requiring strength, timber of lower durability may be used.

#### 9.1.2 Quality

The timber used in boatbuilding shall be long-grained and of best quality, i.e. free from sap, shakes, objectionable knots and other defects. Twisted-grown or rough saw cut shall not be used.

#### 9.1.3 Drying

The timber used shall be well seasoned and sufficiently dried in a suitable drying kiln. In case of forced drying, the residual moisture content shall not be more than 10 %. When processing, this content shall not exceed 15 % as a result of hygroscopic behaviour.

### 9.2 Solid wood

**9.2.1** Radially sawn timber shall mainly be used for boatbuilding. The angle of the annual rings to the lower sawn edge shall not be less than 45°.

**9.2.2** Table 2.9 shows the number of different types of timber and their most important properties, as well as tensile, compressive and bending strength. Since these properties can vary in the case of timber of the same type, or even within the same trunk, no absolute values are indicated in the table, but rather characteristic values. The timber listed is divided into durability groups from I to V. The timber used in boatbuilding shall, if exposed to the weather or used for the primary structural components of a boat, belong to at least durability group III.

**9.2.3** In place of the timber listed in Table 2.9, other types can be used if the durability and the technological values are verified and are equivalent. The manufacturer shall always be responsible for the correct selection of the quality and type of wood.

**9.2.4** The safety factors used in the strength calculation shall be agreed in each case with GL.

### 9.3 Boatbuilding plywood

#### 9.3.1 General

**9.3.1.1** All plywood components exposed to water and weather, or used in primary structural components (such as the deck, shell and bulkheads), shall be produced from boatbuilding plywood that has been tested according to GL Rules.

**9.3.1.2** The boatbuilding plywood consists of at least three veneers bonded crosswise together by means of curable synthetic-resin adhesives. The resistance of these adhesives to water and weather shall be demonstrated by long-term and outdoor testing.

**Table 2.9 Timber durability groups and characteristic values in accordance with DIN 68364**

| **Timber type** | **Durability group** | **Density** | **Mean breaking strengths** | | |
|---|---|---|---|---|---|
| | **I – V** | **[g/cm³]** | **Tension [N/mm²]** | **Compression [N/mm²]** | **Bending [N/mm²]** |
| **Coniferous** | | | | | |
| Pine | III – IV | 0,52 | 100 | 45 | 80 |
| Oregon pine | III | 0,54 | 100 | 50 | 80 |
| Larch | III | 0,59 | 105 | 48 | 93 |
| **Deciduous** | | | | | |
| Mahagony Khaya | III | 0,50 | 75 | 43 | 75 |
| American mahagony | II | 0,54 | 100 | 45 | 80 |
| Sapele | III | 0,64 | 85 | 57 | 69 |
| Utile | II | 0,59 | 100 | 58 | 100 |
| Meranti, red | III | 0,59 | 129 | 53 | 105 |
| Iroko | I – II | 0,63 | 79 | 55 | 95 |
| Makore | I – II | 0,66 | 85 | 53 | 103 |
| Oak | II | 0,67 | 110 | 52 | 95 |
| Teak | I | 0,69 | 115 | 58 | 100 |
| Yang | III | 0,76 | 140 | 70 | 125 |

1 Durability groups:

I = very good
II = good
III = average
IV = moderate
V = poor

**Table 2.10 Plywood strength and durability groups**

| Timber type | Botanical name | Durability group [1] | Density | Mean tensile strength of plywood | |
|---|---|---|---|---|---|
| | | I – V | Approx. [g/cm³] | Longitudinal [N/mm²] | Transverse [N/mm²]<br><br>Bending [N/mm²] |
| **Strength group F1 (for loadbearing components)** | | | | | |
| Teak | Tectona grandis | I | 0,64 | ≥ 40 | ≥ 30 |
| Makoré | Dumoria hekelii | I | 0,62 | ≥ 40 | ≥ 30 |
| Douka | Dumoria africana | I | 0,62 | ≥ 40 | ≥ 30 |
| Utile | Entandro-phragma utile | II | 0,57 | ≥ 40 | ≥ 30 |
| Sapele mahogany | Entandro-phragma cylindricum | III | 0,59 | ≥ 40 | ≥ 30 |
| Oak | Querus robur | II | 0,63 | ≥ 40 | ≥ 30 |
| **Strength group: F2** | | | | | |
| American mahogany | Swietenia macrophylla | II | 0,49 | < 40 | < 30 |
| African mahogany | Khaya ivorensis | II – III | 0,45 | < 40 | < 30 |
| Okoumé (Gaboon) | Aucoumea klaineana | IV – V | 0,41 | < 40 | < 30 |

1 Durability groups:

I = very good
II = good
III = average
IV = moderate
V = poor

**9.3.1.3** As plywood can also be destroyed in specific adverse conditions by animal or plant pests, timber shall be used which offers a natural resistance.

#### 9.3.2 Structure

The selection of timber and the structure of the panels (number of veneer layers) shall be appropriate for the field of application. Depending on the application, strong, durable timber - e. g. makoré and the hard, durable mahogany types of strength group F1 (see Table 2.10) - with several thin inner layers of veneer shall be selected for load carrying components subject to high stresses. On the other hand, plywood panels of lighter, less long and less durable timber of strength group F2 e.g. khaya, mahogany, okumé - with thicker and fewer inner layers of veneer and good surface protection are suitable for linings.

#### 9.3.3 Veneer joints

The veneer joints shall be sealed perfectly and shall bond the veneers to each other by butt joints. The joints shall be glued on a suitable joint bonding machine.

Sealed joints between all layers are a precondition for boatbuilding plywood.

#### 9.3.4 Strength groups

**9.3.4.1** With regard to their suitability for the production of boatbuilding plywood, the types of timber listed in Table 2.10 are currently approved. The timber is subdivided into two strength groups. Also shown is the natural durability and weathering resistance of the mentioned types of timber.

**9.3.4.2** Other types of wood may only be used for making plywood panels upon agreement with GL. The manufacturer shall always remain responsible for the correct selection of quality and type of wood.

### 9.4 Wood protection

#### 9.4.1 Timber

All timber (with exception of the timber durability group I, Table 2.10) shall be protected by several coats of suitable protective paint, or by means of impregnation with a proven wood preservative, against fungi and insect infestation. Impregnation is the preferred method for interior surfaces of the yacht’s components which are exposed to water or weather (e.g. hull, deck, superstructure) and which have received a coat of paint impervious to vapour pressure.

#### 9.4.2 Plywood

All plywood parts shall be protected by several coats of paint or varnish. Special attention shall be paid to plywood edges and drill-holes by pre-treating them with recognized and proven edge protection coatings.

## C. Design Principles

### 1. General

The following contains definitions and general design guidance for hull structural elements made from metallic materials as well as indications concerning structural details.

### 2. Required sectional properties

The required section moduli and web areas are related, on principle, to an axis which is parallel to the connected plating.

For profiles usual in the trade and connected vertically to the plating, in general the appertaining sectional properties are given in tables.

Where webs of stiffeners and girders are not fitted vertically to the plating (e. g. frames on the shell in the flaring fore body) the sectional properties (moment of inertia, section modulus and shear area) have to be determined for an axis which is parallel to the plating.

For bulb profiles and flat bars the section modulus of the inclined profile can be calculated approximately by multiplying the corresponding value for the vertically arranged profile by sinα, where α is the smaller angle between web and attached plating.

### 3. Curved plate panels

The thickness of curved plate panels may be reduced by applying the following correction factor $f_c$ in the formula of D.4.3.

$$f_c = 1{,}1 - 3 \cdot \frac{h}{s} \quad \text{for} \quad 0{,}03 \le \frac{h}{s} \le 0{,}1$$

h = according to Fig. 2.2

s = according to Fig. 2.2

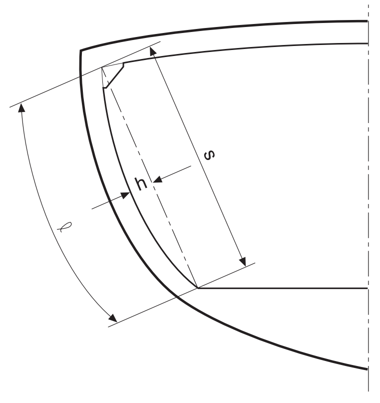



**Fig. 2.2 Curved shell plate panels and frames**

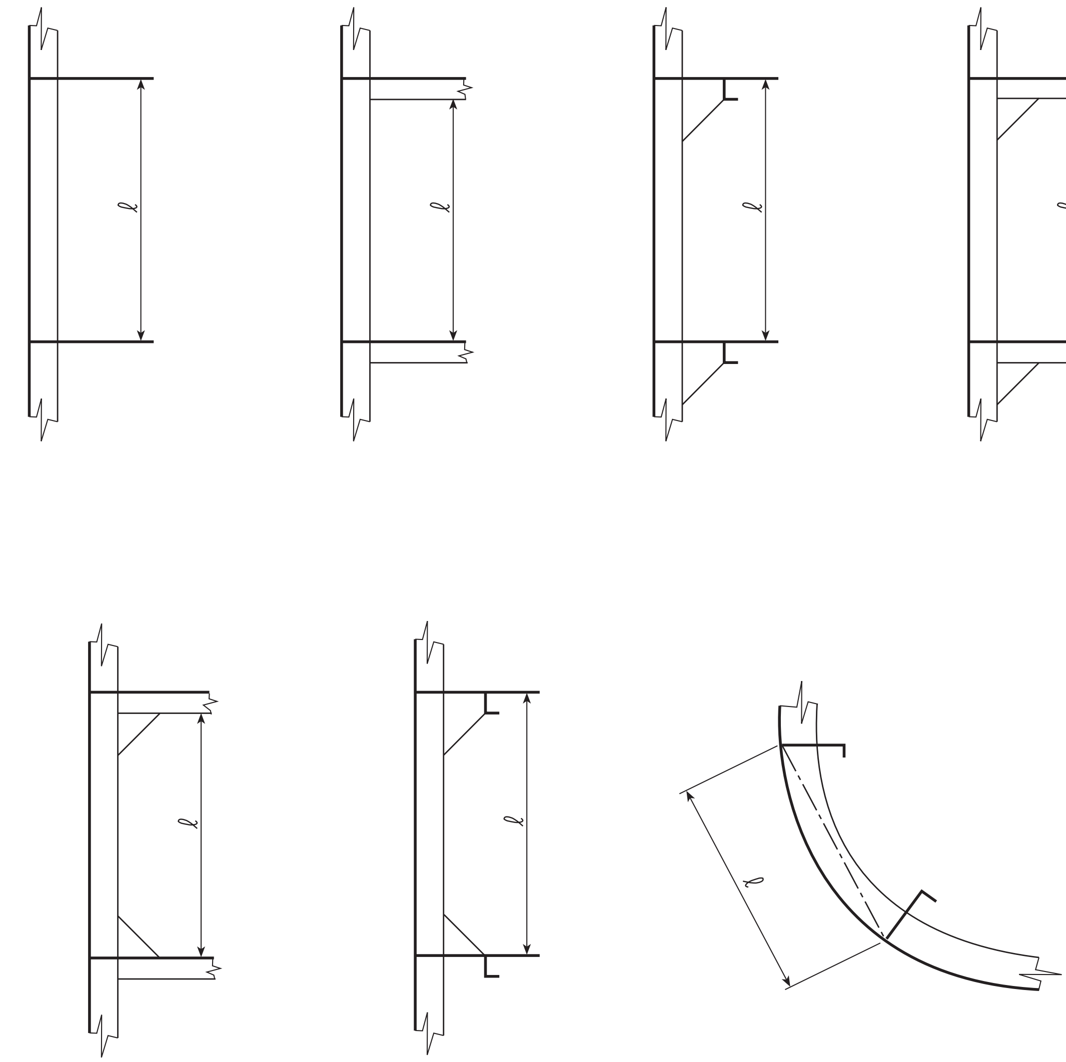



**Fig. 2.3 Unsupported span**

### 4. Curved frames and girders

For curved frames and girders, the section modulus may be reduced by applying the factor $f_{cs}$ in the formula of D.4.4.2.

$$f_{cs} = 1{,}15 - 5 \cdot \frac{h}{s}$$

h = according to Fig. 2.2

s = according to Fig. 2.2

### 5. Unsupported span

#### 5.1 Stiffeners, frames

The unsupported span $\ell$ is the length of the stiffeners between two supporting girders or else their length including end attachments (brackets), see Fig. 2.3.

#### 5.2 Transverses and girders

The unsupported span $\ell$ of transverses and girders is to be determined according to Fig. 2.4, depending on the type of end attachment.

In special cases, the rigidity of the adjoining girders is to be taken into account when determining the span of girder.

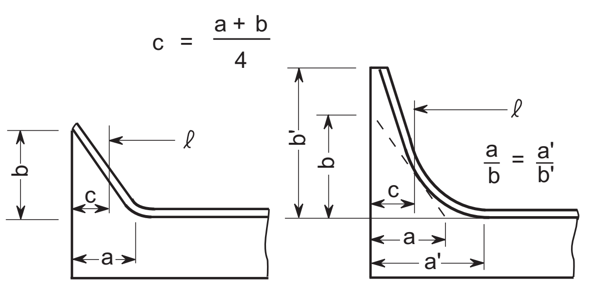



**Fig. 2.4 Unsupported span depending on end attachment**

### 6. End attachments

#### 6.1 Definitions

For determining scantlings of beams, stiffeners and girders the terms "constraint" and "simple support" will be used.

"Constraint" will be assumed where for instance the stiffeners are rigidly connected to other members by means of brackets or are running throughout over supporting girders.

"Simple support" will be assumed where for instance the stiffener ends are sniped or the stiffeners are connected to plating only, see also 6.4.

#### 6.2 Design of details

Structural details are to be so designed and constructed as to minimize hard spots, notches and other structural discontinuities leading to stress concentrations. Therefore sharp corners and abrupt changes in sections are to be avoided. Toes of brackets and ends of members are not to terminate on plating without attachment to an adjacent member, unless specially approved.

#### 6.3 Brackets

**6.3.1** For the scantlings of brackets the required section modulus of the section is decisive. Where sections of different section moduli are connected to each other, the scantlings of the brackets are generally governed by the smaller section.

**6.3.2** The thickness of the brackets is not to be less than:

$$t = c \cdot \sqrt[3]{\frac{W}{k_1}} + t_K \quad [\text{mm}]$$

c = 1,20 for non-flanged brackets

= 0,95 for flanged brackets

$k_1$ = material factor k for the section, according to B.2.2

W = section modulus of smaller section [cm$^3$]

$t_{min}$ = 5,5 mm

$t_{max}$ = web thickness of smaller section

$t_K$ = corrosion allowance according to D.4.1.2

**6.3.3** The arm length of brackets is not to be less than:

$$\ell = 46{,}2 \cdot \sqrt[3]{\frac{W}{k_1}} \cdot \sqrt{k_2} \cdot c_t$$

$$\ell_{min} = 100 \text{ mm}$$

W = see 6.3.2

$k_1$ = see 6.3.2

$k_2$ = material factor k for the bracket, according to B.2.2

$$c_t = \sqrt{\frac{t}{t_a}}$$

$t_a$ = "as built" thickness of bracket [mm] $\geq$ t according to 6.3.2

The arm length $\ell$ is the length of the welded connection.

***Note***

*For deviating arm lengths the thickness of brackets is to be estimated by direct calculations considering sufficient safety against buckling.*

**6.3.4** Where flanged brackets are used, the width of flange is to be determined according to the following formula:

$$b = 40 + \frac{W}{30} \quad [mm]$$

b = not to be taken less than 50, not greater than 90 mm

W = see 6.3.2

### 6.4 Sniped ends of stiffeners

Stiffeners may be sniped at the ends, if the thickness of the plating supported by stiffeners is not less than:

$$t = c\sqrt{\frac{p \cdot a\;(\ell - 0{,}5 \cdot a)}{R_{eH}}} \quad [mm]$$

p = design load in [kN/m²], see GL-Rules Part 1 – Seagoing Ships, Chapter 1 – Hull Structures, Section 4

$\ell$ = unsupported length of stiffener [m]

a = spacing of stiffener in [m]

$R_{eH}$ = minimum nominal upper yield point of the plating's material [N/mm²] according to B.2.2

c = 15,8 for watertight bulkheads and for tank bulkheads when loaded by $p_2$ according to GL-Rules, Part 1 – Seagoing Ships, Chapter 1 – Hull Structures, Section 4

= 19,6 otherwise

## 7. Effective width of plating

### 7.1 Frames and stiffeners

Generally, the spacing of frames and stiffeners may be taken as effective width of plating.

### 7.2 Girders

**7.2.1** The effective width of plating $e_m$ of frames and girders may be determined according to Table 2.11, considering the type of loading.

Special calculations may be required for determining the effective width of one-sided or non-symmetrical flanges.

**Table 2.11 Effective width of plating $e_m$ of frames and girders**

| $\ell$/e | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | ≥ 8 |
|---|---|---|---|---|---|---|---|---|---|
| $e_{m1}$/e | 0 | 0,36 | 0,64 | 0,82 | 0,91 | 0,96 | 0,98 | 1,00 | 1,0 |
| $e_{m2}$/e | 0 | 0,20 | 0,37 | 0,52 | 0,65 | 0,75 | 0,84 | 0,89 | 0,9 |

$e_{m1}$ is to be applied where girders are loaded by uniformly distributed loads or else by not less than 6 equally spaced single loads.

$e_{m2}$ is to be applied where girders are loaded by 3 or less single loads.

Intermediate values may be obtained by direct interpolation.

$\ell$ = length between zero-points of bending moment curve, i.e. unsupported span in case of simply supported girders and 0,6 × unsupported span in case of constraint of both ends of girder

e = width of plating supported, measured from centre to centre of the adjacent unsupported fields

**7.2.2** The effective cross sectional area of plates is not to be less than the cross sectional area of the face plate.

**7.2.3** The effective width of stiffeners and girders subjected to compressive stresses may be determined by proof of buckling strength, but is in no case to be taken greater than determined by 7.2.1.

### 7.3 Cantilevers

Where cantilevers are fitted at every frame, the effective width of plating may be taken as the frame spacing.

Where cantilevers are fitted at a greater spacing, the effective width of plating at the respective cross section may approximately be taken as the distance of the cross section from the point on which the load is acting, however, not greater than the spacing of the cantilevers.

## 8. Rigidity of transverses and girders

The moment of inertia of deck transverses and girders, is not to be less than:

$$I = c \cdot W \cdot \ell \quad \left[cm^4\right]$$

c = 4,0 if both ends are simply supported

= 2,0 if one end is contained

= 1,5 f both ends are contained

W = section modulus of the structural member considered [cm³]

$\ell$ = unsupported span of the structural member considered [m]

## 9. Additional stresses in asymmetrical sections

The additional stress $\sigma_h$ occurring in asymmetric sections may be calculated by the following formula:

$$\sigma_h = \frac{Q \cdot \ell_f \cdot t_f}{c \cdot W_y \cdot W_z}\left(b_1^2 - b_2^2\right) \quad \left[N/mm^2\right]$$

Q = load on section parallel to its web within the unsupported span $\ell_f$ [kN]

= $p \cdot \mathbf{a} \cdot \ell_f$ [kN] in case of uniformly distributed load p [kN/m²]

$\ell_f$ = unsupported span of flange [m]

$t_f$, $b_1$ = flange dimensions [mm]

$b_2$ = as shown in Fig. 2.5

$b_1 \geq b_2$

$W_y$ = section modulus of section related to the y-y axis including the effective width of plating [cm³]

$W_z$ = section modulus of the partial section consisting of flange and half of web area related to the z-z axis [cm³], (bulb sections may be converted into a similar L-section)

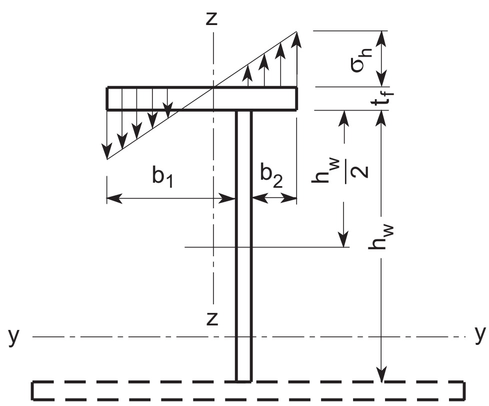



**Fig. 2.5 Additional stresses in asymmetric sections**

c = factor depending on kind of load, stiffness of the section's web and length and kind of support of the section. for sections clamped at both ends c = 80 may be taken as approximation.

This additional stress $\sigma_h$ is to be added directly to other stresses such as those resulting from local and hull girder bending.

The total stress according to local bending thus results in:

$$\sigma_{ges} = \frac{Q \cdot \ell_f \cdot 1000}{12 \cdot W_y}\left(1 + \frac{12 \cdot t_f \left(b_1^2 - b_2^2\right)}{1000 \cdot c \cdot W_z}\right)$$

Therefore the required section modulus $W_y$ according to 2. must be increased by the factor $k_{sp}$ depending on the type of section and the boundary conditions expressed by c.

$$\sigma_{ges} = \frac{Q \cdot \ell_f \cdot 1000}{12 \cdot W_y} k_{sp} \quad \left[N/mm^2\right]$$

For $k_{sp}$ at least the values given in Table 2.12 are to be taken.

**Table 2.12 Factor $k_{sp}$ for asymmetric sections**

| Type of section | $k_{sp}$ |
|---|---|
| Flat bars and symmetric T-sections | 1,00 |
| Bulb sections | 1,03 |
| Unsymmetric T-sections $\left(\frac{b_2}{b_1} \approx 0{,}5\right)$ | 1,05 |
| Rolled angels (L-sections) | 1,15 |

## 10. Proof of buckling strength

### 10.1 General

#### 10.1.1 Principles

The calculation method for buckling strength shown below is based on the standard DIN 18800.

#### 10.1.2 Definitions

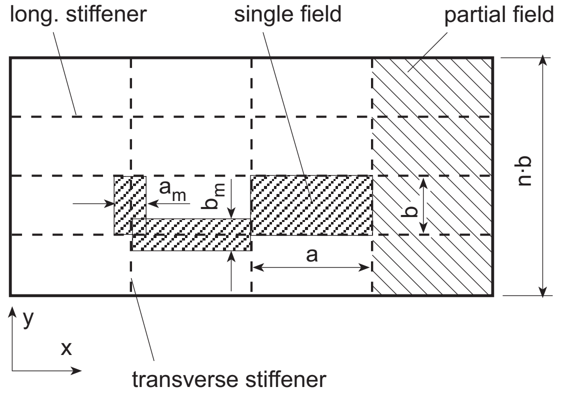
a = length of single or partial plate field [mm]

b = breadth of single plate field [mm]

α = aspect ratio of single plate field

= a / b

n = number of single plate field breadths within the partial or total plate field




longitudinal : stiffener in the direction of the length a
transverse : stiffener in the direction of the breath b

**Fig. 2.6 System of longitudinal and transverse stiffeners**

t = nominal plate thickness [mm]

= $t_a - t_K$ [mm]

$t_a$ = plate thickness as built [mm]

$t_K$ = corrosion addition according to D.4.1.2 [mm]

$\sigma_x$ = membrane stress in x-direction [N/mm²]

$\sigma_y$ = membrane stress in y-direction [N/mm²]

$\tau$ = shear stress in the x-y plane [N/mm²]

Compressive and shear stresses are to be taken positive, tension stresses are to be taken negative.

***Note***

*If the stresses in the x- and y-direction contain already the Poisson - effect, the following modified stress values may be used:*

$$\sigma_x = \left(\sigma_x^* - 0{,}3 \cdot \sigma_y^*\right)/0{,}91$$

$$\sigma_y = \left(\sigma_y^* - 0{,}3 \cdot \sigma_x^*\right)/0{,}91$$

$\sigma_x^*$, $\sigma_y^*$ = *stresses containing the Poisson-effect*

$\psi$ = edge stress ratio according to Table 2.15

$F_1$ = correction factor for boundary condition at the long. stiffeners according to Table 2.15

$\sigma_e$ = reference stress

$$= 0{,}9 \cdot E \left(\frac{t}{b}\right)^2 \quad \left[N/mm^2\right]$$

E = Young's modulus

$$= 2{,}06 \cdot 10^5 \left[N/mm^2\right] \text{ for steel}$$

$$= 0{,}69 \cdot 10^5 \left[N/mm^2\right] \text{ for aluminium alloys}$$

$R_{eH}$ = nominal yield point [N/mm²] for hull structural steels according to B.2.2.

= 0,2 % proof stress [N/mm²] for aluminium alloys

**Table 2.13 Correction factor for boundary conditions**

| | | |
|---|---|---|
| 1,0 | for stiffeners sniped at both ends | |
| Guidance values *: where both ends are effectively connected to adjacent structures | 1,05<br>1,10<br>1,20<br>1,30 | for flat bars<br>for bulb sections<br>for angle and tee-sections<br>for girders of high rigidity (e.g. bottom transverses) |
| * Exact values may be determined by direct calculations. | | |

S = safety factor

= 1,1 in general

= 1,2 for structures which are exclusively exposed to local loads

= 1,05 for combinations of statistically independent loads

For constructions of aluminium alloys the safety factors are to be increased in each case by 0,1.

$\lambda$ = reference degree of slenderness

$$= \sqrt{\frac{R_{eH}}{K \cdot \sigma_e}}$$

K = buckling factor according to Table 2.15 and 2.16

In general, the ratio plate field breadth to plate thickness shall not exceed b/t = 100.

### 10.2 Proof of single plate fields

**10.2.1** Proof is to be provided made that the following condition is complied with for the single plate field a · b:

$$\left(\frac{|\sigma_x| \cdot S}{\kappa_x \cdot R_{eH}}\right)^{e_1} + \left(\frac{|\sigma_y| \cdot S}{\kappa_y \cdot R_{eH}}\right)^{e_2} - B\left(\frac{\sigma_x \cdot \sigma_y \cdot S^2}{R_{eH}^2}\right)$$

$$+ \left(\frac{|\tau| \cdot S \cdot \sqrt{3}}{\kappa_\tau \cdot R_{eH}}\right)^{e_3} \le 1{,}0$$

Each term of the above condition must be less than 1,0.

The reduction factors $\kappa_x$, $\kappa_y$ and $\kappa_\tau$ are given in Table 2.15 and/or 2.16.

Where $\sigma_x \le 0$ (tension stress), $\kappa_x = 1{,}0$.

Where $\sigma_y \leq 0$ (tension stress), $\kappa_y = 1{,}0$.

The exponents $e_1$, $e_2$ and $e_3$ as well as the factor B are calculated or set respectively according to Table 2.14.

**Table 2.14 Exponents $e_1 - e_3$ and factor B**

| Exponents $e_1 - e_3$ and factor B | plate field | |
|---|---|---|
| | plane | curved |
| $e_1$ | $1+\kappa_x^4$ | 1,25 |
| $e_2$ | $1+\kappa_y^4$ | 1,25 |
| $e_3$ | $1+\kappa_x \cdot \kappa_y \cdot \kappa_\tau^2$ | 2,0 |
| B<br>$\sigma_x$ and $\sigma_y$ positive<br>(compression stress) | $\left(\kappa_x \cdot \kappa_y\right)^5$ | 0 |
| B<br>$\sigma_x$ or $\sigma_y$ negative<br>(tension stress) | 1 | — |

### 10.2.2 Effective width of plating

The effective width of plating may be determined by the following formulae:

$$b_m = \kappa_x \cdot b \quad \text{for longitudinal stiffeners}$$

$$a_m = \kappa_y \cdot a \quad \text{for transverse stiffeners}$$

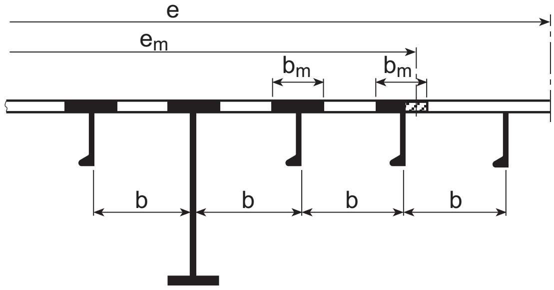
see also Fig. 2.6.

The effective width of plating is not to be taken greater than the value obtained from 7.2.1.

***Note***

*The effective width $e'_m$ of stiffened flange plates of girders may be determined as follows:*

*Stiffening parallel to web of girder:*



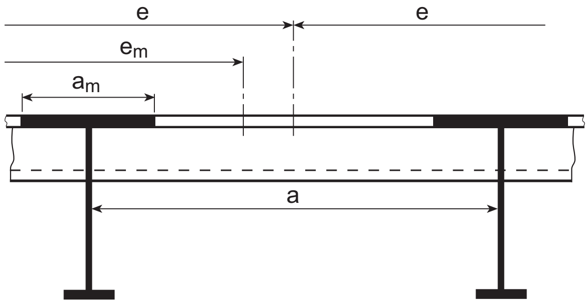

$b < e_m$

$e'_m = n \cdot b_m$

$n$ = *integral number of the stiffener spacing b inside the effective width $e_m$ according to Table 2.11*

$= int\left(\dfrac{e_m}{b}\right)$

*Stiffening vertical to web of girder:*




$a \geq e_m$

$e'_m = n \cdot a_m < e_m$

$n = 2{,}7 \cdot \dfrac{e_m}{a} \leq 1$

$e$ = *width of plating supported according to 7.2.1*

*For $b \geq e_m$ or $a < e_m$ respectively, b and a must be exchanged.*

**Table 2.15 Plane plate fields**

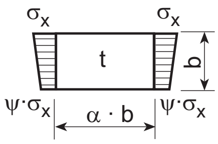
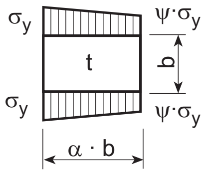
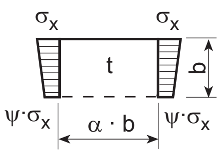
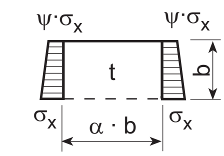
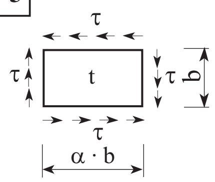
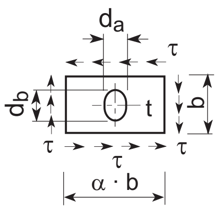
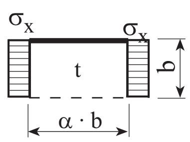
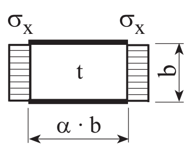
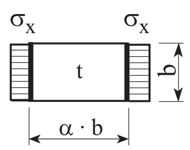
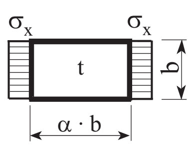
| Load case | Edge stress ratio $\psi$ | Aspect ratio $\alpha$ | Buckling factor K | Reductions factor $\kappa$ |
|---|---|---|---|---|
| **1**   | $1 \geq \psi \geq 0$ | $\alpha > 1$ | $K = \dfrac{8{,}4}{\psi + 1{,}1}$ | $\kappa_x = 1$ for $\lambda \leq \lambda_c$<br>$\kappa_x = c\left(\dfrac{1}{\lambda} - \dfrac{0{,}22}{\lambda^2}\right)$ for $\lambda > \lambda_c$<br>$c = (1{,}25 - 0{,}12\psi) \leq 1{,}25$<br>$\lambda_c = \dfrac{c}{2}\left(1 + \sqrt{1 - \dfrac{0{,}88}{c}}\right)$ |
| | $0 > \psi > -1$ | | $K = 7{,}63 - \psi\,(6{,}26 - 10\,\psi)$ | |
| | $\psi \leq -1$ | | $K = (1 - \psi)^2 \cdot 5{,}975$ | |
| **2**   | $1 \geq \psi \geq 0$ | $\alpha \geq 1$ | $K = F_1\left(1 + \dfrac{1}{\alpha^2}\right)^2 \dfrac{2{,}1}{(\psi + 1{,}1)}$ | $\kappa_y = c\left(\dfrac{1}{\lambda} - \dfrac{R + F^2\,(H - R)}{\lambda^2}\right)$<br>$c = (1{,}25 - 0{,}12\psi) \leq 1{,}25$<br>$R = \lambda\left(1 - \dfrac{\lambda}{c}\right)$ for $\lambda < \lambda_c$<br>$R = 0{,}22$ for $\lambda \geq \lambda_c$<br>$\lambda_c = \dfrac{c}{2}\left(1 + \sqrt{1 - \dfrac{0{,}88}{c}}\right)$<br>$F = \left(1 - \dfrac{\dfrac{K}{0{,}91} - 1}{\lambda_p^2}\right) c_1 \geq 0$<br>$\lambda_p^2 = \lambda^2 - 0{,}5$ $1 \leq \lambda_p^2 \leq 3$<br>$c_1 = 1$ for $\sigma_y$ due to direct loads<br>$c_1 = \left(1 - \dfrac{F_1}{\alpha}\right) \geq 0$ for $\sigma_y$ due to bending (in general)<br>$c_1 = 0$ for $\sigma_y$ due to bending in extreme load cases (e. g. w. t. bulkheads)<br>$H = \lambda - \dfrac{2\lambda}{c\,(T + \sqrt{T^2 - 4})} \geq R$<br>$T = \lambda + \dfrac{14}{15\lambda} + \dfrac{1}{3}$ |
| | $0 > \psi > -1$ | $1 \leq \alpha \leq 1{,}5$ | $K = F_1\left[\left(1 + \dfrac{1}{\alpha^2}\right)^2 \dfrac{2{,}1\,(1 + \psi)}{1{,}1} - \dfrac{\psi}{\alpha^2}\,(13{,}9 - 10\,\psi)\right]$ | |
| | | $\alpha > 1{,}5$ | $K = F_1\left[\left(1 + \dfrac{1}{\alpha^2}\right)^2 \dfrac{2{,}1\,(1 + \psi)}{1{,}1} - \dfrac{\psi}{\alpha^2}\,(5{,}87 + 1{,}87\,\alpha^2 + \dfrac{8{,}6}{\alpha^2} - 10\,\psi)\right]$ | |
| | $\psi \leq -1$ | $1 \leq \alpha \leq \dfrac{3\,(1 - \psi)}{4}$ | $K = F_1\left(\dfrac{1 - \psi}{\alpha}\right)^2 5{,}975$ | |
| | | $\alpha > \dfrac{3\,(1 - \psi)}{4}$ | $K = F_1\left[\left(\dfrac{1 - \psi}{\alpha}\right)^2 3{,}9675 + 0{,}5375\left(\dfrac{1 - \psi}{\alpha}\right)^4 + 1{,}87\right]$ | |
| **3**   | $1 \geq \psi \geq 0$ | $\alpha > 0$ | $K = \dfrac{4\,(0{,}425 + 1/\alpha^2)}{3\,\psi + 1}$ | $\kappa_x = 1$ for $\lambda \leq 0{,}7$<br>$\kappa_x = \dfrac{1}{\lambda^2 + 0{,}51}$ for $\lambda > 0{,}7$ |
| | $0 > \psi \geq -1$ | | $K = 4\left(0{,}425 + \dfrac{1}{\alpha^2}\right)(1 + \psi) - 5 \cdot \psi\,(1 - 3{,}42\,\psi)$ | |
| **4**   | $1 \geq \psi \geq -1$ | $\alpha > 0$ | $K = \left(0{,}425 + \dfrac{1}{\alpha^2}\right) \dfrac{3 - \psi}{2}$ | |

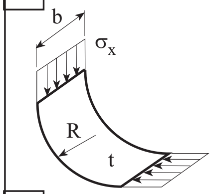
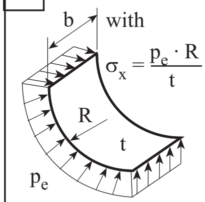
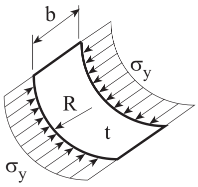
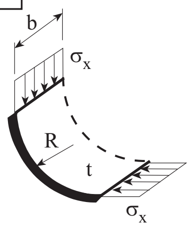
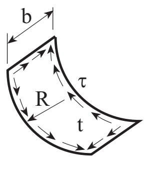
**Table 2.15 Plane plate fields** *(continuous)*

| Load case | Edge stress ratio $\psi$ | Aspect ratio $\alpha$ | Buckling factor K | Reductions factor $\kappa$ |
|---|---|---|---|---|
| **5**   | — | | $K = K_\tau \cdot \sqrt{3}$ | |
| | | $\alpha \geq 1$ | $K_\tau = \left[5{,}34 + \frac{4}{\alpha^2}\right]$ | |
| | | $0 < \alpha < 1$ | $K_\tau = \left[4 + \frac{5{,}34}{\alpha^2}\right]$ | $\kappa_\tau = 1$ for $\lambda \leq 0{,}84$<br>$\kappa_\tau = \frac{0{,}84}{\lambda}$ for $\lambda > 0{,}84$ |
| **6**   | — | | $K = K' \cdot r$<br>$K'$ = K according to load case 5<br>$r$ = Reductions factor<br>$r = (1 - \frac{d_a}{a})(1 - \frac{d_b}{b})$<br>with $\frac{d_a}{a} \leq 0{,}7$ and $\frac{d_b}{b} \leq 0{,}7$ | |
| **7**   | — | $\alpha \geq 1{,}64$ | $K = 1{,}28$ | $\kappa_x = 1$ for $\lambda \leq 0{,}7$ |
| | | $\alpha < 1{,}64$ | $K = \frac{1}{\alpha^2} + 0{,}56 + 0{,}13\,\alpha^2$ | $\kappa_x = \frac{1}{\lambda^2 + 0{,}51}$<br>for $\lambda > 0{,}7$ |
| **8**   | — | $\alpha \geq \frac{2}{3}$ | $K = 6{,}97$ | |
| | | $\alpha < \frac{2}{3}$ | $K = \frac{1}{\alpha^2} + 2{,}5 + 5\,\alpha^2$ | |
| **9**   | — | $\alpha \geq 4$ | $K = 4$ | $\kappa_x = 1$ for $\lambda \leq 0{,}83$ |
| | | $4 > \alpha > 1$ | $K = 4 + \left[\frac{4 - \alpha}{3}\right]^4 2{,}74$ | $\kappa_x = 1{,}13\left[\frac{1}{\lambda} - \frac{0{,}22}{\lambda^2}\right]$<br>for $\lambda > 0{,}83$ |
| | | $\alpha \leq 1$ | $K = \frac{4}{\alpha^2} + 2{,}07 + 0{,}67\,\alpha^2$ | |
| **10**   | — | $\alpha \geq 4$ | $K = 6{,}97$ | |
| | | $4 > \alpha > 1$ | $K = 6{,}97 + \left[\frac{4 - \alpha}{3}\right]^4 3{,}1$ | |
| | | $\alpha \leq 1$ | $K = \frac{4}{\alpha^2} + 2{,}07 + 4\,\alpha^2$ | |

Explanations for boundry conditions

- - - - - - plate edge free
——— plate edge simply supported
▬▬▬ plate edge clamped

**Table 2.16 Curved plate field R/t ≤ 2500** [1]

| Load case | Aspect ratio b / R | Buckling factor K | Reductions factor κ |
|---|---|---|---|
| **1a**   | $\frac{b}{R} \le 1{,}63\sqrt{\frac{R}{t}}$ | $K = \frac{b}{\sqrt{R \cdot t}} + 3\,\frac{(R \cdot t)^{0{,}175}}{b^{0{,}35}}$ | $\kappa_x = 1$ [2]<br>for $\lambda \le 0{,}4$<br>$\kappa_x = 1{,}274 - 0{,}686\,\lambda$<br>for $0{,}4 < \lambda \le 1{,}2$<br>$\kappa_x = \frac{0{,}65}{\lambda^2}$<br>for $\lambda > 1{,}2$ |
| **1b**   $p_e$ = external pressure in [N/mm²] | $\frac{b}{R} > 1{,}63\sqrt{\frac{R}{t}}$ | $K = 0{,}3\,\frac{b^2}{R^2} + 2{,}25\left(\frac{R^2}{b \cdot t}\right)^2$ | |
| **2**   | $\frac{b}{R} \le 0{,}5\sqrt{\frac{R}{t}}$ | $K = 1 + \frac{2}{3}\,\frac{b^2}{R \cdot t}$ | $\kappa_y = 1$ [2]<br>for $\lambda \le 0{,}25$<br>$\kappa_y = 1{,}233 - 0{,}933\,\lambda$<br>for $0{,}25 < \lambda \le 1$<br>$\kappa_y = 0{,}3 / \lambda^3$<br>for $1 < \lambda \le 1{,}5$<br>$\kappa_y = 0{,}2 / \lambda^2$<br>for $\lambda > 1{,}5$ |
| | $\frac{b}{R} > 0{,}5\sqrt{\frac{R}{t}}$ | $K = 0{,}267\,\frac{b^2}{R \cdot t}\left[3 - \frac{b}{R}\sqrt{\frac{t}{R}}\right]$<br>$\ge 0{,}4\,\frac{b^2}{R \cdot t}$ | |
| **3**   | $\frac{b}{R} \le \sqrt{\frac{R}{t}}$ | $K = \frac{0{,}6 \cdot b}{\sqrt{R \cdot t}} + \frac{\sqrt{R \cdot t}}{b} - 0{,}3\,\frac{R \cdot t}{b^2}$ | as in load case 1a |
| | $\frac{b}{R} > \sqrt{\frac{R}{t}}$ | $K = 0{,}3\,\frac{b^2}{R^2} + 0{,}291\left(\frac{R^2}{b \cdot t}\right)^2$ | |
| **4**   | $\frac{b}{R} \le 8{,}7\sqrt{\frac{R}{t}}$ | $K = K_\tau \cdot \sqrt{3}$<br>$K_\tau = \left[28{,}3 + \frac{0{,}67 \cdot b^3}{R^{1{,}5} \cdot t^{1{,}5}}\right]^{0{,}5}$ | $\kappa_\tau = 1$<br>for $\lambda \le 0{,}4$<br>$\kappa_\tau = 1{,}274 - 0{,}686\,\lambda$<br>for $0{,}4 < \lambda \le 1{,}2$<br>$\kappa_\tau = \frac{0{,}65}{\lambda^2}$<br>for $\lambda > 1{,}2$ |
| | $\frac{b}{R} > 8{,}7\sqrt{\frac{R}{t}}$ | $K_\tau = 0{,}28\,\frac{b^2}{R\sqrt{R \cdot t}}$ | |

Explanations for boundry conditions:
- - - - - - plate edge free
——— plate edge simply supported
▬▬▬ plate edge clamped

[1] For curved plate fields with a very large radius the κ-value need not to be taken less than one derived for the expanded plane field.

[2] For curved single fields. e.g. the bilge strake, which are located within plane partial or total fields, the reduction factor κ may taken as follow:

Load case 1b: $\kappa_x = 0{,}8/\lambda^2 \le 1{,}0$: load case 2: $\kappa_y = 0{,}65/\lambda^2 \le 1{,}0$

#### 10.2.3 Webs and flanges

For non-stiffened webs and flanges of sections and girders proof of sufficient buckling strength as for single plate fields is to be provided according to 10.2.1.

***Note***

*Within 0,6 **L** amidships the following guidance values are recommended for the ratio web depth to web thickness and/or flange breadth to flange thickness:*

*flat bars:* $\frac{h_w}{t_w} \le 19{,}5\sqrt{k}$

*angle-, tee and bulb sections:*

*web:* $\frac{h_w}{t_w} \le 60{,}0\sqrt{k}$

*flange:* $\frac{b_i}{t_f} \le 19{,}5\sqrt{k}$

$b_i$ = *$b_1$ or $b_2$ according to Fig. 2.7, the larger value is to be taken.*

### 10.3 Proof of partial and total fields

#### 10.3.1 Longitudinal and transverse stiffeners

Proof is to be provided that the continuous longitudinal and transverse stiffeners of partial and total plate fields comply with the conditions set out in 10.3.2 and 10.3.3.

#### 10.3.2 Lateral buckling

$$\frac{\sigma_a + \sigma_b}{R_{eH}} S \le 1$$

$\sigma_a$ = uniformly distributed compressive stress in the direction of the stiffener axis [N/mm²]

= $\sigma_x$ for longitudinal stiffeners

= $\sigma_y$ for transverse stiffeners

$\sigma_b$ = bending stress in the stiffeners

$$= \frac{M_o + M_1}{W_{st} \cdot 10^3} \quad \left[N/mm^2\right]$$

$M_o$ = bending moment due to deformation w of stiffener

$$= F_{Ki}\frac{p_z \cdot w}{c_f - p_z} \quad [N \cdot mm]$$

$$(c_f - p_z) > 0$$

$M_1$ = bending moment due to the lateral load p

for continuous longitudinal stiffeners:

$$= \frac{p \cdot b \cdot a^2}{24 \cdot 10^3} \quad [N \cdot mm]$$

for transverse stiffeners:

$$= \frac{p \cdot a\,(n \cdot b)^2}{c_s \cdot 8 \cdot 10^3} \quad [N \cdot mm]$$

p = lateral load [kN/m²]

$F_{Ki}$ = ideal buckling force of the stiffener [N]

$$F_{Kix} = \frac{\pi^2}{a^2} E \cdot I_x \cdot 10^4 \quad \text{for long. stiffeners}$$

$$F_{Kiy} = \frac{\pi^2}{(n \cdot b)^2} \cdot E \cdot I_y \cdot 10^4 \quad \text{for transv. stiffeners}$$

$I_x, I_y$ = moments of inertia of the longitudinal or transverse stiffener including effective width of plating according to 10.2.2 [cm⁴]

$$I_x \ge \frac{b \cdot t^3}{12 \cdot 10^4}$$

$$I_y \ge \frac{a \cdot t^3}{12 \cdot 10^4}$$

$p_z$ = nominal lateral load of the stiffener due to $\sigma_x$, $\sigma_y$ and $\tau$ [N/mm²]

for longitudinal stiffeners:

$$p_{zx} = \frac{t_a}{b}\left(\sigma_{x1}\left(\frac{\pi \cdot b}{a}\right)^2 + 2 \cdot c_y \cdot \sigma_y + \sqrt{2}\,\tau_1\right)$$

for transverse stiffeners:

$$p_{zy} = \frac{t_a}{a}\left(2 \cdot c_x \cdot \sigma_{x1} + \sigma_y\left(\frac{\pi \cdot a}{n \cdot b}\right)^2\left(1 + \frac{A_y}{a \cdot t_a}\right) + \sqrt{2}\,\tau_1\right)$$

$$\sigma_{x1} = \sigma_x\left(1 + \frac{A_x}{b \cdot t_a}\right)$$

$c_x, c_y$ = factor taking into account the stresses vertical to the stiffener's axis and distributed variable along the stiffener's length

$$= 0{,}5\,(1 + \psi) \quad \text{for} \quad 0 \le \psi \le 1$$

$$= \frac{0{,}5}{1 - \psi} \quad \text{for} \quad \psi < 0$$

$\psi$ = edge stress ratio according to Table 2.15

$A_x, A_y$ = sectional area of the longitudinal or transverse stiffener respectively [mm²]

$$\tau_1 = \left[\tau - t\sqrt{R_{eH} \cdot E\left(\frac{m_1}{a^2} + \frac{m_2}{b^2}\right)}\right] \geq 0$$

for longitudinal stiffeners:

$$\frac{a}{b} \geq 2{,}0 \; : \; m_1 = 1{,}47 \quad m_2 = 0{,}49$$

$$\frac{a}{b} < 2{,}0 \; : \; m_1 = 1{,}96 \quad m_2 = 0{,}37$$

for transverse stiffeners:

$$\frac{a}{n \cdot b} \geq 0{,}5 \; : \; m_1 = 0{,}37 \quad m_2 = \frac{1{,}96}{n^2}$$

$$\frac{a}{n \cdot b} < 0{,}5 \; : \; m_1 = 0{,}49 \quad m_2 = \frac{1{,}47}{n^2}$$

$w$ = $w_o + w_1$

$w_o$ = assumed imperfection [mm]

$$\frac{a}{250} \geq w_{ox} \leq \frac{b}{250} \quad \text{for long. stiffeners}$$

$$\frac{n \cdot b}{250} \geq w_{oy} \leq \frac{a}{250} \quad \text{for transv. stiffeners}$$

however $w_o \leq 10$ mm

***Note***

*For stiffeners sniped at both ends $w_o$ must not be taken less than the distance from the midpoint of plating to the neutral axis of the profile including effective width of plating.*

$w_1$ = deformation of stiffener due to lateral load p at midpoint of stiffener span [mm]

In case of uniformly distributed load the following values for $w_1$ may be used:

for longitudinal stiffeners:

$$w_1 = \frac{p \cdot b \cdot a^4}{384 \cdot 10^7 \cdot E \cdot I_x}$$

for transverse stiffeners:

$$w_1 = \frac{5 \cdot a \cdot p\,(n \cdot b)^4}{384 \cdot 10^7 \cdot E \cdot I_y \cdot c_s^2}$$

$c_f$ = elastic support provided by the stiffener [N/mm²]

$$c_{fx} = F_{Kix} \cdot \frac{\pi^2}{a^2} \cdot \left(1 + c_{px}\right) \quad \text{for long. stiffeners}$$

$$c_{px} = \frac{1}{1 + \dfrac{0{,}91 \cdot \left(\dfrac{12 \cdot 10^4 \cdot I_x}{t^3 \cdot b} - 1\right)}{c_{x\alpha}}}$$

$$c_{x\alpha} = \left[\frac{a}{2\,b} + \frac{2\,b}{a}\right]^2 \quad \text{for} \quad a \geq 2\,b$$

$$= \left[1 + \left(\frac{a}{2\,b}\right)^2\right]^2 \quad \text{for} \quad a < 2\,b$$

$$c_{fy} = c_s \cdot F_{Kiy} \cdot \frac{\pi^2}{(n \cdot b)^2} \cdot \left(1 + c_{py}\right)$$

for transv. stiffeners

$c_s$ = factor accounting for the boundary conditions of the transverse stiffener

= 1,0 for simply supported stiffeners

= 2,0 for partially constraint stiffeners

$$c_{py} = \frac{1}{1 + \dfrac{0{,}91 \cdot \left(\dfrac{12 \cdot 10^4 \cdot I_y}{t^3 \cdot a} - 1\right)}{c_{y\alpha}}}$$

$$c_{y\alpha} = \left[\frac{n \cdot b}{2\,a} + \frac{2\,a}{n \cdot b}\right]^2 \quad \text{for} \quad n \cdot b \geq 2\,a$$

$$= \left[1 + \left(\frac{n \cdot b}{2\,a}\right)^2\right]^2 \quad \text{for} \quad n \cdot b < 2\,a$$

$W_{st}$ = section modulus of stiffener (long. or transverse) [cm³] including effective width of plating according to 10.2.2

If no lateral load p is acting the bending stress $\sigma_b$ is to be calculated at the midpoint of the stiffener span for that fibre which results in the largest stress value. If a lateral load p is acting, the stress calculation is to be carried out for both fibres of the stiffener's cross sectional area (if necessary for the biaxial stress field at the plating side).

***Note***

*Longitudinal and transverse stiffeners not subjected to lateral load p have sufficient scantlings if their moments of inertia $I_x$ and $I_y$ are not less than obtained by the following formulae:*

$$I_x = \frac{p_{zx} \cdot a^2}{\pi^2 \cdot 10^4}\left(\frac{w_{ox} \cdot h_w}{\dfrac{R_{eH}}{S} - \sigma_x} + \frac{a^2}{\pi^2 \cdot E}\right) \quad \left[cm^4\right]$$

$$I_y = \frac{p_{zy} \cdot (n \cdot b)^2}{\pi^2 \cdot 10^4}\left(\frac{w_{oy} \cdot h_w}{\dfrac{R_{eH}}{S} - \sigma_y} + \frac{(n \cdot b)^2}{\pi^2 \cdot E}\right) \quad \left[cm^4\right]$$

### 10.3.3 Torsional buckling

#### 10.3.3.1 Longitudinal stiffeners:

$$\frac{\sigma_x \cdot S}{\kappa_T \cdot R_{eH}} \leq 1{,}0$$

$\kappa_T$ = 1,0 for $\lambda_T \leq 0{,}2$

$$= \frac{1}{\phi + \sqrt{\phi^2 - \lambda_T^2}} \quad \text{for} \quad \lambda_T > 0{,}2$$

$$\phi = 0{,}5\left(1 + 0{,}21\left(\lambda_T - 0{,}2\right) + \lambda_T^2\right)$$

$\lambda_T$ = reference degree of slenderness

$$= \sqrt{\frac{R_{eH}}{\sigma_{KiT}}}$$

$$\sigma_{KiT} = \frac{E}{I_P}\left(\frac{\pi^2 \cdot I_\omega \cdot 10^2}{a^2}\varepsilon + 0{,}385 \cdot I_T\right)\left[N/mm^2\right]$$

For $I_P$, $I_T$, $I_\omega$ see Fig. 2.7 and Table 2.17.

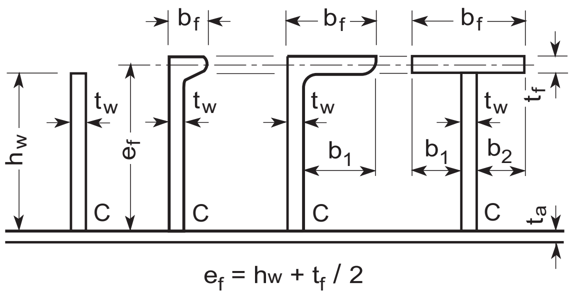



**Fig. 2.7 Main parameters of typical sections**

$I_P$ = polar moment of inertia of the stiffener related to the point C [cm⁴]

$I_T$ = St. Venant's moment of inertia of the stiffener [cm⁴]

$I_\omega$ = sectorial moment of inertia of the stiffener related to the point C [cm⁶]

$\varepsilon$ = degree of fixation

$$= 1 + 10^{-4}\sqrt{\frac{a^4}{I_\omega\left(\frac{b}{t^3} + \frac{4\,h_w}{3\,t_w^3}\right)}}$$

$h_w$ = web height [mm]

$t_w$ = web thickness [mm]

$b_f$ = flange breadth [mm]

$t_f$ = flange thickness [mm]

$A_w$ = web area $h_w \cdot t_w$

$A_f$ = flange area $b_f \cdot t_f$

**Table 2.17 Moments of inertia of typical sections**

| Section | $I_P$ | $I_T$ | $I_\omega$ |
|---|---|---|---|
| Flat bar | $\frac{h_w^3 \cdot t_w}{3 \cdot 10^4}$ | $\frac{h_w \cdot t_w^3}{3 \cdot 10^4}\left(1 - 0{,}63\frac{t_w}{h_w}\right)$ | $\frac{h_w^3 \cdot t_w^3}{36 \cdot 10^6}$ |
| Sections with bulb or flange | $\left(\frac{A_w \cdot h_w^2}{3} + A_f \cdot e_f^2\right)10^{-4}$ | $\frac{h_w \cdot t_w^3}{3 \cdot 10^4}\left(1 - 0{,}63\frac{t_w}{h_w}\right)$ + $\frac{b_f \cdot t_f^3}{3 \cdot 10^4}\left(1 - 0{,}63\frac{t_f}{b_f}\right)$ | for bulb and angle sections: $\frac{A_f \cdot e_f^2 \cdot b_f^2}{12 \cdot 10^6}\left(\frac{A_f + 2{,}6\ A_w}{A_f + A_w}\right)$ for tee-sections: $\frac{b_f^3 \cdot t_f \cdot e_f^2}{12 \cdot 10^6}$ |

#### 10.3.3.2 Transverse stiffeners

For transverse stiffeners loaded by compressive stresses and which are not supported by longitudinal stiffeners, proof is to be provided in accordance with 10.3.3.1 analogously.

## 11. Evaluation of notch stress

### 11.1 Permissible notch stress

The notch stress $\sigma_K$ evaluated for linear-elastic material behaviour at free plate edges, e. g. at openings in decks, walls, girders, etc., should, in general, fulfil the following criterion:

$$\sigma_K \leq f \cdot R_{eH}$$

f = 1,1 for normal strength hull structural steel

= 0,9 for higher strength hull structural steel with $R_{eH}$ = 315 N/mm²

= 0,8 for higher strength hull structural steel with $R_{eH}$ = 355 N/mm²

= 0,73 for higher strength hull structural steel with $R_{eH}$ = 390 N/mm²

For aluminium alloys the permissible notch stress has to be determined individually concerning the respective alloy.

If plate edges are free of notches and corners are rounded-off, a 20 % higher notch stress $\sigma_K$ may be permitted.
A further increase of stresses may be permitted on the basis of a fatigue strength analysis.

### 11.2 Notch factors to evaluate actual notch stress

**11.2.1** The actual notch stress can be determined by multiplying the nominal stress with the notch factor $K_t$.

For some types of openings the notch factors are given in Figs. 2.8 and 2.9.

Where notch factors for circular holes can be decreased by reinforcement with a coaming, the values for the notch factor $K_t$ have to be specially considered.

***Note***

*These notch factors can only be used for girders with multiple openings if there is no correlation between the different openings regarding deformations and stresses.*

### 11.3 Openings in decks contributing to longitudinal strength

**11.3.1** All openings in the decks contributing to longitudinal strength must have well rounded corners. Circular openings are to be edge-reinforced. The sectional area of the face bar is not to be less than:

$$A_f = 0,25 \cdot d \cdot t \quad \left[cm^2\right]$$

d = diameter of openings [cm]

t = deck thickness [cm]

The reinforcing face bar may be dispensed with, where the diameter is less than 300 mm and the smallest distance from another opening is not less than 5 × diameter of the smaller opening. The distance between the outer edge of openings for pipes etc. and the ship's side is not to be less than the opening diameter.

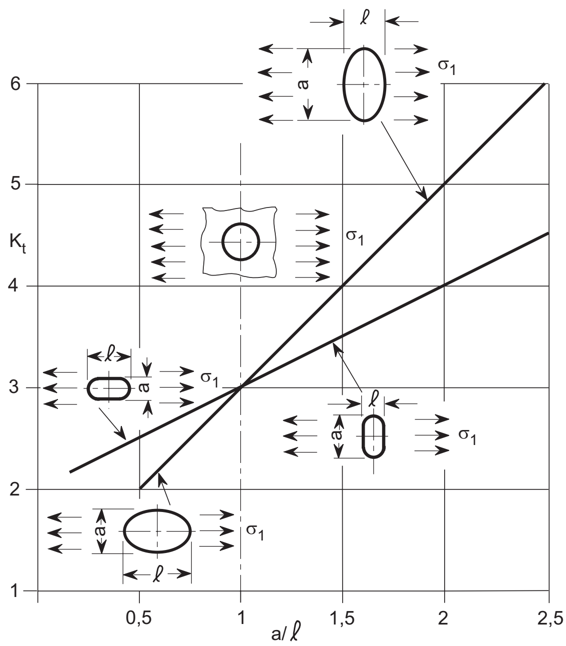



**Fig. 2.8 Notch factor $K_t$ for rounded openings**

**11.3.2** The corners of the opening are to be surrounded by strengthened plates which are to extend over at least one frame spacing fore-and-aft and athwart-ships. Within 0,5 **L** amidships, the thickness of the strengthened plate is to be equal to the deck thickness abreast the opening plus the deck thickness between the openings. Outside 0,5 **L** amidships the thickness of the strengthened plated need not exceed 1,6 times the thickness of the deck plating abreast the opening.

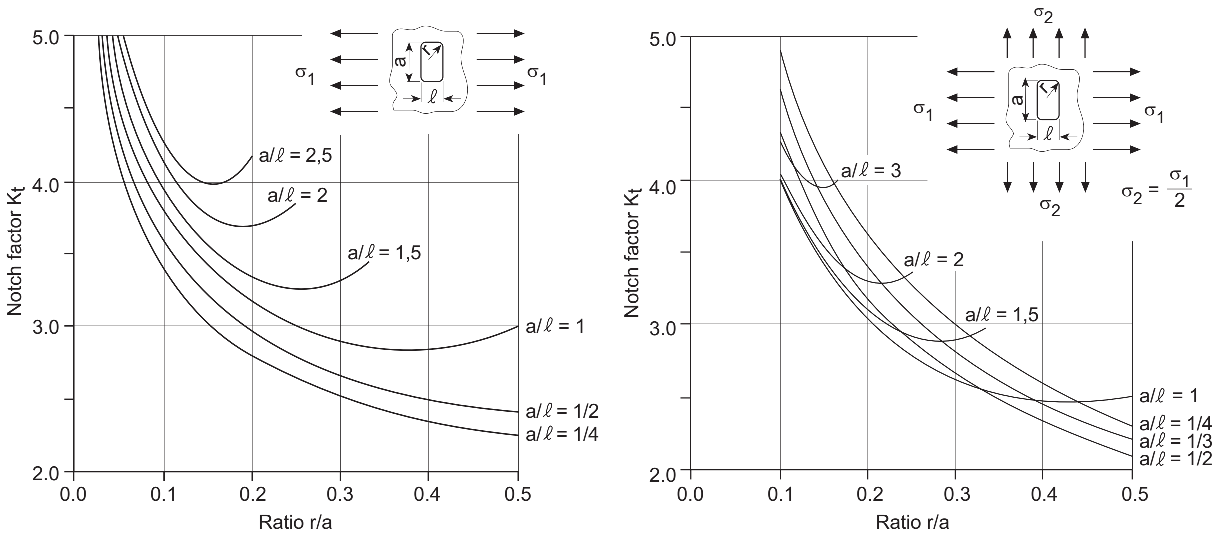



**Fig. 2.9 Notch factor $K_t$ for rectangular openings with rounded corners at uniaxial state of stresses (left) and at multiaxial state of stresses (right)**

**11.3.3** The hatchway corner radius is not to be less than:

$$r = n \cdot b \left(1 - \frac{b}{\mathbf{B}}\right)$$

$$r_{min} = 0{,}1\,\text{m}$$

$n = \dfrac{1}{200}$

$n_{min} = 0{,}1$

$n_{max} = 0{,}25$

$\ell$ = length of opening in [m]

b = breadth in [m], of the opening or total breadth of openings in case of more than one. b/**B** need not to be taken smaller than 0,4.

**11.3.4** Where the corners of openings are elliptic or parabolic, strengthening according to 11.3.2 is not required. The dimensions of the elliptical and parabolical corners shall be as shown in Fig. 2.10:

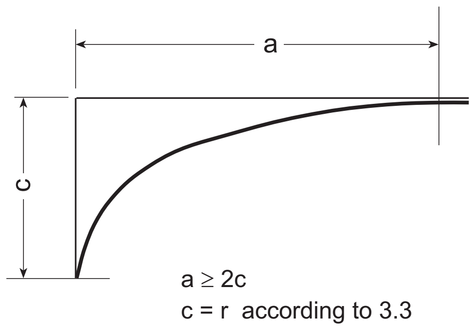



**Fig. 2.10 Dimension of elliptical or parabolical corners**

Where smaller values are taken for a and c, reinforced insert plates are required which will be considered in each individual case.

### 11.4 Actual notch stress calculated by FEM methods

An exact distribution of notch stresses can be evaluated by means of finite element calculations. For fatigue investigations the stress increase due to geometry of cut-outs has to be considered.

## D. Motor und Sailing Yachts, 24 m ≤ L ≤ 48 m Steel and Aluminium Structures

### 1. General

#### 1.1 Scope

The design principles and scantling requirements specified in D. apply to the structure of motor and sailing yachts with 24 m ≤ **L** ≤ 48 m of normal monohull form made from steel or aluminium alloys. Application of these Rules for special designs or shapes as for fast catamarans, etc., may be agreed upon with GL.

The following contains definitions and principles for using the scantling formulae as well as indications concerning structural details.

#### 1.2 Materials

The requirements for construction materials are defined in B.2. and B.3. Materials with properties deviating from the requirements therein may only be used upon special GL approval.

#### 1.3 Welding

Welding work is to be in compliance with the Rules for Classification and Construction II – Materials and Welding, Part 3 – Welding. An excerpt thereof is given in B.

Shipyards and welding shops, including branches and subcontractors, wishing to perform welding work and to use specific welding procedures covered by these Rules must have been approved for this work by GL.

### 2. Principles for structural design

#### 2.1 General

**2.1.1** The hull structural arrangement shall consist of an effective strengthening system of bulkheads, web frames, longitudinal girders, etc. as well as transverse frames and/or longitudinal stiffeners. Longitudinal stiffeners are to be supported by transverse web frames or transverse bulkheads. Transverse frames are to be supported by longitudinal girders or other longitudinal structural members, see Fig. 2.11 and Fig. 2.12.

**2.1.2** Care is to be taken to ensure structural continuity and to avoid sharp corners. Therefore abrupt discontinuities of longitudinal members are to be avoided and where members having different scantlings are connected with each other, smooth transitions have to be provided. At the end of longitudinal bulkheads or continuous longitudinal walls, suitable scarping brackets are to be provided.

**2.1.3** Bottom longitudinals are preferably continuous through the transverse elements. Where longitudinals are interrupted in way of watertight bulkheads or reinforced transverse structures, the continuity of the structure is to be maintained by means of brackets penetrating the transverse element. GL may allow double brackets welded to the transverse element, provided that special attention is given to the alignment of longitudinals and full penetration welding is used.

In case of continuous longitudinal stiffeners penetrating transverse structural members sufficient effective welding section must be ensured between the two elements.

**2.1.4** Floors are to be fitted in line with transverse frames or transverse webs. Alternatively, floors may terminate at longitudinal girders which in turn are supported by transverse bulkheads or deep web rings.

**2.1.5** Where frames, beams and stiffeners are intercostal at an intersecting member, the connections have to provide continuity of strength.

**2.1.6** Sailing yachts shall have transverse bulkheads or equivalent structures in way of mast(s) in order to achieve adequate transverse rigidity. Bulkheads or deep brackets are to be provided in way of chain plates. Any other arrangement shall be subject to special approval.

#### 2.2 Longitudinal strength

Under certain conditions after consultation with GL, a check of longitudinal strength is to be carried out.

#### 2.3 Bulkheads

**2.3.1** Number and location of watertight bulkheads should be considered in an early design phase to ensure compliance with these Rules and other relevant regulations, if applicable. For the arrangement of bulkheads see also Section 3, D.8.

#### 2.3.2 Collision bulkhead

The collision bulkhead shall extend watertight up to the freeboard deck. Steps or recesses may be permitted.

Openings in the collision bulkhead shall be watertight and permanently closed in sailing condition. Closing appliances and their number shall be reduced to the minimum, compatible with the design and proper working of the yacht.

Where pipes are piercing the collision bulkhead, screwdown valves are to be fitted directly at the collision bulkhead. Such valves are to be operable from outside the forepeak.

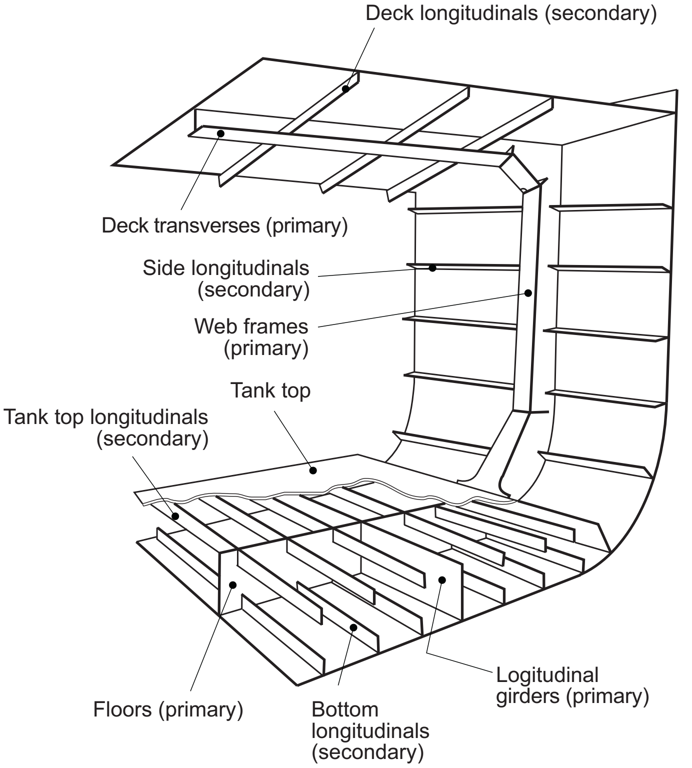



**Fig. 2.11 Definition of primary and secondary members of the hull structure (longitudinal framing system)**

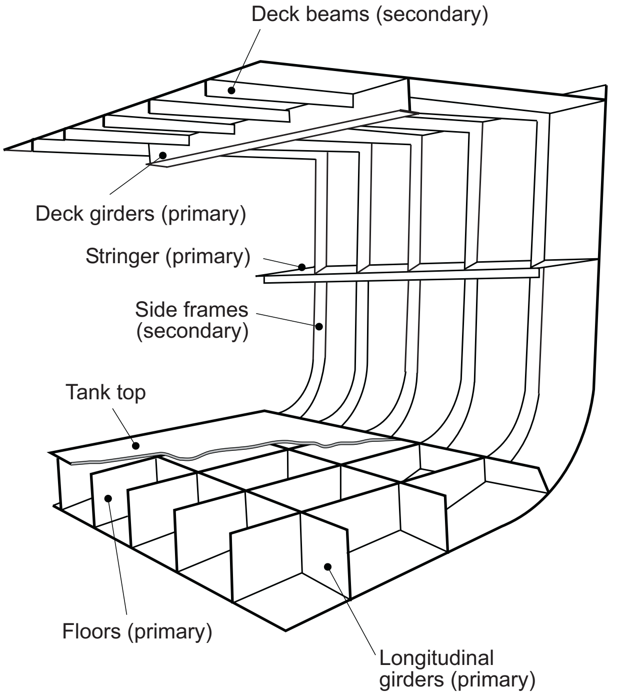



**Fig. 2.12 Definition of primary and secondary members of the hull structure (transverse framing system)**

#### 2.3.3 Stern tube bulkhead

All yachts are to have a stern tube bulkhead which is, in general, to be so arranged that the stern tube and the rudder trunk are enclosed in a watertight compartment. The stern tube bulkhead shall extend to the freeboard deck or to a watertight platform situated above the load waterline.

Where a complete stern tube bulkhead is not practicable, only watertight void spaces enclosing the stern tube entrance, providing the possibility for a second watertight sealing may be provided after agreement with GL. The same arrangement can be applied for the rudder trunk.

#### 2.3.4 Remaining watertight bulkheads

Remaining watertight bulkheads are, depending on the type of the yacht and the Classification for damage stability, to extend to the freeboard deck. Wherever practicable, they shall be arranged in one transverse plane, otherwise those portions of decks situated between parts of transverse bulkheads are to be watertight.

It is recommended that bulkheads shall be fitted separating the machinery space from service spaces and accommodation rooms forward and aft and made watertight and gastight up to the freeboard deck.

#### 2.3.5 Bulkhead stiffening

Bulkhead stiffening members are to be located in way of hull and deck longitudinal girders or stiffeners respectively. Where vertical stiffeners are cut in way of watertight doors, reinforced stiffeners are to be fitted on each side of the door opening and crossbars are to be provided to support the cut-off stiffeners.

#### 2.3.6 Openings in watertight bulkheads

**2.3.6.1** Type and arrangement of doors are to be submitted for approval.

In watertight bulkheads other than collision bulkheads, watertight doors may be fitted. Below the deepest load waterline, they are to be constructed as sliding doors, exemptions may be granted on case by case. Above that waterline, hinged doors may be approved.

Watertight doors are to be sufficiently strong and of an approved design. The thickness of plating is not to be less than the minimum thickness according to 4.3.

Openings for watertight doors in the bulkheads are to be effectively framed such as to facilitate proper fitting of the doors and to guarantee watertightness.

**2.3.6.2** Watertight bulkhead doors and their frames, are to be tested before they are fitted onboard by a head of water corresponding to the freeboard deck height or the results from damage stability calculation. Alternatively watertight doors may be used which have been type approved in accordance with GL special acceptance procedure. After having been fitted on board, the doors are to be soap-tested for tightness and to be subject to an operational test.

**2.3.6.3 Penetrations through watertight bulkheads**

Where bulkhead fittings are penetrating watertight bulkheads, care is to be taken to maintain watertightness. For penetrations through the collision bulkhead 2.3.2 is to be observed.

### 2.4 Openings

**2.4.1** In highly stressed areas openings are to be generally avoided.

Bulwark openings shall not be located at ends of superstructures.

**2.4.2** Corners of all openings in strength structures are to be well rounded. If necessary, the shape of the openings is to be designed to reduce stress concentrations.

### 2.5 Side doors

**2.5.1** In general, doors in the side shell shall not extend below the load waterline.

**2.5.2** Door openings in the shell are to have well rounded corners and adequate compensation of the opening is to be arranged with web frames at sides and stringers above and below. In general the strength of side doors is to be equivalent to the strength of the surrounding structure.

**2.5.3** Doors shall preferably be designed to open outwards.

### 2.6 Bottom structure

**2.6.1** Generally, a centreline girder shall be fitted for docking purposes unless sufficient strength and stiffness is already achieved by the external keel or the bottom shape. Additional bottom girders may be appropriate. The centreline and the off-centreline bottom girders are to extend as far forward and aft as practicable. The girders shall be fitted with a continuous face plate.

Lightening holes in girders shall generally not exceed half the depth of the girder and their length shall not exceed half the frame spacing.

**2.6.2** Floors or equivalent structural components are to be fitted in the area of the engine foundations, the rudder skeg and the propeller bracket, if applicable. Plating is to be locally increased in way of rudder bearings, propeller brackets and stabilizers by 1,5 times of the adjacent plate thickness.

**2.6.3** Manholes and other openings are not to be located at the ends of floor or girder spans, unless shear stress checks are carried out in such areas.

**2.6.4** In case of sailing yachts with ballast keel, the bottom structure is to be reinforced due to additional loads transmitted by the keel. Special care is to be taken with the structural support of fin keel's leading and trailing edge.

### 2.7 Engine foundation

The foundation shall be constructed for the proper transmission of forces in the transverse and longitudinal directions. Longitudinal girders forming seatings of the engine, the gearbox and the thrust block shall therefore extend to the engine room bulkheads and are to be supported transversely by floors, web frames or wing bulkheads. Floors in the engine room are generally to be fitted at every frame. Additional intermediate frames may be appropriate.

### 2.8 Side structure and bulwarks

**2.8.1** Side frames shall be connected to keel floors and deck beams by brackets. Alternatively, a continuous transition between such elements is to be adequately rounded.

Continuity of longitudinal stiffeners is to be ensured, if applicable.

**2.8.2** Bulwark plating is to be determined by applying the side design pressure for the relevant vertical height. Bulwark stanchions must be in line with transverse beams or adequate substructure must be provided by other means. Bulwarks are to be provided with freeing ports of sufficient size, see Section 3, D.5.

### 2.9 Tank structures

**2.9.1** The fore peak shall not be used for carrying fuel oil.

**2.9.2** Fresh water tanks are to be separated from other tanks such as waste water tanks by cofferdams. The same applies to fuel tanks. Generally, also tanks such as lubricating or hydraulic oil tanks shall be separated from each other by equivalent means.

**2.9.3** Each tank is to be fitted with air pipes, overflow and sounding pipes, see Section 1, C.7.11.

### 2.10 Deck

**2.10.1** In case of longitudinal deck stiffeners, deck beams are to be located in way of the vertical web frames of the side shell. Structural continuity of the stiffeners is to be ensured, see Fig. 2.11.

**2.10.2** In case of a transversely stiffened deck, deck beams are to be generally fitted at every frame and shall be in line with the side stiffening members, see Fig. 2.12.

### 2.11 Superstructures and deckhouses

**2.11.1** Ends of superstructures and deckhouses are to be sufficiently supported by bulkheads, pillars or other equivalent arrangements. Superstructure front and aft bulkheads are to be aligned with bulkheads in the hull or must be equivalently supported by pillars.

In extension of superstructures and deckhouses, girders shall be arranged under the main deck extending at least three frame spaces beyond the ends of the longitudinal walls. These girders shall overlap the longitudinal walls at least by two frame spaces.

**2.11.2** Webframes or partial bulkheads are to be provided to ensure transverse rigidity in large deckhouses. The strength members are to be suitably reinforced in the area of masts and other load concentrations.

As a rule, the spacing of stiffeners on sides of superstructures and deckhouses are to be the same as those of beams on supporting decks.

**2.11.3** Structural discontinuities and rigid points are to be avoided. When the strength of a structural element is reduced by the presence of an attachment or an opening, proper compensation is to be provided.

### 2.12 Pillars

For the structural arrangement of pillars see 4.6.

### 2.13 Further design principles

Further design principles for metallic structures are summarized in C.

## 3. Design loads

### 3.1 General

**3.1.1** For "high speed" motor yachts which are capable of speeds:

$$\mathbf{v} = 7{,}2 \cdot \sqrt[6]{\nabla} \ [\text{kn}]$$

$\nabla$ = moulded volume [m$^3$] according to A.6.6.

The relevant design loads and scantling requirements of the GL Rules Part 1 – Seagoing Ships, Chapter 5 – High Speed Craft apply.

**3.1.2** The design loads for sailing and motor yachts not considered as of the "high speed" type are specified in the following. The design loads are to be applied at the following load points:

– for panels: lower edge of the plate

– for structural members: centre of the area supported by the element

### 3.1.3 Definition of symbols

$L_{SC}$ = scantling length [m]

$$= \frac{L_H + L_{WL}}{2}$$

$L_H$ = length of the yacht's hull measured parallel to the design waterline [m], see Fig. 2.13

$L_{WL}$ = length of the yacht from the foreside of the stem to the after side of the stern or transom, measured at the design waterline [m], see Fig. 2.13

$T_H$ = see A.6.2.10

## 3.2 Loads on hull

**3.2.1** The load $p_H$ on the yacht's hull is to be determined as follows:

$$p_H = 10 \cdot T_H \left(1 - \frac{z}{H}\right) + c_{RY} \cdot c_p \cdot c_L \cdot L_{SC} \left(1 + \frac{v_0}{3 \cdot \sqrt{L_{SC}}}\right) \cdot \cos\left(\frac{\alpha}{1,5}\right)$$

$c_p$ = panel size factor as a function of f, see also Fig. 2.14

$$= 0,54 \cdot f^2 - 1,29 \cdot f + 1$$

$$f = \frac{a - 250}{55 \cdot L_{SC} + 550}$$

a = panel's short span respectively load span of stiffener [mm], not to be taken $> 1\,300$ mm

$c_L$ = hull longitudinal distribution factor

= for sailing yachts, see Fig. 2.15, $c_L$ is:

– for $\frac{x}{L_{WL}} < 0$:

$c_L = 0,80$ for **L** = 24 m

$c_L = 0,60$ for **L** = 48 m

– for $0 \le \frac{x}{L_{WL}} < 0,65$:

$c_L = 0,80 + 0,615 \cdot \frac{x}{L_{WL}}$ for **L** = 24 m

$c_L = 0,60 + 0,538 \cdot \frac{x}{L_{WL}}$ for **L** = 48 m

– for $\frac{x}{L_{WL}} \ge 0,65$:

$c_L = 1,20$ for **L** = 24 m

$c_L = 0,95$ for **L** = 48 m

= for motor yachts, see Fig. 2.16, $c_L$ is:

– for $\frac{x}{L_{WL}} < 0$:

$c_L = 0,85$ for **L** = 24 m

$c_L = 0,65$ for **L** = 48 m

– for $0 \le \frac{x}{L_{WL}} < 0,5$:

$c_L = 0,85 + 0,8 \cdot \frac{x}{L_{WL}}$ for **L** = 24 m

$c_L = 0,65 + 0,7 \cdot \frac{x}{L_{WL}}$ for **L** = 48 m

– for $\frac{x}{L_{WL}} \ge 0,65$:

$c_L = 1,25$ for **L** = 24 m

$c_L = 1,00$ for **L** = 48 m

z = vertical distance between the load point and the moulded base line [m], see Fig. 2.13

$\alpha$ = $\beta - 20°$ for sailing yachts (not smaller than 0°)

= $\beta - 5°$ for motor yachts (not smaller than 0°)

$\beta$ = deadrise angle at the load point, see Fig. 2.13

$c_{RY}$ = factor for restricted range of service, see Section 1, A.7.

= 0,95 for **M,** restricted international service

= 0,90 for **K**, coastal service

= 0,85 for **W**, sheltered water service

**3.2.2** In any case the load $p_H$ shall not be smaller than:

$$p_{H\,min} = 10 \cdot \mathbf{H} \quad \left[kN/m^2\right]$$

for the area of the hull below the full displacement waterline

$$p_{H\,min} = 5 \cdot \mathbf{H} \quad \left[kN/m^2\right]$$

for the area of the hull above the full displacement waterline

**3.2.3** The design load for the ballast keel area of sailing yachts as indicated in Fig. 2.19 shall be taken as:

$$p_{keel} = 2 \cdot p_H$$

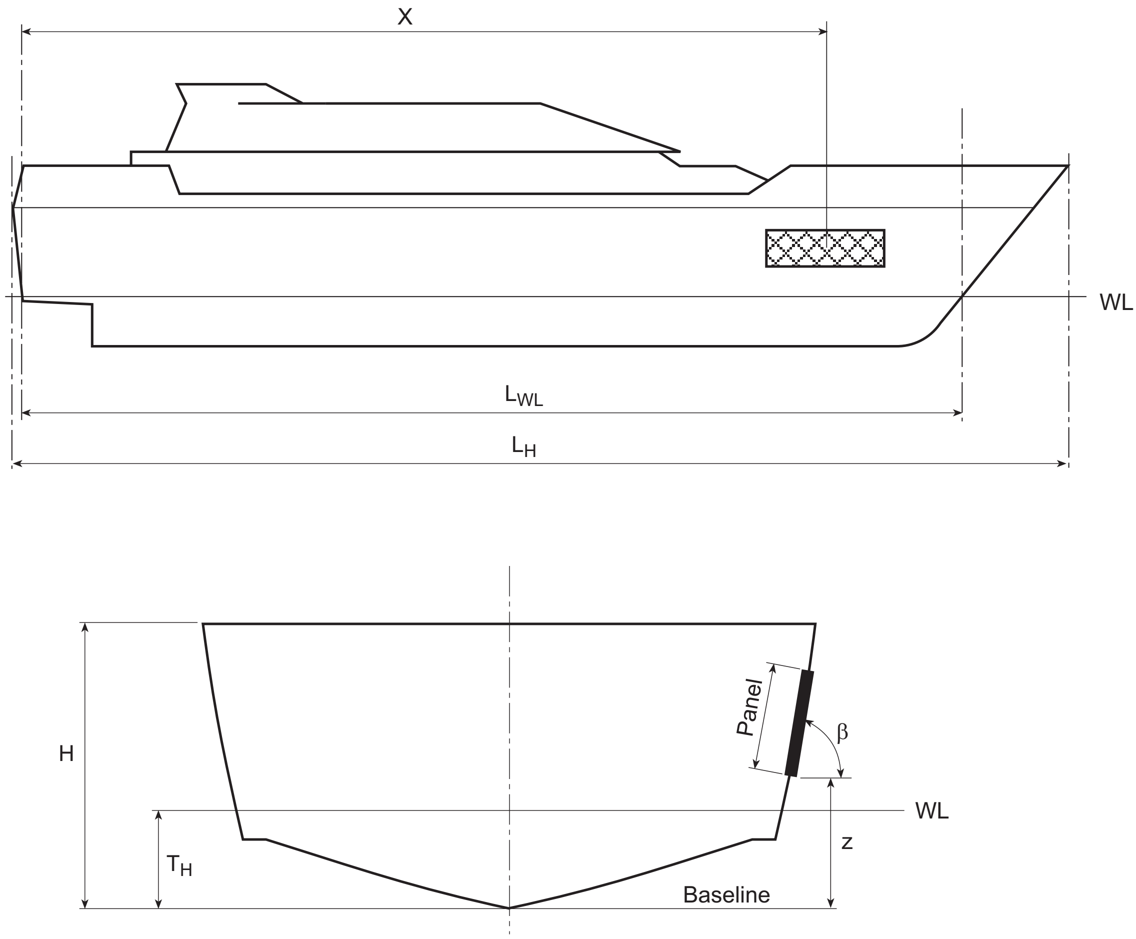



**Fig. 2.13 Characteristic parameters for panels of a motor yacht's hull**

### 3.3 Loads on weather decks

**3.3.1** The design pressure on weather decks is to be determined according to the following formula:

$$p_D = 2{,}7 \cdot c_D \cdot \sqrt{\frac{L_{SC}}{T_H + z}}$$

$$P_{D,min} = 6{,}0 \ [\mathrm{N/m^2}]$$

z = local height of weather deck above WL [m]

$c_D$ = deck longitudinal distribution factor

= for sailing yachts, see Fig. 2.17, $c_D$ is:

– for $\frac{x}{L_{WL}} < 0{,}05: \quad c_D = 1{,}20$

– for $0{,}05 \le \frac{x}{L_{WL}} < 0{,}25:$

$$c_D = 1{,}25 - \frac{x}{L_{WL}}$$

– for $0{,}25 \le \frac{x}{L_{WL}} < 0{,}70:$

$$c_D = 1{,}00$$

– for $0{,}70 \le \frac{x}{L_{WL}} < 0{,}90:$

$$c_D = 2{,}5 \cdot \frac{x}{L_{WL}} - 0{,}75$$

– for $\frac{x}{L_{WL}} \geq 0{,}90: \quad c_D = 1{,}50$

= for motor yachts, see Fig. 2.18, $c_D$ is:

– for $\frac{x}{L_{WL}} < 0:$

$$c_D = 1{,}10$$

– for $0 \leq \frac{x}{L_{WL}} < 0{,}25:$

$$c_D = 1{,}10 - 0{,}4 \cdot \frac{x}{L_{WL}}$$

– for $0{,}25 \leq \frac{x}{L_{WL}} < 0{,}70:$

$$c_D = 1{,}00$$

– for $0{,}70 \leq \frac{x}{L_{WL}} < 1{,}00:$

$$c_D = \frac{2}{3} \cdot \frac{x}{L_{WL}} + \frac{8}{15}$$

– for $\frac{x}{L_{WL}} \geq 1{,}00: \quad c_D = 1{,}20$

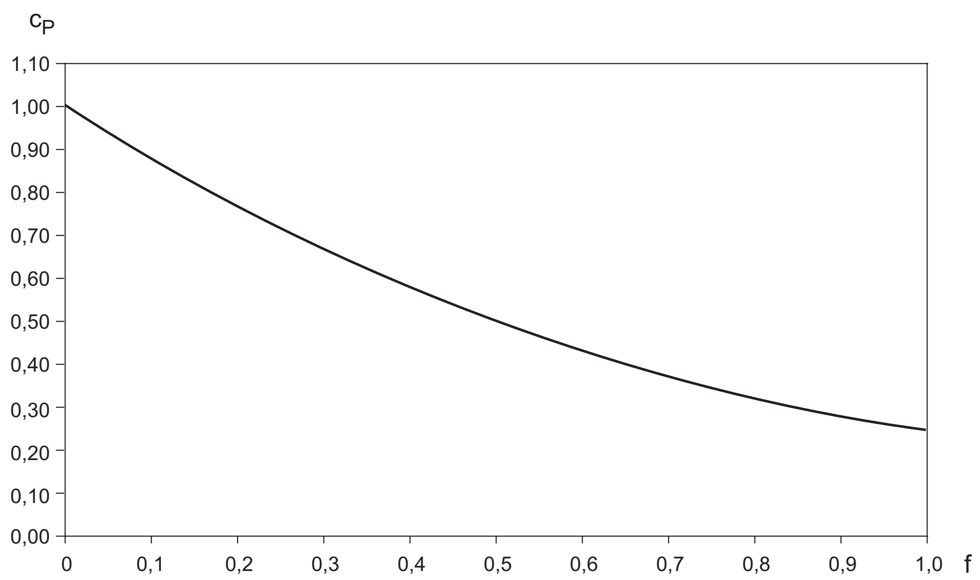



**Fig. 2.14 Panel size factor $c_p$**

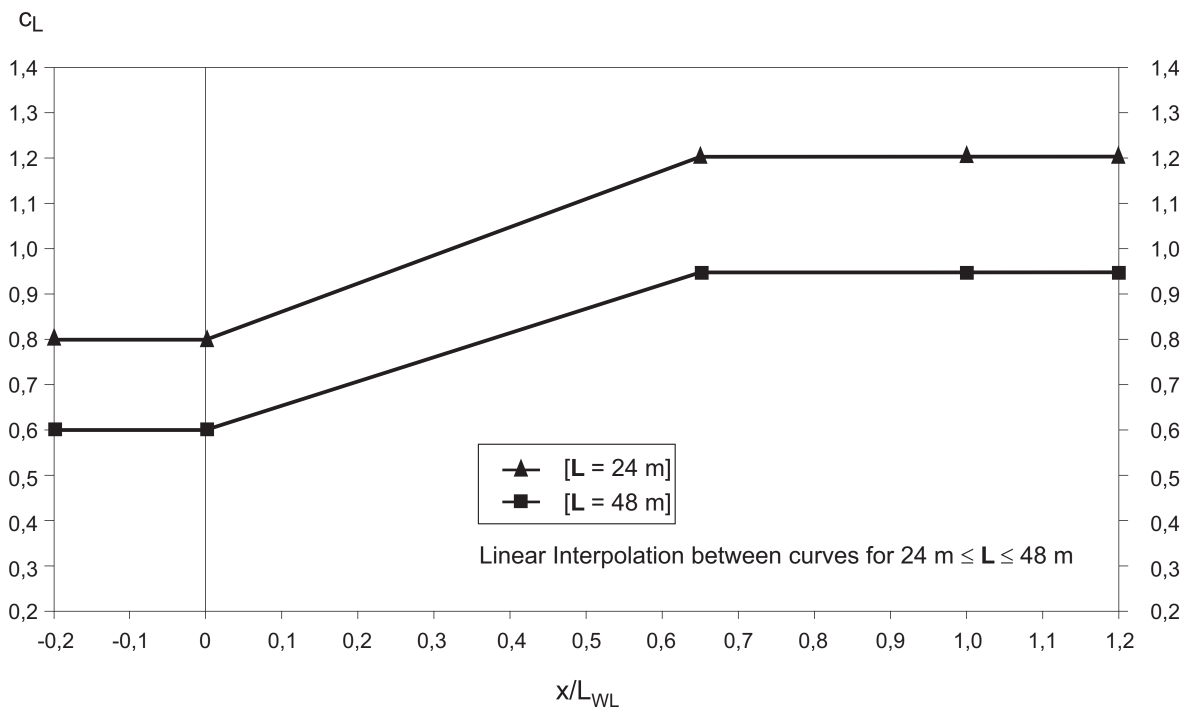



**Fig. 2.15 Hull longitudinal distribution factor for sailing yachts $c_L$**

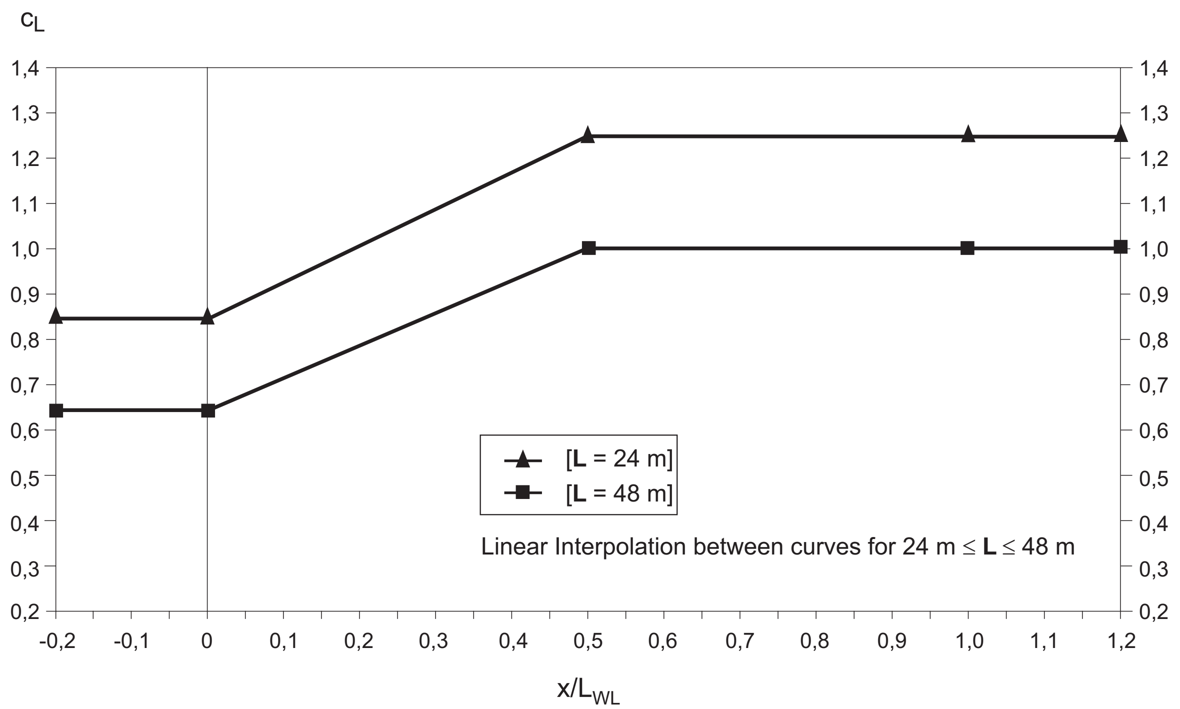



**Fig. 2.16 Hull longitudinal distribution factor for motor yachts $c_L$**

### 3.4 Loads on superstructures and deckhouses

#### 3.4.1 Loads on walls

##### 3.4.1.1 Front walls

The design load is:

$$p_{AFW} = 1{,}5 \cdot p_D \quad \left[\mathrm{kN}/\mathrm{m}^2\right]$$

##### 3.4.1.2 Side walls

The design load is:

$$p_{ASW} = 1{,}2 \cdot p_D \quad \left[\mathrm{kN}/\mathrm{m}^2\right]$$

##### 3.4.1.3 Aft walls

The design load is:

$$p_{AAW} = 0{,}8 \cdot p_D \quad \left[\mathrm{kN}/\mathrm{m}^2\right]$$

#### 3.4.2 Loads on superstructure decks

The load on decks of superstructures and deckhouses is based on the load on the weather deck according to 3.3 and is defined by the following formula:

$$p_{DA} = p_D \cdot n \left(0{,}7 \cdot \frac{b'}{B'}\right) + 0{,}3$$

$n = 1 - \dfrac{z - \mathbf{H}}{10}$

$z$ = vertical distance of the deck above the base line [m]

$b'$ = breadth of the deckhouse/superstructure [m]

$B'$ = largest breadth of the yacht at the longitudinal position considered [m]

### 3.5 Loads on accommodation decks

The load on accommodation decks can be assumed as:

$$p_L = p_C \cdot c_D \quad \left[\mathrm{kN}/\mathrm{m}^2\right]$$

$p_C$ = to be defined by the designer in connection with the owner's specification [kN/m²]

$p_{Cmin}$ = 3,5 kN/m²

$c_D$ = deck longitudinal distribution factor according to Fig. 2.17 and 2.18

### 3.6 Loads on bulkheads

#### 3.6.1 Collision bulkhead

The design load is:

$$p_{CBH} = 11{,}5 \cdot z_{BH} \quad \left[\mathrm{kN}/\mathrm{m}^2\right]$$

$z_{BH}$ = vertical distance from the load centre to the top of the bulkhead [m]

#### 3.6.2 Other bulkheads

The design load is:

$$p_{BH} = 10{,}0 \cdot z_{BH} \quad \left[\mathrm{kN}/\mathrm{m}^2\right]$$

### 3.7 Loads on tank structures

The design load is:

$$p_T = 10{,}0 \cdot z_T \quad \left[\mathrm{kN}/\mathrm{m}^2\right]$$

$z_T$ = vertical distance from the load centre to the top of the tank overflow [m]

= not to be taken less than 2,0 m

## 4. Scantlings

### 4.1 General

For the scantlings of "high speed" motor yachts see 3.1.1.

#### 4.1.1 Rounding-off tolerances

If the determined plate thickness differs from full or half mm they may be rounded off to full or half mm up to 0,2 mm or 0,7 mm; above 0,2 and 0,7 mm they are to be rounded up.

#### 4.1.2 Corrosion allowances

The following, reduced corrosion allowances may be applied for yachts, if special care for maintenance and special attention for measures of corrosion protection can be assumed.

##### 4.1.2.1 Steel

The scantlings require the following allowances $t_k$ to the theoretical, rounded-off plate thickness:

– $t_K$ = 0,5 mm in general

– $t_K$ = 0,7 mm for lubrication oil, gas oil or equivalent tanks

– $t_K$ = 1,0 mm for water ballast and heavy oil tanks

– for special applications $t_K$ shall be agreed with GL

For all elements of the yacht’s structure which are forming a boundary of tanks, the $t_K$ values for tanks have to be considered.

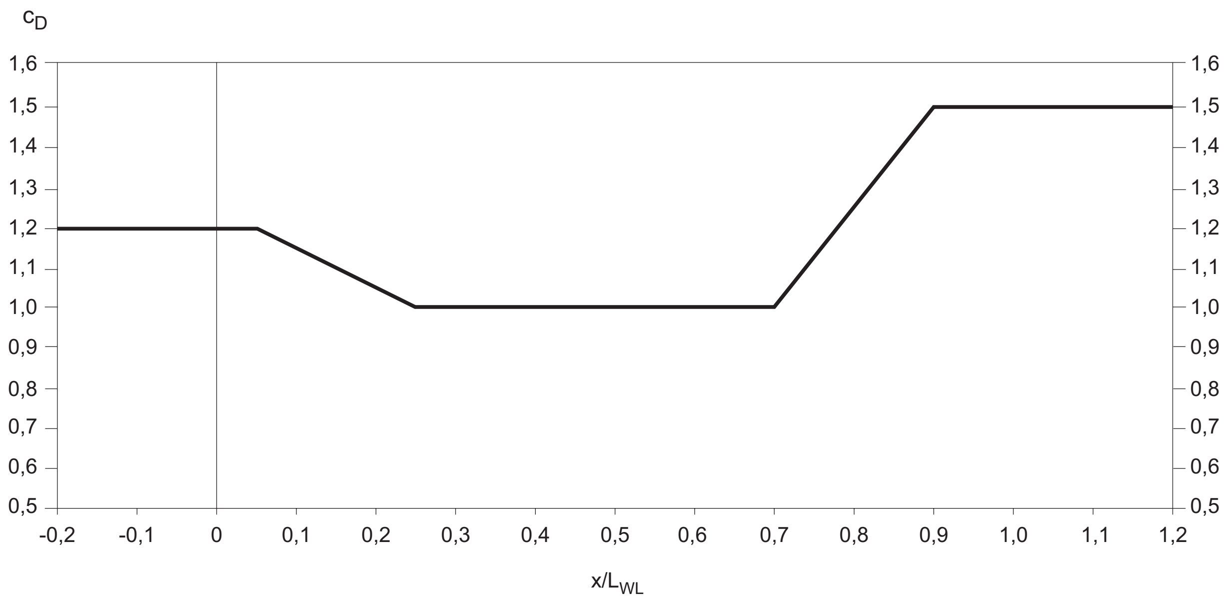



**Fig. 2.17 Deck longitudinal distribution factor $c_D$ for sailing yachts**

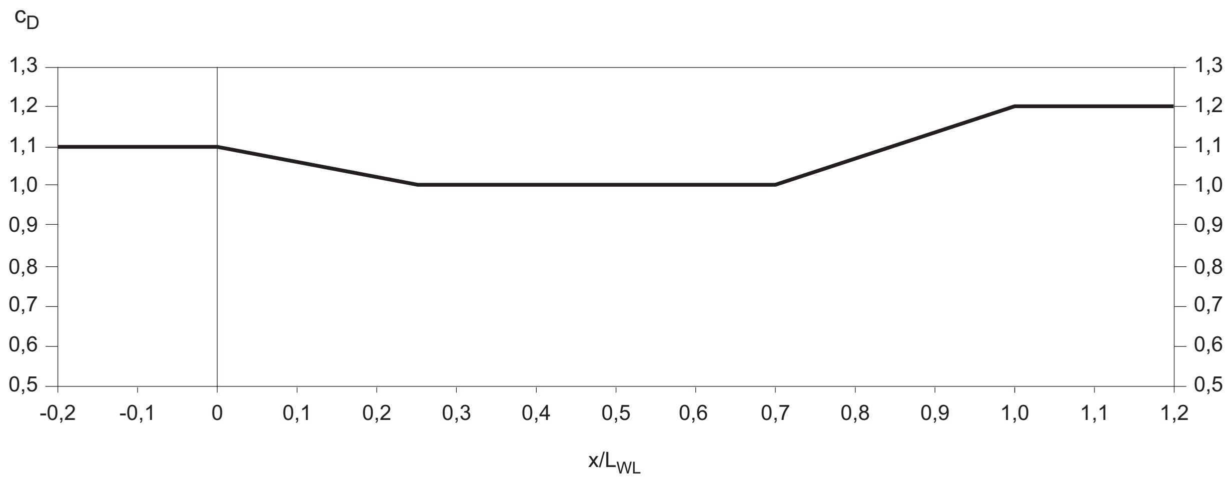



**Fig. 2.18 Deck longitudinal distribution factor $c_D$ for motor yachts**

#### 4.1.2.2 Aluminium alloys

If the measures for corrosion protection described in B.6. are fully applied, the corrosion allowance $t_K$ can be assumed as 0 for the types of aluminium alloys defined in B.3.4 and B.3.5. In any way $t_K$ shall not be less than the fabrication tolerances, see GL Rules II – Materials and Welding, Part 1 – Metallic Materials, Chapter 3 – Non-Ferrous Metals.

### 4.1.3 Minimum plate thickness

In general the minimum plate thicknesses for steel and aluminium alloy structures defined in Table 2.18 shall be met. In exceptional cases other values may be agreed with GL.

**Table 2.18 Minimum plate thickness for steel and aluminium plating**

| Element | Minimum thickness [mm] |
|---|---|
| Bottom shell plating | $0,9 \cdot \sqrt{k} \cdot \mathbf{L}$ |
| Side shell plating | $0,8 \cdot \sqrt{k} \cdot \mathbf{L}$ |
| Deck plating | $0,7 \cdot \sqrt{k} \cdot \mathbf{L}$ |
| All other strength relevant plating | 3,0 |
| k = material factor<br>= for steel according to B.2.1 and B.2.2<br>= for aluminium = $k_{A\ell}$ according to B.3.8 | |

## 4.2 Keel

### 4.2.1 Flat plate keel and garboard strake

**4.2.1.1** The width of the flat plate keel b is not to be less than:

$$b = (650 + 5 \cdot \mathbf{L}) \cdot \sqrt{k}$$

k = material factor, see 4.3.1

**4.2.1.2** The thickness of the flat plate keel is not to be less then:

$$t_{keel} = t + 2,0 \quad [\mathrm{mm}]$$

t = thickness of the adjacent bottom plating [mm]

Where a single bottom plating is provided, the thickness of the flat plate keel and the garboard strake is to be adequately increased in the machinery space.

These requirements for the flat plate keel are valid for motor yachts. For sailing yachts scantlings of the ballast keel area (refer to Fig. 2.19) and the ballast keel itself are to be determined for a design load of $p_{keel} = 2 \cdot p_H$ (see 3.2.3).

### 4.2.2 Bar keel

Where a bar keel is provided, its height h and thickness t are recommended to be determined according to following formulae:

$$h = (1{,}1 \cdot \mathbf{L} + 110) \cdot \sqrt{k} \quad [\mathrm{mm}]$$

$$t = (0{,}6 \cdot \mathbf{L} + 12) \cdot \sqrt{k} \quad [\mathrm{mm}]$$

k = material factor, see 4.3.1

The adjoining garboard strake shall have the scantlings of a flat plate keel. Minor deviations of the above values are admissible provided the required sectional area is maintained.

## 4.3 Plating

**4.3.1** The thickness of the plating of hull, decks, superstructures, bulkheads and tanks is not to be less than:

$$t = 22{,}4 \cdot a \cdot \sqrt{\frac{p}{\sigma_{perm}}} \cdot f_a \cdot f_c + t_K \quad [\mathrm{mm}]$$

a = shorter span of panel [m], respectively frame spacing **a**

b = longer span of panel in [m]

p = applicable design load

= $p_H$ on hull according to 3.2

= $p_D$ on weather deck according to 3.3

= $p_A$ on superstructures and deckhouses according to 3.4

= $p_L$ on accommodation decks according to 3.5

= $p_{BH}$ on watertight bulkheads according to 3.6

= $p_T$ in tanks according to 3.7

$$\sigma_{perm} = \frac{185}{k} \quad \left[\mathrm{N/mm^2}\right]$$

k = material factor for steel materials according to B.2.1 and B.2.2 as well as for aluminium alloys according to B.3.8

$f_a$ = aspect ratio factor

$$= 054 + 0{,}23 \cdot \frac{b}{a} \quad \text{for } 1 \le \frac{b}{a} \le 2$$

$$= 1 \quad \text{for } \frac{b}{a} > 2$$

$f_c$ = correction factor for plate panels with simple convex curvature according to C.3.

$t_K$ = corrosion allowance according to 4.1.2

**4.3.2** Compliance with minimum thickness requirements according to 4.1.3 is always mandatory.

### 4.4 Structural members

#### 4.4.1 General

The following formulae to determine the required section modulus and shear area apply to stiffeners, frames, floors, beams and girders. They are valid for stiffening members with webs either perpendicular to the plating or deviating not more than 15° from the perpendicular. In case this angle $\alpha$ exceeds 15°, the required values are obtained by dividing the results of the following formulae by cos $\alpha$.

#### 4.4.2 Section modulus

The section modulus W of a stiffening member required for support of the plating loaded with the design pressure is not to be less than:

$$W = \frac{c \cdot p \cdot a \cdot \ell^2}{\sigma_{perm}} \cdot f_{cs}$$

c = correction factor for boundary conditions

= 83 for both ends constraint, see C.6.

= 125 for one or both ends simply supported, see C.6.

p = applicable design load [kN/m²] according to 3.

a = load span [m]

$\ell$ = unsupported length of stiffener [m], see C.5.

$f_{cs}$ = correction factor for plate panels with simple convex curvature according to C.4.

$\sigma_{perm}$ = permissible stress

$$= \frac{150}{k} \quad \left[N/mm^2\right]$$

k = material factor for steel materials according to B.2.1 and B.2.2 as well as for aluminium alloys according to B.3.8

#### 4.4.3 Shear area

The shear area, i.e. the cross sectional area of the web of the stiffening member A is not to be less than:

$$A = \frac{5 \cdot p \cdot a \cdot \ell}{\tau_{perm}} \quad \left[cm^2\right]$$

p, a, $\ell$, k as defined in 4.4.2

$\tau_{perm}$ = permissible shear stress

$$= \frac{100}{k} \quad \left[N/mm^2\right]$$

#### 4.4.4 Brackets

Required scantlings for brackets are defined in C.6.3.

### 4.5 Permissible equivalent stress

**4.5.1** The equivalent stress $\sigma_v$ for hull structural members is to be determined according to:

$$\sigma_v = \sqrt{\sigma_b^2 + 3 \cdot \tau^2} \quad \left[N/mm^2\right]$$

$\sigma_b$ = bending stress [N/mm²]

$\tau$ = shear stress [N/mm²]

**4.5.2** The equivalent stress for steel structures is not to exceed the following value:

$$\sigma_v = \frac{190}{k} \quad \left[N/mm^2\right]$$

k = material factor for steel according to B.2.1 and B.2.2

**4.5.3** The equivalent stress for aluminium structures is not to exceed the following value:

$$\sigma_v = \frac{190}{k_{A\ell}} \quad \left[N/mm^2\right]$$

$k_{A\ell}$ = material factor for aluminium according to B.3.8

### 4.6 Pillars

#### 4.6.1 General

**4.6.1.1** Structural members at heads and heels of pillars as well as substructures are to be constructed according to the forces they are subject to. Pillars shall rest on girders, floors or other pillars. Openings in webs of floors and girders below pillars are to be avoided. Where pillars on the inner bottom are not in way of intersections of floors and girders, partial floors or other structures are to be provided to support the load transmitted.

**4.6.1.2** At the head and the heel of tubular pillars, plates are generally to be arranged. The connection is to be so dimensioned that at least 1 cm² cross sectional area is available for 10 kN of load.

**4.6.1.3** Where possible, upper deck pillars shall be aligned with pillars below. Stiffeners ensuring efficient load distribution are to be fitted at the ends of pillars.

**4.6.1.4** Pillars in tanks are to be checked for tension. Tubular pillars are not permitted in tanks for flammable liquids.

#### 4.6.2 Definition of loads and geometric parameters

$P_S$ = pillar load [kN]

$$= p_L \cdot A + P_i$$

$p_L$ = load on decks [kN/m²] according to 3.3 to 3.5

A = load area for one pillar [m²]

$P_i$ = load from pillars located above the pillar considered [kN]

$\ell_S$ = length of the pillar [cm]

= moment of inertia of the pillar [cm⁴] considering effective width

$I_S = A_S \cdot i_S^2$

$A_S$ = sectional area of the pillar [cm²]

$i_S$ = radius of gyration of the pillar [cm]

= $0{,}25 \cdot d_S$ for solid pillars of circular cross section

$= 0{,}25\sqrt{d_a^2 + d_i^2}$

$d_a$ = outside diameter of tubular pillars [cm]

$d_i$ = inside diameter of pillar [cm]

$d_S$ = pillar diameter of solid pillars [cm]

#### 4.6.3 Buckling criterion

The chosen scantlings of a pillar have to meet the following buckling criterion:

$$\frac{1{,}1 \cdot \sigma_x}{\kappa \cdot R_{eH}} \le 1$$

In case of aluminium alloy pillars $R_{eH}$ is to be substituted by $R_{p0,2}$ (see B.3.8)

$\sigma_x$ = buckling stress in longitudinal direction of the pillar [N/mm²]

$$\sigma_x = \frac{\nu \cdot P_S \cdot 10}{A_S}$$

$\nu$ = safety factor

= 1,50

$\kappa$ = reduction factor

$$\kappa = \frac{1}{\phi + \sqrt{\phi^2 - \lambda^2}}$$

$$\phi = 0{,}5\left(1 + n_p\left(\lambda - 0{,}2\right) + \lambda^2\right)$$

$n_P$ = 0,34 for pipes and box sections

= 0,49 for open sections

$$\lambda = \sqrt{\frac{R_{eH}}{\sigma_{ki}}}$$

$R_{eH}$ = minimum nominal upper yield stress [N/mm²] according to B.2.1 and B.2.2

$\sigma_{ki}$ = pillar buckling stress [N/mm²]

$$= \frac{\pi^2 \cdot E \cdot I_S}{\ell_s^2 \cdot k_S^2 \cdot A_S}$$

E = modulus of elasticity [N/mm²]

$k_S$ = 1,0 in general. For pillars which end supports can be considered as rigidly fixed, $k_S$ may be reduced accordingly.

#### 4.6.4 Minimum wall thickness

The wall thickness of tubular pillars which may be expected to be damaged during equipment handling, etc. is not to be less than:

$$t_w = 4{,}5 + 0{,}015\ d_a \quad [\text{mm}]$$

for $d_a \le 300$ mm

$$t_w = 0{,}03\ d_a \quad [\text{mm}]$$

for $d_a > 300$ mm

### 4.7 Foundations for main propulsion engines

#### 4.7.1 General

**4.7.1.1** The following requirements apply to diesel engines, gears and generators.

**4.7.1.2** The rigidity of the engine seating and the surrounding bottom structure must be adequate to keep the deformations of the system due to the loads within the permissible limits. In special cases, proof of deformations and stresses may be required.

**4.7.2** Due regard is to be paid, at the initial design stage, to a good transmission of forces in transverse and longitudinal direction.

**4.7.3** The foundation bolts for fastening the engine at the seating shall be spaced no more than 3 × d apart from the longitudinal foundation girder. Where the distance of the foundation bolts from the longitudinal foundation girder is greater, proof of equivalence is to be provided.

d = diameter of the foundation bolts

**4.7.4** In the whole speed range of main propulsion installations for continuous service resonance vibrations with inadmissible vibration amplitudes must not occur; if necessary structural variations have to be provided for avoiding resonance frequencies. Otherwise, a barred speed range has to be fixed. Within a range of – 10 % to + 5 % related to the rated speed no barred speed range is permitted. GL may require a vibration analysis and, if deemed necessary, vibration measurement.

#### 4.7.5 Longitudinal girders

**4.7.5.1** The thickness of longitudinal girders for internal combustion engines is not to be less than:

$$t = \left(\frac{P}{n \cdot e_1 \cdot c} + \frac{G}{280}\right)\frac{3,75}{\ell_m}$$

$$c = 1 - \frac{1}{0,025 \cdot \sqrt{P}}$$

$0,2 \leq c \leq 0,5$ for 4-stroke engines

$$= 1 - \frac{1}{0,05 \cdot \sqrt{P}}$$

$\geq 0,5$ for 2-stroke engines

$$t_{min} = 0,4 \cdot t_p \quad [mm]$$

$t_p$ = thickness of top plate, see 4.7.5.3

$P$ = rated driving power of the engine [kW]

$n$ = rated speed at output [1/min]

$G$ = weight of engine [kN]

$\ell_m$ = bolted length of engine on foundation [m]

$e_l$ = distance of the longitudinal girders [m]

The web thickness of longitudinal girders for elastically mounted four-stroke internal combustion engines may be reduced to

$$t' = 0,4 \cdot t$$

if brackets are provided below the mountings, besides each bolt. The web thickness may be reduced to

$$t' = 0,9 \cdot t$$

if two longitudinal girders are provided at each side of an internal combustion engine.

**4.7.5.2** The thickness of the longitudinal girders for gears or generators is not to be less than:

$$t = \frac{P}{n \cdot e_1\left(\ell_m + \frac{e_1}{3}\right)}$$

$P$ = rated output of gear or generator [kW]

$e_l$, $\ell_m$ = see 4.7.5.1

**4.7.5.3** The sizes of the top plate (width and thickness) shall be sufficient to attain efficient attachment and seating of the engine and – depending on seating height and type of engine – adequate transverse rigidity.

The thickness of the top plate shall be:

$$t_p = 0,9 \cdot d \quad [mm]$$

$d$ = diameter of the foundation bolts [mm]

The cross sectional area of the top plate is not to be less than:

$$A_T = \frac{P}{15} + 30 \quad [cm^2] \quad \text{for } P \leq 750 \text{ kW}$$

$$A_T = \frac{P}{75} + 70 \quad [cm^2] \quad \text{for } P > 750 \text{ kW}$$

$P$ = see 4.7.5.1

Where twin engines are fitted, a continuous top plate is to be arranged in general if the engines are coupled to one propeller shaft.

**4.7.5.4** Top plates are preferably to be connected to longitudinal and transverse girders thicker than approx. 15 mm by means of a double bevel butt joint (K butt joint).

### 4.8 Transverse support of longitudinal girders

**4.8.1** The sectional modulus and the cross sectional area of the floor plates between longitudinal girders are not to be less than:

$$W = \left(\frac{120 \cdot P}{n} + e_1 \cdot G\right)\frac{7 \cdot a}{\ell_m} \quad [cm^3]$$

$$A_S = \frac{0,35 \cdot a \cdot G}{\ell_m} \quad [cm^2]$$

$a$ = distance of the floor plates [m]. For all other parameters see 4.7.5.1.

**4.8.2** The longitudinal girders of the engine seating are to be supported transversely by means of web frames or wing bulkheads.

### 4.9 Foundations for deck machinery and mooring equipment

**4.9.1** For deck machinery, like anchor windlasses, mooring winches, boat davits, etc. the most critical operational loads have to be considered for an analysis.

**4.9.2** For windlasses and chain stoppers the acting forces on the foundation are to be calculated for 100 % of the rated breaking load of the chain cable. The resulting normal stress in the supporting structure shall not exceed the minimum nominal upper yield point $R_{eH}$. Shear stress is to be within:

$$\frac{R_{eH}}{\sqrt{3}}$$

## E. Motor and Sailing Yachts, 24 m ≤ L ≤ 48 m, Composite Structures

### 1. General

#### 1.1 Scope

**1.1.1** The following specifies requirements for design and construction of hulls for motor and sailing yachts with 24 m ≤ **L** ≤ 48 m, made from composite materials. The term composite refers to fibre reinforced plastic (FRP) materials of the single skin type or to FRP skins in conjunction with lightweight core materials, i.e. sandwich types. For lengths **L** above 48 m special considerations for the extrapolation of these Rules have to be agreed with GL. The requirements apply also to hulls of cold-moulded wood construction.

**1.1.2** The following may be also used for craft other than yachts, like work boats, patrol boats, etc. For such craft an additional safety factor of 1,2 regarding permissible stresses shall be applied.

**1.1.3** Different types of fibres and the multitude of fibre arrangements, as well as different core materials give rise to sophisticated laminate lay-ups of components specifically designed for the loads expected. Strength and stiffness calculations for such structures require careful analysis.

#### 1.2 Materials

**1.2.1** Regarding FRP and core materials, the GL Rules II – Materials and Welding, Part 2 – Non-metallic Materials, Chapter 1 – Fibre Reinforced Plastics and Adhesive Joints apply. An excerpt of these Rules is contained in B.7.

**1.2.2** The actual mechanical properties of all FRP layers and the core materials have to be submitted to GL and are to be verified by tests. The information about the properties shall also include nominal thickness of each ply, specific weight per area and fibre content.

### 2. Design principles

#### 2.1 General structural arrangement

**2.1.1** The hull structural arrangement shall consist of an effective strengthening system of bulkheads, web frames, longitudinal girders, etc. as well as transverse and/or longitudinal frames or stiffeners. Longitudinal stiffeners are to be supported by transverse web frames or transverse bulkheads. Transverse frames are to be supported by longitudinal girders or other longitudinal structural members.

Where bulkheads, bunks, shelves, or other structurally effective interior components are laminated to the hull to provide structural support, they are generally to be bonded by laminate angles on both sides.

**2.1.2** Care is to be taken to ensure structural continuity and to avoid sharp corners and abrupt changes in section and shape.

Where frames, beams and stiffeners are intercostal at an intersecting member, the connections are to provide continuity of strength.

**2.1.3** Floors are to be fitted in line with transverse webs or transverse frames. Alternatively, floors may terminate at longitudinal girders which in turn are supported by deep web rings or transverse bulkheads. Floors or equivalent stiffeners are to be fitted in the area of the engine foundations, the rudder skeg and the propeller bracket, if applicable. For sailing yachts with short ballast keels, a reinforced floor at the leading and trailing edge of the keel is to be arranged.

**2.1.4** Sailing craft shall have transverse bulkheads or equivalent structures in way of mast(s) in order to achieve adequate transverse rigidity. Transverse bulkheads or deep brackets are to be provided in way of chainplates.

#### 2.2 Longitudinal strength

Under certain conditions after consultation with GL a check of longitudinal strength is to be carried out.

#### 2.3 Bulkheads

**2.3.1** Number and location of watertight bulkheads should be considered in the early design phase to ensure compliance with these Rules and possibly other relevant regulations.

Bulkhead stiffeners, where required, are to be aligned with hull girders. Where vertical stiffeners are cut in way of watertight doors, reinforced stiffeners are to be fitted on each side of the door opening and crossbars are to be provided to support the cut-off stiffeners.

**2.3.2 Collision bulkhead**

The collision bulkhead shall extend up to the freeboard deck. Steps or recesses may be permitted.

Openings in the collision bulkhead shall be watertight and permanently closed in sailing condition. Closing appliances and their number shall be reduced to the minimum, compatible with the design and proper working of the yacht.

Where pipes are penetrating the collision bulkhead, screwdown valves are to be fitted directly at the collision bulkhead. Such valves are to be operable from outside the forepeak.

**2.3.3 Stern tube bulkhead**

All yachts are to have a stern tube bulkhead which is, in general, to be so arranged that the stern tube and rudder trunk are enclosed in a watertight compartment. The stern tube bulkhead shall extend to the freeboard deck or to a watertight platform situated above the load waterline.

Where a complete stern tube bulkhead is not practicable, only watertight void spaces enclosing the stern tube entrance, providing the possibility for a second watertight sealing may be provided after agreement with GL. The same arrangement can be applied for the rudder trunk.

#### 2.3.4 Remaining watertight bulkheads

Remaining watertight bulkheads are, depending on the type of yacht and the Classification for damage stability, to extend to the freeboard deck. Wherever practicable, they shall be situated in one frame plane, otherwise those portions of decks situated between parts of transverse bulkheads are to be watertight.

It is recommended that bulkheads shall be fitted separating the machinery space from service spaces and accommodation rooms forward and aft and made watertight and gastight up to the freeboard deck.

#### 2.3.5 Openings in watertight bulkheads

**2.3.5.1** Type and arrangement of doors are to be submitted for approval.

In watertight bulkheads other than collision bulkheads, watertight doors may be fitted. Below the deepest load waterline, they are to be constructed as sliding doors, exemptions may be granted on case by case. Above that waterline, hinged doors may be approved.

Watertight doors are to be sufficiently strong and of an approved design.

Openings for watertight doors in the bulkheads are to be effectively framed such as to facilitate proper fitting of the doors and to guarantee watertightness.

**2.3.5.2** Watertight bulkhead doors and their frames are to be tested before they are fitted onboard by a head of water corresponding to the freeboard deck height or the results from damage stability calculation. Alternatively, watertight doors may be used which have been type approved in accordance with GL special acceptance procedure. After having been fitted on board, the doors are to be soap-tested for tightness and to be subject to an operational test.

**2.3.5.3 Penetrations through watertight bulkheads**

Where bulkhead fittings are penetrating watertight bulkheads, care is to be taken to maintain watertightness. For penetrations through the collision bulkhead 2.3.2 is to be observed.

### 2.4 Openings

Corners of all openings in strength structures are to be well rounded. If necessary, the shape of openings is to be so designed as to reduce stress concentrations. Structural integrity must be maintained around openings. In highly stressed areas openings should be avoided as far as possible.

### 2.5 Bottom structure

**2.5.1** In general, continuous longitudinal girders are to be provided and shall extend as far aft and forward as practicable. A centreline girder is to be fitted for docking purposes unless sufficient strength and stiffness is already achieved by the external keel or the bottom shape.

**2.5.2** Size and location of cut-outs in floors and girders must be appropriately designed for the occurring loads. Particularly at the ends of floors and girders sufficient shear area is required.

**2.5.3** A floor or a girder is to be provided under each line of pillars.

**2.5.4** In case of a double bottom, manholes must be arranged for access to all parts of the double bottom.

**2.5.5** Where solid ballast is fitted, it is to be securely positioned. If necessary, intermediate floors may be fitted for this purpose.

If a ballast keel is fitted, the bottom structure is to be reinforced due to additional loads transmitted by the keel. Special care is to be taken with the structural support of fin keel's leading and trailing edge.

### 2.6 Engine foundation

Longitudinal girders forming the engine seatings must extend fore and aft as far as possible and are to be suitably supported by floors, transverse frames and/or brackets. In way of thrust bearing additional strengthening is to be provided.

### 2.7 Side structure and bulwarks

**2.7.1** Longitudinal stiffeners, if fitted, shall be continuous as far as possible.

**2.7.2** Bulwark plating is to be determined by applying the side design pressure for the relevant vertical height. Bulwark stanchions must be in line with transverse beams, or adequate substructure must be provided by other means.

### 2.8 Tank structures

**2.8.1** Fore peak tanks shall not be used for carrying fuel oil.

**2.8.2** Fresh water tanks are to be separated from other tanks such as waste water tanks by cofferdams. The same applies to fuel tanks. Generally, also tanks such as lubricating or hydraulic oil tanks shall be separated from each other by equivalent means.

**2.8.3** Each tank is to be fitted with air pipes, overflow and sounding pipes, see Section 1, C.7.11.

### 2.9 Deck

**2.9.1** In case of longitudinal deck stiffeners, deck beams are to be located in way of the vertical web frames of the side shell. Structural continuity of the stiffeners is to be ensured.

**2.9.2** In case of transverse deck stiffeners, deck beams are to be, in general, fitted at every frame, in line with side shell stiffeners.

### 2.10 Superstructures and deckhouses

**2.10.1** Superstructure and deckhouse front and aft bulkheads are to be aligned with bulkheads, web frames or pillars in the hull or in the superstructure or deckhouse below.

**2.10.2** Web frames or partial/wing bulkheads are to be provided to ensure transverse rigidity in large deckhouses. The strength members are to be suitably reinforced in the area of masts and other load concentrations.

**2.10.3** Ends of superstructures and deckhouses are to be efficiently supported by bulkheads, pillars or other equivalent arrangements

**2.10.4** As a rule, the spacing of stiffeners on sides of superstructures and deckhouses is to be the same as those of beams on supporting decks

**2.10.5** Structural discontinuities and rigid points are to be avoided. Where structural elements are weakened, e.g. by openings, proper compensation is to be provided.

### 2.11 Constructional details

**2.11.1** Cut-outs for the passage of ordinary stiffeners through primary stiffeners, like girders, etc. are to be as small as possible. As a rule, the depth of cut-outs is not to be greater than half the web height of the primary stiffener.

**2.11.2** Changes of thickness for a single-skin laminate are to be made as gradually as possible and over a width which is, in general, not to be less than thirty times the difference in thickness.

The connection between a single-skin laminate and a sandwich laminate is to be carried out as gradually as possible over a width which is, in general, not to be less than three times the thickness of the sandwich core.

**2.11.3** Laminate edges and holes are to be sealed.

**2.11.4** In way of bolted connections and fittings, the sandwich core is to be replaced by inserts of high density foam or single-skin laminate.

## 3. Design loads

### 3.1 General

**3.1.1** For "high speed" motor yachts which are capable of speeds

$$v \geq 7{,}2 \cdot \sqrt[6]{\nabla} \quad [\text{kn}]$$

where

$\nabla$ = moulded volume [m³] according to A.6.6

the relevant design loads of the GL Rules Part 1 – Seagoing Ships, Chapter 5 – High Speed Craft, see Annex A apply in combination with the scantling requirements of 4.

**3.1.2** The design loads for sailing and motor yachts not considered as of the "high speed" type are specified in the following. The design loads are to be applied at the following load points:

– for panels: lower edge of panel

– for structural members: centre of the area supported by the element

### 3.1.3 Definition of symbols

$L_{SC}$ = scantling length [m]

$$= \frac{L_H + L_{WL}}{2}$$

$L_H$ = length of the yacht's hull measured parallel to the design waterline [m], see Fig. 2.19

$L_{WL}$ = length of the yacht from the foreside of the stem to the after side of the stern or transom, measured at the design waterline [m], see Fig. 2.19

$T_H$ = see A.6.2.10

### 3.2 Loads on hull

**3.2.1** The load $p_H$ on the yacht's hull is to be determined as follows:

$$p_H = 10 \cdot T_H \left(1 - \frac{z}{H}\right) + c_{RY} \cdot c_p \cdot c_L \cdot L_{SC} \left(1 + \frac{v_0}{3 \cdot \sqrt{L_{SC}}}\right) \cdot \cos\left(\frac{\alpha}{1{,}5}\right)$$

$c_p$ = panel size factor as a function of f, see also Fig. 2.20

$$= 0{,}54 \cdot f^2 - 1{,}29 \cdot f + 1$$

$f = \dfrac{a - 250}{55 \cdot L_{SC} + 550}$

a = panel's short span respectively load span of stiffener [mm], not to be taken > 1 300 mm

$c_L$ = hull longitudinal distribution factor

= for sailing yachts, see Fig. 2.21, $c_L$ is:

– for $\dfrac{x}{L_{WL}} < 0$:

$c_L = 0{,}80$ for **L** = 24 m

$c_L = 0{,}60$ for **L** = 48 m

– for $0 \le \dfrac{x}{L_{WL}} < 0{,}65$:

$c_L = 0{,}80 + 0{,}615 \cdot \dfrac{x}{L_{WL}}$ for **L** = 24 m

$c_L = 0{,}60 + 0{,}538 \cdot \dfrac{x}{L_{WL}}$ for **L** = 48 m

– for $\dfrac{x}{L_{WL}} \ge 0{,}65$:

$c_L = 1{,}20$ for **L** = 24 m

$c_L = 0{,}95$ for **L** = 48 m

= for motor yachts, see Fig. 2.22, $c_L$ is:

– for $\dfrac{x}{L_{WL}} < 0$:

$c_L = 0{,}85$ for **L** = 24 m

$c_L = 0{,}65$ for **L** = 48 m

– for $0 \le \dfrac{x}{L_{WL}} < 0{,}5$:

$c_L = 0{,}85 + 0{,}8 \cdot \dfrac{x}{L_{WL}}$ for **L** = 24 m

$c_L = 0{,}65 + 0{,}7 \cdot \dfrac{x}{L_{WL}}$ for **L** = 48 m

– for $\dfrac{x}{L_{WL}} \ge 0{,}65$:

$c_L = 1{,}25$ for **L** = 24 m

$c_L = 1{,}00$ for **L** = 48 m

z = vertical distance between the load point and the moulded base line [m], see Fig. 2.19

α = β – 20° for sailing yachts (not smaller than 0°)

= β – 5° for motor yachts (not smaller than 0°)

β = deadrise angle at the load point, see Fig. 2.19

$c_{RY}$ = factor for restricted range of service, see Section 1, A.7.

= 0,95 for **M,** restricted international service

= 0,90 for **K**, coastal service

= 0,85 for **W**, sheltered water service

**3.2.2** In any case the load $p_H$ shall not be smaller than:

– $p_{H\,min} = 10 \cdot \mathbf{H} \quad \left[kN/m^2\right]$

for the area of the hull below the full displacement waterline

– $p_{H\,min} = 5 \cdot \mathbf{H} \quad \left[kN/m^2\right]$

for the area of the hull above the full displacement waterline

**3.2.3** The design load for the ballast keel area of sailing yachts as indicated in Fig. 2.19 shall be taken as:

$p_{keel} = 2 \cdot p_H$

### 3.3 Loads on weather decks

**3.3.1** The design pressure on weather decks is to be determined according to the following formula:

$$p_D = 2{,}7 \cdot c_D \cdot \sqrt{\frac{L_{SC}}{T_H + z}}$$

$P_{D,min}$ = 6,0 [N/m²]

z = local height of weather deck above WL [m]

$c_D$ = deck longitudinal distribution factor

= for sailing yachts, see Fig. 2.23, $c_D$ is:

– for $\dfrac{x}{L_{WL}} < 0{,}05$: $c_D = 1{,}20$

– for $0{,}05 \le \dfrac{x}{L_{WL}} < 0{,}25$:

$c_D = 1{,}25 - \dfrac{x}{L_{WL}}$

– for $0{,}25 \le \dfrac{x}{L_{WL}} < 0{,}70$:

$c_D = 1{,}00$

– for $0,70 \le \frac{x}{L_{WL}} < 0,90$:

$$c_D = 2,5 \cdot \frac{x}{L_{WL}} - 0,75$$

– for $\frac{x}{L_{WL}} \ge 0,90$: $c_D = 1,50$

= for motor yachts, see Fig. 2.24, $c_D$ is:

– for $\frac{x}{L_{WL}} < 0$: $c_D = 1,10$

– for $0 \le \frac{x}{L_{WL}} < 0,25$:

$$c_D = 1,10 - 0,4 \cdot \frac{x}{L_{WL}}$$

– for $0,25 \le \frac{x}{L_{WL}} < 0,70$:

$$c_D = 1,00$$

– for $0,70 \le \frac{x}{L_{WL}} < 1,00$:

$$c_D = \frac{2}{3} \cdot \frac{x}{L_{WL}} + \frac{8}{15}$$

– for $\frac{x}{L_{WL}} \ge 1,00$: $c_D = 1,20$

### 3.4 Loads on superstructures and deckhouses

#### 3.4.1 Load on walls

##### 3.4.1.1 Front walls

The design load is:

$$p_{AFW} = 1,5 \cdot p_D \quad \left[kN/m^2\right]$$

##### 3.4.1.2 Side walls

The design load is:

$$p_{ASW} = 1,2 \cdot p_D \quad \left[kN/m^2\right]$$

##### 3.4.1.3 Aft walls

The design load is:

$$p_{AAW} = 0,8 \cdot p_D \quad \left[kN/m^2\right]$$

#### 3.4.2 Loads on superstructure decks

The load on decks of superstructures and deckhouses is based on the load on the weather deck according to 3.3. and is defined by the following formula:

$$p_{DA} = p_D \cdot n \left(0,7 \frac{b'}{B'}\right) + 0,3 \quad \left[kN/m^2\right]$$

$$n = 1 - \frac{z - \mathbf{H}}{10}$$

z = vertical distance of the deck above the base line [m]

b' = breadth of the deckhouse/superstructure

B' = largest breadth of the yacht at the longitudinal position considered

### 3.5 Loads on accommodation decks

The load on accommodation decks can be assumed as:

$$p_L = p_C \cdot c_D \quad \left[kN/m^2\right]$$

$p_C$ = to be defined by the designer in connection with the owner's specification [$kN/m^2$]

$p_{Cmin}$ = 3,5 $kN/m^2$

$c_D$ = longitudinal distribution factor according to Fig. 2.23 and 2.24

### 3.6 Loads on bulkheads

#### 3.6.1 Collision bulkhead

The design load is:

$$p_{BH} = 11,5 \cdot z_{BH} \quad \left[kN/m^2\right]$$

$z_{BH}$ = vertical distance from the load centre to the top of the bulkhead in [m]

#### 3.6.2 Other bulkheads

The design load is:

$$p_{BH} = 10,0 \cdot z_{BH} \quad \left[kN/m^2\right]$$

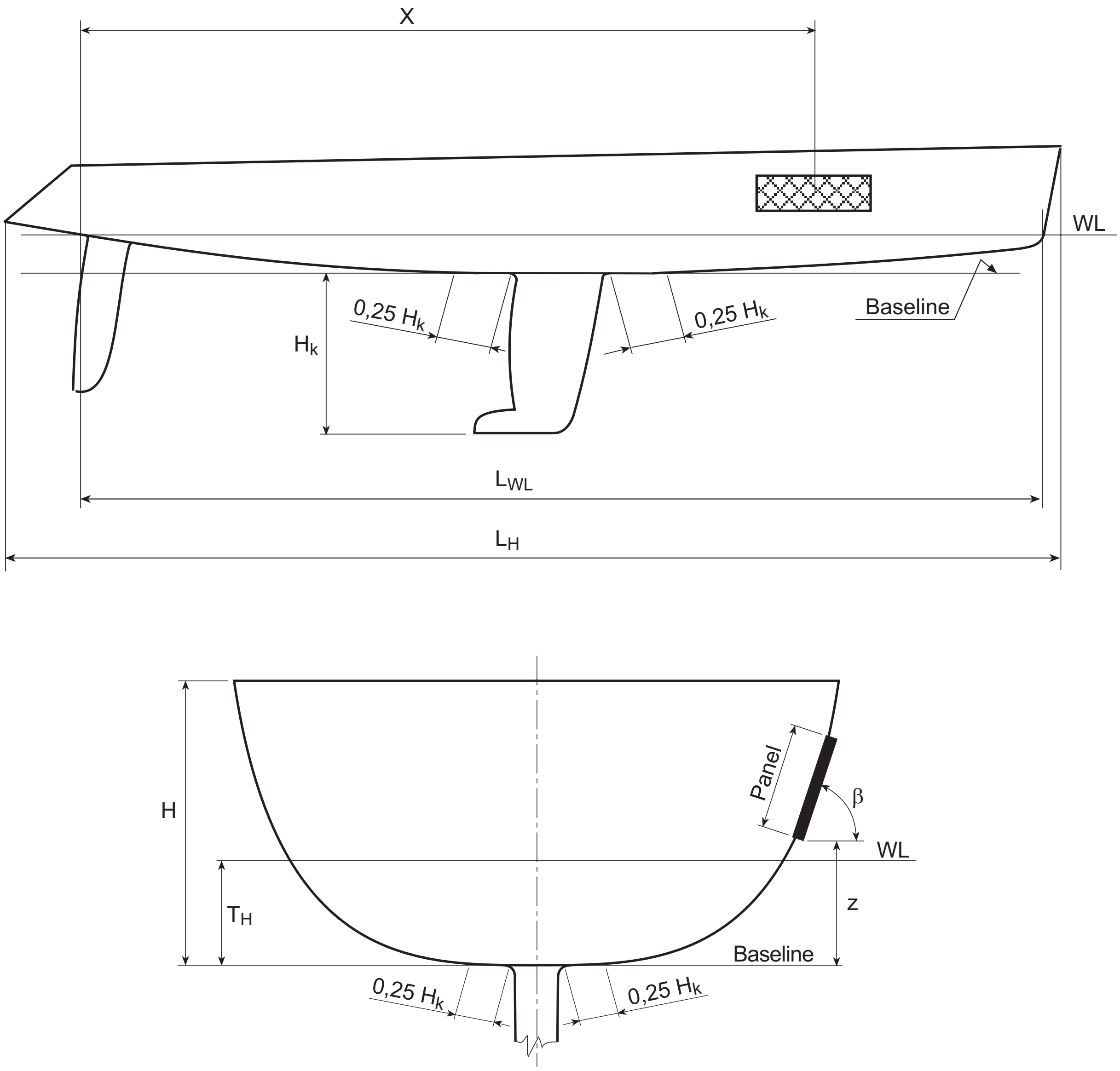



**Abb. 2.19 Characteristic parameters for panels of the yacht's hull**

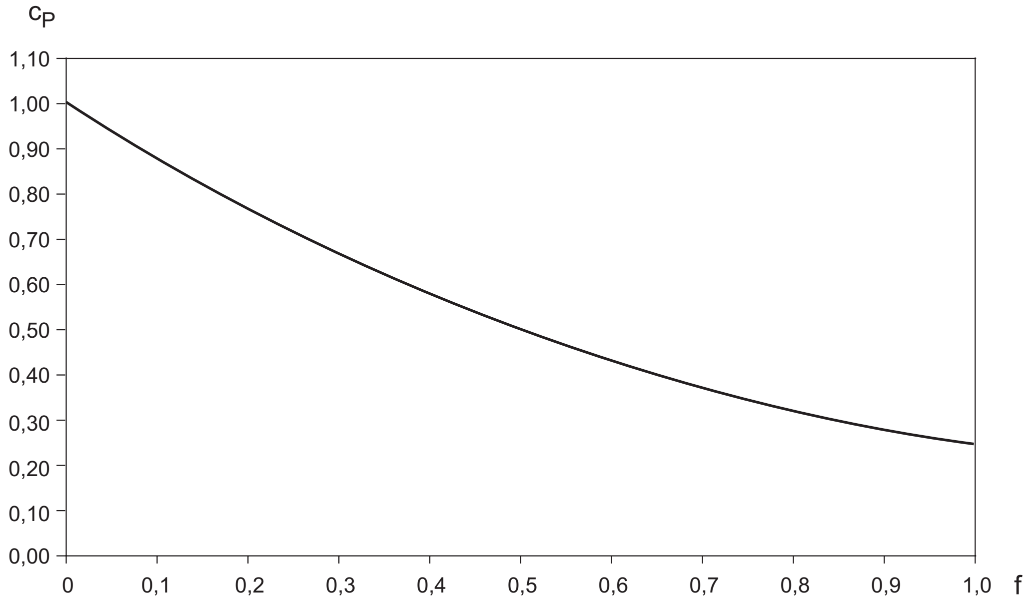



**Abb. 2.20 Panel size factor $c_p$**

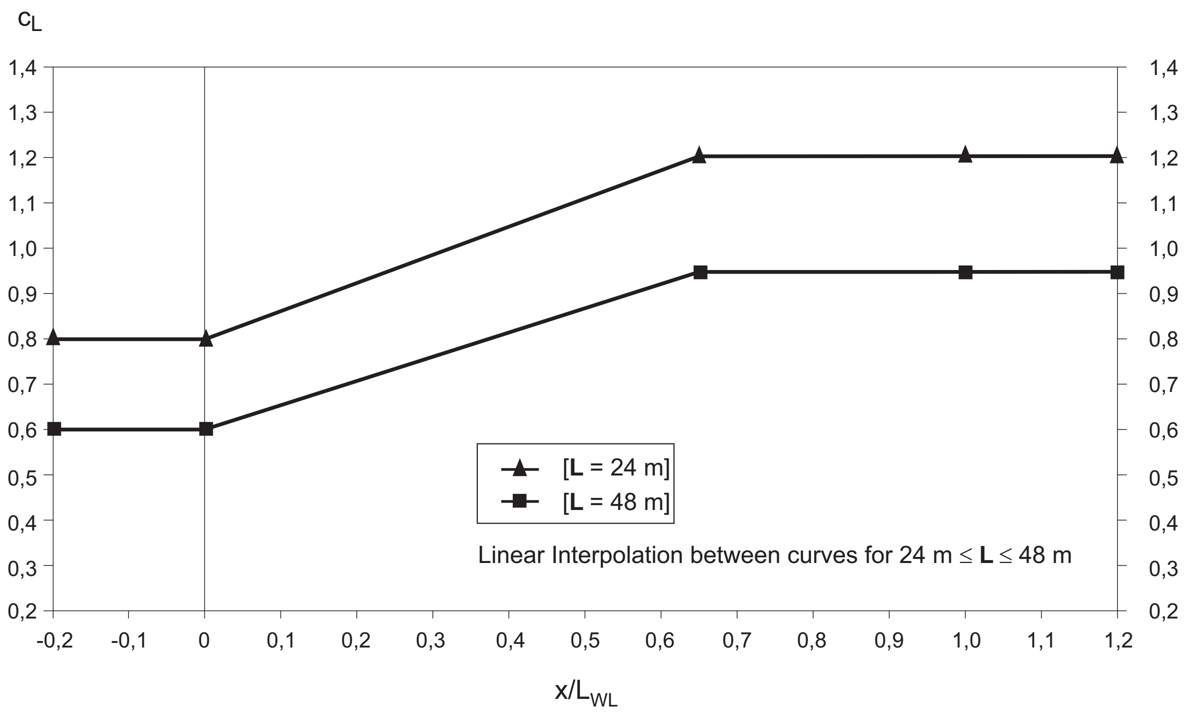



**Fig. 2.21 Hull longitudinal distribution factor for sailing yachts $c_L$**

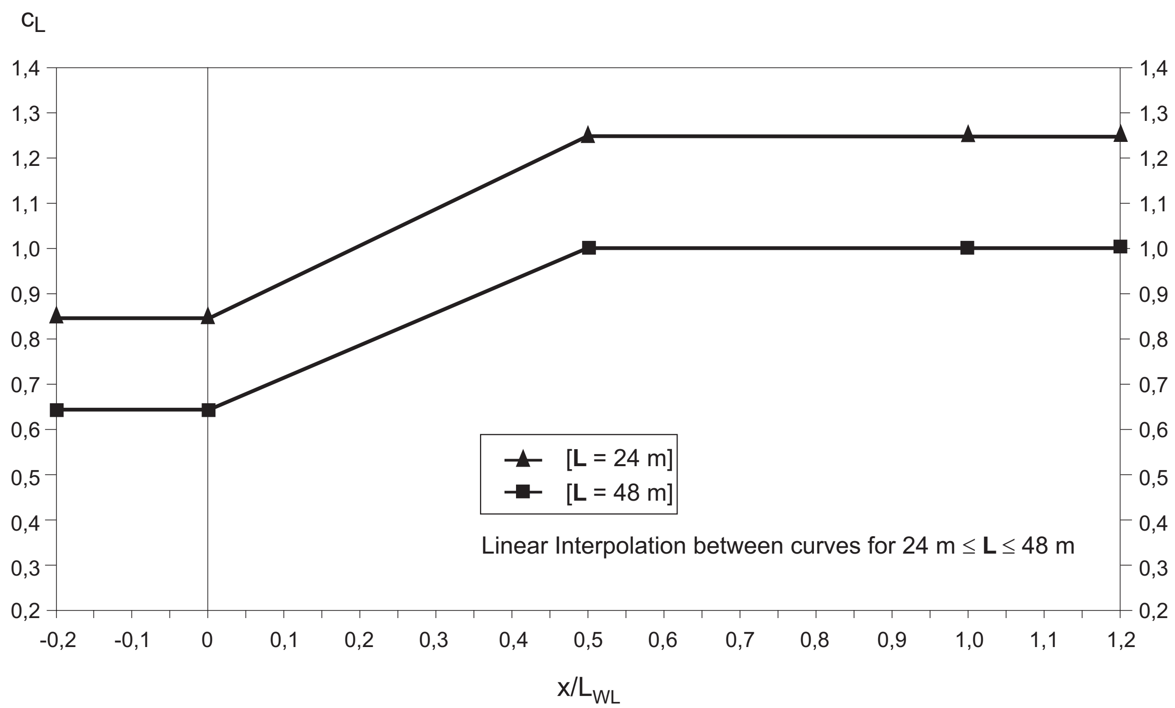



**Fig. 2.22 Hull longitudinal distribution factor for motor yachts $c_L$**

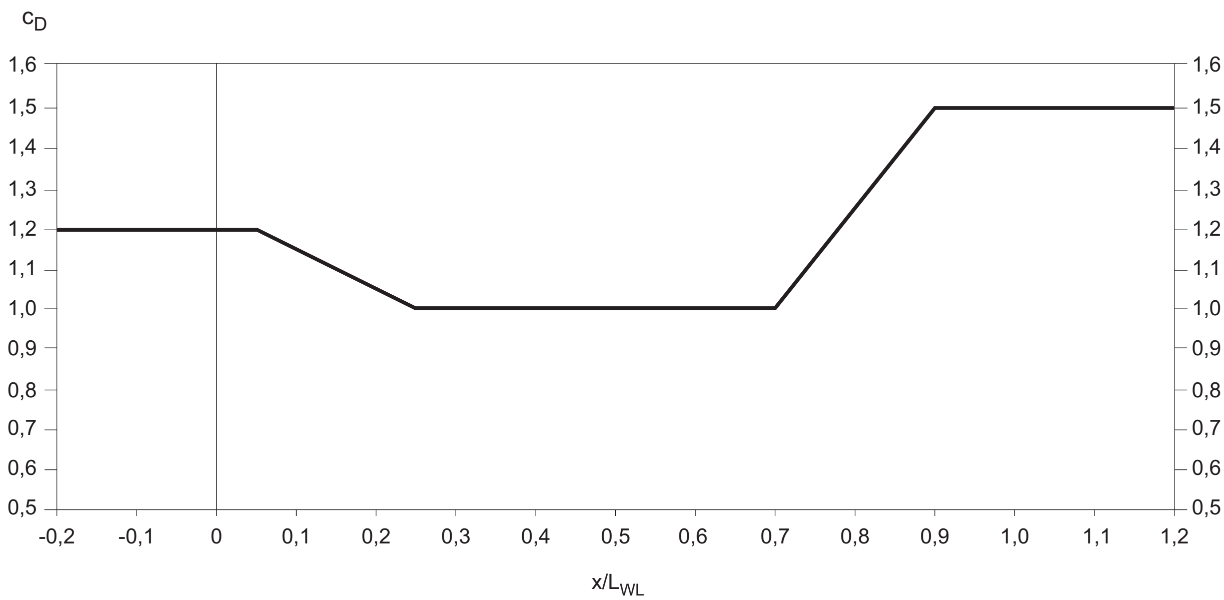



**Abb. 2.23 Deck longitudinal distribution factor for sailing yachts $c_D$**

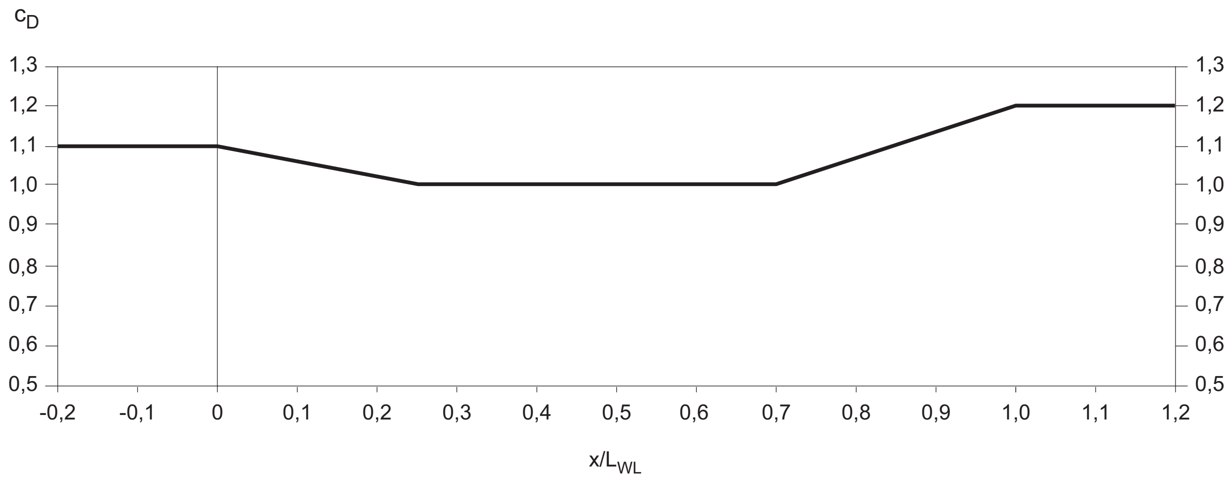



**Fig. 2.24 Deck longitudinal distribution factor for motor yachts $c_D$**

### 3.7 Loads on tank structures

The design load is:

$$p_T = 10,0 \cdot z_T \quad \left[\mathrm{kN}/\mathrm{m}^2\right]$$

$z_T$ = vertical distance from the load centre to the top of the tank overflow in [m]

= not to be taken less than 2,0 m

## 4. Scantlings

These scantling requirements have also to be applied for "high speed" motor yachts.

### 4.1 General

#### 4.1.1 Single skin design

Single skin laminates have to be designed regarding the panel scantling criteria specified below, if applicable. Other kinds of loading and related failure modes of single skin laminates such as buckling must also be considered.

#### 4.1.2 Sandwich design

**4.1.2.1** A sandwich structure generally consists of two FRP skins and a core of lightweight material. In case of flexural loading the skins mainly absorb tension and compression stress, whereas the core mainly absorbs shear stress. In general, the minimum tensile/compressive strength of the outer skin and the inner skin are to be approximately the same.

**4.1.2.2** For sandwich structures, additional failure modes must be considered which can occur before ultimate stress of the skin is attained. Among these are:

– shear failure of the core material
– failure of skin/core bonding
– wrinkling
– core failure under point load
– panel buckling

**4.1.2.3** Sandwich core materials can be:

– rigid foam materials of the closed-cell type with a minimum apparent density of 60 kg/$m^3$
– end-grained balsa wood
– honeycomb materials

#### 4.1.3 Transitions from single-skin laminate to sandwich construction

Where sandwich construction changes to single skin laminate, the required single skin laminate is to be determined by the scantlings for the whole panel. A proper core taper ratio shall be provided for.

**4.1.4** Single skin construction is recommended in the following areas:

– keel root area of sailing yachts, see Fig. 2.19
– major penetrations of the hull below the design waterline (WL)

### 4.2 Panels

#### 4.2.1 Data

The following data have to be specified.

#### 4.2.1.1 Materials

For all structural composite materials used, the following descriptions shall be provided.

Fibre and resin materials:

– resin system, specific gravity

Cured ply properties for:

– fibre areal weight
– fibre orientation
– consolidation method and fibre volume fraction
– thickness
– defined direction of mechanical properties
– longitudinal and transverse stiffness, in-plane shear stiffness [1]
– longitudinal, transverse ultimate tensile and compressive strength, in-plane ultimate shear strength [1]

Core materials:

– type, manufacturer
– nominal density
– thickness
– ultimate shear strength
– compressive stiffness
– shear stiffness

#### 4.2.1.2 Laminates

For each structural component, the documentation must contain data covering:

– laminate layup including listing of individual layers and their orientation vs. defined coordinate system
– geometrical data about location, longitudinal and transverse span of panel
– curvature of panel

### 4.2.2 Applicable design load

Design loads as defined in 3. have to be applied.

### 4.2.3 Calculation method

The calculation shall be based on classic beam/plate and laminate theory.

### 4.2.4 Design criteria

The following requirements are to be met:

– a safety factor $SF \geq 4{,}0$ relative to ultimate stress for each FRP layer
– a safety factor $SF \geq 2{,}5$ relative to ultimate shear stress for the sandwich core
– 1,5 % permissible panel deflection relative to the short span for single skin laminate
– 1,0 % permissible panel deflection relative to the short span for sandwich construction

## 4.3 Stiffeners and girders

### 4.3.1 Data

The following data have to be specified.

#### 4.3.1.1 Materials

For all structural composite materials used, the following descriptions shall be provided.

Fibre and resin materials:

– resin system, specific gravity

Cured ply properties for:

– fibre areal weight
– fibre orientation
– consolidation method and fibre volume fraction
– thickness
– defined direction of mechanical properties
– longitudinal and transverse stiffness, in-plane shear stiffness [1]
– longitudinal, transverse ultimate tensile and compressive strength, in-plane ultimate shear strength [1]

Core materials:

– type, manufacturer
– nominal density
– compressive stress

#### 4.3.1.2 Laminates

For each structural component the documentation must contain data covering:

– laminate layup including listing of individual layers and their orientation vs. defined coordinate system
– geometrical data about location, span of supported panel, unsupported span of girder/stiffener
– data about section geometry of stiffener/girder
– bonding details
– curvature of panel

### 4.3.2 Applicable design load

Design loads as defined in 3. have to be applied.

---
1 In plane shear properties are relevant for layers containing a high percentage of off-axis fibres.

#### 4.3.3 Calculation method

The calculation shall be based on classic beam/plate and laminate theory.

#### 4.3.4 Design criteria

The following requirements have to be met:

– a safety factor SF ≥ 4,0 relative to ultimate stress for bending of each FRP layer

– a safety factor SF ≥ 4,0 relative to ultimate shear stress in stiffener webs

– 0,5 % permissible stiffener deflection relative to the unsupported span of the stiffener

– 0,3 % permissible stiffener deflection relative to the unsupported span of engine foundations

## F. Motor und Sailing Yachts, 24 m ≤ L ≤ 48 m, Wooden Structures

### 1. General

#### 1.1 Scope

The following references to rules and requirements applicable for traditionally built wooden hull structures of motor and sailing yachts.

Yacht hulls of cold moulded wood are to be built according to the requirements of E.

#### 1.2 Materials

An excerpt regarding material requirements is given in B.9. Furthermore reference is made to the GL Rules II – Materials and Welding, Part 2 – Non-metallic Materials, Chapter 2 – Wood.

### 2. Scantlings

The actual determination of scantlings can be carried out according to the GL Rules for Classification and Construction:

I – Schiffstechnik, Teil 1 – Seeschiffe, Kapitel 13– Vorschriften für Klassifikation und Bau von hölzernen Seeschiffen [2]

Regarding anchor equipment and rudder and manoeuvring arrangement the requirements of J. and K. apply.

2 Translation: "Rules for Classification and Construction of Wooden Seagoing Ships" (not available in English).

## G. Motor and Sailing Yachts, L > 48 m, Steel and Aluminium Structures

### 1. General

#### 1.1 Scope

The following references to GL Rules applicable for scantling determination of the hull structures of sailing and motor yachts with **L** > 48 m, see 2.

Regarding corrosion allowances and minimum thickness of plating the requirements specified in 2.2.2 and 2.2.3 are applicable.

#### 1.2 Materials

See B.

### 2. Scantlings

#### 2.1 Scantlings for high speed yachts

If a yacht is capable of a maximum speed equal to or exceeding

$$v = 7{,}2 \cdot \sqrt[6]{\nabla} \quad [\text{kn}]$$

$\nabla$ = moulded volume [m³] according to A.6.6

The GL Rules Part 1 – Seagoing Ships, Chapter 5 – High Speed Craft, Section 3 will be applied.

#### 2.2 Scantlings for moderate speed yachts

**2.2.1** For determination of the scantlings of yachts with lower speeds than defined in 2.1. The GL Rules Part 1 – Seagoing Ships, Chapter 1 – Hull Structures have to be applied. The deviations defined in 2.2.2 and 2.2.3 have to be observed.

Upon request further deviations of the scantlings may be granted by GL after detailed judgement of the actual project.

#### 2.2.2 Corrosion allowances

The following, reduced corrosion allowances may be applied for yachts, if special care for maintenance and special attention for measures of corrosion protection can be assumed.

#### 2.2.2.1 Steel

The scantlings require the following allowances $t_K$ to the theoretical, rounded-off plate thickness:

– $t_K$ = 0,5 mm in general

– $t_K$ = 0,7 mm for lubrication oil, gas oil or equivalent tanks

– $t_K$ = 1,0 mm for water ballast and heavy oil tanks

– for special applications $t_K$ shall be agreed with GL

For all elements of the yacht's structure which form a boundary of tanks, the $t_K$ values for tanks have to be considered.

#### 2.2.2.2 Aluminium alloys

If the measures for corrosion protection described in B.6. are fully applied, the corrosion allowance $t_K$ can be assumed as 0 for the types of aluminium alloys defined in B.3.4 and B.3.5. In any way $t_K$ shall not be less than the fabrication tolerances, see GL Rules II – Materials and Welding, Part 1 – Metallic Materials, Chapter 3 – Non-Ferrous Metals, Section 1 – Aluminium Alloys.

### 2.2.3 Minimum thickness

The minimum thickness requirements of the plating of different elements of the hull structure are summarized in Table 2.19.

For comparison the table indicates references to the GL Rules Part 1 – Seagoing Ships, Chapter 1 – Hull Structures.

## H. Tank Structures

### 1. General

### 1.1 Subdivision of tanks

**1.1.1** In tanks which extend over the full breadth of the yacht and are intended to be used for partial filling (e.g. fuel oil and fresh water tanks), at least one longitudinal bulkhead is to be fitted, which may be a swash bulkhead.

**1.1.2** Where the forepeak is intended to be used as tank, at least one complete or partial longitudinal swash bulkhead is to be fitted, if the tank breadth exceeds 0,5 **B** or 6 m, whichever is the greater.

When the after peak is intended to be used as tank, at least one complete or partial longitudinal swash bulkhead is to be fitted. The largest breadth of the liquid surface should not exceed 0,3 **B** in the aft peak.

**1.1.3** Peak tanks exceeding 0,06 **L** or 6 m in length, whichever is greater, shall be provided with a transverse swash bulkhead.

### 1.2 Air, overflow and sounding pipes

**1.2.1** Each tank is to be fitted with air pipes, overflow pipes and sounding pipes. The air pipes are to be led to above the exposed deck. The arrangement is to be such as to allow complete filling of the tanks. The height from the deck to the point where seawater may have access is to be at least 760 mm on the freeboard deck and 450 mm on a superstructure deck.

**1.2.2** Suitable closing appliances are to be provided for air pipes, overflow pipes and sounding pipes, see also Section 1, C.7.11.

**1.2.3** Closely below the inner bottom or the tank top, holes are to be cut into floor plates and side girders as well as into beams, girders, etc., to give the air free access to the air pipes. Besides, all floor plates and side girders are to be provided with limbers to permit the water or oil to reach the pump suctions.

**1.2.4** Sounding pipes are to be led to the bottom of the tank. The shell plating is to be strengthened by thicker plates or doubling plates under the sounding pipes.

### 1.3 Forepeak tank

Oil is not to be carried in a forepeak tank, see also D.2.9.1.

### 1.4 Cross references

**1.4.1** Where a tank bulkhead forms part of a watertight bulkhead, its strength is not to be less than required by C. to G. as applicable.

**1.4.2** For pumping and piping and oil fuel tanks see Section 1, C.7. For tanks in the double bottom see C. to G. as applicable.

**1.4.3** For testing of tanks, see 6.

**1.4.4** Where tanks are provided with cross flooding arrangements the increase of the pressure head is to be taken into consideration.

### 1.5 Separation of oil fuel tanks from tanks for other liquids

**1.5.1** Fresh water tanks are to be separated from other tanks such as waste water tanks by cofferdams. The same applies to fuel tanks. Generally, also tanks such as lubricating or hydraulic oil tanks shall be separated from each other by equivalent means.

**Table 2.19 Minimum thickness of plating**

| **Elements of the hull structure** | | **Minimum thickness $t_{min}$ of plating [mm]** |
|---|---|---|
| **Designation** | **Reference** [1] | **Formulae for yachts** |
| Brackets | Section 3, D.2.2 | 5,5 |
| Bottom | Section 6, B.3.1 | $0,9 \cdot \sqrt{\mathbf{L} \cdot k}$ |
| Flat plate keel | Section 6, B.5.1 | $t_{min}$ (bottom) + 2,0 mm<br>for 0,7 **L** midships and in way of engine seating;<br>$t_{min}$ (bottom ) otherwise |
| Side shell | Section 6, C.2. | $0,8 \cdot \sqrt{\mathbf{L} \cdot k}$ |
| Strength deck for 0,4 **L** amidships outside line of openings | Section 7, A.6. | $(3,5 + 0,05 \cdot \mathbf{L})\sqrt{k}$ |
| Strength deck inside line of openings and 0,1 **L** from the ends | Section 7, A.7. | $(4,5 + 0,02 \cdot \mathbf{L})\sqrt{k}$ |
| Lower decks (2nd deck) | Section 7, B.1.1 | $(4,5 + 0,02 \cdot \mathbf{L})\sqrt{k}$ |
| Other lower decks | Section 7, B.1.1 | 5,0 |
| Floor plates in the peaks | Section 8, A.1.2.3 | 5,0 with lightening holes<br>4,0 without lightening holes |
| Web of single bottom centre girder | Section 8, A.2.2.1 | $(4,5 + 0,07 \cdot \mathbf{L})\sqrt{k}$ |
| Web of single bottom side girder | Section 8, A.2.2.2 | $(4,0 + 0,04 \cdot \mathbf{L})\sqrt{k}$ |
| Double bottom longitudinal girders | Section 8, B.7.5.2 | $5,0 \cdot \sqrt{k}$ |
| Web frames in machinery spaces | Section 9, A.6.2.1 | $8,0 \cdot \sqrt{k}$ |
| Bulkhead plating | Section11, B.2.1 | $5,0 \cdot \sqrt{\frac{235}{R_{eH}}}$ |
| Internal wall plating | — | 3,0 |
| Tank structures | Section 12, A.7.1 | $(5,5 + 0,02 \cdot \mathbf{L})\sqrt{k}$ |
| Rudder horn plating | Section 13, C.5.5 | $2,4 \cdot \sqrt{\mathbf{L} \cdot k}$ |
| Webs of rudders | Section 14, E.2.3 | $8,0 \cdot \sqrt{k}$ |
| Non-effective Superstructure side walls | Section 16, B.1.1 | $0,64 \cdot \sqrt{\mathbf{L} \cdot k}$ |
| Non-effective superstructure deck | Section 16, B.2.1 | $(4,5 + 0,02 \cdot \mathbf{L})\sqrt{k}$ |
| Superstructure end bulkheads and deckhouse walls/lowest tier | Section 16, C.3.2 | $(4,0 + 0,01 \cdot \mathbf{L})\sqrt{k}$ and 4,0 |
| Superstructure end bulkheads and deckhouse walls/upper tier | Section 16, C.3.2 | $(3,0 + 0,01 \cdot \mathbf{L})\sqrt{k}$ and 3,0 |
| Short deckhouse deck | Section 16, D.1. | 4,0 |
| Hatchway coamings | Section 17, B.1. | 7,5 |
| Steel hatch covers | Section 17, C.5.1.1 | 6,0 |

[1] in GL Rules Part 1– Seagoing Ships, Chapter 1– Hull Structures.

**1.5.2** Upon special approval, the arrangement of cofferdams between oil fuel and lubricating oil tanks may be dispensed with on relatively small yachts, provided that:

– the common boundary is continuous, i.e. it does not abut at the adjacent tank boundaries, see Fig. 2.25

  Where the common boundary cannot be constructed continuously according to Fig. 2.25, the fillet welds on both sides of the common boundary are to be welded in two layers and the throat thickness is not to be less than 0,5 × t (t = plate thickness)

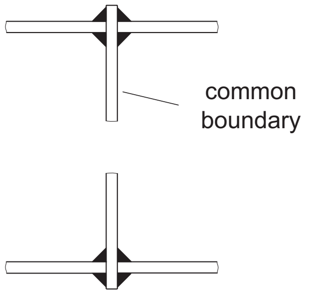



**Fig. 2.25 Welding at non-continuous tank boundaries**

– stiffeners or pipes do not penetrate the common boundary

– the corrosion allowance $t_K$ for the common boundary is not less than 1,5 mm.

**1.5.3** Fuel oil tanks adjacent to lubricating oil circulation tanks are subject to the provisions of Section 1, C.7. in addition to the requirements stipulated in 1.5.2 above.

## 2. Scantlings

### 2.1 Design loads

The design loads are defined in D.3.7.

### 2.2 Scantling requirements

Tank plating and stiffener scantlings are to be determined according to D.4.

**2.3** The stiffeners of tank bulkheads exceeding 2 m length are to be attached at their ends by brackets according to the arrangements defined in C. The scantlings of the brackets are to be determined according to the section modulus of the stiffeners.

The brackets of stiffeners are to extend to the next beam, the next floor, the next frame, or are to be otherwise supported at their ends.

## 3. Detached tanks

### 3.1 General

**3.1.1** Detached tanks are to be adequately secured against forces due to the ship's motions.

**3.1.2** Detached tanks in hold or storage spaces are also to be provided with anti-floatation devices. It is to be assumed that the hold/storage spaces are flooded to the design water line. The stresses in the anti-floatation devices caused by the floatation forces are not to exceed the material's yield stress.

**3.1.3** Fittings and pipings on detached tanks are to be protected by battens, and gutterways are to be fitted on the outside of tanks for draining any leakage oil.

### 3.2 Scantlings

#### 3.2.1 Design loads

The design load is:

$$p_{DT} = 10 \cdot h \quad \left[\mathrm{kN/m^2}\right]$$

h = head measured from the load point of plate panel or stiffener respectively to the top of overflow. The height of overflow is not to be taken less than 2,0 m.

#### 3.2.2 Scantling requirements

Tank plating and stiffener scantlings are to be determined according to D.4.

## 4. Potable water tanks

**4.1** Potable water tanks shall be separated from tanks containing liquids other than potable water, ballast water, distillate or feed water.

**4.2** In no case sanitary installations or corresponding piping are to be fitted directly above the potable water tanks.

**4.3** If pipes carrying liquids other than potable water are to be led through potable water tanks, they are to be fitted in a pipe tunnel.

**4.4** Air and overflow pipes of potable water tanks are to be separated from pipes of other tanks.

## 5. Swash bulkheads

**5.1** The total area of perforation shall not be less than 5 % and should not exceed 10 % of the total bulkhead area.

### 5.2 Design loads

For the design pressure for partially filled tanks $p_d$ a direct calculation is required.

**5.3 Scantling requirements**

The plate thickness shall, in general, be equal to the minimum thickness according to D.4.1.3. Strengthening may be required for load bearing structural parts. The free lower edge of a wash bulkhead is to be adequately stiffened.

**6. Testing for tightness**

**6.1** Testing of fuel oil, ballast, trimming, feed water, fresh water and anti-rolling tanks is to be effected by a combination of a leak test by means of air pressure and an operational test by means of water or the liquid for which the tank is intended to be used. The air pressure is not to exceed 0,2 bar gauge. The increased risk of accident while the tanks are subjected to the air pressure is to be observed.

**6.2** Where one tank boundary is formed by the ship's shell, the leak test is to be carried out before launching. For all other tanks leak testing may be carried out after launching. Erection welds as well as welds of assembly openings are to be coated[1] after the leak test is carried out. This applies also to manually welded connections of bulkheads with other tank boundaries and to collaring arrangements at intersections of tank boundaries and frames, beams, girders, pipes, etc. If it is ensured that in adjacent tanks the same type of liquid is carried, e.g. in adjacent ballast tanks, the above mentioned weld connections may be coated [1] prior to the leak test.

All other welded connections in tank boundaries may be coated prior to the leak test if it is ensured by suitable means (e.g. by visual examination of the welded connections) that the connections are completely welded and the surfaces of the welds do not exhibit cracks or pores.

**6.3** Where the tanks are not subjected to the leak test as per 6.2 but are leak tested with water, the bulkheads are, in general, to be tested from one side. The testing should be carried out prior to launching or in the dock. Subject to approval by GL, the test may also be carried out after launching. Water testing may be carried out after application of a coating[1], provided that during the visual inspection as per 6.2 above deficiencies are not found. The test head must correspond to a head of water of 2,5 m above the top of tank or to the top of overflow or air pipe, whichever is the greater.

**6.4** The operational test may be carried out when the ship is afloat or during the trial trip. For all tanks the proper functioning of filling and suction lines and of the valves as well as functioning and tightness of the vent, sounding and overflow pipes is to be tested.

## I. Chainplates, Ballast Keel, Propeller Brackets

**1. General**

The following specifies scantling requirements for the above elements and their structural attachment to the yacht's hull.

**2. Chainplates and substructures**

**2.1 Design loads**

Where no other indications are available, the dimensioning load will be equal to the breaking load of the attached shrouds and stays.

If there are two shrouds attached to a chainplate, the dimensioning load for the chainplate is F = 1,0 times the breaking load of the stronger shroud plus 0,5 times the breaking load of the weaker shroud [kN]

**2.2 Permissible stresses**

For dimensioning of chainplates made of metallic materials the following permissible stresses are to be complied with:

– permissible bearing stress between chainplate and pin

$$\sigma_{LL,perm} = \frac{R_{eH} + R_m}{2} \quad \left[N/mm^2\right]$$

– for tension and shear loading:

$$\sigma_{perm} = R_{eH} \quad \left[N/mm^2\right]$$

$$\tau = \sqrt[3]{R_{eH}} \quad \left[N/mm^2\right]$$

$R_{eH}$ is the steel's minimum nominal upper yield point [N/mm²]. In case of aluminium alloys $R_{eH}$ is to be replaced by $R_{p0,2}$, i.e. the 0,2 % proof stress [N/mm²].

**2.3 Determination of chainplate geometry**

**2.3.1 Metallic chainplates**

Determination of geometry and thickness of a metallic chainplate according to Fig. 2.26.

$$a_{min} = \frac{F}{2 \cdot t \cdot \sigma_{perm}} + \frac{2}{3} \cdot d_L \quad [mm]$$

[1] Shop primers are not regarded as a coating within the scope of these requirements.

$$c_{min} = \frac{F}{2 \cdot t \cdot \sigma_{perm}} + \frac{1}{3} \cdot d_L \quad [mm]$$

$d_L$ = pin hole diameter [mm]

t = thickness of the chainplate [mm]

Thereby it is assumed that the gap between bearing hole and pin is smaller than $0,1 \cdot d_L$. Also the bearing stress limit according to 2.2 must be observed.

### 2.3.2 Metallic chainplate structure

The dimensioning principles, i.e. design load and permissible stress for chainplates of metallic materials as outlined above are to be applied analogously to the metallic chainplate substructure, e.g. tie rods, etc.

### 2.3.3 Chainplates of composite materials

Regarding chainplate components made of composite materials, e.g. carbon fibre tapes, and composite structures to which chainplates are attached, e.g. FRP bulkheads, dimensioning is to be carried out as follows.

**2.3.3.1** The relevant stress in the composite component, e.g. tension or shear, is to be calculated applying the design load according to 2.1.

**2.3.3.2** The permissible stress shall be less than or equal to the ultimate stress of the composite component divided by 1,6.

### 2.4 Structural members in way of chainplates

Scantlings of structural members in way of chainplates must ensure sufficient strength and rigidity of the hull under the consideration of the design loads defined in 2.1.

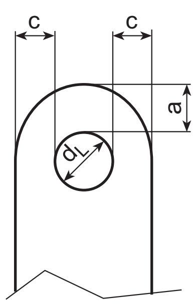



**Fig. 2.26 Geometry of the chainplate**

## 3. Structural integration of the ballast keel

The design principles presented in the following are exemplified for a fin ballast keel bolted to the hull. Special ballast keel arrangements of high complexity, e. g. canting or lifting keels, centreboards, etc. are to be considered case by case.

### 3.1 Design loads

**3.1.1** Forces and moments for dimensioning purposes are those caused when the sailing yacht is supposed to heel over 90°, i.e. the keel is not submerged and parallel to the water surface. In addition to bending and shear, torsional loads can become significant if the longitudinal position of the keel's centre of gravity is unusual, e.g. as for L-bulbed fin keels.

**3.1.2** The defined basic load case is also valid for other ballast keel arrangements than those described in the following.

**3.1.3** Each cross section along the fin ballast keel must withstand the forces and moments caused by the basic load case depending on the distance between the considered cross section and the keel's centre of gravity.

### 3.2 Dimensioning of keel bolts

**3.2.1** Keel bolts which are to be strongly and durably anchored to the ballast keel shall be positioned as close as possible to the keel floors of the hull to ensure effective transmission of the loads. The bolt arrangement on the keel root profile is shown in Fig. 2.27

**3.2.2** The required keel bolt core diameter is to be determined according to the following formula:

$$d_k = \sqrt{\frac{2 \cdot W_k \cdot h_k \cdot b_{max}}{R_{eH} \cdot \sum b_i^2}} \quad [mm]$$

$W_k$ = weight of ballast keel [N]

$h_k$ = distance between the keel's centre of gravity and the keel root profile [mm], see Fig. 2.27

$b_i$ = $0,5 \cdot b_{bi} + 0,4 \cdot b_{ki}$, see Fig. 2.27

$b_{max}$ = maximum value of $b_i$

$R_{eH}$ = minimum nominal upper yield point of bolt steel [N/mm²]

**3.2.3** Large washers or counter plates are to be arranged to distribute the loads on a wide area. Bolts including washers or counter plates, nuts and locking device are to be made of an approved corrosion resistant material.

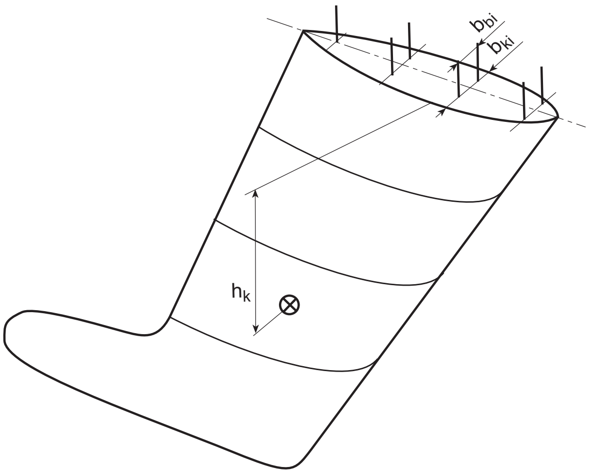



**Fig. 2.27 Bolt arrangement on the keel root**

### 3.3 Absorption of forces and moments in the yacht's hull

**3.3.1** Bottom structural members in way of the ballast keel must absorb the external design loads defined for the different yacht types and also the forces and moments caused by the ballast keel.

Each floor at the bottom of the hull absorbs a certain percentage of the transverse bending moment. This percentage depends on the width of the keel root at the respective floor; the wider the keel root, the higher the moment which can be absorbed by the floor.

However, in case of grounding the floors (or other structural members) above the leading and trailing edge of the fin ballast keel have to withstand the biggest reaction forces.

**3.3.2** In addition to bending moments the keel floors are loaded by shear forces caused by the weight of the ballast keel and possibly other forces caused e.g. in the case of grounding. Therefore the webs of the keel floors are to have sufficient height and thickness.

**3.3.3** The keel floors must be supported by other structural members, e.g. longitudinal girders, bulkheads, etc.

## 4. Propeller brackets

### 4.1 Arrangement

The strut axes should intersect in the axis of the propeller shaft as far as practicable. The angle between two struts shall be in the range from 50° to 120 °. The struts are to be extended through the shell plating and are to be attached in an efficient manner to the frames and plate floors respectively. The construction in way of the shell is to be carried out with special care. In case of welded connection, the struts are to have a weld flange or a thickened part or are to be connected with the shell plating in another suitable manner.

### 4.2 Strengthening of shell

The strengthening of the shell in way of struts and shaft bossings has to be done in the following way:

The thickness of the shell plating is to be the same as at 0,4 amidships. In way of struts, the shell is to have a strengthened plate of 1,5 times the midship thickness.

Where propeller revolutions are exceeding 300 rpm (approx.), particularly in case of flat bottoms intercostal carlings are to be fitted above or forward of the propeller in order to reduce the size of the bottom plate panels.

### 4.3 Design force

The design force $F_u$ acting on propeller brackets is defined by the following formula:

$$F_u = c \cdot 10^{-5} \cdot M_p \cdot n_2^2 \quad [\text{kN}]$$

$$c = \frac{1{,}3 \cdot D}{z + 1} \geq 2{,}5$$

$D$ = diameter of propeller [mm]

$n_2$ = propeller speed at 100 % performance [$\text{min}^{-1}$]

$M_p$ = mass of propeller [t]

$z$ = number of propeller blades

### 4.4 Scantlings

**4.4.1** The sectional A of each strut shall not be less than:

$$A = \frac{100 \cdot F_u \cdot \ell}{E} \quad \left[\text{cm}^2\right]$$

$\ell$ = length of strut [mm]

$E$ = modulus of elasticity [$\text{N/mm}^2$]

**4.4.2** The moment of inertia I of each strut shall not be less than:

$$I = \frac{600 \cdot F_u \cdot \ell^3}{E} \quad \left[\text{cm}^4\right]$$

**4.4.3** For propeller brackets with one strut the following condition has to be met in addition to 4.4.1 and 4.4.2:

The section modulus W of the strut shall not be less than:

$$W = c_1 \cdot F_u \cdot \ell \quad \left[\text{cm}^3\right]$$

$c_1$ = material dependent factor

= 0,08 for steel

= 0,25 for aluminium alloys

For propeller brackets with one strut a vibration and fatigue analysis has to be carried out.

## J. Rudder and Manoeuvring Arrangement

### 1. General

#### 1.1 Manoeuvring arrangement

**1.1.1** Yachts have to be provided with a manoeuvring arrangement which will guarantee sufficient manoeuvring capability.

**1.1.2** The manoeuvring arrangement includes all parts, from the rudder and steering gear to the steering position necessary for steering of yachts.

**1.1.3** Rudder stock, rudder coupling, rudder bearings and rudder body are dealt with in the following. The steering gear is to comply with references given in Section 1, C.

**1.1.4** The steering gear compartment shall be readily accessible and, as far as practicable, separated from machinery space.

***Note***

*Concerning use of non-magnetizable material in the wheel house in way of a magnetic compass, the requirements of the national Administration concerned are to be observed.*

#### 1.2 Structural details

**1.2.1** Effective means are to be provided for supporting the weight of the rudder body without excessive bearing pressure, e.g. by a rudder carrier attached to the upper part of the rudder stock. The hull structure in way of the rudder carrier is to be suitably strengthened.

**1.2.2** Suitable arrangements are to be provided to prevent the rudder from lifting.

**1.2.3** The rudder stock is to be carried through the hull either enclosed in a watertight trunk, or glands are to be fitted above the deepest load waterline, to prevent water from entering the steering gear compartment and the lubricant from being washed away from the rudder carrier. If the top of rudder trunk is below the deepest waterline, two separate stuffing boxes are to be provided.

#### 1.3 Size of rudder area

In order to achieve sufficient manoeuvring capability, the size of the movable rudder area A is recommended to be not less than obtained from following formula:

$$A = c_1 \cdot c_2 \cdot c_3 \cdot c_4 \,\frac{1{,}75 \cdot \mathbf{L} \cdot \mathbf{T}}{100} \quad \left[m^2\right]$$

$c_1$ = factor for yacht type

= 1,0 in general

$c_2$ = factor for rudder type:

= 1,0 in general

= 0,9 for semi-spade rudders

= 0,7 for high lift rudders

$c_3$ = factor for rudder profile:

= 1,0 for NACA-profiles and plate rudder

= 0,8 for hollow profiles and mixed profiles

$c_4$ = factor for rudder arrangement:

= 1,0 for rudders in propeller jet

= 1,5 for rudders outside propeller jet

For semi-spade rudders 50 % of the projected area of the rudder horn may be included into the rudder area A. If several rudders are arranged, the area of each rudder can be reduced by 20 %.

When estimating the rudder area A, 2.1. is to be observed.

#### 1.4 Materials

**1.4.1** For materials for rudder stock, pintles, coupling bolts, etc. see GL Rules II - Materials and Welding. Special material requirements are to be observed for ice notations, see A.1.2.

**1.4.2** In general, materials having a minimum nominal upper yield point $R_{eH}$ of less than 200 N/mm² and a minimum tensile strength of less than 400 N/mm² or more than 900 N/mm² shall not be used for rudder stocks, pintles, keys and bolts. The requirements of J. are based on a material's minimum nominal upper yield point $R_{eH}$ of 235 N/mm². If material is used having a $R_{eH}$ differing from 235 N/mm², the material factor $k_r$ is to be determined as follows:

$$k_r = \left(\frac{235}{R_{eH}}\right)^{0,75} \quad \text{for } R_{eH} > 235 \quad \left[N/mm^2\right]$$

$$= \frac{235}{R_{eH}} \quad \text{for } R_{eH} \le 235 \quad \left[N/mm^2\right]$$

$R_{eH}$ = minimum nominal upper yield point of the material used [N/mm²]

$R_{eH}$ is not to be taken greater than $0{,}7 \cdot R_m$ or 450 N/mm², whichever is less. $R_m$ = tensile strength of the material used

**1.4.3** Before significant reductions in rudder stock diameter due to application of steels with $R_{eH}$ exceeding 235 N/mm² are accepted, GL may require the evaluation of elastic rudder stock deflections. Large deflections should be avoided in order to avoid excessive edge pressures in way of bearings.

**1.4.4** Permissible stresses given in 7.1 are applicable for normal strength hull structural steel. When higher strength hull structural steels are used, higher values may be used which will be determined in each individual case.

### 1.5 Definitions

$C_R$ = rudder force [N]

$Q_R$ = rudder torque [Nm]

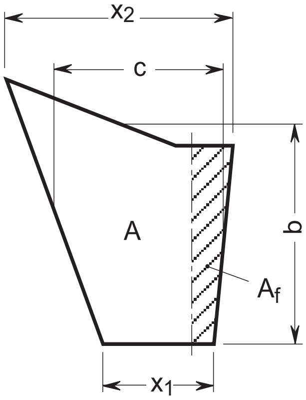
A = total movable area of rudder [m²]

$A_t$ = A + area of a rudder horn, if any [m²]

$A_f$ = portion of rudder area located ahead of the rudder stock axis [m²]

b = mean height of rudder area [m]

c = mean breadth of rudder area [m], see Fig. 2.28)




$$c = \frac{x_1 + x_2}{2} \qquad b = \frac{A}{c}$$

**Fig. 2.28 Rudder area**

$\Lambda$ = aspect ratio of rudder area $A_t$

$$\Lambda = \frac{b^2}{A_t}$$

$v_0$ = ahead speed of the yacht in [kn] as defined in A.6.5

if this speed is less than 10 kn, $v_0$ is to be taken as

$$v_{min} = \frac{v_0 + 20}{3} \quad [kn]$$

$v_a$ = astern speed of the yacht in [kn]; if the astern speed $v_a$ is less than $0,4 \cdot v_0$ or 6 kn, whichever is less, determination of rudder force and torque for astern condition is not required. For greater astern speeds special evaluation of rudder force and torque as a function of rudder angle may be required. If no limitation for the rudder angle at astern condition is stipulated, the factor $\kappa_2$ is not to be taken less than given in Table 2.20 for astern condition.

k = material factor according to B.

## 2. Rudder force and torque

### 2.1 Rudder force and torque for normal rudders

**2.1.1** The rudder force is to be determined according to the following formula:

$$C_R = 132 \cdot A \cdot v^2 \cdot \kappa_1 \cdot \kappa_2 \cdot \kappa_3 \cdot \kappa_t \quad [N]$$

v = $v_0$ for ahead condition

= $v_a$ for astern condition

$\kappa_1$ = coefficient, depending on the aspect ratio $\Lambda$

= $(\Lambda + 2)/3$, where $\Lambda$ need not be taken greater than 2

$\kappa_2$ = coefficient, depending on type of rudder and rudder profile according to Table 2.20.

$\kappa_3$ = coefficient, depending on location of the rudder

= 0,8 for rudders outside propeller jet

= 1,0 elsewhere, including also rudders within propeller jet

$\kappa_t$ = coefficient depending on thrust coefficient $c_t$

= 1,0 normally

In special cases, for propeller thrust coefficients $C_{Th} > 1,0$ determination of $\kappa_t$ according to the following formula may be required:

$$\kappa_t = \frac{C_R(C_{Th})}{C_R(C_{Th} = 1{,}0)}$$

**Table 2.20 Coefficient $\kappa_2$ for different types of rudder profiles**

| Profile / type of rudder | $\kappa_2$ ahead | $\kappa_2$ astern |
|---|---|---|
| NACA-00 series Göttingen profiles | 1,1 | 1,4 |
| flat side profiles | 1,1 | 1,4 |
| mixed profiles (e. g. HSVA) | 1,21 | 1,4 |
| hollow profiles | 1,35 | 1,4 |
| high lift rudders | 1,7 | to be specially considered; if not known: 1,7 |

**2.1.2** The rudder torque is to be determined by the following formula:

$$Q_R = C_R \cdot r \quad [\mathrm{Nm}]$$

$r = c\,(\alpha - k_b) \quad [\mathrm{m}]$

$\alpha$ = 0,33 for ahead condition

= 0,66 for astern condition (general)

= 0,75 for astern condition (hollow profiles)

For parts of a rudder behind a fixed structure such as a rudder horn:

$\alpha$ = 0,25 for ahead condition

= 0,55 for astern condition

For high lift rudders $\alpha$ is to be specially considered. If not known, $\alpha$ = 0,40 may be used for ahead condition

$k_b$ = balance factor as follows:

$= \dfrac{A_f}{A}$

= 0,08 for unbalanced rudders

$r_{min}$ = $0{,}1 \cdot c$ [m] for ahead condition

**2.1.3** Effects of the provided type of rudder/profile on choice and operation of the steering gear are to be observed.

## 2.2 Rudder force and torque for rudder blades with cut-outs (semi-spade rudders)

**2.2.1** The total rudder force $C_R$ is to be calculated according to 2.1.1. The pressure distribution over the rudder area, upon which determination of rudder torque and rudder blade strength is to be based, is to be derived as follows:

The rudder area may be divided into two rectangular or trapezoidal parts with areas $A_1$ and $A_2$, see Fig. 2.29.

The resulting force of each part may be taken as:

$$C_{R1} = C_R \frac{A_1}{A} \quad [\mathrm{N}]$$

$$C_{R2} = C_R \frac{A_2}{A} \quad [\mathrm{N}]$$

**2.2.2** The resulting torque of each part may be taken as:

$$Q_{R1} = C_{R1} \cdot r_1 \quad [\mathrm{Nm}]$$

$$Q_{R2} = C_{R2} \cdot r_2 \quad [\mathrm{Nm}]$$

$r_1 = c_1\,(\alpha - k_{b1}) \quad [\mathrm{m}]$

$r_2 = c_2\,(\alpha - k_{b2}) \quad [\mathrm{m}]$

$k_{b1} = \dfrac{A_{1f}}{A_1}$

$k_{b2} = \dfrac{A_{2f}}{A_2}$

$A_{1f}$, $A_{2f}$ see Fig. 2.29

$c_1 = \dfrac{A_1}{b_1}$

$c_2 = \dfrac{A_2}{b_2}$

$b_1$, $b_2$ = mean heights of partial rudder areas $A_1$ and $A_2$, see Fig. 2.29.

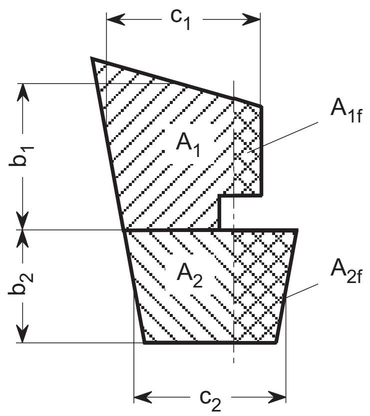



**Fig. 2.29 Rudder areas**

**2.2.3** The total rudder torque is to be determined according to the following formulae:

$$Q_R = Q_{R1} + Q_{R2} \quad [\text{Nm}] \quad \text{or}$$

$$Q_{R\,min} = C_R \cdot r_{1,2\,min} \quad [\text{Nm}]$$

$$r_{1,2min} = \frac{0,1}{A}\,(c_1 \cdot A_1 + c_2 \cdot A_2) \quad [\text{m}]$$

for ahead condition

The greater value is to be taken.

### 3. Scantlings of the rudder stock

#### 3.1 Rudder stock diameter

**3.1.1** The diameter of the rudder stock for transmitting the rudder torque is not to be less than:

$$D_t = 4,2\,\sqrt[3]{Q_R \cdot k_r} \quad [\text{mm}]$$

$Q_R$ = see 2.1.2, 2.2.2 and 2.2.3

The related torsional stress is:

$$\tau_t = \frac{68}{k_r} \quad \left[\text{N/mm}^2\right]$$

$k_r$ = see 1.4.2

**3.1.2** The diameter of the rudder stock determined according to 3.1.1 is decisive for steering gear, stopper and locking device.

**3.1.3** In case of mechanical steering gear, the diameter of the rudder stock in its upper part, which is only intended for transmission of the torsional moment from the auxiliary steering gear may be 0,9 $D_t$. The length of the edge of the quadrangle for the auxiliary tiller must not be less than 0,77 $D_t$ and the height not less than 0,8 $D_t$.

**3.1.4** The rudder stock is to be secured against axial sliding. The degree of the permissible axial clearance depends on the construction of steering engine and bearing.

#### 3.2 Strengthening of rudder stock

**3.2.1** If the rudder is so arranged that additional bending stresses occur in the rudder stock, the stock diameter has to be suitably increased. The increased diameter is, where applicable, decisive for the scantlings of the coupling.

For the increased rudder stock diameter the equivalent stress of bending and torsion is not to exceed the following value:

$$\sigma_v = \sqrt{\sigma_b^2 + 3\tau^2} \le \frac{118}{k_r} \quad \left[\text{N/mm}^2\right]$$

Bending stress:

$$\sigma_b = \frac{10,2 \cdot M_b}{D_1^3} \quad \left[\text{N/mm}^2\right]$$

$M_b$ = bending moment at the neck bearing [Nm]

Torsional stress:

$$\tau = \frac{5,1 \cdot Q_R}{D_1^3} \quad \left[\text{N/mm}^2\right]$$

$D_1$ = increased rudder stock diameter [cm]

The increased rudder stock diameter may be determined by the following formula:

$$D_1 = D_t\,\sqrt[6]{1 + \frac{4}{3}\left(\frac{M_b}{Q_R}\right)^2}$$

$Q_R$ = see 2.1.2, 2.2.2 and 2.2.3

$D_t$ = see 3.1.1

***Note***

*Where a double-piston steering gear is fitted, additional bending moments may be transmitted from the steering gear into the rudder stock. These additional bending moments are to be taken into account for determining the rudder stock diameter.*

#### 3.3 Analysis

##### 3.3.1 General

The evaluation of bending moments, shear forces and support forces for the system rudder - rudder stock may be carried out for some basic rudder types as shown in Figs. 2.30 to 2.32 as outlined in 3.3.2 to 3.3.3.

##### 3.3.2 Data for the analysis

$\ell_{10} - \ell_{50}$ = lengths of the individual girders of the system [m]

$I_{10} - I_{50}$ = moments of inertia of these girders [cm⁴]

For rudders supported by a sole piece, the length $\ell_{20}$ is the distance between lower edge of rudder body and centre of sole piece, and $I_{20}$ is the moment of inertia of the pintle in the sole piece.

Load on rudder body (general):

$$p_R = \frac{C_R}{\ell_{10} \cdot 10^3} \quad [\text{kN/m}]$$

Load on semi-spade rudders:

$$p_{R10} = \frac{C_{R2}}{\ell_{10} \cdot 10^3} \quad [\text{kN/m}]$$

$$p_{R20} = \frac{C_{R1}}{\ell_{20} \cdot 10^3} \quad [\text{kN/m}]$$

$C_R$, $C_{R1}$, $C_{R2}$ = see 2.1 and 2.2

Z = spring constant of support in the sole piece or rudder horn respectively

for support in the sole piece (Fig. 2.30):

$$Z = \frac{6{,}18 \cdot I_{50}}{\ell_{50}^3} \quad [\text{kN/m}]$$

for support in the rudder horn (Fig. 2.31):

$$Z = \frac{1}{f_b + f_t} \quad [\text{kN/m}]$$

$f_b$ = unit displacement of rudder horn [m] due to a unit force of 1 kN acting in the centre of support

$$= 0{,}21 \frac{d^3}{I_n} \quad [\text{m/kN}] \text{ (guidance value for steel)}$$

$I_n$ = moment of inertia of rudder horn around the x-axis at d/2 [cm⁴], see also Fig. 2.31.

$f_t$ = unit displacement due to a torsional moment of the amount 1 · e [kN · m]

$$= \frac{d \cdot e^2}{G \cdot J_t}$$

$$= \frac{d \cdot e^2 \cdot \Sigma\, u_i / t_i}{3{,}14 \cdot 10^8 \cdot F_T^2} \quad [\text{m/kN}] \quad \text{for steel}$$

G = modulus of rigity

G = $7{,}92 \cdot 10^7$ [kN/m²] for steel

$J_t$ = torsional moment of inertia [m⁴]

$F_T$ = mean sectional area of rudder horn [m²]

$u_i$ = breadth [mm] of individual plates forming the mean horn sectional area

$t_i$ = plate thickness within individual breadth $u_i$ [mm]

e, d = distances [m] according to Fig. 2.31

### 3.3.3 Moments and forces to be evaluated

**3.3.3.1** The bending moment $M_R$ and the shear force $Q_1$ in the rudder body, the bending moment $M_b$ in the neck bearing and the support forces $B_1$, $B_2$, $B_3$ are to be evaluated.

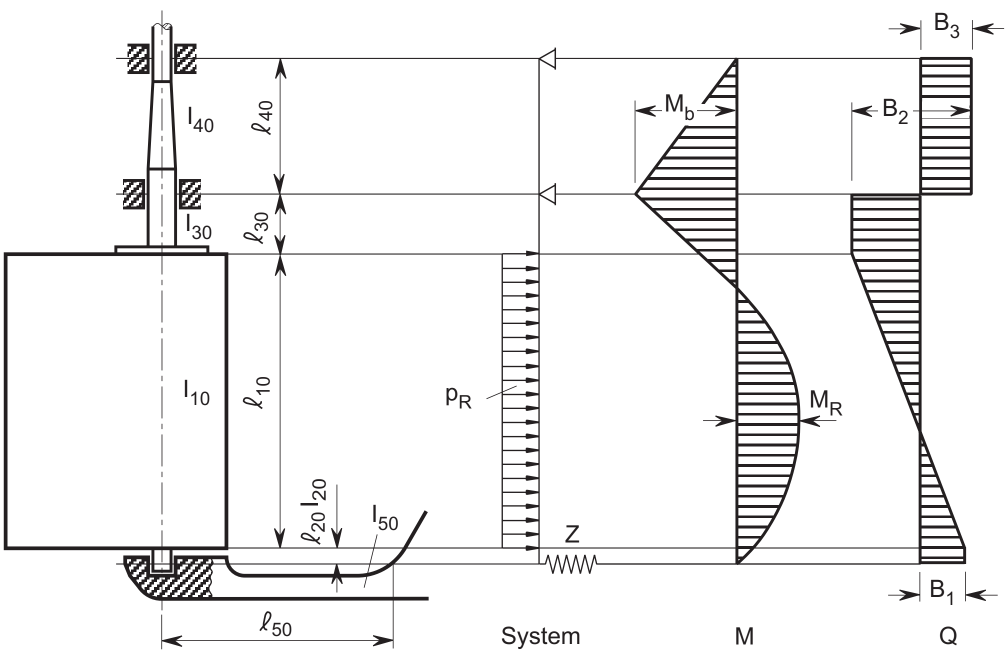



**Fig. 2.30 Rudder supported by sole piece**

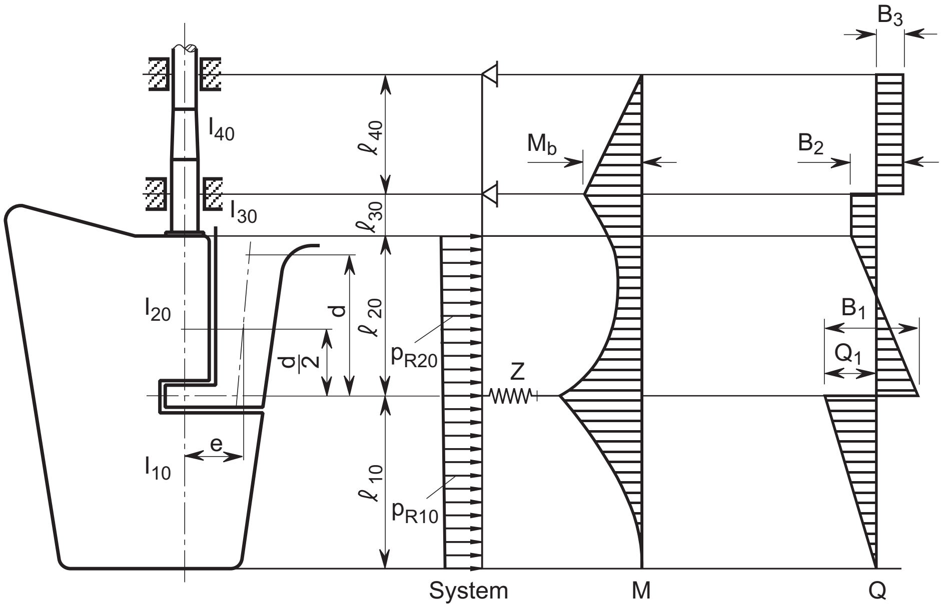



**Fig. 2.31 Semi-spade rudder**

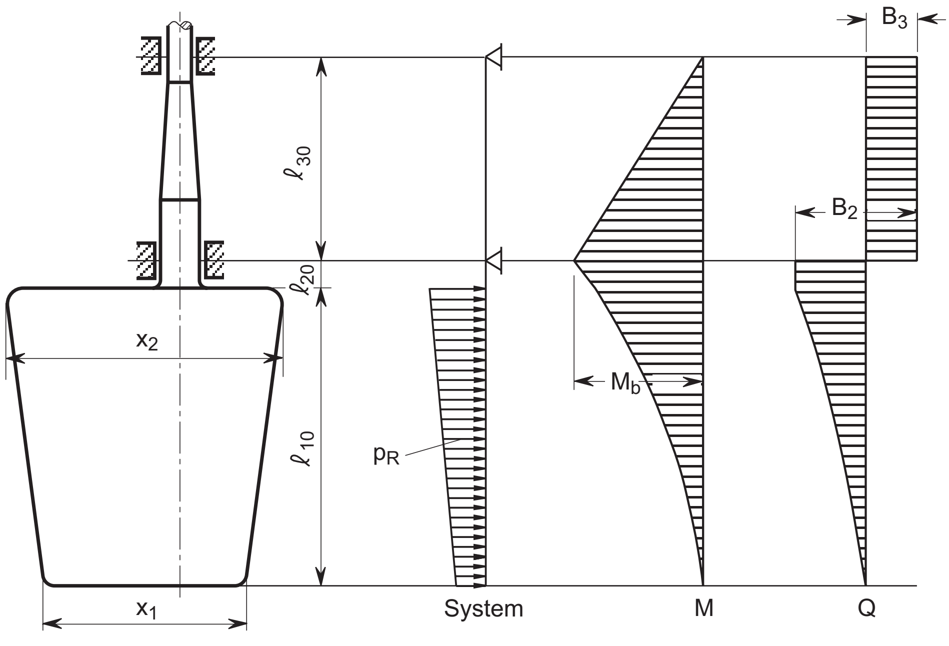



**Fig. 2.32 Spade rudder**

The so evaluated moments and forces are to be used for the stress analyses required by 3.2 and 5.1 and for calculation of sole piece and rudder horn.

**3.3.3.2** For spade rudders moments and forces may be determined by the following formulae:

$$M_b = C_R \left( \ell_{20} + \frac{\ell_{10}\,(2\,x_1 + x_2)}{3\,(x_1 + x_2)} \right) \quad [\text{Nm}]$$

$$B_3 = \frac{M_b}{\ell_{30}} \quad [\text{N}]$$

$$B_2 = C_R + B_3 \quad [\text{N}]$$

### 3.4 Rudder trunk

Where the rudder stock is arranged in a trunk in such a way that the trunk is stressed by forces due to rudder action, the scantlings of the trunk are to be such that the equivalent stress due to bending and shear does not exceed $0{,}35 \cdot R_{eH}$ of the material used.

## 4. Sole piece

**4.1** The section modulus of the sole piece related to z-axis is not to be less than:

$$W_z = \frac{B_1 \cdot x \cdot k}{80} \quad \left[\text{cm}^3\right]$$

$B_1$ = see 5.
For rudders with two supports the support force is approximately $B_1 = C_R/2$, when the elasticity of the sole piece is ignored.

$x$ = distance of the respective cross section from the rudder axis [m]

$x_{min} = 0{,}5 \cdot \ell_{50}$

$x_{max} = \ell_{50}$

$\ell_{50}$ = see Fig. 2.33 and 3.3.2

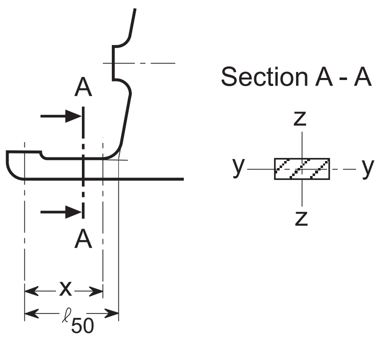



**Fig. 2.33 Sole piece parameters**

**4.2** The section modulus related to y-axis is not to be less than:

– where no rudder post or rudder axle is fitted:

$$W_y = \frac{W_z}{2}$$

– where a rudder post or rudder axle is fitted:

$$W_y = \frac{W_z}{3}$$

**4.3** The sectional area at the location $x = \ell_{50}$ is not to be less than:

$$A_s = \frac{B_1}{48}\,k \quad \left[\text{mm}^2\right]$$

**4.4** The equivalent stress taking into account bending and shear stresses at any location within length $\ell_{50}$ is not to exceed:

$$\sigma_v = \sqrt{\sigma_b^2 + 3\tau^2} = \frac{115}{k} \quad \left[\text{N/mm}^2\right]$$

$$\sigma_b = \frac{B_1 \cdot x}{W_z} \quad \left[\text{N/mm}^2\right]$$

$$\tau = \frac{B_1}{A_s} \quad \left[\text{N/mm}^2\right]$$

## 5. Rudder horn of semi spade rudders

**5.1** The distribution of the bending moment, shear force and torsional moment is to be determined according to the following formulae:

– bending moment: $M_b = B_1 \cdot z$ [Nm]

$M_{bmax} = B_1 \cdot d$ [Nm]

– shear force: $Q = B_1$ [N]

– torsional moment: $M_T = B_1 \cdot e(z)$ [Nm]

For determining preliminary scantlings flexibility of the rudder horn may be ignored and the supporting force $B_1$ be calculated according to the following formula:

$$B_1 = C_R\,\frac{b}{c} \quad [\text{N}]$$

b, c, d, e(z) and z see Fig. 2.34 and 2.35

b = results from position of the centre of gravity of the rudder area

**5.2** The section modulus of the rudder horn in transverse direction related to the horizontal x-axis is at any location z not to be less than:

$$W_x = \frac{M_b \cdot k}{67} \quad \left[\text{cm}^3\right]$$

**5.3** At no cross section of the rudder horn the shear stress due to the shear force Q is to exceed the value:

$$\tau = \frac{48}{k} \quad \left[N/mm^2\right]$$

The shear stress is to be determined by following formula:

$$\tau = \frac{B_1}{A_h} \quad \left[N/mm^2\right]$$

$A_h$ = effective shear area of rudder horn in y-direction [mm²]

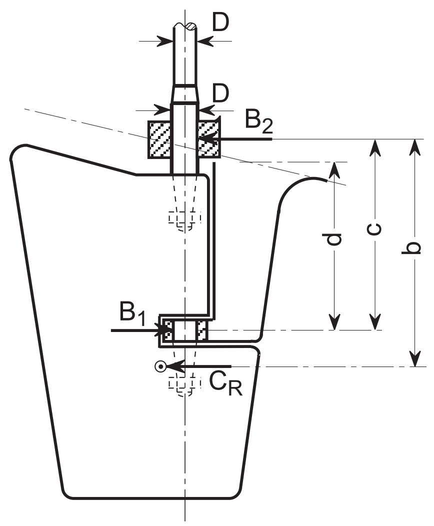



**Fig. 2.34 Parameters for semi spade rudders**

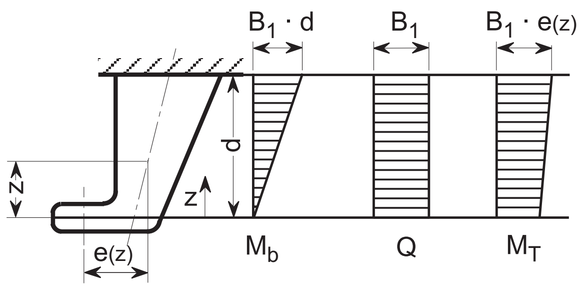



**Fig. 2.35 Forces on rudder horn**

**5.4** The equivalent stress at any location (z) of the rudder horn shall not exceed following value:

$$\sigma_v = \sqrt{\sigma_b^2 + 3\left(\tau^2 + \tau_T^2\right)} = \frac{120}{k} \quad \left[N/mm^2\right]$$

$$\sigma_b = \frac{M_b}{W_x} \quad \left[N/mm^2\right]$$

$$\tau_T = \frac{M_T \cdot 10^3}{2 \cdot A_T \cdot t_h} \quad \left[N/mm^2\right]$$

$A_T$ = sectional area [mm²] surrounded by the rudder horn at the location examined

$t_h$ = thickness of rudder horn plating in [mm]

**5.5** When determining the thickness of rudder horn plating the provisions of 5.2 to 5.4 are to be complied with. The thickness is, however, not to be less than:

$$t_{min} = 2,4\sqrt{\mathbf{L} \cdot k} \quad [mm]$$

**5.6** The rudder horn plating is to be effectively connected to the aft ship structure, e.g. by connecting the plating to longitudinal girders, in order to achieve a proper transmission of forces, see Fig. 2.36.

**5.7** Transverse webs of the rudder horn are to be led into the hull up to the next deck in a sufficient number and must be of adequate thickness.

**5.8** Strengthened plate floors are to be fitted in line with transverse webs in order to achieve a sufficient connection with the hull structure. The thickness of these plate floors is to be increased by 50 per cent above the Rule values as required by D. to G.

**5.9** The centre line bulkhead (wash-bulkhead) in the afterpeak is to be connected to the rudder horn.

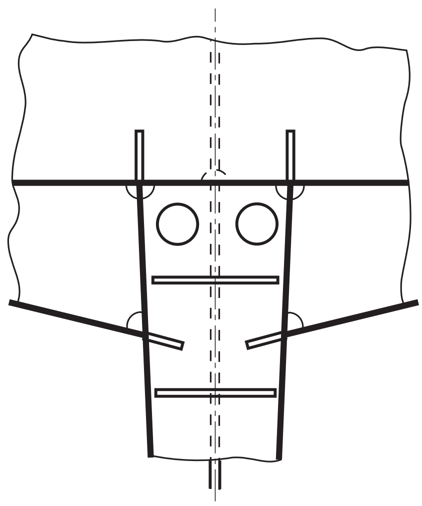


**Fig. 2.36 Connection of rudder horn to the aft ship structure**

**5.10** Where the transition between rudder horn and shell is curved, about 50 % of the required total section modulus of the rudder horn is to be formed by webs in a Section A - A located in the centre of the transition zone, i.e. 0,7 r above beginning of the transition zone. See Fig. 2.37.

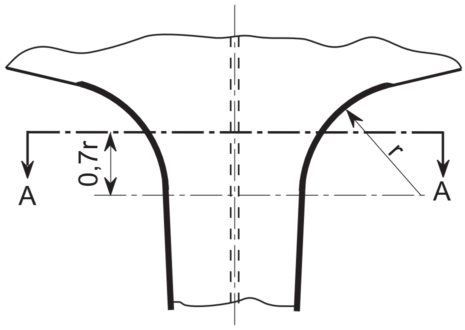



**Fig. 2.37 Transition between rudder horn and curved shell**

## 6. Rudder couplings

### 6.1 General

**6.1.1** Couplings are to be designed in such a way as to enable them to transmit the full torque of the rudder stock.

**6.1.2** The distance of bolt axis from the edges of the flange is not to be less than 1,2 the diameter of the bolt. In horizontal couplings, at least 2 bolts are to be arranged forward of the rudder stock axis.

**6.1.3** Coupling bolts are to be fitted bolts. Bolts and nuts are to be effectively secured against loosening.

**6.1.4** For spade rudders horizontal couplings according to 6.2 are permissible only where the required thickness of the coupling flanges $t_f$ is less than 50 mm, otherwise cone couplings according to 6.3 are to be applied. For spade rudders of the high lift type, only cone couplings according to 6.3 are permitted.

### 6.2 Horizontal couplings

**6.2.1** The diameter of coupling bolts is not to be less than:

$$d_b = 0,62 \sqrt{\frac{D^3 \cdot k_b}{k_r \cdot n \cdot e}} \quad [\mathrm{mm}]$$

D = rudder stock diameter according to 3. [mm]

n = total number of bolts, which is not to be less than 6

e = mean distance of bolt axes from centre of bolt system [mm]

$k_r$ = material factor for the rudder stock as given in 1.4.2

$k_b$ = material factor for bolts analogously to 1.4.2

**6.2.2** The thickness of the coupling flanges is not to be less than determined by the following formulae:

$$t_f = 0,62 \sqrt{\frac{D^3 \cdot k_f}{k_r \cdot n \cdot e}} \quad [\mathrm{mm}]$$

$t_{fmin}$ = 0,9 · $d_b$

$k_f$ = material factor for the coupling flanges analogously to 1.4.2

The thickness of the coupling flanges clear of the bolt holes is not to be less than 0,65 · $t_f$.

The width of material outside the bolt holes is not to be less than 0,67 · $d_b$.

**6.2.3** Coupling flanges are to be equipped with a fitted key according to DIN 6885 or equivalent standard for relieving the bolts.

The fitted key may be dispensed with if the diameter of the bolts is increased by 10 %.

**6.2.4** Horizontal coupling flanges shall either be forged together with the rudder stock or be welded to the rudder stock as outlined in the GL Rules Part 1 – Seagoing Ships, Chapter 1 – Hull Structures, Section 19, B.4.4.3.

**6.2.5** For the connection of the coupling flanges with the rudder body see also GL Rules Part 1 – Seagoing Ships, Chapter 1 – Hull Structures, Section 19, B.4.4.

### 6.3 Cone couplings

#### 6.3.1 Cone couplings with key

**6.3.1.1** Cone couplings should have a taper c on diameter of 1 : 8 - 1 : 12.

c = $(d_0 - d_u)/\ell$ according to Fig. 2.38

The cone shape should be very exact. The nut is to be carefully secured, e.g. by a securing plate as shown in Fig. 2.38.

**6.3.1.2** The coupling length $\ell$ should, in general, not be less than 1,5 · $d_0$.

**6.3.1.3** For couplings between stock and rudder a key is to be provided, the shear area of which is not to be less than:

$$a_s = \frac{16 \cdot Q_F}{d_k \cdot R_{eH1}} \quad \left[\mathrm{cm}^2\right]$$

$Q_F$ = design yield moment of rudder stock [Nm] according to 8.

$d_k$ = diameter of the conical part of rudder stock [mm] at the key

$R_{eH1}$ = minimum nominal upper yield point of key material [N/mm²]

**6.3.1.4** The effective surface area of the key (without rounded edges) between key and rudder stock or cone coupling is not to be less than:

$$a_k = \frac{5 \cdot Q_F}{d_k \cdot R_{eH2}} \quad \left[cm^2\right]$$

$R_{eH2}$ = minimum nominal upper yield point of key, stock or coupling material [N/mm²], whichever is less.

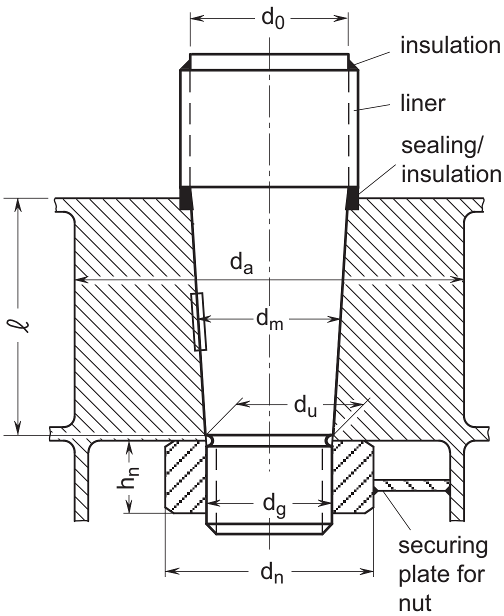



**Fig. 2.38 Cone coupling**

**6.3.1.5** The dimensions of the slugging nut are to be as follows:

– height:

$$h_n = 0{,}6 \cdot d_g$$

– outer diameter (the greater value to be taken):

$$d_n = 1{,}2 \cdot d_u \quad \text{or} \quad d_n = 1{,}5 \cdot d_g$$

– external thread diameter:

$$d_g = 0{,}65 \cdot d_0$$

See Fig. 2.38.

**6.3.1.6** It is to be proved that 50 % of the design yield moment will be solely transmitted by friction in the cone couplings. This can be done by calculating the required push-up pressure and push-up length according to 6.3.2.3 for a torsional moment $Q'_F = 0{,}5 \cdot Q_F$.

**6.3.2 Cone couplings with special arrangements for mounting and dismounting of couplings**

**6.3.2.1** Where the stock diameter exceeds 200 mm the press fit is recommended to be effected by a hydraulic pressure connection. In such cases the cone should be more slender, c ≈ 1 : 12 to ≈ 1 : 20.

**6.3.2.2** In case of hydraulic pressure connections the nut is to be effectively secured against the rudder stock or the pintle. A securing plate for securing the nut against the rudder body is not to be provided, see Fig. 2.39.

***Note***

*A securing flat bar will be regarded as an effective securing device of the nut, if its shear area is not less than:*

$$A_s = \frac{P_s \cdot \sqrt{3}}{R_{eH}} \quad \left[mm^2\right]$$

$P_s$ = *shear force as follows*

$$= \frac{P_e}{2} \cdot \mu_1 \left(\frac{d_1}{d_g} - 0{,}6\right) \quad [N]$$

$P_e$ = *push-up force according to 6.3.2.3 [N]*

$\mu_1$ = *frictional coefficient between nut and rudder body, normally $\mu_1 = 0{,}3$*

$d_1$ = *mean diameter of frictional area between nut and rudder body*

$d_g$ = *thread diameter of nut*

$R_{eH}$ = *yield point [N/mm²] of securing flat bar material*

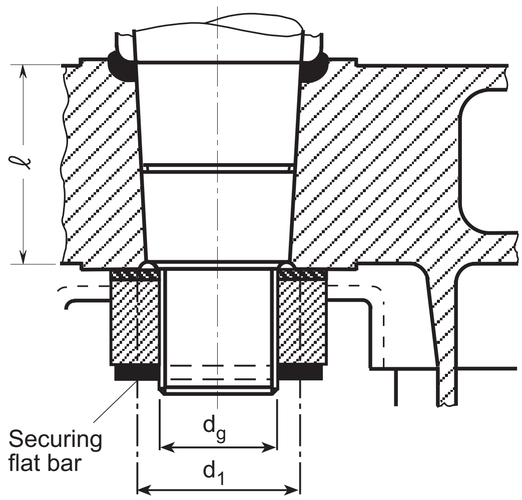



**Fig. 2.39 Cone coupling with special arrangements for mounting and dismounting**

**6.3.2.3** For safe transmission of the torsional moment by the coupling between rudder stock and rudder body the push-up length and the push-up pressure are to be determined by following formulae.

**Push-up pressure**

The push-up pressure is not to be less than the greater of the two following values:

$$p_{req1} = \frac{2 \cdot Q_F \cdot 10^3}{d_m^2 \cdot \ell \cdot \pi \cdot \mu_0} \quad \left[N/mm^2\right]$$

or

$$p_{req2} = \frac{6 \cdot M_b \cdot 10^3}{\ell^2 \cdot d_m} \quad \left[N/mm^2\right]$$

$Q_F$ = design yield moment of rudder stock according to 8. [Nm]

$d_m$ = mean cone diameter [mm]

$\ell$ = cone length [mm]

$\mu_0$ = 0,15 (frictional coefficient)

$M_b$ = bending moment in cone coupling (e.g. in case of spade rudders) [Nm]

It has to be proved that the push-up pressure does not exceed the permissible surface pressure in the cone. The permissible surface pressure is to be determined by following formula:

$$p_{perm} = \frac{0{,}8 \cdot R_{eH}\left(1 - \alpha^2\right)}{\sqrt{3 + \alpha^4}}$$

$R_{eH}$ = yield point [N/mm²] of the material of the gudgeon

$\alpha = \frac{d_m}{d_a}$ (see Fig. 2.38)

The outer diameter of the gudgeon should not be less than:

$$d_a = 1{,}5 \cdot d_m \quad [mm]$$

**Push-up length**

The push-up length is not to be less than:

$$\Delta\ell_1 = \frac{p_{req} \cdot d_m}{E\left(\frac{1 - \alpha^2}{2}\right)c} + \frac{0{,}8 \cdot R_{tm}}{c} \quad [mm]$$

$R_{tm}$ = mean roughness [mm]

$R_{tm}$ ≈ 0,01 mm

c = taper on diameter according to 6.3.2.1

E = Young's modulus ($2{,}06 \cdot 10^5$ N/mm²)

The push-up length is, however, not to be taken greater than:

$$\Delta\ell_2 = \frac{1{,}6 \cdot R_{eH} \cdot d_m}{\sqrt{3 + \alpha^4}\; E \cdot c} + \frac{0{,}8 \cdot R_{tm}}{c} \quad [mm]$$

***Note***

*In case of hydraulic pressure connections the required push-up force $P_e$ for the cone may be determined by the following formula:*

$$P_e = p_{req} \cdot d_m \cdot \pi \cdot \ell\left(\frac{c}{2} + 0{,}02\right) \quad [N]$$

*Where due to the fitting procedure a partial push-up effect caused by the rudder weight is given, this may be taken into account when fixing the required push-up length, subject to approval by GL.*

**6.3.2.4** The required push-up pressure for pintle bearings is to be determined by following formula:

$$p_{req} = 0{,}4\,\frac{B_1 \cdot d_0}{d_m^2 \cdot \ell} \quad \left[N/mm^2\right]$$

$B_1$ = supporting force in pintle bearing [N], see also Fig. 2.31

$d_m$, $\ell$ = see 6.3.2.3

$d_0$ = pintle diameter [mm] according to Fig. 2.38.

## 7. Rudder body, rudder bearings

### 7.1 Strength of rudder body

**7.1.1** The rudder body is to be stiffened by horizontal and vertical webs in such a manner that the rudder body will be effective as a beam. The rudder should be additionally stiffened at the aft edge.

**7.1.2** The strength of the rudder body is to be proved by direct calculation according to 3.3.

**7.1.3** For rudder bodies without cut-outs the permissible stress are limited to:

bending stress due to $M_R$:

$$\sigma_b = 110 \quad \left[N/mm^2\right]$$

shear stress due to $Q_1$:

$$\tau = 50 \quad \left[N/mm^2\right]$$

equivalent stress due to bending and shear:

$$\sigma_v = \sqrt{\sigma_b^2 + 3\tau^2} = 120 \quad \left[N/mm^2\right]$$

$M_R$, $Q_1$ see 3.3.3 and Fig. 2.30 and 2.31.

In case of openings in the rudder plating for access to cone coupling or pintle nut the permissible stresses according to 7.1.4 apply. Smaller permissible stress values may be required if the corner radii are less than 0,15· $h_0$, where $h_0$ = height of opening.

**7.1.4** In rudder bodies with cut-outs (semi-spade rudders) the following stress values are not to be exceeded:

bending stress due to $M_R$:

$$\sigma_b = 90 \quad \left[N/mm^2\right]$$

shear stress due to $Q_1$:

$$\tau = 50 \quad \left[N/mm^2\right]$$

torsional stress due to $M_t$:

$$\tau_t = 50 \quad \left[N/mm^2\right]$$

equivalent stress due to bending and shear and equivalent stress due to bending and torsion:

$$\sigma_{v1} = \sqrt{\sigma_b^2 + 3\tau^2} = 120 \quad \left[N/mm^2\right]$$

$$\sigma_{v2} = \sqrt{\sigma_b^2 + 3\tau_t^2} = 100 \quad \left[N/mm^2\right]$$

$$M_R = C_{R2} \cdot f_1 + B_1 \frac{f_2}{2} \quad [Nm]$$

$Q_1$ = $C_{R2}$ [N]

$f_1$, $f_2$ = see Fig. 2.40

The torsional stress may be calculated in a simplified manner as follows:

$$\tau_t = \frac{M_t}{2 \cdot \ell \cdot h \cdot t} \quad \left[N/mm^2\right]$$

$$M_t = C_{R2} \cdot e \quad [Nm]$$

$C_{R2}$ = partial rudder force [N] of the partial rudder area $A_2$ below the cross section under consideration

e = lever for torsional moment [m]

(horizontal distance between the centroid of area $A_2$ and centre line a-a of the effective cross sectional area under consideration, see Fig. 2.40. The centroid is to be assumed at 0,33 · $c_2$ aft of the forward edge of area $A_2$, where $c_2$ = mean breadth of area $A_2$).

h, $\ell$, t = in [cm], see Fig. 2.40

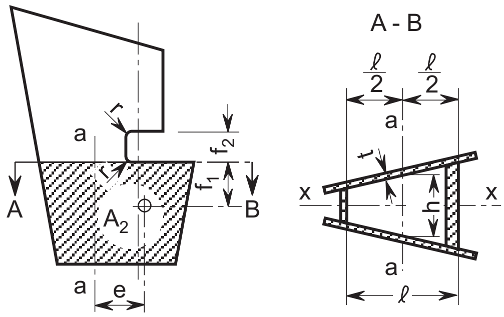



**Fig. 2.40 Rudder body**

The distance $\ell$ between vertical webs should not exceed 1,2 · h.

The radii in the rudder plating are not to be less than 4 – 5 times the plate thickness, but in no case less than 50 mm.

***Note***

*It is recommended to keep the natural frequency of the fully immersed rudder and of local structural components at least 10 % above the exciting frequency of the propeller (number of revolutions × number of blades) or if relevant above higher order.*

## 7.2 Rudder plating

**7.2.1** The thickness of rudder plating is to be determined according to following formula:

$$t = 1{,}74 \cdot a \sqrt{p_R \cdot k} + 2{,}5 \quad [mm]$$

$$p_R = 10 \cdot \mathbf{T} + \frac{C_R}{10^3 \cdot A} \quad \left[kN/m^2\right]$$

a = smaller unsupported width of a plate panel [m]

The influence of the aspect ratio of the plate panels may be taken into account as given in D.4.3.

The thickness shall, however, not be less than the thickness $t_2$ of the shell plating at the ends according to the scantlings for different yacht types.

**7.2.2** For connecting the side plating of the rudder to the webs tenon welding is not to be used. Where application of fillet welding is not practicable, the side plating is to be connected by means of slot welding to flat bars which are welded to the webs.

**7.2.3** The thickness of the webs is not to be less than 70 % of the thickness of the rudder plating according to 7.2.1, but not less than:

$$t_{min} = 8\sqrt{k} \quad [mm]$$

Webs exposed to seawater must be dimensioned according to 7.2.1.

### 7.3 Transmitting of rudder torque

**7.3.1** For transmitting the rudder torque, the rudder plating according to 7.2.1 is to be increased by 25 % in way of the coupling. A sufficient number of vertical webs is to be fitted in way of the coupling.

**7.3.2** If the torque is transmitted by a prolonged shaft extended into the rudder, the latter must have the diameter $D_t$ or $D_1$, whichever is greater, at the upper 10 % of the intersection length. Downwards it may be tapered to 0,6 $D_t$, in spade rudders to 0,4 times the strengthened diameter, if sufficient support is provided for.

### 7.4 Rudder bearings

**7.4.1** In way of bearings liners and bushes are to be fitted. Where in case of small ships bushes are not fitted, the rudder stock is to be suitably increased in diameter in way of bearings enabling the stock to be re-machined later.

**7.4.2** An adequate lubrication is to be provided.

**7.4.3** The bearing forces result from the direct calculation mentioned in 3.3. As a first approximation the bearing force may be determined without taking account of the elastic supports. This can be done as follows:

– normal rudder with two supports:

The rudder force $C_R$ is to be distributed to the supports according to their vertical distances from the centre of gravity of the rudder area.

– semi-spade rudders:

– support force in the rudder horn:

$$B_1 = C_R \cdot \frac{b}{c} \quad [N]$$

– support force in the neck bearing:

$$B_2 = C_R - B_1 \quad [N]$$

For b and c see Fig. 2.34

**7.4.4** The projected bearing surface $A_b$ (bearing height × external diameter of liner) is not to be less than:

$$A_b = \frac{B}{q} \quad [mm^2]$$

B = support force [N]

q = permissible surface pressure according to Table 2.21

**7.4.5** Stainless and wear resistant steels, bronce and hot-pressed bronce-graphit materials have a considerable difference in potential to non-alloyed steel. Respective preventive measures are required.

**7.4.6** The bearing height shall be equal to bearing diameter, however, is not to exceed 1,2 times the bearing diameter. Where bearing depth is less than bearing diameter, higher specific surface pressures may be allowed.

**7.4.7** The wall thickness of pintle bearings in sole piece and rudder horn shall be approximately ¼ of pintle diameter.

**Table 2.21 Permissible surface pressure for bearing materials**

| Bearing material | q [N/mm²] |
|---|---|
| lignum vitae | 2,5 |
| white metal, oil lubricated | 4,5 |
| synthetic material [1] | 5,5 |
| steel [2], bronze and hot-pressed bronze-graphite materials | 7,0 |

1 Synthetic materials to be of approved type.
Surface pressures exceeding 5,5 N/mm² may be accepted in accordance with bearing manufacturer's specification and tests, but in no case more than 10 N/mm².

2 Stainless and wear resistant steel in an approved combination with stock liner. Higher surface pressures than 7 N/mm² may be accepted if verified by tests.

### 7.5 Pintles

**7.5.1** Pintles are to have scantlings complying with conditions given in 7.4.4 and 7.4.6. The pintle diameter is not to be less than:

$$d = 0{,}35\sqrt{B_1 \cdot k_r} \quad [mm]$$

$B_1$ = support force [N]

$k_r$ = see 1.4.2

**7.5.2** The thickness of any liner or bush shall not be less than:

$$t = 0{,}01\sqrt{B_1} \quad [mm]$$

$t_{min}$ = 8 mm for metallic materials and synthetic material

= 22 mm for lignum material

**7.5.3** Where pintles are of conical shape, they are to comply with the following:

taper on diameter 1 : 8 to 1 : 12 if keyed by slugging nut

taper on diameter 1 : 12 to 1 : 20 if mounted with oil injection and hydraulic nut

**7.5.4** Pintles are to be arranged in such a manner as to prevent unintentional loosening and falling out.

For nuts and threads the requirements of 6.3.1.5 and 6.3.2.2 apply accordingly.

### 7.6 Guidance values for bearing clearances

**7.6.1** For metallic bearing material the bearing clearance should generally not be less than:

$$\frac{d_b}{1000} + 1,0 \quad [\mathrm{mm}]$$

$d_b$ = inner diameter of bush [mm]

**7.6.2** If non-metallic bearing material is applied, the bearing clearance is to be specially determined considering the material's swelling and thermal expansion properties.

**7.6.3** Clearance is in no way to be taken less than 1,5 mm on diameter. In case of self lubricating bushes going down below this value can be agreed to on the basis of the manufacturer's specification.

## 8. Design yield moment of rudder stock

The design yield moment of the rudder stock is to be determined by the following formula:

$$Q_F = 0,02664 \frac{D_t^3}{k_r} \quad [\mathrm{Nm}]$$

$D_t$ = stock diameter [mm] according to 3.1.

Where the actual diameter $D_{ta}$ is greater than the calculated diameter $D_t$, diameter $D_{ta}$ is to be used. However, $D_{ta}$ need not be taken greater than $1,145 \cdot D_t$.

## 9. Stopper, locking device

### 9.1 Stopper

The motions of quadrants or tillers are to be limited on either side by stoppers. The stoppers and their foundations connected to the ship's hull are to be of strong construction so that the yield point of the applied materials is not exceeded at the design yield moment of the rudder stock.

### 9.2 Locking device

Each steering gear is to be provided with a locking device in order to keep the rudder fixed at any position. This device as well as the foundation in the ship's hull are to be of strong construction so that the yield point of the applied materials is not exceeding the design yield moment of the rudder stock as specified in 8. Where the ship's speed exceeds 12 kn, the design yield moment need only be calculated for a stock diameter based on a speed $v_0$ = 12 kn.

## 10. Fin stabilizers

### 10.1 General

Hydrodynamic effects of fin stabilizers on rolling behavior of yachts are not part of the classification procedure. The classification however includes the integration of such systems into the hull structure.

### 10.2 Integration into ship's structure

**10.2.1** The complete bearing system and the drive unit directly mounted at the fin stock are to be situated within an own watertight compartment at ship's side or bottom. For installation purposes, inspection and maintenance watertight closable openings (with safeguards that they can be opened only during docking) have to be provided in suitable number and size. For retracable fins a recess of sufficient size to harbour the complete fin has to be provided in addition at the ship's shell.

**10.2.2** At the penetration of the fin stock and at the slot of retractable fins, the shell has to be strengthened in a sufficient way.

**10.2.3** Watertight boundaries of the fin recess, if applicable, and of the drive compartment have to be dimensioned according to C. to G. Special attention has to be given to the transmission of the fin support forces from the stock bearings into the ship's structure. The local reinforcements and the overall transmission of forces by girders, web frames, etc. have to be defined by direct calculations considering fatigue strength and have to be included in the hull structure drawings to be submitted.

**10.2.4** Calculations have to be submitted, which show that the hull structure is not compromised if the fin and/or the fin stock are damaged by a collision, by grounding, etc. If the fin body reaches over the maximum breadth of the ship, the location of non-retractable fins should be marked on the shell.

## K. Anchor and Mooring Equipment

### 1. General

**1.1** The equipment of anchors, chain cables, wires and ropes is to be determined from Table 2.22 in accordance with the equipment numeral EN.

***Note***

*Anchoring equipment as required hereinafter is intended for temporary mooring of a yacht within a harbour or sheltered area when the yacht is awaiting berth, tide, etc.*

*The equipment is, therefore, not designed to hold a yacht off fully exposed coasts in rough weather or to stop a yacht which is moving or drifting. In this condition the loads on the anchoring equipment increase to such a degree that its components may be damaged or lost owing to the high energy forces generated, particularly in sailing yachts.*

*Anchoring equipment as required hereinafter is designed to hold a yacht in good holding ground in conditions such as to avoid dragging of the anchor. In poor holding ground the holding power of the anchors will be significantly reduced.*

*The equipment numeral formula for anchoring equipment is based on an assumed current speed of 2,5 m/s, wind speed of 25 m/sec and a scope of chain cable between 6 and 10, the scope being the ratio between length of chain paid out and water depth.*

*It is assumed that under normal circumstances a yacht will use only one bow anchor and chain cable at a time.*

**1.2** Every yacht is to be equipped with at least one anchor windlass.

Windlass and chain stopper, if fitted, are to comply with the GL Rules Part1 – Seagoing Ships, Chapter 2 – Machinery Installations, Section 14, D.

**1.3** For yachts having a navigation notation **K**(20) or **K**(50) (coastal service) affixed to their Character of Classification, the equipment may be determined as for one numeral range lower than required in accordance with the equipment numeral EN.

**1.4** When determining the equipment for yachts having a navigation notation **W** (sheltered water service) affixed to their Character of Classification, the anchor mass may be 60 % of the value required by Table 2.22. The chain diameter may be determined according to the reduced anchor mass. The length of the ropes is recommended to be 50 % of the length given in Table 2.22.

**1.5** Yachts built under survey of GL and which are to have the mark ✠ stated in their Certificate and in the Register Book, must be equipped with anchors and chain cables complying with the GL Rules II – Materials and Welding, Part 1 – Metallic Materials, Chapter 4 – Equipment and have to be tested on approved machines in presence of a GL Surveyor.

### 2. Equipment numeral

**2.1** For monohull yachts the equipment numeral is to be calculated as follows:

$$EN = \sqrt[3]{\Delta^2} + 2\left(a \cdot \mathbf{B} + \sum b_i \cdot h_i \cdot \sin\Theta_i\right) + 0{,}1 \cdot A$$

$\Delta$ = moulded displacement [t] to design waterline in sea water with a density of 1,025 t/m$^3$

a = distance [m], from design waterline, amidships, to upper deck at side, as shown in Fig. 2.41

**B** = greatest moulded breadth [m]

$b_i$ = actual breadth of deckhouses with a breadth greater **B**/4

$h_i$ = height [m] on centreline of each tier of superstructures and deckhouses corresponding to $b_i$ (deck sheer, if any, is to be ignored)

$\Theta i$ = the angle of inclination aft of each front bulkhead, as shown in Fig. 2.41

A = area [m$^2$], in profile view of the hull, superstructures and houses, having a breadth greater then **B**/4, above the design waterline within the length **L** and up to the height $a + \Sigma h_i$

For sailing yachts the rig has to be appropriately considered when determining area A.

***Note***

*The influence of windage effects on masts and rigging for square rigged sailing yachts on the equipment numeral be assumed as follows:*

– *for yachts with* $\boldsymbol{L} < 48$ *m, typically 50 % increase in relation to a motor yacht having the same total longitudinal profile area of hull and superstructure*

– *for yachts with* $\boldsymbol{L} \geq 100$ *m, typically 30 % increase in relation to a motor yacht having the same total longitudinal profile area of hull and superstructure*

– *for yachts with a length in between linear interpolation may be used*

Where a deckhouse having a breadth greater than **B**/4 is located above a deckhouse having a breadth of **B**/4 or less, the wide house is to be included and the narrow house ignored.

Windscreens or bulwarks 1,5 m or more in height above deck at side are to be regarded as parts of houses when determining h and A, e.g. the areas specially marked in Fig. 2.41 are to be included in A.

**2.2** For multihull yachts the equipment numeral has to be defined in analogous way, details are given in GL Rules Part 1 – Seagoing Ships, Chapter 5 – High Speed Craft, Section 6.

## 3. Anchors

### 3.1 Number and arrangement of bower anchors

**3.1.1** Normally two bower anchors according to Table 2.22 have to be provided.

**3.1.2** For yachts with a length **L** ≤ 48 m having at least two independent propulsion systems and an adequate steering system the following reductions may be granted:

– reduction of the number of bower anchors to one, and/or

– reduction of weight of the bower anchors and chain cables

according to a decision of GL Head Office. In this case sails are not considered as a propulsion system.

**3.1.3** Bower anchors are to be connected to their chain cables and positioned on board ready for use. A third, spare anchor is not required for yachts.

It is to be ensured that each anchor can be stowed in hawse and hawse pipe in such a way that it remains firmly secured in seagoing conditions.

***Note***

*National Regulations concerning provision of a spare anchor, stream anchor or a stern anchor may need to be observed.*

**3.1.4** For yachts of new design special requirements may be agreed with GL.

### 3.2 Anchor design

**3.2.1** Anchors must be of approved design. The mass of the heads of patent (ordinary stockless) anchors, including pins and fittings, is not to be less than 60 per cent of the total mass of the anchor.

**3.2.2** For stock anchors, the total mass of the anchor, including stock, shall comply with the values in Table 2.22. The mass of the stock shall be 20 percent of this total mass.

**3.2.3** The mass of each individual bower anchor may vary by up to 7 per cent above or below required individual mass provided that the total mass of all the bower anchors is not less than the sum of the required individual masses.

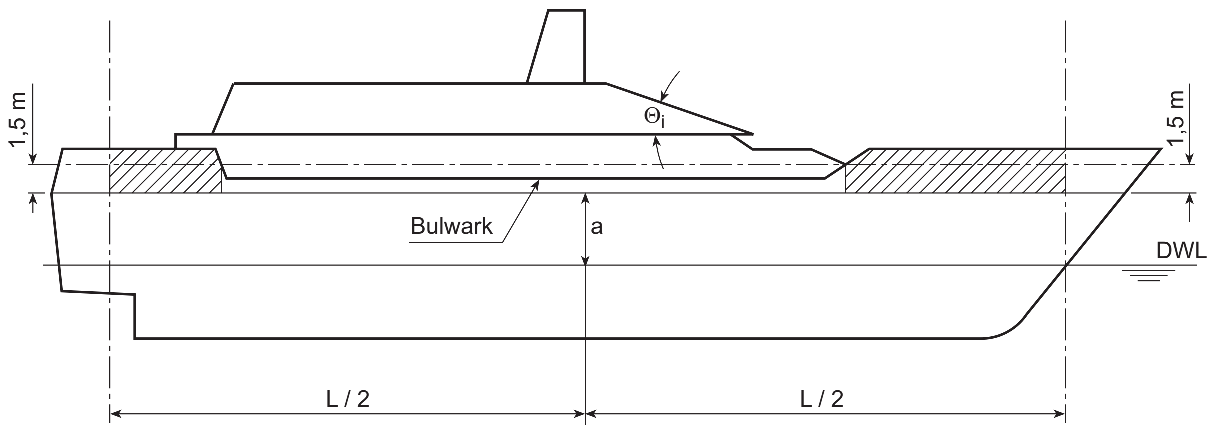



**Fig. 2.41 Profile view of hull, superstructure and deckhouses relevant for equipment numeral**

### 3.3 High holding power anchors

**3.3.1** Where special anchors are approved by GL as "High Holding Power Anchors" (HHP), the anchor mass may be 75 per cent of anchor mass as per Table 2.22.

"High Holding Power Anchors" are anchors which are suitable for the yacht's use at any time and which do not require prior adjustment or special placement on sea bed.

**3.3.2** For approval as a "High Holding Power Anchor", satisfactory tests are to be made on various types of bottom and the anchor is to have a holding power at least twice that of a patent anchor ("Admiralty Standard Stockless") of the same mass. Tests have to be approved by GL.

**3.3.3** Dimensioning of chain cable and windlass is to be based on the undiminished anchor mass according to Table 2.22.

### 3.4 Very high holding power anchors

Where special anchors are approved by GL as "Very High Holding Power Anchors" (VHHP), anchor mass may be not less than 2/3 of the mass required for the HHP anchor it replaces.

### 3.5 Stern anchors

Where stern anchor equipment is fitted, such equipment is to comply in all respects with the rules for anchor equipment. The mass of each stern anchor shall be at least 35 per cent of that of bower anchors. The diameter of chain cables is to be determined from Table 2.22 in accordance with anchor mass. Where a stern anchor windlass is fitted, the requirements of the GL Rules Part 1 – Seagoing Ships, Chapter 2 – Machinery Installations, Section 14, D., are to be observed.

## 4. Chain cables

**4.1** Chain cable diameters given in Table 2.22 apply to chain cables made of chain cable materials specified in the requirements of the GL Rules II – Materials and Welding, Part 1 – Metallic Materials, Chapter 4 – Equipment for following grades:

- Grade K 1 (ordinary quality)
- Grade K 2 (special quality)
- Grade K 3 (extra special quality)

**4.2** Grade K 1 material used for chain cables in conjunction with "High Holding Power Anchors" must have a tensile strength $R_m$ of not less than 400 $N/mm^2$.

**4.3** Grade K 2 and K 3 chain cables must be purchased from and re-heat treated by recognized manufacturers only.

**4.4** The total length of chain given in Table 2.22 is to be divided in approximately equal parts between two bower anchors.

**4.5** For connection of the anchor with the chain cable approved Kenter-type anchor shackles may be chosen in lieu of the common Dee-shackles. A forerunner with swivel is to be fitted between anchor and chain cable. In lieu of a forerunner with swivel an approved swivel shackle may be used. However, swivel shackles are not to be connected to the anchor shank unless specially approved.

**4.6** Steel wire and synthetic wire ropes may be used as an alternative to stud link chain cables defined in Table 2.22 for yachts upon request and agreement with GL.

**4.7** The attachment of the inboard ends of chain cables to the yacht's structure is to be provided with means suitable to permit, in case of emergency, an easy slipping of chain cables to sea operable from an accessible position outside of chain locker.

Inboard ends of the chain cables are to be secured to the hull structures by a fastening able to withstand a force not less than 15 % nor more than 30 % of rated breaking load of the chain cable.

## 5. Chain locker

**5.1** The chain locker is to be of capacity and depth adequate to provide an easy direct lead of the cables through the chain pipes and self-stowing of the cables.

The minimum required stowage capacity without mud box for the two bow anchor chains is as follows:

$$S = 1{,}1 \cdot d^2 \cdot \frac{\ell}{100\,000} \quad \left[m^3\right]$$

d = chain diameter [mm] according to Table 2.22

$\ell$ = total length of stud link chain cable according to Table 2.22

The total stowage capacity is to be distributed on two chain lockers of equal size for port and starboard chain cables. The shape of the base areas shall, as far as possible, be quadratic with the maximum edge length of 33 · d. As an alternative, circular base areas may be selected, the diameter of which shall not exceed 30 – 35 d.

Above the stowage of each chain locker in addition a free depth of at least

h = 750 mm for **L** = 24 m

h = 1 500 mm for **L** ≥ 48 m

is to be provided; if the size of the yacht enables this. For intermediate lengths **L** linear interpolation is to be applied for the depth h.

**5.2** The chain locker boundaries and their access openings are to be watertight as necessary to prevent accidental flooding of the chain locker from damaging essential auxiliaries or equipment or affecting the proper operation of the yacht.

**5.3** Adequate drainage facilities of chain locker are to be provided.

**5.4** Where chain locker boundaries are also tank boundaries, their scantlings of stiffeners and plating are to be determined as for tanks in accordance with H.2.

Where this is not the case, plate thickness and section modulus of stiffening are also to be determined according to H.2. using the pressure $p_2$ only. The distance from the load centre to the top of chain locker pipe is to be taken for calculating the load. A corrosion allowance of 1,5 mm has to be applied.

## 6. Mooring equipment

***Note***

*For approximating mooring forces, a GL computer program system is available.*

### 6.1 Ropes

**6.1.1** The tow lines and mooring ropes specified in Table 2.22 and the content of the following up to 6.1.3 are recommendations only, a compliance with them is not a condition of Class.

#### 6.1.2 Breaking load

For tow lines and mooring lines, steel wire ropes as well as fibre ropes made of natural or synthetic fibres or wire ropes consisting of steel wire and fibre cores may be used. Nominal breaking loads specified in Table 2.22 are valid for wire ropes only. Where ropes of synthetic fibre are used, the breaking load is to be increased above the table values. The extent of increase depends on the material quality.

The required diameters of synthetic fibre ropes used in lieu of steel wire ropes may be taken from Table 2.23.

Regardless of the breaking load, recommended in Table 2.22, the diameter of the fibre roped should not be less than 20 mm.

#### 6.1.3 Length

The length of the individual mooring ropes may be up to 7 per cent less than that given in Table 2.22, provided that the total length of all the wires and ropes is not less than the sum of the individual lengths.

### 6.2 Mooring winches, bollards, hawses

**6.2.1** Mooring winches are to be designed taking into account the actual mooring lines and 80 % of their nominal breaking loads.

**6.2.2** Hawses, bollards and cleats shall be so designed as to protect the ropes against excessive wear. They are to be of proved construction and shall comply with relevant standards.

***Note***

*Attention is drawn to relevant National Standards.*

**6.2.3** Hawses, bollards, cleats and their substructure are to be strengthened, if they are intended to be belayed by multiple lines. In this case 80 % of the nominal breaking load of the individual lines has to be used as pulling forces.

# L. Masts and Rigging

## 1. General

**1.1** The requirements stated below generally apply to large motor and sailing yachts, under the condition that the yacht is handled correctly in terms of good seamanship.

**1.2** The principles presented are to be seen as a general guidance. Any detailed analysis which is leading to different reserve or reduction factors can be submitted on the basis of an equivalent safety.

**1.3** During the standard Classification procedure only the dimensions of the masts and the standing rigging will be checked and approved. For an extended examination of the complete rigging application for a "Rig Design Certificate" has to be made.

## 2. Bermudian Rigging

For Bermudian rigging the GL Rules Part 4 – Special Equipment, Chapter 5 – Guidelines for Design and Construction of Large Modern Yacht Rigs are applicable for yachts.

Scope of these guidelines is the structural dimensioning of standing rigging, mast and boom sections as well as local design in way of attached structural fittings.

**Table 2.22 Anchor, chain cables and ropes**

| Equipment numeral EN | 2 stockless bower anchors | Stud link chain cables | | | | Recommended ropes | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Bower anchors | | | | Towline | | Mooring ropes | | |
| | Mass per anchor | Total length | Diameter [1] d1 | d2 | d3 | Length | Break. Load [2] | Number | Length | Break. Load [2] |
| | [kg] | [m] | [mm] | [mm] | [mm] | [m] | [kN] | | [m] | [kN] |
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** |
| – 50 | 120 | 165 | 12,5 | 12,5 | 12,5 | 180 | 100 | 3 | 80 | 35 |
| 50 – 70 | 180 | 220 | 14 | 12,5 | 12,5 | 180 | 100 | 3 | 80 | 35 |
| 70 – 90 | 240 | 220 | 16 | 14 | 14 | 180 | 100 | 3 | 100 | 40 |
| 90 – 110 | 300 | 247,5 | 17,5 | 16 | 16 | 180 | 100 | 3 | 110 | 40 |
| 110 – 130 | 360 | 247,5 | 19 | 17,5 | 17,5 | 180 | 100 | 3 | 110 | 45 |
| 130 – 150 | 420 | 275 | 20,5 | 17,5 | 17,5 | 180 | 100 | 3 | 120 | 50 |
| 150 – 175 | 480 | 275 | 22 | 19 | 19 | 180 | 100 | 3 | 120 | 55 |
| 175 – 205 | 570 | 302,5 | 24 | 20,5 | 20,5 | 180 | 110 | 3 | 120 | 60 |
| 205 – 240 | 660 | 203,5 | 26 | 22 | 20,5 | 180 | 130 | 4 | 120 | 65 |
| 240 – 280 | 780 | 330 | 28 | 24 | 22 | 180 | 150 | 4 | 120 | 70 |
| 280 – 320 | 900 | 357,5 | 30 | 26 | 24 | 180 | 175 | 4 | 140 | 80 |
| 320 – 360 | 1020 | 357,5 | 32 | 28 | 24 | 180 | 200 | 4 | 140 | 85 |
| 360 – 400 | 1140 | 385 | 34 | 30 | 26 | 180 | 225 | 4 | 140 | 95 |
| 400 – 450 | 1290 | 385 | 36 | 32 | 28 | 180 | 250 | 4 | 140 | 100 |
| 450 – 500 | 1440 | 412,5 | 38 | 34 | 30 | 190 | 275 | 4 | 140 | 110 |
| 500 – 550 | 1590 | 412,5 | 40 | 34 | 30 | 190 | 305 | 4 | 160 | 120 |
| 550 – 600 | 1740 | 440 | 42 | 36 | 32 | 190 | 340 | 4 | 160 | 130 |
| 600 – 660 | 1920 | 440 | 44 | 38 | 34 | 190 | 370 | 4 | 160 | 145 |
| 660 – 720 | 2100 | 440 | 46 | 40 | 36 | 190 | 405 | 4 | 160 | 160 |
| 720 – 780 | 2280 | 467,5 | 48 | 42 | 36 | 190 | 440 | 4 | 170 | 170 |
| 780 – 840 | 2460 | 467,5 | 50 | 44 | 38 | 190 | 480 | 4 | 170 | 185 |
| 840 – 910 | 2640 | 467,5 | 52 | 46 | 40 | 190 | 520 | 4 | 170 | 200 |
| 910 – 980 | 2850 | 495 | 54 | 48 | 42 | 200 | 560 | 4 | 170 | 215 |
| 980 – 1060 | 3060 | 495 | 56 | 50 | 44 | 200 | 600 | 4 | 180 | 230 |
| 1060 – 1140 | 3300 | 495 | 58 | 50 | 46 | 200 | 645 | 4 | 180 | 250 |
| 1140 – 1220 | 3540 | 522,5 | 60 | 52 | 46 | 200 | 690 | 4 | 180 | 270 |
| 1220 – 1300 | 3780 | 522,5 | 64 | 54 | 48 | 200 | 740 | 4 | 180 | 285 |
| 1300 – 1390 | 4050 | 522,5 | 64 | 65 | 50 | 200 | 785 | 4 | 180 | 305 |
| 1390 – 1480 | 4320 | 550 | 66 | 58 | 50 | 220 | 835 | 4 | 180 | 325 |
| 1480 – 1570 | 4590 | 550 | 68 | 60 | 52 | 220 | 890 | 5 | 190 | 325 |
| 1570 – 1670 | 4890 | 550 | 70 | 62 | 54 | 220 | 940 | 5 | 190 | 335 |
| 1670 – 1790 | 5250 | 577,5 | 73 | 64 | 56 | 220 | 1025 | 5 | 190 | 350 |
| 1790 – 1930 | 5610 | 577,5 | 76 | 66 | 58 | 220 | 1110 | 5 | 190 | 375 |

[1] $d_1$ = Chain diameter Grade K1 (Ordinary quality)
$d_2$ = Chain diameter Grade K2 (Special quality)
$d_3$ = Chain diameter Grade K3 (Extra special quality)
See also 4.1

[2] See 6.1.2.

**Table 2.23 Equivalent diameters of synthetic wire and fibre ropes**

| Steel wire ropes [1] | Synthetic wire ropes | Fibre ropes | | |
|---|---|---|---|---|
| | Polyamide [2] | Polyamide | Polyester | Polypropylene |
| Diameter [mm] | Diameter [mm] | Diameter [mm] | Diameter [mm] | Diameter [mm] |
| 12 | 30 | 30 | 30 | 30 |
| 13 | 32 | 32 | 32 | 32 |
| 14 | 36 | 36 | 36 | 36 |
| 16 | 40 | 40 | 40 | 40 |
| 18 | 44 | 44 | 44 | 44 |
| 20 | 48 | 48 | 48 | 48 |
| 22 | 48 | 48 | 48 | 52 |
| 24 | 52 | 52 | 52 | 56 |
| 26 | 56 | 60 | 60 | 64 |

[1] according to DIN 3068 or similar

[2] Regular laid ropes of refined polyamide monofilements and filament fibres

## 3. Traditional rigging

GL has developed Rules for the following types of sailing ships, respectively yachts with traditional rigging:

– yachts with square rigs or fore and aft rigging

– two masted yachts, like brigs, schooner brigs, schooners

– three masted yachts, like barks, topsail schooners and full rigged yachts

– four and five masts yachts, like barks and full rigged yachts.

The details for the rigging of such type are contained in the GL Rules Part 4 – Special Equipment, Chapter 2 – Rigging Design, which can fully be applied to yachts.

## 4. Signal and radar masts

### 4.1 General

**4.1.1** Drawings of masts, mast substructures and hull connections are to be submitted for approval.

**4.1.2** Loose component parts are to comply with the GL Rules VI – Additional Rules and Guidelines, Part 2 – Life Saving Appliances – Lifting Appliances – Towing Gears – Accesses, Chapter 2 – Guidelines for the Construction and Survey of Lifting Appliances.

**4.1.3** Other masts than covered by 4.2 and 4.3 as well as special designs must, as regards dimensions and construction, in each case be individually agreed with GL.

### 4.2 Single tubular masts

The following requirements apply to tubular or equivalent rectangular sections made of steel with an ultimate tensile strength of 400 N/mm², which are designed to carry only signals (navigation lanterns, flag and day signals).

#### 4.2.1 Stayed masts

**4.2.1.1** Stayed masts may be constructed as simply supported masts (rocker masts) or may be supported by one or more decks (constrained masts).

**4.2.1.2** The diameter of stayed steel masts in the uppermost support is to be at least 18 mm for each 1m length of mast ($l_W$) from the uppermost support to the fixing point of shrouds. The length of the mast top above the fixing point is not to exceed 1/3 $l_W$.

**4.2.1.3** Masts according to 4.2.1.2 may be gradually tapered towards the fixing point of shrouds to 75 per cent of the diameter at the uppermost support. The plate thickness is not to less than 1/70 of the diameter at the uppermost support or at least 3,6 mm, see 4.4.1.

**4.2.1.4** Wire ropes for shrouds are to be thickly galvanized. It is recommended to use wire ropes composition of a minimum number of thick wires, as for instance a rope composition 6 × 7 with a tensile breaking strength of 1 570 N/mm² or more on which Table 2.24 is based. Other rope compositions shall be of equivalent stiffness.

**4.2.1.5** Where masts are stayed forward and aft by two shrouds on each side of the yacht, steel wire ropes are to be used according to Table 2.24.

**Table 2.24 Definition of ropes for stays**

| **h [m]** | **4** | **6** | **8** | **10** |
|---|---|---|---|---|
| Rope diameter [mm] | 12 | 14 | 16 | 18 |
| Nominal size of shackle, rigging screw, rope socket | 1,6 | 1,6 | 2 | 2,5 |
| h = height of shroud fixing point above shroud foot point | | | | |

**4.2.1.6** Where steel ropes according to Table 2.24 are used, the following conditions apply:

$$b \geq 0{,}3 \cdot h$$

$$0{,}15 \cdot h \leq a \leq b$$

a = the longitudinal distance from a shroud's foot point to its fixing point

b = the transverse distance from a shroud's foot point to its fixing point

Alternative arrangements of stayings are to be of equivalent stiffness.

### 4.2.2 Unstayed masts

**4.2.2.1** Unstayed masts may be completely constrained in the uppermost deck or to be supported by two or more decks. (In general the fastenings of masts to the hull of a yacht should extend over at least one deck height.

**4.2.2.2** The scantlings of unstayed steel masts are given in Table 2.25.

**Table 2.25 Scantlings of unstayed steel masts**

| **Length of mast $\ell_m$ [m]** | **4** | **6** | **8** | **10** |
|---|---|---|---|---|
| $D \cdot t$ [mm] | $127 \cdot 3{,}6$ | $168 \cdot 3{,}6$ | $216 \cdot 3{,}6$ | $267 \cdot 3{,}6$ |
| $\ell_m$ = length of mast from uppermost support to the top<br>D = diameter of mast at uppermost support<br>t = plate thickness of mast | | | | |

**4.2.2.3** The diameter of masts may be gradually tapered to D/2 at the height of 0,75 $\ell_m$.

### 4.3 Box girder and frame work masts

**4.3.1** For dimensioning the dead loads, acceleration forces and wind loads are to be considered.

**4.3.2** Where necessary, additional loads, e.g. loads caused by tension wires are also to be considered.

**4.3.3** The design loads for 4.3.1 and 4.3.2 as well as the allowable stresses can be taken from the GL Rules defined in 4.1.2.

**4.3.4** Single tubular masts mounted on the top of box girder or frame work masts may be dimensioned according to 4.2.

**4.3.5** In case of thin walled box girder masts stiffeners and additional buckling stiffeners may be necessary.

### 4.4 Structural details

**4.4.1** Steel masts closed all-round must have a wall thickness of at least 3,6 mm.

For masts not closed all-round the minimum wall thickness is 5 mm.

For masts used as funnels a corrosion addition of at least 1 mm is required.

**4.4.2** The mast’s foundations are to be dimensioned in accordance with the acting forces.

**4.4.3** Doubling plates at mast feet are permissible only for the transmission of compressive forces since they are generally not suitable for the transmission of tensile forces or bending moments.

**4.4.4** In case of tubular constructions, all welds for fastenings and connections must be of full penetration weld type.

**4.4.5** If necessary, slim tubular structures are to be additionally braced in order to avoid vibrations.

**4.4.6** The dimensioning normally does not require a calculation of vibrations. However, in case of undue vibrations occurring during the yacht's trials a respective calculation will be required.

**4.4.7** For determining scantlings of masts made from aluminium, the requirements of B.3. apply.

**4.4.8** At masts solid ladders have to be fixed at least up to 1,50 m below top, if they have to be climbed for operational or maintenance purposes. Above them, suitable handgrips are necessary.

**4.4.9** If possible from the construction point of view, ladders should be at least 0,30 m wide. The distance between the rungs must be 0,30 m. The horizontal distance of the rung centre from fixed parts must not be less than 0,15 m.

**4.4.10** Platforms on masts which have to be used for operational reasons, shall have a rail of at least 0,90 m height with one intermediate bar and a foot bar. Safe access from the mast ladders to the platform is to be provided.

**4.4.11** If needed, additional devices have to be installed at the mast's consisting of foot, back and hand rings enabling safe work in places of servicing and maintenance.