# SECTION 2 RUDDER STOCK AND RUDDER BLADE

## Symbols

V1 : Maximum ahead service speed, in knots, at maximum displacement in still water.

$V_{AV}$ :
- For all Yachts except high speed motor yachts as defined in Ch 5, Sec 1, [2.1.1], $V_{AV}$ is defined by the following formula:

$$V_{AV} = V_1 \quad \text{if} \quad V_1 \geq 10$$

$$V_{AV} = \frac{V_1 + 20}{3} \quad \text{if} \quad V_1 < 10$$

- For high speed motor yachts as defined in Ch 5, Sec 1, [2.1.5], $V_{AV}$ is defined by the following formula:

$$V_{AV} = \min\left[V_1, \frac{2}{3} \cdot (V_1 + 2\sqrt{L})\right]$$

$V_{AD}$ : Maximum astern speed, in knots, to be taken not less than 0,5 $V_{AV}$

A : Total area of the rudder blade, in $m^2$, bounded by the blade external contour, including the mainpiece and the part forward of the centreline of the rudder pintles, if any

k : Material factor, defined in [1.4.1]

$C_R$ : Rudder force, in N, acting on the rudder blade, defined in [2.1.2]

$M_{TR}$ : Rudder torque, in N.m, acting on the rudder blade, defined in [2.1.3] and [2.2.3]

$M_B$ : Bending moment, in N.m, in the rudder stock, to be calculated according to [3].

## 1 General

### 1.1 Application

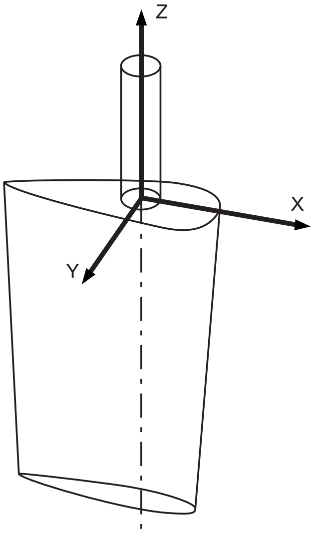
**1.1.1** Requirements of this Section apply to arrangement and the component of the rudder and also to their scantlings. It is assumed that requirements apply to yachts correctly used by a competent and qualified crew.

For this section, system of reference is considered as follow:

- X axis : longitudinal axis aligned with chord of the rudder profile as described on Fig 1
- Y axis : transversal axis perpendicular to XZ plan
- Z axis : vertical axis aligned with Z axis from reference co-ordinate system of the Yacht.

**1.1.2** Requirements of this section apply to ordinary profile rudders without any special arrangement for increasing the rudder force. Other type of rudder are to be considered by the Society on a case-by-case basis. Rudder forces are to be calculated by designer for the most severe combination between orientation angle and ship speed.

**Figure 1 :**




**1.1.3** Rudder system is to have a rotation limitation system made with mechanical or physical means for maximum angulation of the rudder.

As a rule, maximum orientation of the rudder is limited to 35°. Angles greater than 35° are accepted for manoeuvres or navigation with an appropriate reduced speed. When the maximum speed is limited to an angle smaller than 35° by physical or software devices, the Society may accept reductions of scantlings, on a case by case basis.

### 1.2 Arrangement

**1.2.1** Effective means are to be provided for supporting the weight of the rudder without excessive bearing pressure, e.g. by means of 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. In addition, structural rudder stops of suitable strength are to be provided, except where the steering gear is provided with its own rudder stopping devices, as detailed in Pt C, Ch 1, Sec 3, [3].

**1.2.3** In rudder trunks which are open to the sea, a seal or stuffing box is 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 the rudder trunk is below the deepest waterline two separate stuffing boxes are to be provided.

## 1.3 Documents to be submitted

**1.3.1** Following drawings and documents are to be submitted for examination by the Society:

- Rudder arrangement including location of rudder stock, bearings, pintles, rudder carrier, and steering gear (speed $V_{AV}$ and $V_{AR}$ to be specified)
- Rudder blade structure including details of pintles, bearings, stiffenings, connection to rudder stock
- Rudder horn if any
- For all component of the rudder system types of materials and their mechanical characteristics are to be specified.

## 1.4 Materials

### 1.4.1 Rudder made of steel

a) Rudder stocks, pintles, coupling bolts, keys and cast parts of rudders are to be made of rolled steel, steel forging or steel castings according to applicable requirements of the Rule Note NR216 Materials and Welding, Chapter 2

b) The material used for rudder stocks, pintles, keys and bolts is to have a minimum yield stress not less than 200 N/mm²

c) The requirements relevant to the determination of scantlings contained in this section apply to steels having yield stress equal to 235 N/mm². Scantlings calculated with the formulae contained in the requirements of this section are to be modified, as indicated, depending on the material factor k, to be obtain from the following formula:

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

where:

c : material factor taken equal to:
- 1 for steel elements except stainless steel
- 0,9 for aluminium alloy, stainless steel or other materials elements non affected by corrosion

$R_{eH}$ : Design yield stress, in N/mm², calculated as follow:

If $R_m > 1,4\ R_{p0,2}$ $R_{eH} = R_{p0,2}$

If $Rm < 1,4\ R_{p0,2}$ $R_{eH} = 0,417(R_{p0,2} + R_m)$

$Rp_{0,2}$ : Minimum guaranteed yield strength, in N/mm², of the steel used

$R_m$ : Minimum guaranteed ultimate tensile strength, in N/mm², of the steel used.

d) Significant reductions in rudder stock diameter due to the application of steels with yield stresses greater than 235 N/mm² may be accepted by the Society subject to the results of a check calculation of the rudder stock deformations. In this case rudder stock slope in way of bearing is subject to an additional check to make sure that those slopes are acceptable regarding lengths and bearing clearances as described respectively in [8.2.4]

e) Welded parts of rudders are to be made of approved rolled hull materials. For these members, the material factor k defined in Ch 4, Sec 3 is to be used.

### 1.4.2 Rudder made of aluminium

a) Materials for rudder socks, rudder plate, are to comply with requirements of the Rule Note NR216 Materials and Welding, Ch 3, Sec 2

b) The materials used for rudder stocks, pintles, keys and bolts is to have a minimum yield stress of not less than 200 N/mm². Selection of materials is to be carefully made to avoid any risk of galvanic corrosion

c) Requirements relevant to the determination of scantlings contained in this section apply to aluminium alloys described in Ch 4, Sec 3, Tab 3

d) The material factor k for aluminium alloys is to be obtain from the following formula:

$$k = \frac{100}{R'_{lim}}$$

where:

R'lim : Minimum of $R'_{p0,2}$ and $0,7R'_m$ as defined in Ch 4, Sec 3, [4.3.1].

In case of welding of two different aluminium alloys, the material factor k to be taken for the scantling is to be the greater material factor of the aluminium alloys of the assembly.

e) The loss of mechanical properties of some aluminium alloys (6000 series) induced by welding operation is to be taken into account for scantling.

### 1.4.3 Rudder made of composite

a) Materials for rudder stocks, rudder plates, are to comply with requirements of Part B, Chapter 12

b) Calculations for scantling of such type of rudder are to be made in accordance with Ch 4, Sec 3, [5].

# 2 Force and torque acting on the rudder

## 2.1 Rudder blade without cut-outs

### 2.1.1 Rudder blade description

A rudder blade without cut-outs may have trapezoidal or rectangular contour.

### 2.1.2 Rudder force

The rudder force $C_R$ is to be obtained, in N, from the following formula:

$$C_R = \frac{1}{2} \cdot \rho \cdot A \cdot V^2 \cdot c$$

where:

r : Specific gravity of sea water, taken equal to 1025 kg/m³

A : Area, in m², of the rudder blade as defined at beginning of the present Section

V : $V_{AV}$ or $V_{AD}$, depending on the condition under consideration

c : coefficient equal to:

$$c = 0,514^2 \cdot r_1 \cdot r_2 \cdot r_3$$

where:

$r_1$ : Shape factor, to be taken equal to:

$$r_1 = \frac{\lambda + 2}{3}$$

$\lambda$ : Coefficient, to be taken equal to:

$$\lambda = \frac{h^2}{A_T}$$

and not greater than 2

h : Mean height, in m, of the rudder area to be taken equal to (see Fig 2):

$$h = \frac{z_3 + z_4 - z_2}{2}$$

AT : Area, in m², to be calculated by adding the rudder blade area A to the area of the rudder post or rudder horn, if any, up to the height h

$r_2$ : Maximum lifting coefficient of rudder profile to be obtained from Tab 1 could be reduced according that rudder angles is limited by physical means to value less than 35°. Other value of r2 based on designer justification could be accepted on case by case basis

$r_3$ : Coefficient to be taken equal to:

- $r_3$ = 0,8 for rudders outside or far from the propeller jet (more than L/5)
- $r_3$ = 1,15 for rudders behind a fixed propeller nozzle
- $r_3$ = 1,0 inside propeller jet

#### 2.1.3 Rudder torque

The rudder torque $M_{TR}$, for both ahead and astern conditions, is to be obtained, in N.m, from the following formula:

$$M_{TR} = C_R \cdot r$$

where:

r : Lever of the force $C_R$, in m, equal to:

$$r = b\left(\alpha - \frac{A_F}{A}\right)$$

and to be taken not less than 0,1 b for the ahead condition

where:

b : Mean breadth, in m, of rudder area to be taken equal to (see Fig 2):

$$b = \frac{x_2 + x_3 - x_1}{2}$$

$\alpha$ : Coefficient to be taken equal to:

- $\alpha$ = 0,33 for ahead condition
- $\alpha$ = 0,66 for astern condition

For rudder parts located behind a fixed structure such as a rudder horn, $\alpha$ is to be taken equal to:

- $\alpha$ = 0,25 for ahead condition
- $\alpha$ = 0,55 for astern condition

Other values of $\alpha$ provided by designers may be taken. Those values are to be considered by Society on a case by case basis

$A_F$ : Area, in m², of the rudder blade portion afore the centreline of rudder stock (see Fig 2).

**Table 1 : Values of coefficient $r_2$ (given for an angle of attack of profile equal to 35°)**

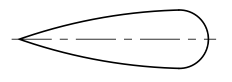
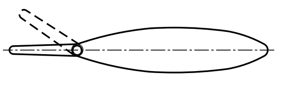
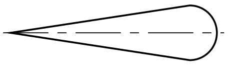
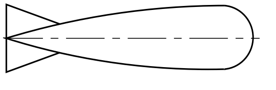
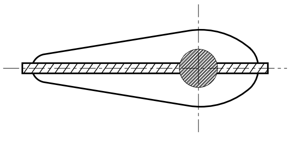
| Rudder profile type | $r_2$ for ahead condition | $r_2$ for astern condition |
|---|---|---|
| **NACA profile**  | 1,20 | 0,80 |
| **High lift**  | 1,7 | 1,3 |
| **Flat side**  | 1,10 | 0,90 |
| **Fish tail**  | 1,40 | 0,80 |
| **Single plate**  | 1,00 | 1,00 |

**Figure 2 : Geometry of rudder blade without cut-outs**

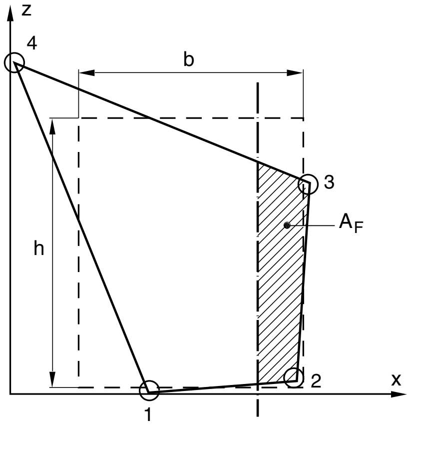
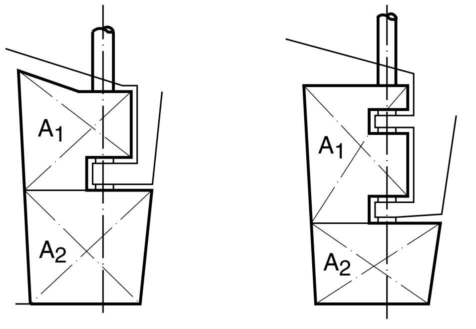


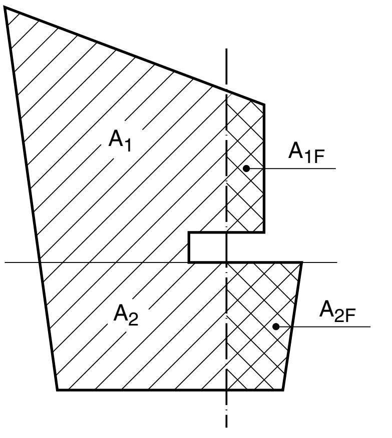
**Figure 3 : Rudder blades with cut-outs**




Trapezoidal rudder blade
Semi-spade rudder with
rudder horn - 2 bearings

Trapezoidal rudder blade
Semi-spade rudder with
rudder horn - 3 bearings

**Figure 4 : Geometry of rudder blade with cut-outs**




## 2.2 Rudder blade with cut-outs (semi-spade rudders)

### 2.2.1 Rudder blade description

A rudder blade with cut-outs may have trapezoidal or rectangular contour, as indicated in Fig 3.

### 2.2.2 Rudder force

The rudder force $C_R$ , in N, acting on the blade is to be calculated in accordance with [2.1.2].

### 2.2.3 Rudder torque

The rudder torque $M_{TR}$, in N.m, is to be calculated in accordance with the following procedure.

The rudder blade area A is to be divided into two rectangular or trapezoidal parts having areas $A_1$ and $A_2$, defined in Fig 3, so that:

$A = A_1 + A_2$

The rudder forces $C_{R1}$ and $C_{R2}$ , acting on each part $A_1$ and $A_2$ of the rudder blade, respectively, are to be obtained, in N, from the following formulae:

$$C_{R1} = C_R \frac{A_1}{A}$$

$$C_{R2} = C_R \frac{A_2}{A}$$

The levers $r_1$ and $r_2$ of the forces $C_{R1}$ and $C_{R2}$ , respectively, are to be obtained, in m, from the following formulae:

$$r_1 = b_1\left(\alpha - \frac{A_{1F}}{A_1}\right)$$

$$r_2 = b_2\left(\alpha - \frac{A_{2F}}{A_2}\right)$$

where:

$b_1$, $b_2$ : Mean breadths of the rudder blade parts having areas $A_1$ and $A_2$, respectively, to be determined according to [2.1.3]

$A_{1F}$, $A_{2F}$ : Areas, in $m^2$, of the rudder blade parts, defined in Fig 4

$\alpha$ : Coefficient to be taken equal to:

- $\alpha = 0{,}33$ for ahead condition
- $\alpha = 0{,}66$ for astern condition

For rudder parts located behind a fixed structure such as a rudder horn, $\alpha$ is to be taken equal to:

- $\alpha = 0{,}25$ for ahead condition
- $\alpha = 0{,}55$ for astern condition.

Other values of $\alpha$ provided by designers may be taken. Those values are to be considered by Society on case by case basis.

The torques $M_{TR1}$ and $M_{TR2}$ , relevant to the rudder blade parts $A_1$ and $A_2$ respectively, are to be obtained, in N.m, from the following formulae:

$M_{TR1} = C_{R1}\ r_1$

$M_{TR2} = C_{R2}\ r_2$

The total torque $M_{TR}$ acting on the rudder stock, for both ahead and astern conditions, is to be obtained, in N.m, from the following formula:

$M_{TR} = M_{TR1} + M_{TR2}$

For the ahead condition only, $M_{TR}$ is to be taken not less than the value obtained, in N.m, from the following formula:

$$M_{TR,MIN} = 0{,}1\,C_R \frac{A_1 b_1 + A_2 b_2}{A}$$

# 3 Rudder types, relevant loads, moments and forces acting on the rudder structure for direct calculations

## 3.1 General

### 3.1.1 Loads per rudder category - basic assumptions

Depending on the shape of the rudder blade and arrangement of the rudder, four types of rudders are considered. In case of different arrangement, special examination on case by case basis is to be carried out.

### 3.1.2 Loads, forces, and moments acting on the rudder

The force and torque acting on rudders as defined in [2], may induce the following loads in the rudder structure:

- bending moment and torque in the rudder stock
- support reactions at pintle and rudder stock bearings
- bending moment, shear force and torque in the rudder body
- bending moment, shear force and torque in rudder horns and solepieces.

These loads are calculated according to formulae given from [3.2] to [3.5] as appropriate. Alternatively loads calculation derived from direct beam analysis may be accepted, provided corresponding calculations are submitted for information.

## 3.2 Rudder type 1

### 3.2.1 Description

Type 1 rudders are considered as follow: 4 bearings including 3 pintle bearings and 1 rudder bearing as described in Fig 5.

### 3.2.2 Bending moment, shear forces and reactions

a) Bending moment

- in rudder stock:

$$M_B = 0$$

- in the rudder blade for streamlined rudder:

$$M_R = \frac{C_R \cdot L_{10}}{24}$$

where:

$M_R$ : Moment in the rudder blade, in N.m

$C_R$ : Lifting force, in N, as calculated in [2.1.2]

$L_{10}$ : Length, in m, as defined on Fig 5.

b) Reaction at supports

- at upper bearing:

$$R_{40} = 0$$

- at lower bearing:

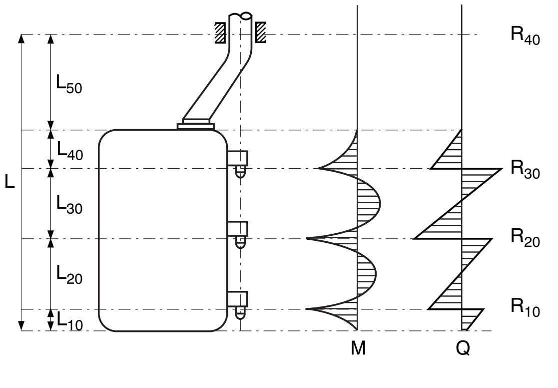
$$R_{10} = R_{20} = R_{30} = \frac{C_R}{3}$$

where:

$R_i$ : Reaction, in N, at supports as defined in Fig 5

$C_R$ : Lifting force, in N, as calculated in [2.1.2].

**Figure 5 : Rudder type 1**




## 3.3 Rudder type 5

### 3.3.1 Description

Type 5 rudders are considered as follow: 3 bearings including 1 pintle bearing and 2 rudder stock bearing as described in Fig 6.

Note 1: When the scantling of the solepiece is not sufficient to procure a fixed support in way of the pintle bearing, a direct calculation taking into account the solepiece rigidity is to be carried out to determine the bending moment and shear force in the rudder stock.

### 3.3.2 Bending moment, shear forces and reactions at supports

For this rule requirement, rudder structure is to be calculated according to the following approximate formula with assumption on lower pintle which is considered as a fixed support:

a) Bending moment

- at lower bearing:

$$M_{BLOSB} = \frac{p \cdot L_{10}^2}{8} \cdot \left(\frac{L_{10}}{L_{10} + L_{20}}\right)$$

where:

$M_{MBLOSB}$ : Bending moment, in N.m, in way of lower bearing

$L_{10}$, $L_{20}$ : Lengths, in m, as defined on Fig 6

p : Linear pressure, in N/m, acting on rudder blade defined as follow:

$$p = \frac{C_R}{A} \cdot b$$

where:

$C_R$ : Lifting force, in N, as calculated in [2.1.2]

A : Total area of rudder blade, in $m^2$

b : Mean breadth, in m of rudder blade as defined in [2.1.3].

- at upper bearing:

$$M_{BUpSB} = 0$$

- At pintle:

$$M_{BPib} = 0$$

**Figure 6 : Rudder type 5**

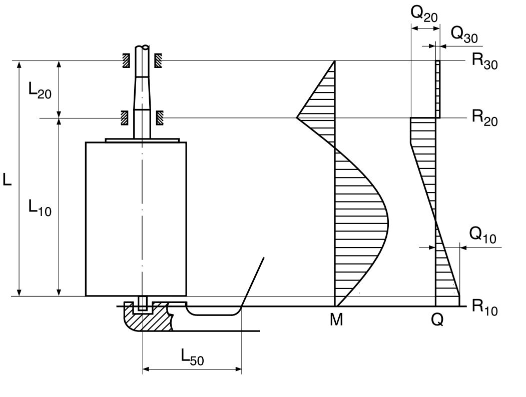
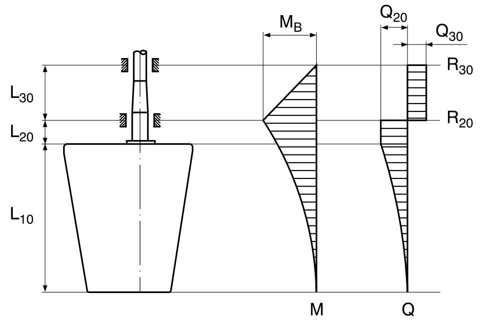


**Figure 7 : Rudder type 6**




b) Shear force in N

- at upper bearing

$$Q_{30} = \frac{M_{BLoSB}}{L_{20}}$$

- at lower bearing

$$Q_{20} = \frac{p \cdot L_{10}}{2} + \frac{M_{BLoSB}}{L_{10}}$$

- at pintle:

$$Q_{10} = \frac{p \cdot L_{10}}{2} - \frac{M_{BLoSB}}{L_{10}}$$

where:

Qi : Shear forces, in N, as described in Fig 6

$M_{BLOSB}$ : Bending moment, in N.m as defined in [3.3.2] a)

$L_{10}$, $L_{20}$ : Length, in m, as defined on Fig 6

p : Linear pressure in N/m as defined in [3.3.2] a).

c) Reaction at supports in N

- at upper bearing

$$R_{30} = Q_{30}$$

- at Lower bearing

$$R_{20} = Q_{20} + Q_{30}$$

- at neck

$$R_{10} = Q_{10}$$

where:

$R_{10}$, $R_{20}$, $R_{30}$ : Reaction at supports, in N

$Q_{10}$, $Q_{20}$, $Q_{30}$ : Shear forces, in N, as calculated in [3.3.2] b).

## 3.4 Rudder type 6

### 3.4.1 description

Type 6 rudders are considered as follow: 2 rudder stock bearings as described in Fig 7.

### 3.4.2 Bending moment, shear forces and reactions

a) Bending moment

- In rudder stock:

$$M_B = \frac{C_R \cdot (L_{10} + 2 \cdot L_{20})}{2}$$

where:

$M_B$ : Maximum bending moment, in N.m, in the rudder stock

$C_R$ : Lifting force, in N, applied on rudder blade

$L_{10}$ : Length, in m, as defined in Fig 7

$L_{20}$ : Length, in m, as defined in Fig 7.

b) Shear force

- In the rudder stock, at upper bearing

$$Q_{30} = \frac{M_B}{L_{30}}$$

- in the rudder stock, at lower bearing

$$Q_{20} = C_R$$

where:

$Q_i$ : Shear force, in N, acting on rudder stock as shown on Fig 7

$C_R$ : Lifting force, in N, applied on rudder blade

$M_B$ : Maximum bending moment, in N.m, in the rudder stocks calculated in [3.4.2] a)

$L_{30}$ : Length, in m, as defined in Fig 7.

c) Reaction at supports

- at upper bearing

$$R_{30} = \frac{M_B}{L_{30}}$$

- at Lower bearing

$$R_{20} = C_R + \frac{M_B}{L_{30}}$$

where:

$R_i$ : Reactions at supports, in N, as described on Fig 7

$C_R$ : Lifting force, in N, applied on rudder blade

$M_B$ : Maximum bending moment, in N.m, in the rudder stock as calculated in [3.4.2] a)

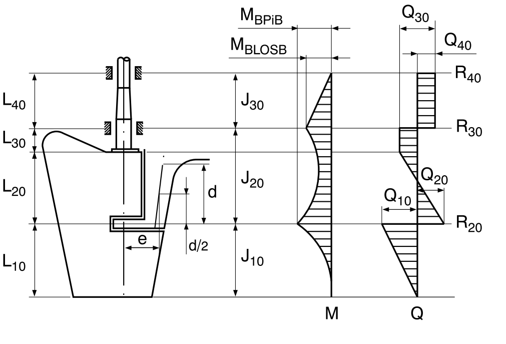
$L_{30}$ : Length, in m, as defined in Fig 7.

## 3.5 Rudder type 7

### 3.5.1 description

Type 7 rudders are considered as follow: 3 bearings semi-spade rudder, including 1 pintle bearing and 2 rudder stock bearings, as described in Fig 8.

**Figure 8 : Rudder type 7**



#### 3.5.2 Bending moment, shear forces and reactions at supports

a) Bending moment

- at lower stock bearing:

$$M_{BLoSB} = \frac{p_1 \cdot (L_{20}^{\ 2} - L_{30}^{\ 2}) \cdot \left[\frac{1}{2} + \frac{u}{8}\right] + p_2 \cdot L_{10}^{\ 2} \cdot \left[\frac{1}{2} + \frac{L_{20}}{L_{10}} - \frac{u}{4}\right]}{1 + u \cdot \left[1 + \frac{L_{40}}{L_{20}} \cdot \frac{J_{20}}{J_{40}} \cdot \frac{E_{20}}{E_{40}}\right]}$$

Where:

$L_{10}$, $L_{20}$,$L_{30}$, $L_{40}$ : Lengths, in m, as defined on Fig 8

$J_{10}$, $J_{20}$, $J_{30}$ : Moments of inertia about X axis, in cm[4] of the different parts constituting the rudder system having $L_{10}$, $L_{20}$ and $L_{30}$, $L_{40}$ respectively for lengths

$$p_1 = \frac{C_R \cdot \left(A_1 + \frac{A_2}{2}\right)}{A \cdot L_{20}}$$

$$p_2 = \frac{C_R \cdot \left(A_3 + \frac{A_2}{2}\right)}{A \cdot L_{10}}$$

$$u = \frac{L_{20}^{\ 3}}{3 \cdot J_{20} \cdot E_{20} \cdot d \cdot \left[\frac{e^2}{G_{50} \cdot K_{50}} + \frac{d^2}{3 \cdot J_{50} \cdot E_{50}}\right]}$$

where:

$C_R$ : Lifting force, in N, as calculated in [2.1.2]

$A_1$, $A_2$, $A_3$: Areas, in m², as defined in Fig 8

$G_{50}$, $E_{50}$ : Respectively shear and elastic modulus, in N/mm², of the rudder horn

$K_{50}$, $J_{50}$ : Respectively torsional (about z axis) and flexural (about x axis) inertia, in cm[4], of rudder horn

e : Torsion lever, in m, of rudder horn as defined in Fig 8

d : Flexural lever, in m, of rudder horn as defined in Fig 8

- at pintle bearing:

$$M_{BPiB} = \frac{p_2 \cdot L_{10}^{\ 2}}{2}$$

Where:

$M_{BPiB}$ : Bending moment, in N.m at pintle bearing

$C_R$ : Lifting force, in N, applied on rudder blade

$L_{10}$ : Length, in m as defined on Fig 8

b) Shear force

- At upper bearing:

$$Q_{40} = \frac{M_{BLoSB}}{L_{40}}$$

- At lower bearing:

$$Q_{30} = \frac{M_{BLoSB}}{(L_{20} + L_{30})} + \frac{p_1 \cdot (L_{20} + L_{30} - L_{40})^2}{2 \cdot (L_{20} + L_{30})} - \frac{M_{BPiB}}{L_{20}}$$

- at pintle bearing:

$$Q_{20} = C_R + Q_{40} - Q_{30} - (p_2 \cdot L_{10})$$

$$Q_{10} = p_2 \cdot L_{10}$$

where:

$Q_i$ : Shear forces, in N, as shown on Fig 8

$M_{BPiB}$ : Bending moment, in N.m, at pintle bearing as defined in [3.5.2] a)

$M_{BLoSB}$ : Bending moment, in N.m, in way of lower bearing as defined in [3.5.2] a)

$L_i$ : Distances, in m, between lower bearing and upper bearing as defined in Fig 8

$p_1$, $p_2$ : Value as defines in [3.5.2] a)

c) Reactions at supports:

- at upper bearing:

$$R_{40} = Q_{40}$$

- at lower bearing:

$$R_{30} = Q_{30} + Q_{40}$$

- at pintle bearing:

$$R_{20} = Q_{20} + Q_{10}$$

where:

$R_i$ : Reactions at supports in N.

## 4 Rudder stock scantlings

### 4.1 General

**4.1.1** Suitable tapering is to be carried out in case of significant change in the cross section of rudder stock, to avoid hard points. Abrupt changes in cross section of rudder stock may be accepted by Society on case by case basis.

**4.1.2** Tiller or quadrant is to be fitted as far as practicable, such in a way that they will not induce secondary moment or reaction in the rudder stock. If any, bending moment and torque, respectively MB and Mtr, are to be corrected for the calculation of rudder stock scantling.

**4.1.3** As a rule, for rudder stock made in composites, section is to be designed either as a ring or as hollow square.

In case of hollow square, angle of the square is to be rounded with a minimum radius of 5 mm.

### 4.2 Basic formulation

**4.2.1** The scantling of the rudder stock diameter is based on direct calculations regarding each corresponding stress induced by combined bending moment MB and torque Mtr acting on rudder stock.

They are given by the following formulae:

$\sigma_B$ : Bending stress, in N/mm², to be obtained from the following formula:

$$\sigma_B = \frac{M_B}{w_B}$$

$\tau_T$ : Torsional stress, in N/mm², to be obtained from the following formula:

$$\tau_T = \frac{M_{TR}}{w_{TR}}$$

where:

$W_B$ : Section modulus of rudder stock, in cm$^3$, to be obtained from the following formula:

$$w_B = \frac{I_{xx}}{v_y}$$

$W_{TR}$ : Section modulus of rudder stock, in cm$^3$, to be obtained from the following formula:

$$w_{TR} = \frac{I_{zz}}{v_z}$$

with:

$I_{XX}$ : Moment of inertia about x axis, in cm$^3$, of rudder stock corresponding to $M_B$

$I_{ZZ}$ : Torsional inertia about z axis, in cm3, of rudder stock corresponding to $M_{tr}$

$v_Y$ : Greatest distance taken along y axis between yy' neutral axis and the most external point of the section

$v_Z$ : Greatest distance, in cm, between zz' neutral axis and the most external point located of the section.

## 4.3 Combination of stresses

### 4.3.1 Metallic rudder stock

For the check of steel rudder stock, calculations are based on the Von Mises equivalent criterion, $\sigma_E$, in N/mm$^2$, calculated for this state of stress, is to be in compliance with the following formula:

For bending moment $M_B$ not equal to 0:

$\sigma_E \leq \sigma_{E,all}$

For null bending moment $M_B$:

$\tau_T \leq \tau_{all}$

with:

$$\sigma_E = \sqrt{\sigma_B{}^2 + 3\tau_T{}^2}$$

- For steel rudder stock:

$$\sigma_{E,all} = \frac{118}{k}$$

$$\tau_{all} = \frac{68}{k}$$

- For aluminium rudder stock

$$\sigma_{E,all} = \frac{56}{k}$$

$$\tau_{all} = \frac{32}{k}$$

The rudder stock diameter is to be not less than value the value obtained, in mm, from the following formula:

- For steel rudder stock

$$d_{TFi} = 4,2(M_{TR}k)^{1/3} \cdot \left[1 + \frac{4}{3}\left(\frac{M_{Bi}}{M_{TR}}\right)^2\right]^{1/6}$$

- For aluminium rudder stock

$$d_{TFi} = 5,4(M_{TR}k)^{1/3} \cdot \left[1 + \frac{4}{3}\left(\frac{M_{Bi}}{M_{TR}}\right)^2\right]^{1/6}$$

where $M_{Bi}$ is to be obtained according to [3].

Diameter of rudder stock subject to torque and bending may be gradually tapered above the lower stock bearing so as to reach, from $d_{TF}$ value in way of lower bearing part, the value $d_T$ (equal to $d_{TF}$ with null bending moment) in way of upper bearing.

If not otherwise specified, the notation $d_1$ used in this Section is equivalent to $d_{TF}$.

### 4.3.2 Composite rudder stock

For the scantling of composites rudder stocks, special consideration are to be taken: breaking criterion are to be taken from Ch 4, Sec 3, [5.3].

Calculations given in this part are given for the analysis of type 6 rudder with rudder stock made with an hollow square section. For other type of rudder than type 6 or if rudder stock is made with hollow circular section, examination will be based on case by case basis.

a) Loading of the side parts of rudder stock

As a rule, for the scantlings of sides of rudder stock, assumptions are made by considering the mechanical behaviour of the sides stock as a sandwich beam constituted by two skins and a thickness core with quasi-null mechanical properties.

Assumption is made on torque which neglected in the calculation of stress at lower bearing.

In way of lower bearing the loading is to be made with the two following formulae.

$$M_X = \frac{M_B}{L_X}$$

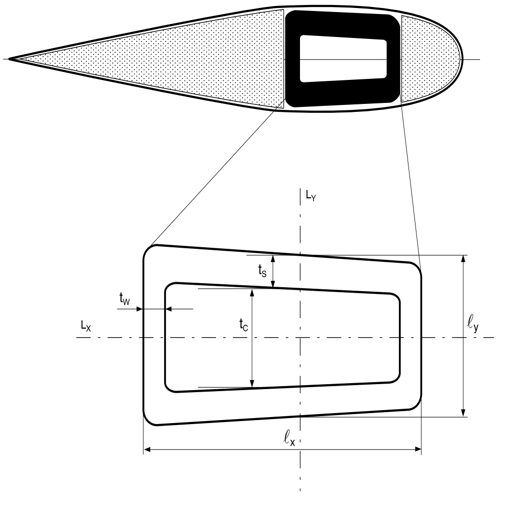
Where:

$M_X$ : Bending moment, in kN.m/m, for loading of side parts of stock in bending according to input of BV composites software specified in Ch 1, Sec 4, [2.2]

$M_B$ : Bending moment, in N.m, applied on rudder stock as defined in [3.4.2] for the corresponding type of rudder

$L_X$ : Distance, in mm, as described in Fig 9

**Figure 9 : Typical section of composite rudder stock**



b) Loading of web part of rudder stock

Web parts of the rudder stock are subject to the load due to the bending moment and bending torque. For the loading, each skin constituting of the web parts of rudder stock is to be considered separately.

Calculations of each web parts are to be made in way of the upper bearing and lower bearing.

1) Loading in way of lower bearing:

$$N_{XY} = \frac{Q_{20}}{2 \cdot L_Y}$$

where:

- $N_{XY}$ : In plain shear load, in kN/m applied in front web or aft web of rudder stock
- $Q_{20}$ : shear force in way of lower bearing, in N, as defined in [3.4.2]
- $L_Y$ : Dimension, in mm, of rudder stock section as shown on Fig 9.

2) Loading in way of upper bearing:

$$N_{XY} = \frac{Q_{30} + M_{TR}/L_Y}{2 \cdot L_Y}$$

where:

- $N_{XY}$ : In plain shear load, in kN/m applied on front web or aft web of rudder stock
- $M_{TR}$ : Rudder torque, in N.m, as defined in [2.1.3]
- $L_Y$ : Dimension, in mm, of rudder stock section as shown on Fig 9
- $Q_{30}$ : Shear force in way of upper bearing , in N, applied on rudder stock as defined in [3.4.2]

c) Check of rudder stock:

On each layer of rudder stock laminate, check is to be made with the breaking criterion defined in Ch 4, Sec 3, [5.3]:

For maximum stress criterion check, safety coefficients are to be not less than those calculated in the following formula:

$$\frac{\sigma_{br1}}{\sigma_1} \geq 1,1 \cdot SF \qquad \frac{\tau_{br12}}{\tau_{12}} \geq SF$$

$$\frac{\sigma_{br2}}{\sigma_2} \geq 1,1 \cdot SF \qquad \frac{\tau_{brIL}}{\tau_{13} \text{ or } \tau_{23}} \geq SF$$

with:

- $\sigma_1$ : Single layer or core longitudinal tensile or compression stresses, calculated according to Ch 12, Sec 4, [6.2.4] and Ch 12, Sec 4, [6.2.5]
- $\sigma_2$ : Single layer or core transversal tensile or compression stresses, calculated according to Ch 12, Sec 4, [6.2.4] and Ch 12, Sec 4, [6.2.5]
- $\tau_{12}$ : Single layer or core in plane shear stresses, calculated according to Ch 12, Sec 4, [6.2.4] and Ch 12, Sec 4, [6.2.5]
- $\tau_{13}$ and $\tau_{23}$ : Single layer interlaminar shear stresses (out of plane), calculated according to Ch 12, Sec 4, [4.3.2]
- $\sigma_{br1}$ : Single layer or core longitudinal breaking stress (in tensile or in compression modes) calculated with requirements of Ch 12, Sec 4, [5.2]
- $\sigma_{br2}$ : Single layer or core transversal breaking stress (in tensile or in compression modes) calculated with requirements of Ch 12, Sec 4, [5.2]
- $\tau_{br12}$ : Single layer or core in plane breaking shear stress calculated with requirements of Ch 12, Sec 4, [5.2]
- $\tau_{brIL}$ : Single layer interlaminar breaking shear stress calculated with requirements of Ch 12, Sec 4, [5.2]
- SF : Safety coefficient as defined in Ch 4, Sec 3, [5.4]

# 5 Rudder blade scantlings

## 5.1 General

### 5.1.1 Application

The requirements from [5.1] to [5.3] apply to streamlined rudders and, when applicable, to rudder blades of single plate rudders.

### 5.1.2 Rudder blade structure

The structure of the rudder blade is to be such that stresses are correctly transmitted to the rudder stock and pintles.

To this end, for metallic rudder blade, horizontal and vertical web plates are to be provided. Horizontal and vertical webs acting as main bending girders of the rudder blade are to be suitably reinforced.

For composite rudder blade, scantling of the skin constituting the rudder blade is to be sufficient to allow a good transmission of loads form rudder blade to stock. Cohesion between this two part is to be ensure either by gluing or laminating. Other system of connecting will be examined on case by case basis.

### 5.1.3 Dismounting

Dismounting system on every type of rudder is provided.

The corners of openings intended for the passage of the rudder horn heel and for the dismantling of pintle or stock nuts are to be rounded off with a radius as large as practicable.

On metallic rudder, where the access to the rudder stock nut is closed with a welded plate, a full penetration weld is to be provided.

### 5.1.4 Connection of the rudder blade to the trailing edge and nose for rudder blade area

- On metallic rudder, where the rudder blade area is greater than 6 $m^2$, the connection of the rudder blade plating to the trailing edge is to be made by means of a forged or cast steel fashion piece, a flat or a round bar.
- For composite rudder, where the rudder blade area is greater than 3 $m^2$, reinforcements made by laminate are provided (e.g. unidirectional tapes).

**Table 2 : Allowable stresses for steel rudder blade scantlings**

| Type of rudder blade | Allowable bending stress $\sigma_{ALL}$ in N/mm² | Allowable shear stress $\tau_{ALL}$ in N/mm² | Allowable equivalent stress $\sigma_{E,ALL}$ in N/mm² |
|---|---|---|---|
| Without cut-outs | 110 / k | 50 / k | 120 / k |
| With cut-outs (see Fig 3) | 75 / k | 50 / k | 100 / k |

## 5.2 Metallic rudder blade

### 5.2.1 Bending stresses

For the generic horizontal section of the rudder blade it is to be checked that the bending stress $\sigma$, in N/mm², induced by the loads defined in [3.1], is in compliance with the following formula:

$\sigma \leq \sigma_{ALL}$

where:

$\sigma_{ALL}$ : Allowable bending stress, in N/mm², specified in Tab 2 and Tab 3

### 5.2.2 Shear stresses

For the generic horizontal section of the rudder blade it is to be checked that the shear stress $\tau$, in N/mm², induced by the loads defined in [3.1], is in compliance with the following formula:

$\tau \leq \tau_{ALL}$

where:

$\tau_{ALL}$ : Allowable shear stress, in N/mm², specified in Tab 2 and Tab 3

### 5.2.3 Combined bending and shear stresses

For the generic horizontal section of the rudder blade it is to be checked that the equivalent stress, $\sigma_E$, is in compliance with the following formula:

$\sigma_E \leq \sigma_{E,ALL}$

where:

$\sigma_E$ : Equivalent stress induced by the loads defined in [3.1], to be obtained, in N/mm², from the following formula:

$$\sigma_E = \sqrt{\sigma^2 + 3\tau^2}$$

$\sigma$ : Bending stress, in N/mm²

$\tau$ : Shear stress, in N/mm²

$\sigma_{E,ALL}$ : Allowable equivalent stress, in N/mm², specified in Tab 2 and Tab 3.

### 5.2.4 Plating

As a rule, rule thickness of metallic plates sustaining lateral pressure is given, in mm, by the formula:

$$t = 22,4 \cdot coeff \cdot \mu \cdot s \cdot \sqrt{\frac{p}{\sigma_{am}}}$$

where:

coeff : Coefficient equal to:

- In case of uniformly distributed hydrodynamic loads, as defined here above:

  coeff = 1

$\mu$ : Aspect ratio coefficient of the elementary plate panel, equal to:

$$\sqrt{1,1 - \left(0,5 \cdot \frac{s^2}{\ell^2}\right)}$$

without being taken more than 1, where:

- $\ell$ : Longer side, in m, of the elementary plate panel
- s : Smaller side, in m, of the elementary plate panel

$\sigma_{am}$ : Rule admissible stress, in N/mm², defined in Ch 4, Sec 3, Tab 2 or Ch 4, Sec 3, Tab 4 respectively for steel and aluminium as hydrodynamic load for plating

p : Pressure, in kN/m², acting on rudder blade to be calculated with the following formula:

$$p = 9,807 \cdot \rho \cdot z + \frac{C_R}{A} \cdot 10^{-3}$$

z : Vertical distance, in m, from calculation point to the full load water line. Calculation point is to be taken at mid-height of the elementary panel

r : Specific gravity of sea water taken equal to 1025 kg/m3

$C_R$ : Lifting force applied on rudder blade as defined in [2.1.2]

A : Total area of the rudder blade, in m², as defined in [2.1.2].

The thickness of the top and bottom plates of the rudder blade is to be taken as the maximum of:

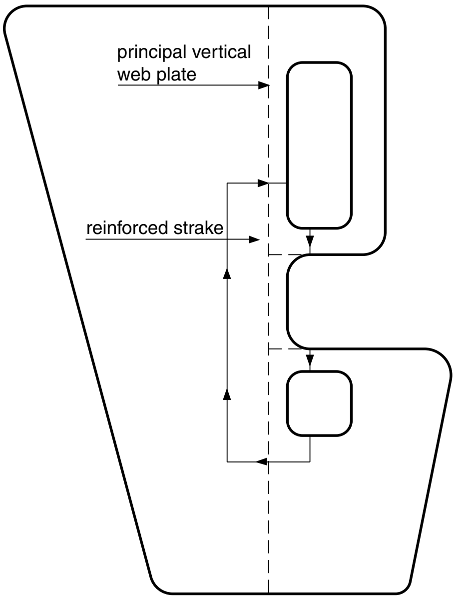
- the thickness $t_F$ defined in [5.2.4], by considering the relevant values of s and $\ell$, for both the top and bottom plates
- 1,2 times the thicknesses obtained for the attached side platings around the top and bottom plates, respectively, calculated according to [5.2.4], by considering the relevant values of s and $\ell$

Where the rudder is connected to the rudder stock with a coupling flange, the thickness of the top plate which is welded in extension of the rudder flange is to be not less than 1,1 times the thickness calculated above.

**Table 3 : Allowable stresses for aluminium rudder blade scantlings**

| Type of rudder blade | Allowable bending stress $\sigma_{ALL}$ in N/mm² | Allowable shear stress $\tau_{ALL}$ in N/mm² | Allowable equivalent stress $\sigma_{E,ALL}$ in N/mm² |
|---|---|---|---|
| Without cut-outs | 52 / k | 23/ k | 56 / k |
| With cut-outs (see Fig 3) | 35 / k | 23 / k | 47 / k |

**Figure 10 : Reinforced strake extension for semi-spade rudders**




### 5.2.5 Stiffeners

a) Arrangement of stiffeners

The spacing between horizontal web plates is to be not greater than 1,20m.

Vertical webs are to have a spacing not greater than twice that horizontal spacing.

b) Web thickness

Web thickness is to be at least 70% of that required for rudder plating except for the upper and lower horizontal webs, for which the requirements in [5.2.4] apply.

When the design of the rudder does not incorporate a mainpiece and the rudder stock is not continuous, this is to be replaced by two vertical webs closely spaced, having thickness not less than that obtained from Tab 4. In rudders having area less than 6 m$^2$, one vertical web only may be accepted provided its thickness is at least twice that of normal webs.

c) Thickness of side plating and vertical web plates welded to a solid part or to rudder flanges

The thickness, in mm, of the vertical web plates welded to the solid part where the rudder stock is housed, or welded to the rudder flange, as well as the thickness of the rudder side plating under this solid part, or under the rudder coupling flange, is to be not less than the value obtained, in mm, from Tab 4.

d) Reinforced strake of semi-spade rudders

A reinforced strake is to be provided in the lower pintle zone of semi-spade rudders. Its thickness is to be not less than 1,6 $t_F$, where $t_F$ is defined in [5.2.4]. This strake is to be extended forward of the main vertical web plate (see Fig 10).

e) Main vertical webs of semi spade rudders

The thickness of the main vertical web plate in the area between the rudder blade upper part and the pintle housing of semi-spade rudders is to be not less than 2,6 $t_F$, where $t_F$ is defined in [5.2.4].

Under the pintle housing the thickness of this web is to be not less than the value obtained from Tab 4.

Where two main vertical webs are fitted, the thicknesses of these webs are to be not less than the values obtained from Tab 4 depending on whether the web is fitted in a rudder blade area without opening or if the web is along the recess cut in the rudder for the passage of the rudder horn heel.

f) Welding:

The welded connections of blade plating to vertical and horizontal webs are to be in compliance with the applicable requirements of the Rule Note NR216 Materials and Welding.

Where the welds of the rudder blade are accessible only from outside of the rudder, slots on a flat bar welded to the webs are to be provided to support the weld root, to be cut on one side of the rudder only.

### 5.2.6 Connections of rudder blade structure with solid parts in forged or cast steel

a) General

Solid parts in forged or cast steel which ensure the housing of the rudder stock or of the pintle are in general to be connected to the rudder structure by means of two horizontal web plates and two vertical web plates.

b) minimum section modulus of the connection with rudder stock housing

The section modulus of the cross-section of the structure of the rudder blade which is connected with the solid part where the rudder stock is housed, which is made by vertical web plates and rudder plating, is to be not less than that obtained, in cm$^3$, from the following formula:

$$w_S = c_S d_1^3 \left(\frac{H_E - H_X}{H_E}\right)^2 \frac{k}{k_1} 10^{-4}$$

where:

- $c_S$ : Coefficient, to be taken equal to:
  - $c_S$ = 1,0 if there is no opening in the rudder plating
  - $c_S$ = 1,5 if there is an opening in the considered cross-section of the rudder
- $d_1$ : Rudder stock diameter, in mm, defined in [4.3.1]
- $H_E$ : Vertical distance, in m, between the lower edge of the rudder blade and the upper edge of the solid part
- $H_X$ : Vertical distance, in m, between the considered cross-section and the upper edge of the solid part
- $k$, $k_1$ : Material factors, defined in [1.4], for the rudder blade plating and the rudder stock, respectively.

c) calculation of the actual section modulus

The actual section modulus of the cross-section of the structure of the rudder blade which is connected with the solid part where the rudder stock is housed is to be calculated with respect to the symmetrical axis of the rudder.

The breadth of the rudder plating to be considered for the calculation of this actual section modulus is to be not greater than that obtained, in m, from the following formula:

$$b = s_V + 2\frac{H_X}{m}$$

where:

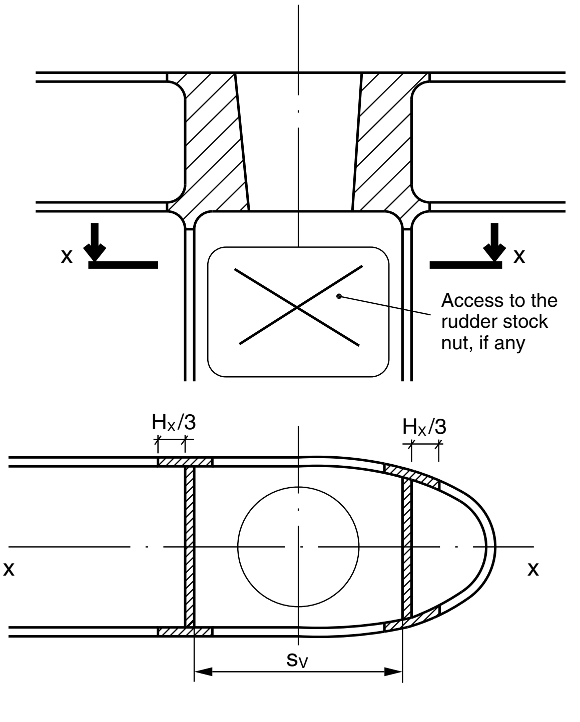
$s_V$ : Spacing, in m, between the two vertical webs (see Fig 11)

$H_X$ : Distance defined in [5.2.6] b)

m : Coefficient to be taken, in general, equal to 3.

Where openings for access to the rudder stock nut are not closed by a full penetration welded plate according to [5.1.3], they are to be deducted (see Fig 11).

**Figure 11 : Cross-section of the connection between rudder blade structure and rudder stock housing**




d) thickness of horizontal web plates

In the vicinity of the solid parts, the thickness of the horizontal web plates, as well as that of the rudder blade plating between these webs, is to be not less than the greater of the values obtained, in mm, from the following formulae:

$t_H = 1{,}2\ t_F$

$$t_H = 0{,}045\frac{d_S^2}{s_H}$$

where:

$t_F$ : Defined in [5.2.4]

$d_S$ : Diameter, in mm, to be taken equal to:

- $d_1$ for the solid part connected to the rudder stock
- $d_A$ for the solid part connected to the pintle

$d_1$ : Rudder stock diameter, in mm, defined in [4.3.1]

$d_A$ : Pintle diameter, in mm, defined in [8.4.1]

$s_H$ : Spacing, in mm, between the two horizontal web plates.

Different thickness may be accepted when justified on the basis of direct calculations submitted to the Society for approval.

e) Thickness of side plating and vertical web plates welded to solid part.

The thickness of the vertical web plates welded to the solid part where the rudder stock is housed as well as the thickness of the rudder side plating under this solid part is to be not less than the values obtained, in mm, from Tab 4.

f) Solid part protrusions

The solid parts are to be provided with protrusions. Vertical and horizontal web plates of the rudder are to be butt welded to these protrusions.

These protrusions are not required when the web plate thickness is less than:

- 10 mm for web plates welded to the solid part on which the lower pintle of a semi-spade rudder is housed and for vertical web plates welded to the solid part of the rudder stock coupling of spade rudders
- 20 mm for the other web plates.

**Table 4 : Thickness of the vertical webs and rudder side plating welded to solid part or to rudder flange**

| Type of rudder | Thickness of vertical web plates, in mm | | Thickness of rudder plating, in mm | |
|---|---|---|---|---|
| | Rudder blade without opening | At opening boundary | Rudder blade without opening | Area with opening |
| Hinged rudders on pintles type 1 rudder | $t_F$ | $1{,}3\ t_F$ | $t_F$ | $1{,}2\ t_F$ |
| Rudder without intermediate pintle type 5 rudder | $1{,}2\ t_F$ | $1{,}6\ t_F$ | $1{,}2\ t_F$ | $1{,}4\ t_F$ |
| Spade and semi spade type 6 and 7 rudders | $1{,}4\ t_F$ | $2{,}0\ t_F$ | $1{,}3\ t_F$ | $1{,}6\ t_F$ |
| $t_F$ : Defined in [5.2.4]. | | | | |

#### 5.2.7 Connection of the rudder blade with the rudder stock by means of horizontal flanges

a) Minimum section modulus of the connection

The section modulus of the cross-section of the structure of the rudder blade which is directly connected with the flange, which is made by vertical web plates and rudder blade plating, is to be not less than the value obtained, in cm³, from the following formula:

$w_S = 1,3\ d_1^3\ 10^{-4}$

where $d_1$ is the rudder stock diameter $d_{TF}$ , in mm, to be calculated in compliance with [4.3.1], taking k equal to 1.

b) Section modulus of the connection

The section modulus of the cross-section of the structure of the rudder blade which is directly connected with the flange is to be calculated with respect to the symmetrical axis of the rudder.

For the calculation of this actual section modulus, the length of the rudder cross-section equal to the length of the rudder flange is to be considered.

Where the rudder plating is provided with an opening under the rudder flange, the actual section modulus of the rudder blade is to be calculated in compliance with [5.2.6] c).

c) Welding of the rudder blade structure to the rudder blade flange

The welds between the rudder blade structure and the rudder blade flange are to be full penetrated (or of equivalent strength) and are to be 100% inspected by means of non-destructive tests.

Where the full penetration welds of the rudder blade are accessible only from outside of the rudder, a backing flat bar is to be provided to support the weld root.

The external fillet welds between the rudder blade plating and the rudder flange are to be of concave shape and their throat thickness is to be at least equal to 0,5 times the rudder blade thickness.

Moreover, the rudder flange is to be checked before welding by non-destructive inspection for lamination and inclusion detection in order to reduce the risk of lamellar tearing.

d) Thickness of side plating and vertical web plates welded to the rudder flange

The thickness of the vertical web plates directly welded to the rudder flange as well as the plating thickness of the rudder blade upper strake in the area of the connection with the rudder flange are to be not less than the values obtained, in mm, from Tab 4.

#### 5.2.8 Single plate rudders

a) Main piece diameter

The mainpiece diameter is to be obtained from the formulae in [4.3.1].

In any case, the mainpiece diameter is to be not less than the stock diameter.

For spade rudders the lower third may taper down to 0,75 times the stock diameter.

b) Blade thickness

The blade thickness is to be not less than the value obtained, in mm, from the following formula:

$$t_B = (1{,}5\, s V_{AV} + 2{,}5)\sqrt{k}$$

where:

s : Spacing of stiffening arms, in m, to be taken not greater than 1 m (see Fig 12).

c) Arms

The thickness of the arms is to be not less than the blade thickness.

The section modulus of the generic section is to be not less than the value obtained, in cm³, from the following formula:

$Z_A = 0,5\ s\ C_H^2\ V_{AV}^2\ k$

where:

$C_H$ : Horizontal distance, in m, from the aft edge of the rudder to the centreline of the rudder stock (see Fig 12)

s : Defined in item b).

### 5.3 Composite rudder blade

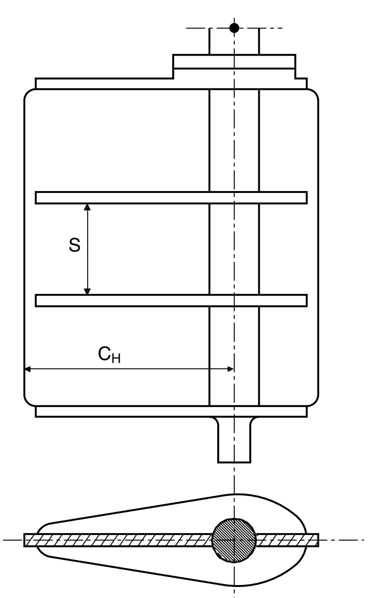
#### 5.3.1 General

As a rule rudders made of composite materials, are streamlined rudders. Skins constituting the rudder blade are made of single skin laminate separated by a core.

For the generic horizontal section of the rudder blade, check are to be made on:

- Skins constituting the rudder blade loaded under bending induced by the rudder torque. Check will be made with breaking criterion defined in Ch 4, Sec 3, [5.3]
- Core constituting the inner web of rudder blade loaded under shearing induced by lifting force.

**Figure 12 : Single plate rudder**



#### 5.3.2 Checking criteria

On each layer of rudder blade laminate, check is to be made with breaking criterion defined in Ch 4, Sec 3, [5.3]:

For maximum stress criterion check, safety coefficients are to be not less than those calculated in the following formula:

$$\frac{\sigma_{br1}}{\sigma_1} \geq 1{,}1SF \qquad \frac{\tau_{br12}}{\tau_{12}} \geq SF$$

$$\frac{\sigma_{br2}}{\sigma_2} \geq 1{,}1SF \qquad \frac{\tau_{brIL}}{\tau_{13} or \tau_{23}} \geq SF$$

with:

$\sigma_1$ : Single layer or core longitudinal tensile or compression stresses, calculated according to Ch 12, Sec 4, [6.2.4] and Ch 12, Sec 4, [6.2.5]

$\sigma_2$ : Single layer or core transversal tensile or compression stresses, calculated according to Ch 12, Sec 4, [6.2.4] and Ch 12, Sec 4, [6.2.5]

$\tau_{12}$ : Single layer or core in plane shear stresses, calculated according to Ch 12, Sec 4, [6.2.4] and Ch 12, Sec 4, [6.2.5]

$\tau_{13}$ and $\tau_{23}$ : Single layer interlaminar shear stresses (out of plane), calculated according to Ch 12, Sec 4, [4.3.2]

$\sigma_{br1}$ : Single layer or core longitudinal breaking stress (in tensile or in compressive modes) calculated with requierements of Ch 12, Sec 3, [5.2]

$\sigma_{br2}$ : Single layer or core transversal breaking stress (in tensile or in compression modes) calculated with requirements of Ch 12, Sec 3, [5.2]

$\tau_{br12}$ : Single layer or core in plane breaking shear stress calculated with requirements of Ch 12, Sec 3, [5.2]

$\tau_{brIL}$ : Single layer interlaminar breaking shear stress calculated with requirements of Ch 12, Sec 3, [5.2]

SF : Safety coefficient as defined in Ch 4, Sec 3, [5.4].

#### 5.3.3 Plating

As a rule, for each skin, laminates constituting the blade plating are to be check with the following formulae:

$$M_Y = \frac{M_{TR}}{L_{10}} \cdot 10^3$$

where:

$M_y$ : Moment, in kN.m/m, for the loading of plating with BV software

$M_{TR}$ : Rudder torque, in N.m, as defined in [2.1.3] [2.1.3]

$L_{10}$ : Dimension, in mm, of rudder stock section as shown on Fig 7.

## 6 Couplings between rudder stock and rudder blade

### 6.1 Coupling between metallic stock and blade

#### 6.1.1 General

As a rule, coupling between rudder stock and rudder blade is to be made by horizontal stiffening. Other system will be considered on case by case basis.

Coupling flange and rudder stock could be build up by forging, manufacturing or assembled by welding. the rudder stock are to be forged from a solid piece.

#### 6.1.2 Coupling with non continuous rudder stock

a) forged or manufactured pieces for coupling flange and rudder stock

The coupling flange is to have a thickness at least equal to one-quarter of the rule diameter of the stock lower part. A shoulder radius as large as practicable is to be provided for between the rudder stock and the coupling flange. This radius is to be not less than 0,15 $d_1$, where $d_1$ is defined in [4.3.1].

b) Welded coupling flanges

Where the rudder stock diameter does not exceed 350 mm, the coupling flange may be welded onto the stock, provided that its thickness is increased by 10% and that the weld extends through the full thickness of the coupling flange and that the assembly obtained is subjected to heat treatment. This heat treatment is not required if the diameter of the rudder stock is less than 75 mm.

Where the coupling flange is welded, the grade of the steel used is to be of weldable quality, with a carbon content not exceeding 0,23% on laddle analysis and a carbon equivalent CEQ not exceeding 0,41. The welding conditions (preparation before welding, choice of electrodes, pre- and post-heating, inspection after welding) are to be defined to the satisfaction of the Society. The throat weld at the top of the flange is to be concave shaped to give a fillet shoulder radius as large as practicable. This radius:

- is to be not less than 0,15$d_1$ , where $d_1$ is defined as in [4.3.1]
- may be obtained by grinding. If disk grinding is carried out, score marks are to be avoided in the direction of the weld
- is to be checked with a template for accuracy. Four profiles at least are to be checked. A report is to be submitted to the Surveyor.

The inspection is to include full non destructive tests at weld location (dye penetrant or magnetic particle test and ultrasonic test).

#### 6.1.3 Couplings by continuous rudder stock welded to the rudder blade

When the rudder stock extends through the upper plate of the rudder blade and is welded to it, the thickness of this plate in the vicinity of the rudder stock is to be not less than 0,20 $d_1$, where $d_1$ is defined in [4.3.1].

The welding of the upper plate of the rudder blade with the rudder stock is to be made with a full penetration weld and is to be subjected to non-destructive inspection through dye penetrant or magnetic particle test and ultrasonic test.

The throat weld at the top of the rudder upper plate is to be concave shaped to give a fillet shoulder radius as large as practicable. This radius:

- is to be not less than $0,15d_1$, where $d_1$ is defined in [4.3.1]
- may be obtained by grinding. If disk grinding is carried out, score marks are to be avoided in the direction of the weld
- is to be checked with a template for accuracy. Four profiles, at least, are to be checked. A report is to be submitted to the Surveyor.

#### 6.1.4 Connection between rudder blade and coupling flange

a) By bolts

Flange couplings are to be connected by fitted bolts having a diameter not less than the value obtained, in mm, from the following formula:

$$d_B = 0{,}62\sqrt{\frac{d_1^3 k_B}{n_B e_M k_S}}$$

where:

$d_1$ : Rudder stock diameter, in mm, defined in [4.3.1]

$k_S$ : Material factor k for the steel used for the rudder stock

$k_B$ : Material factor k for the steel used for the bolts

$e_M$ : Mean distance, in mm, of the bolt axes from the centre of the bolt system

$n_B$ : Total number of bolts, which is to be not less than: 6 if d>75mm and 4 if less than 75 mm

A suitable locking device on nuts is to be provided.

The distance from the bolt axes to the external edge of the coupling flange is to be not less than 1,2 $d_B$.

b) Other coupling system

Connection made by other system than described in [6.1.4] a) will be examined on case by case basis and are subject to direct calculation.

#### 6.1.5 Coupling flange

The thickness of the coupling flange is to be not less than the value obtained, in mm, from the following formula:

$$t_P = d_B\sqrt{\frac{k_F}{k_B}}$$

where:

$d_B$ : Bolt diameter, in mm, calculated in accordance with [6.1.4], where the number of bolts $n_B$ is to be taken not greater than 8

$k_F$ : Material factor k for the metallic material used for the flange

$k_B$ : Material factor k for the metallic material used for the bolts

In any case, the thickness $t_P$ is to be not less than 0,9 $d_B$.

### 6.2 Coupling between composite rudder stock and composite rudder blade

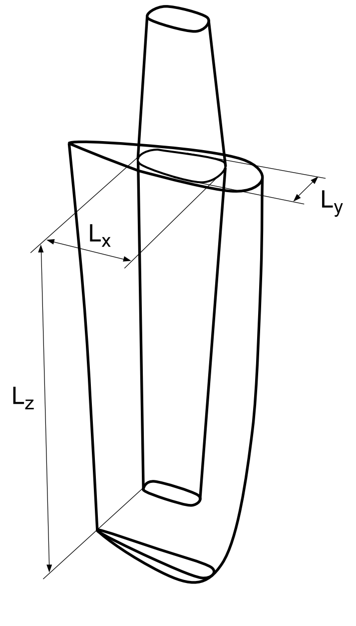
#### 6.2.1 General

As a rule, composite rudder stock are to have flat surfaces for the part integrated in the rudder blade as described in Fig 13. The rudder blade for such type of arrangement is constituted of skins made of composite and a core made of foam glued on flat surfaces of the rudder stock. Other systems of coupling is to be considerated by Society on case by case basis.

For coupling between composite rudder stock to composite rudder blade the following ratio are to be checked:

- ratio between Shear stress in the glue due to applied shear force and shear breaking stress of glue
- Ratio between shear stress in the web due to applied shear force and shear breaking stress of the web.

**Figure 13 : Coupling for composite rudder**




#### 6.2.2 Calculation of shear force

The shear Force acting on connection between rudder stock and rudder blade is to be calculated with the following formula:

$$T = \frac{M_{TR}}{L_Y}$$

with:

$M_{TR}$ : Torsional moment, in N.m as defined in [2.1.3]

$L_Y$ : Dimension, in mm, of rudder stock on Y axis.

#### 6.2.3 Shear stress

a) Shear stress in the gluing surface between rudder stock and rudder blade.

The surface considered for the calculations of the shear stress is the lateral projected area (in XZ plan) of the rudder stock. Shear stress in the glue is to be calculated as indicated in the following formula:

$$\tau_g = \frac{T}{S_g}$$

with:

$\tau_g$ : Shear stress in the glue in N/mm²

T : Shear force, in N, calculated as [6.2.2]

$S_g$ : Contact surface, in mm²

and Sg to be calculated as follow:

$S_g = L_Z\ L_X$

with:

- $L_Z$: Length, in mm, of rudder stock inserted in rudder blade
- $L_X$: Dimension, in mm, in x axis direction, of rudder stock to be taken at mid-length of $L_Z$

b) Shear stress in the rudder blade

Once shear force is transmitted through the gluing materials, the surface considered for the calculations of the shear stress is the frontal projected area (in YZ plan) of the rudder stock. Shear stress in the core is to be calculated as indicated in the following formula:

$$\tau_C = \frac{T}{S_C}$$

with:

$\tau_C$ : Shear stress in N/mm²

T : Shear force, in N, calculated as [6.2.2]

$S_C$ : Contact surface, in mm²

and $S_C$ to be calculated as follow:

$S_C = L_Z\ L_Y$

with:

- $L_Z$: Length, in mm, of rudder stock inserted in rudder blade
- $L_Y$: Dimension, in mm, in Y axis direction, of rudder stock to be taken at mid-length of $L_Z$.

### 6.2.4 Calculation of ratio

Ratio are to be calculated as follow and are to be not less than security factors:

$$\frac{\tau_{brg}}{\tau_g} \geq SF$$

$$\frac{\tau_{brC}}{\tau_C} \geq SF$$

with:

$\tau_g$ : Shear stress, in N/mm², in the gluing surface (XZ plan)

$\tau_{brg}$ : Shear breaking stress of the glue, in N/mm²

$\tau_C$ : Shear stress, in N/mm², in the core (YZ plan)

$\tau_{brc}$ : Shear breaking stress of the core, in N/mm²

Values of SF are listed in Ch 4, Sec 3, [5.4.1] shear stress in the core.

## 6.3 Coupling between metallic rudder stock and composite rudder blade

### 6.3.1 General

As a rule, for this type of system, arms are fitted on rudder stock and are perpendicular to the axis of rotation of rudder stock.

Connection between arms and rudder blade is to be sufficient to ensure a good transmission of rudder torque. In case where arms of rudder stock are not in contact with rudder blade, coupling material is to be checked. Special care must be taken for the fitting of arms on rudder stock if welded.

For aluminium rudder stock, mechanical properties for the check of rudder stock and arms are to be made with the properties of the metal as in welded condition (see Ch 4, Sec 3, Tab 3).

### 6.3.2 Check of couplings arms between rudder stock and rudder blade

Depending of the connection between rudder stock and arms check is to be made in accordance with the following requirements:

a) Bending check

As a rule for metallic arms fitted on metallic rudder stock, check is to be made on stress, obtained from the following formula:

$$\sigma_{am} \geq \frac{M_{TR}}{n} \times \frac{1}{w_z}$$

where:

$\sigma_{am}$ : Admissible stress, in N/mm², taken from Ch 4, Sec 3, Tab 2 and Ch 4, Sec 3, Tab 4 as a stiffeners local stress induced by local hydrodynamic loads

$M_{TR}$ : Rudder torque, in N.m, applied on rudder blade as defined in [2.1.3]

n : Number of arms connected to the rudder stock

$w_z$ : Minimum arms section modulus, in cm3, around z axis.

b) Shearing check

As a rule, the design shear area Ash, in cm², of metallic arms fitted on metallic rudder stock is given by the following formula:

$$\tau_{Am} \geq \frac{C_R}{n} \times \frac{1}{A_{sh}} \cdot 10^2$$

where:

$\tau_{Am}$ : Admissible stress, in N/mm², taken from Ch 4, Sec 3, Tab 2 and Ch 4, Sec 3, Tab 4 as a stiffeners local stress induced by local hydrodynamic loads

$A_{sh}$ : Minimum arms shear section in cm²

$C_R$ : Lifting force, in N, applied on rudder blade

n : Number of arms connected to the rudder stock.

# 7 Rudder trunks

## 7.1 Arrangement

**7.1.1** As a rule rudder trunks are to be fitted in a such way that lower end of rudder trunk is flush with hull plating.

**7.1.2** The steel grade used for the rudder trunk is to be of weldable quality, with a carbon content not exceeding 0,23% on laddle analysis and a carbon equivalent CEQ not exceeding 0,41.

**7.1.3 Connection between rudder trunk and shell plating**

As far as practicable, a shoulder radius is provided at the connection between rudder trunk and shell plating.

a) For steel and aluminium rudder trunks

The weld at the connection between the rudder trunk and the shell or the bottom of the skeg is to be full penetration.

The fillet shoulder radius r is to be as large as practicable and to comply with the following formulae:

r = 60 mm when

$\sigma \geq 40/ k$ N/mm² for steel, and

$\sigma \geq 19/ k$ N/mm² for aluminium

r = 0,1 $d_1$ when

$\sigma < 40 / k$ N/mm² for steel, and

$\sigma < 19/ k$ N/mm² for aluminium

without being less than 30 mm,

where $d_1$ is defined in [4.3.1].

The radius may be obtained by grinding. If disk grinding is carried out, score marks are to be avoided in the direction of the weld.

The radius is to be checked with a template for accuracy. Four profiles at least are to be checked. A report is to be submitted to the Surveyor.

b) For composite rudder trunks

Connection between rudder trunk and shell plating is to be made with a radius, made of compliant resin, which is to be as large as practicable.

**7.1.4** Before welding is started, a detailed welding procedure specification is to be submitted to the Society covering the weld preparation, welding positions, welding parameters, welding consumable, preheating, post weld heat treatment and inspection procedures. This welding procedure is to be supported by approval tests in accordance with the applicable requirements of the Rule Note NR216 Materials and Welding, Ch 5, Sec 4.

The manufacturer is to maintain records of welding, subsequent heat treatment and inspections traceable to the welds. These records are to be submitted to the Surveyor.

Non destructive tests are to be conducted at least 24 hours after completion of the welding. The welds are to be 100% magnetic particle tested and 100% ultrasonic tested. The welds are to be free from cracks, lack of fusion and incomplete penetration. The non destructive tests reports are to be handed over to the Surveyor.

**7.1.5** The thickness of the shell or of the bottom plate is to be compatible with the trunk thickness.

# 8 Rudder stock and pintle bearings

## 8.1 Forces on rudder stock and pintle bearings

**8.1.1** Support forces $R_i$ , for i = 1, 2, 3, on pintles are to be obtained according to [3.2.2], depending on the rudder type.

**8.1.2** Supporting structure in way of bearing is to be examined with loads as in defined in [3]. This examination will be based on direct calculation.

## 8.2 Rudder stock bearing

**8.2.1** The mean bearing pressure acting on the rudder stock bearing is to be in compliance with the following formula:

$p_F \leq p_{F,ALL}$

where:

$p_F$ : Mean bearing pressure acting on the rudder stock bearings, in N/mm², equal to:

$$p_F = \frac{R_i}{d_m h_m}$$

$R_i$ : Support force acting on the rudder stock bearing, in N

$d_m$ : Actual inner diameter, in mm, of the rudder stock bearings (contact diameter)

$h_m$ : Bearing length, in mm (see [8.2.3])

$p_{F,ALL}$ : Allowable bearing pressure, in N/mm², defined in Tab 5

Values greater than those given in Tab 5 may be accepted by the Society on the basis of specific tests.

**8.2.2** An adequate lubrication of the bearing surface is to be ensured.

**8.2.3** As a rule the length/diameter ratio of the bearing surface is not to be greater than 1,2. Other ratio could be accepted and will be considered on case by case basis.

**Table 5 : Allowable bearing pressure**

| Bearing material | $p_{F,ALL}$ , in N/mm² |
|---|---|
| Lignum vitae | 2,5 |
| White metal, oil lubricated | 4,5 |
| Synthetic material with hardness between 60 and 70 Shore D **(1)** | 5,5 |
| Steel, bronze and hot-pressed bronze-graphite materials **(2)** | 7,0 |

**(1)** Indentation hardness test at 23°C and with 50% moisture to be performed according to a recognised standard. Type of synthetic bearing materials is to be approved by the Society.
**(2)** Stainless and wear-resistant steel in combination with stock liner approved by the Society.

**8.2.4** The manufacturing clearance $t_0$ on the diameter of metallic supports is to be not less than the value obtained, in mm, from the following formula:

$$t_0 = \frac{d_m}{1000} + 1$$

In the case of non-metallic supports, the clearances are to be carefully evaluated on the basis of the thermal and distortion properties of the materials employed. In any case, for non metallic supports, the clearance on support diameter is to be not less than 1,5 mm.

### 8.3 Pintle bearings

**8.3.1** The mean bearing pressure acting on the gudgeons is to be in compliance with the following formula:

$p_F \leq p_{F,ALL}$

where:

$p_F$ : Mean bearing pressure acting on the gudgeons, in N/mm², equal to:

$$p_F = \frac{R_i}{d_{AC} h_L}$$

$R_i$ : Support force acting on the pintle, in N

$d_{AC}$ : Actual diameter, in mm, of the rudder pintles (contact diameter)

$h_L$ : Bearing length, in mm (see [8.3.3])

$p_{F,ALL}$ : Allowable bearing pressure, in N/mm², defined in Tab 5

Values greater than those given in Tab 5 may be accepted by the Society on the basis of specific tests.

**8.3.2** An adequate lubrication of the bearing surface is to be ensured.

**8.3.3** As a rule the length/diameter ratio of the bearing surface is to not be greater than 1,2 and to be not less than 1. Other ratio could be accepted and will be considered on case by case basis.

**8.3.4** The manufacturing clearance $t_0$ on the diameter of metallic supports is to be not less than the value obtained, in mm, from the following formula:

$$t_0 = \frac{d_{AC}}{1000} + 1$$

In the case of non-metallic supports, the clearances are to be carefully evaluated on the basis of the thermal and distortion properties of the materials employed. In any case, for non-metallic supports, the clearance on support diameter is to be not less than 1,5 mm.

### 8.4 Pintles

**8.4.1** Rudder pintles are to have a diameter not less than the value obtained, in mm, from the following formula:

$$d_A = \frac{0{,}38 V_{AV}}{V_{AV} + 3} \sqrt{R_i k} + f_C$$

where:

$R_i$ : Reaction, in N, induced by loading of rudder blade acting on the pintle, as specified in [3]

$f_C$ : Coefficient depending on corrosion, whose value may generally be obtained from the following formula:

$$f_C = 30\sqrt{k}$$

The Society may accept lower values of $f_C$, considering the ship's dimensions and satisfactory service experience of corrosion control systems adopted.

**8.4.2** Suitable tapering is provided on pintles.

**8.4.3** The length of the pintle housing in the gudgeon is to be not less than the value obtained, in mm, from the following formula:

$$h_L = 0{,}35\sqrt{R_i k}$$

where:

$R_i$ : Force, in N, acting on the pintle, as specified in [3]

The thickness of pintle housing in the gudgeon, in mm, is to be not less than 0,25 $d_A$, where $d_A$ is defined in [8.4.1].

## 9 Metallic rudder horn and solepiece scantlings

### 9.1 General

**9.1.1** The weight of the rudder is normally supported by a carrier bearing inside the rudder trunk.

In the case of unbalanced rudders having more than one pintle, the weight of the rudder may be supported by a suitable disc fitted in the solepiece gudgeon.

Robust and effective structural rudder stops are to be fitted, except where adequate positive stopping arrangements are provided in the steering gear compartment, in compliance with the applicable requirements of Pt C, Ch 1, Sec 3.

Structure in way of rudder horn or solepiece is to extend as far as possible inside the hull, and if possible, up to an horizontal stiffener.

Connecting radius between outer shell of the hull and rudder horn or solepiece is to be as large as possible.

### 9.2 Metallic Rudder horn

#### 9.2.1 General

When the connection between the rudder horn and the hull structure is designed as a curved transition into the hull plating, special consideration is to be paid to the effectiveness of the rudder horn plate in bending and to the stresses in the transverse web plates.

#### 9.2.2 Loads

The following loads acting on the generic section of the rudder horn are to be considered:

- bending moment
- shear force
- torque.

Bending moment, shear forces and torque are to be calculated according to [3], depending on the relevant type of rudder.

#### 9.2.3 Shear stress check for metallic rudder horn

For the generic section of the rudder horn it is to be checked that:

$\tau_S + \tau_T \leq \tau_{ALL}$

where:

$\tau_S$ , $\tau_T$ : Shear and torsional stresses, in N/mm², to be obtained according to [3]

$\tau_{ALL}$ : Allowable torsional shear stress, in N/mm²:

$\tau_{ALL}$ = 48/ k for steel

$\tau_{ALL}$ = 23/ k for aluminium.

#### 9.2.4 Combined stress strength check for metallic rudder horn

For the generic section of the rudder horn, it is to be checked that:

$\sigma_E \leq \sigma_{E,ALL}$

$\sigma_B \leq \sigma_{B,ALL}$

where:

$\sigma_E$ : Equivalent stress to be obtained, in N/mm², from the following formula:

$$\sigma_E = \sqrt{\sigma_B^2 + 3(\tau_S^2 + \tau_T^2)}$$

$\sigma_B$ : Bending stress, in N/mm², to be obtained from [3], depending on the rudder type

$\tau_S$ , $\tau_T$ : Shear and torsional stresses, in N/mm², to be obtained according to [3]

$\sigma_{E,ALL}$ : Allowable equivalent stress, in N/mm², equal to:

$\sigma_{E,ALL}$ = 115 / k for steel

$\sigma_{E,ALL}$ = 55 / k for aluminium

$\sigma_{B,ALL}$ : Allowable bending stress, in N/mm², equal to:

$\sigma_{B,ALL}$ = 80 / k for steel

$\sigma_{B,ALL}$ = 38 / k for aluminium

#### 9.2.5 Rudder horn calculation for type 7 rudder

a) Bending moment

The bending moment acting on the generic section of the rudder horn is to be obtained, in N.m, from the following formula:

$M_H = R_{20}\, z$

where:

$R_{20}$ : Support force at the rudder horn lower-pintle, in N, according to [3.5.2] c)

z : Distance, in m, defined in Fig 14, to be taken less than the distance d.

b) Shear force

The shear force $Q_H$ acting on the generic section of the rudder horn is to be obtained, in N, according to the following formula:

$Q_H = R_{20}$

where:

$R_{20}$ : Support force at the rudder horn lower-pintle, in N, according to [3.5.2] c)

c) Torque

The torque acting on the generic section of the rudder horn is to be obtained, in N.m, from the following formula:

$M_T = R_{20}\, e_{(z)}$

where:

$R_{20}$ : Support force at the rudder horn lower-pintle, in N, to be obtained according [3.5.2] c)

$e_{(z)}$ : Torsion lever, in m, defined in Fig 14

d) Stress calculations for metallic rudder horn

For the generic section of the rudder horn within the length d, defined in Fig 14, the following stresses are to be calculated:

$\sigma_B$ : Bending stress to be obtained, in N/mm², from the following formula:

$$\sigma_B = \frac{M_H}{W_X}$$

$M_H$ : Bending moment at the section considered, in N.m, defined in [9.2.5] a)

$W_X$ : Section modulus, in cm³, around the horizontal axis X (see Fig 14)

$\tau_S$ : Shear stress to be obtained, in N/mm², from the following formula:

$$\tau_S = \frac{R_{20}}{A_H}$$

$R_{20}$ : Support force at the rudder horn lower-pintle, in N, to be obtained according [3.5.2] c)

$A_H$ : Effective shear sectional area of the rudder horn, in mm², in y-direction

$\tau_T$ : Torsional stress to be obtained for hollow rudder horn, in N/mm², from the following formula:

$$\tau_T = \frac{M_{TR}\, 10^3}{2\, F_T\, t_H}$$

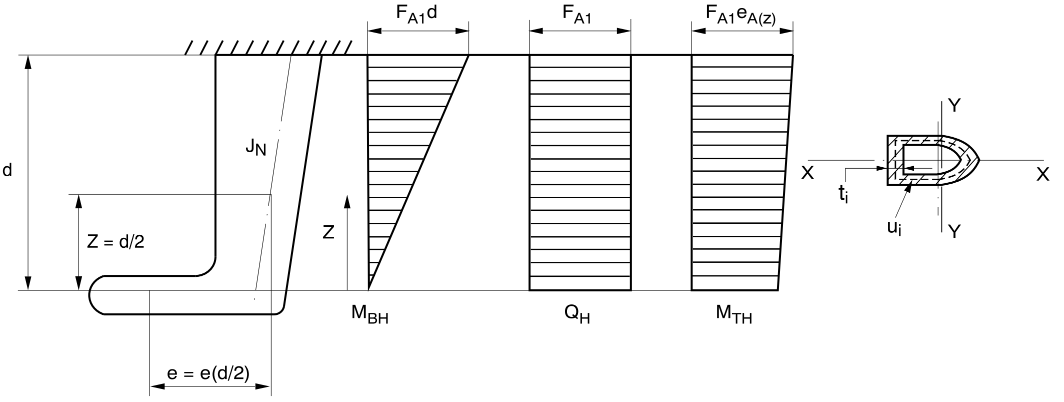
For solid rudder horn, $\tau_T$ is to be considered by the Society on a case-by-case basis.

$M_{TR}$ : Torque, in N.m, defined in [2.1.3] and [2.2.3]

$F_T$ : Mean of areas enclosed by outer and inner boundaries of the thin walled section of rudder horn, in m²

$t_H$ : Plate thickness of rudder horn, in mm. For a given cross section of the rudder horn, the maximum value of $\tau_T$, is obtained at the minimum value of $t_H$ .

**Figure 14 : Rudder horn geometry**




## 9.3 Metallic Solepieces

### 9.3.1 Strength checks

For the generic section of the solepiece, it is to be checked that:

$\sigma_E \leq \sigma_{E,ALL}$

$\sigma_B \leq \sigma_{B,ALL}$

$\tau \leq \tau_{ALL}$

where:

$\sigma_E$ : Equivalent stress, in N/mm², to be obtained from the following formula:

$$\sigma_E = \sqrt{\sigma_B^2 + 3\tau^2}$$

$\sigma_B$ : Bending stress, in N/mm², to be obtained according to [4.2.1]

$\tau$ : Shear stress, in N/mm², to be obtained according to [9.3.3] b)

$\sigma_{E,ALL}$ : Allowable equivalent stress, in N/mm², equal to:

$\sigma_{E,ALL}$ = 115 / k for steel solepiece

$\sigma_{E,ALL}$ = 55 / k for aluminium solepiece

$\sigma_{B,ALL}$ : Allowable bending stress, in N/mm², equal to:

$\sigma_{B,ALL}$ = 80 / k for steel

$\sigma_{B,ALL}$ = 38 / k for aluminium

$\tau_{ALL}$ : Allowable torsional shear stress, in N/mm²:

$\tau_{ALL}$ = 48 / k for steel component

$\tau_{ALL}$ = 23 / k for aluminium.

### 9.3.2 Minimum section modulus around the horizontal axis

The section modulus around the horizontal axis Y (see Fig 15) is to be not less than the value obtained, in cm³, from the following formula:

$W_Y = 0,5\ W_Z$

where:

$W_Z$ : Section modulus, in cm³, around the vertical axis Z (see Fig 15)

### 9.3.3 Calculation of the solepiece for type 5 rudder

a) Bending moment

The bending moment acting on the generic section of the solepiece is to be obtained, in N.m, from the following formula:

$M_S = R_{10}\ x$

$R_{10}$ : Supporting force, in N, in the pintle bearing, to be determined according to [3.2.2] c)

where:

x : Distance, in m, defined in Fig 15.

b) Stress calculations for metallic solepiece

For the generic section of the solepiece within the length $\ell_{50}$, defined in Fig 15, the following stresses are to be calculated:

sb : Bending stress to be obtained, in N/mm², from the following formula:

$$\sigma_B = \frac{M_S}{W_Z}$$

$\tau$ : Shear stress to be obtained, in N/mm², from the following formula:

$$\tau = \frac{R_{10}}{A_S}$$

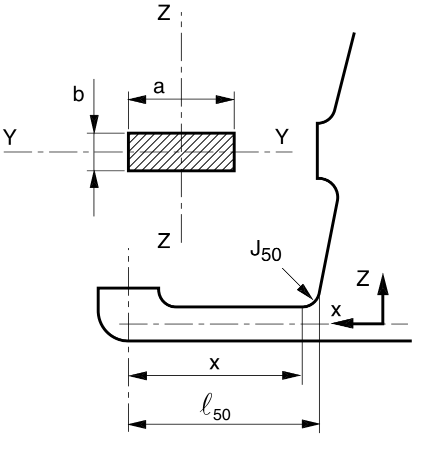
$M_S$ : Bending moment, in N.m, at the section considered, as defined in [9.3.3] a)

$R_{10}$ : Supporting force, in N, in the pintle bearing, to be determined according to [3.3.2] c)

$W_Z$ : Section modulus, in cm³, around the vertical axis Z (see Fig 15)

$A_S$ : Shear sectional area, in mm², in a plane perpendicular to the X axis of the solepiece.

**Figure 15 : Solepiece geometry**



### 9.4 Rudder horn and solepiece made of composites

#### 9.4.1 General

For rudder horn and solepiece made in composite, direct calculation will be carried out.

#### 9.4.2 Rudder horn

a) For rudder horn made of composites, calculations will be made with the following loads:
   - Bending moment MH as defined in [9.2.5] a)
   - Shear force QH as defined in [9.2.5] b)
   - Torque MT as defined in [9.2.5] c)

b) Analysis

   Analysis will be carried out on the following basis:
   - rudder horn behaviour is considered as a cantilever beam fitted on the hull
   - Section of the beam considered is the generic section as defined in Fig 14

     Analysis of the surrounding structure (e.g. hull structure) is, also, to be carried out

c) Check

   Calculation is to be made with formulae written in Ch 12, Sec 4, [6]. Check of the results is to be made with Ch 4, Sec 3, [5.3] for breaking criterion and Ch 4, Sec 3, [5.4] for safety coefficients.

#### 9.4.3 Rudder solepiece

a) Loads

   For solepiece made of composite, calculation will be made with the following load:
   - Bending moment $M_S$ as defined [9.3.3] a)
   - Shear force $Q_S$ equal to $R_{10}$

b) Analysis

   Analysis will be carried out on the following basis:
   - Solepiece behaviour is considered as a cantilever beam
   - Section of the beam considered is the generic section within the length $L_{50}$

     Analysis of the surrounding structure (e.g. hull structure) is, also, to be carried out

c) Check

   Calculation is to be made with formulae written in Ch 12, Sec 4, [6]. Check of the results is to be made with Ch 4, Sec 3, [5.3] for breaking criterion and Ch 4, Sec 3, [5.4] for safety coefficients.

## 10 Coupling between rudder stock and tillers or quadrants

### 10.1 Arrangement

#### 10.1.1 general

Coupling of rudder stock and tillers could be made by key or by flat areas on rudder stock in way of tiller or quadrants.

The tillers or quadrants are to be efficiently tightened on the rudder stock by means such as:

- Bolting (split or two half tillers)
- Tapered connecting on steel rudder stock
- Cylindrical connecting with shrink fit on steel rudder stock.

The requirements of this sub-article apply in addition to those specified in Pt C, Ch 1, Sec 3, [2].

### 10.2 Cone coupling on steel rudder stock

#### 10.2.1 General

The entrance edge of the tiller bore and that of the rudder stock cone are to be rounded or bevelled.

The right fit of the tapered bearing is to be checked before final fit up, to ascertain that the actual bearing is evenly distributed and at least equal to 80% of the theoretical bearing area; push-up length is measured from the relative positioning of the two parts corresponding to this case.

The required push-up length is to be checked after releasing of hydraulic pressures applied in the hydraulic nut and in the assembly.

#### 10.2.2 Materials

The requirements specified in [10.2.3] and [10.2.4] apply to solid rudder stocks in steel and to tiller bosses, either in steel or in SG iron, with constant external diameter. Solid rudder stocks others than those above will be considered by the Society on a case-by-case basis, provided that the relevant calculations, to be based on the following criteria, are submitted to the Society:

System made with materials other than those described in this requirement, will be examined on case by case basis

- Young's modulus:
  - $E = 2,06.10^5$ N/mm$^2$ for steel
  - $E = 1,67.10^5$ N/mm$^2$ for SG iron
- Poisson's ratio:
  - $\nu = 0,30$ for steel
  - $\nu = 0,28$ for SG iron
- Frictional coefficient:
  - $\mu = 0,15$ for contact steel/steel
  - $\mu = 0,13$ for contact steel/SG iron
- Torque $C_T$ transmissible through friction:

  $C_T \geq \eta\ M_{TR}$

  where $\eta$ is defined in [10.2.3]
- Combined stress in the boss:

  $(\sigma_R^2 + \sigma_T^2 + \sigma_R\ \sigma_T) \leq (0,5 + 0,2\ \eta)\ R_{eH}$

  where $\sigma_R$ and $\sigma_T$ are, in N/mm$^2$, the radial compression stress and tangent tensile stress, respectively, induced by the grip pressure, considered as positive, and calculated at the bore surface ($\sigma_R = p_F$, where $p_F$ is the grip pressure in the considered horizontal cross-section of the boss)
- Where the rudder stock is hollow, the following strength criterion is to be complied with at any point of the rudder stock cross-section:

  $(\sigma_R^2 + \sigma_T^2 - \sigma_R\ \sigma_T + 3\ \tau^2) \leq 0,7\ R_{eH}$

  where:

$\sigma_R$, $\sigma_T$ : Radial and tangent compression stresses, respectively, in N/mm², induced by the grip pressure, considered as positive

$\tau$ : Shear stress, in N/mm², induced by the torque $M_{TR}$

#### 10.2.3 Push-up length of cone couplings with hydraulic arrangements for assembling and disassembling the coupling

It is to be checked that the push-up length $\Delta_E$, in mm, of the rudder stock tapered part into the tiller boss is in compliance with the following formula:

$\Delta_0 \le \Delta_E \le \Delta_1$

where:

$$\Delta_0 = 6{,}2\frac{M_{TR}\eta\gamma}{c d_M t_S \mu_A \beta}10^{-3}$$

$$\Delta_1 = \frac{2\eta + 5}{1{,}8}\frac{\gamma d_0 R_{eH}}{c}10^{-6}$$

$\eta$ : Coefficient to be taken equal to:
- $\eta = 1$ for keyed connections
- $\eta = 2$ for keyless connections

c : Taper of conical coupling measured on diameter, to be obtained from the following formula:

$c = (d_U - d_0) / t_S$

$t_S$, $d_U$, $d_0$ : Geometrical parameters of the coupling, defined in Fig 16

$\beta$ : Coefficient to be taken equal to:

$$\beta = 1 - \left(\frac{d_M}{d_E}\right)^2$$

$d_M$ : Mean diameter, in mm, of the conical bore, to be obtained from the following formula:

$d_M = d_U - 0{,}5\ c\ t_S$

$d_E$ : External boss diameter, in mm

$\mu_A$ : Coefficient to be taken equal to:

$$\mu_A = \sqrt{\mu^2 - 0{,}25c^2}$$

$\mu$, $\gamma$ : Coefficients to be taken equal to:
- for rudder stocks and bosses made of steel:

  $\mu = 0{,}15$

  $\gamma = 1$
- for rudder stocks made of steel and bosses made of SG iron:

  $\mu = 0{,}13$

  $\gamma = 1{,}24 - 0{,}1\ \beta$

$R_{eH}$ : Defined in [1.4].

#### 10.2.4 Boss of cone couplings with hydraulic arrangements for assembling and disassembling the coupling

The scantlings of the boss are to comply with the following formula:

$$\frac{1{,}8}{2\eta + 5}\cdot\frac{\Delta_E c}{\gamma d_0}10^6 \le R_{eH}$$

where:

$\Delta_E$ : Push-up length adopted, in mm

c, $\eta$, $\gamma$ : Defined in [10.2.3]

$d_0$ : Defined in Fig 16

$R_{eH}$ : Defined in [1.4.1]

#### 10.2.5 Cylindrical couplings by shrink fit

It is to be checked that the diametral shrinkage allowance $\delta_E$, in mm, is in compliance with the following formula:

$\delta_0 \le \delta_E \le \delta_1$

where:

$$\delta_0 = 6{,}2\frac{M_{TR}\eta\gamma}{d_U t_S \mu \beta_1}10^{-3}$$

$$\delta_1 = \frac{2\eta + 5}{1{,}8}\gamma d_U R_{eH}10^{-6}$$

$\eta$, $\mu$, $\gamma$, c : Defined in [10.2.3]

$d_U$ : Defined in Fig 16

$\beta_1$ : Coefficient to be taken equal to:

$$\beta_1 = 1 - \left(\frac{d_U}{d_E}\right)^2$$

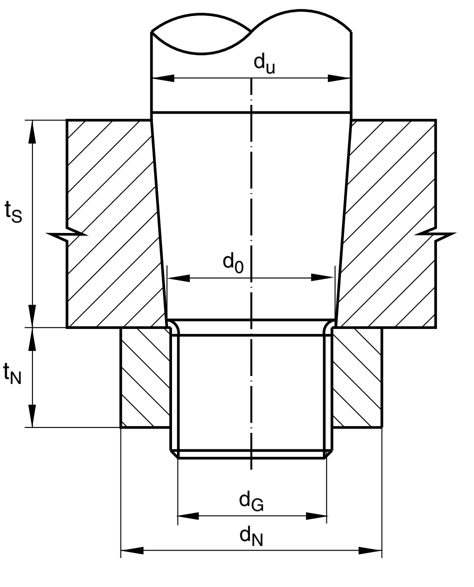
$R_{eH}$ : Defined in [1.4.1].

#### 10.2.6 Keyless couplings through special devices

The use of special devices for frictional connections, such as expansible rings, may be accepted by the Society on a case-by-case basis provided that the following conditions are complied with:

- evidence that the device is efficient (theoretical calculations and results of experimental tests, references of behaviour during service, etc.) are to be submitted to the Society
- the torque transmissible by friction is to be not less than 2 $M_{TR}$
- design conditions and strength criteria are to comply with [10.2.2]
- instructions provided by the manufacturer are to be complied with, notably concerning the pre-stressing of the tightening screws.

**Figure 16 : Geometry of cone coupling**



## 10.3 Coupling made by key

### 10.3.1 General

As a rule, this type of system is only allowed on metallic solid rudder stock.

As a rule, keys are to be fitted in way of a tiller or quadrants or a reinforced parts of the tiller or quadrant boss.

The ends of the keyways in the rudder stocks and in the tiller or quadrant are to be rounded and corners at the bottom of the keyway are to be provided.

The key is to be embedded at half thickness in the metallic solid rudder stock.

Material constituting the key is to be such as his yield stress is not less than that of the rudder stock and that of tiller or quadrant.

### 10.3.2 Check of the key

As a rule, stresses induced either by rudder blade or steering gear on the key are to comply with the following formula:

$$\tau_{ALL} > \frac{2 \cdot M_{TR}}{d_T \cdot S_K} \cdot 10^3$$

where:

$\tau_{AAA}$ : Allowable shear stress, in N/mm², of key material to be taken not less than:

- 70/k for steel
- 30/k for aluminium alloy

$M_{TR}$ : Torque, in N.m, as defined in [2.1.3]

$d_T$ : Rules diameter, in mm, of rudder stock calculated with null bending moment as defined in [4.3.1] for steel and aluminium

$S_K$ : Surface, in mm², subject to shear force of the key.

## 10.4 Other coupling systems

### 10.4.1 General

Other type of couplings between rudder stock and tiller may be accepted by the Society on a case by case basis, provided relevant justification is submitted.