APPENDIX 1  
CRITERIA FOR DIRECT CALCULATION OF RUDDER LOADS

Symbols

$\ell_{10}, \ell_{20}, \ell_{30}, \ell_{40}$: lengths, in m, of the individual girders of the rudder system (see Fig 1, Fig 2 and Fig 3)

$\ell_{50}$: length, in m, of the solepiece (see Fig 2 and Fig 4)

$J_{10}, J_{20}, J_{30}, J_{40}$: moments of inertia about the x axis, in cm$^4$, of the individual girders of the rudder system having lengths $\ell_{10}, \ell_{20}, \ell_{30}, \ell_{40}$ (see Fig 1, Fig 2 and Fig 3). For rudders supported by a solepiece only, $J_{20}$ indicates the moment of inertia of the pintle in the sole piece

$J_{50}$: moment of inertia about the z axis, in cm$^4$, of the solepiece (see Fig 2 and Fig 4)

$C_R$: rudder force, in N, acting on the rudder blade, defined in Sec 1, [2.1.1]

$C_{R1}, C_{R2}$: rudder forces, in N, defined in Sec 1, [2.2.3].

1 Criteria for direct calculation of the loads acting on the rudder structure

1.1 General

1.1.1 Application

The requirements of this Appendix apply to the following types of rudders:

• spade rudders (see Fig 1),
• 2 bearing rudders with solepiece (see Fig 2),
• 2 bearing semi-spade rudders with rudder horn (see Fig 3).

The requirements of this Appendix provide the criteria for calculating the following loads:

• bending moment $M_B$ in the rudder stock,
• support forces $F_A$,
• bending moment $M_R$ and shear force $Q_R$ in the rudder body.

1.1.2 Load calculation

The loads in [1.1.1] are to be calculated through direct calculations based on the model specified in Fig 1, Fig 2 and Fig 3, depending on the type of rudder.

They are to be used for the stress analysis required in:

• Sec 1, [4], for the rudder stock,
• Sec 1, [6], for the rudder pintles and the pintle bearings,
• Sec 1, [7] for the rudder blade,
• Sec 1, [8] for the rudder horn and the solepiece.

1.1.3 Specific case of spade rudders

For spade rudders, the results of direct calculations carried out in accordance with [1.1.2] may be expressed in an analytical form. The loads in [1.1.1] may therefore be obtained from the following formulae:

- maximum bending moment in the rudder stock, in N.m:
  \[ M_B = C_A \left( \ell_{20} + \ell_{40} \right) \left( \frac{2}{3} C_1 + C_3 \right) \]

  where $C_1$ and $C_2$ are the lengths, in m, defined in Fig 1,

- support forces, in N:
  \[ F_A1 = \frac{M_B}{\ell_{50}} \]
  \[ F_A3 = C_R + F_A3 \]

- maximum shear force in the rudder body, in N:
  \[ Q_R = C_R \]

1.2 Data for the direct calculation

1.2.1 Forces per unit length

The following forces per unit length are to be calculated, in N/m, according to [1.3]:

• $p_R$ for spade rudders and rudders with solepiece (see Fig 1 and Fig 2, respectively),
• $p_{R10}$ and $p_{R20}$ for semi-spade rudders with rudder horn (see Fig 3).

1.2.2 Spring constant

The following support spring constants are to be calculated, in N/m, according to [1.4]:

• $Z_C$ for rudders with solepiece (see Fig 2),
• $Z_P$ for semi-spade rudders with rudder horn (see Fig 3).

1.3 Force per unit length on the rudder body

1.3.1 Spade rudders and 2 bearing rudders with solepiece

The force per unit length $p_R$ (see Fig 1 and Fig 2) acting on the rudder body is to be obtained, in N/m, from the following formula:

\[ p_R = \frac{C_R}{\ell_{10}} \]

1.3.2 2 bearing semi-spade rudders with rudder horn

The forces per unit length $p_{R10}$ and $p_{R20}$ (see Fig 3) acting on the rudder body are to be obtained, in N/m, from the following formulae:
1.4 Support spring constant

1.4.1 Sole piece

The spring constant $Z_c$ for the support in the solepiece (see Fig 2) is to be obtained, in N/m, from the following formula:

$$Z_c = \frac{6180 J_{10}}{\ell_{10}}$$

1.4.2 Rudder horn

The spring constant $Z_p$ for the support in the rudder horn (see Fig 3) is to be obtained, in N/m, from the following formula:

$$Z_p = \frac{f_B}{f_T}$$

where:

- $f_B$ : unit displacement of rudder horn due to a unit force of 1 N acting in the centroid of the rudder horn, to be obtained, in m/N, from the following formula:
  $$f_B = \frac{d}{6180 J_N}$$
- $d$ : height, in m, of the rudder horn, defined in Fig 3,
- $J_N$ : moment of inertia of rudder horn about the x axis, in cm$^4$ (see Fig 5),
- $f_T$ : unit displacement due to torsion to be obtained, in m/N, from the following formula:
  $$f_T = 10^{-3} \frac{d e \ell}{3140 F_T} \sum \frac{u_i}{t_i}$$
- $d$, $e$ : lengths, in m, defined in Fig 3
- $F_T$ : mean sectional area of rudder horn, in m$^2$,
- $u_i$ : length, in mm, of the individual plates forming the mean horn sectional area,
- $t_i$ : thickness of the individual plates mentioned above, in mm.

Figure 1: Spade rudders

Figure 2: Two bearing rudders with solepiece
Figure 3: Two bearing semi-spade rudders with rudder horn

Figure 4: Solepiece geometry

Figure 5: Rudder horn geometry