SECTION 9

Rudders, Rudder Supports, and Keels

9.1 Rudder Stocks

9.1.1 Solid Stocks

The rudder stock diameter, d, is to be not less than required by the following equation.

$$d = \sqrt[3]{\frac{32}{\pi\sigma_r}(0.5M + 0.5\sqrt{M^2 + 4T^2})} \quad \text{cm or ins.}$$

where

$\sigma_r = \dfrac{U}{1.75}$ or Y, whichever is lesser, for metals

$= \dfrac{U}{2.33}$ or $\dfrac{Y}{1.33}$, whichever is lesser, for other accepted materials

U = the minimum ultimate tensile strength of the material in N/cm² (kgf/cm², psi)

Y = the minimum yield strength of the material in N/cm² (kgf/cm², psi)

M and T = respectively the bending moments and torques, in N-cm (kgf-cm, lbf-in) imposed on the rudder stock, determined as given in 9.1.3 and 9.1.4

Changes in rudder stock diameter are to be gradual; notches are to be avoided.

9.1.2 Tubular Stocks

Where tubular stocks are fitted, the outer and inner diameters, d_0 and d_i are to comply with the following equation.

$$d = \sqrt[3]{\frac{d_0^4 - d_i^4}{d_0}} \quad \text{cm or in.}$$

where

d = the required diameter of solid stock given in 9.1.1 in cm or in.

d_0 = the required external diameter of stock in cm or in.

d_i = the required internal diameter of stock in cm or in.

The wall thickness of tubular stock is also to provide adequate local strength for the loads imposed at the lower end of the neck bearing.

9.1.3 Spade Rudders

The bending moment and torque to be used in 9.1.1 are given by the following equation.

$M_n = P\,|\,h_b - h + h_c|$ N-cm (kgf-cm, lbf-in)

$T_n = P\ell_c$ N-cm (kgf-cm, lbf-in)

$P = k\,CL_{WL}\,AN$ N (kgf, lbf)

where

M_n = the bending moment at the neck bearing in N-cm (kgf-cm, lbf-in)

T_n = the torque at the neck bearing in N-cm (kgf-cm, lbf-in)

P = the total force on the rudder in N (kgf, lbf)

k = 984 (SI), 100.4 (metric), 6.25 (lbf-in)

ℓ_c = $0.33\ell - x_\ell$, ℓ_c is not to be taken as less than 0.125ℓ

ℓ = the horizontal length of the rudder in cm or in. at the centroid of the total projected area of the rudder, see Figures 9.1 and 9.1a

x_ℓ = the distance in cm or in. at the same position, from the leading edge of the rudder to the centerline of the rudder stock, see Figures 9.1 and 9.1a

C = the lift co-efficient of the rudder and is to be taken as 1.5 for rudders having both $\dfrac{h}{\ell}$ between 2 and 6 and $\dfrac{W}{\ell} \geq 0.06$.

h_c = the vertical distance from the top of the rudder at the center of the stock to be centroid of area of the blade. For trapezoidal profile rudders, h_c may be taken as $[h(\ell_u + 2\ell_\ell)]/[3(\ell_u + \ell_\ell)]$. See Figures 9.1 and 9.1a.

h_a, h_b, h, ℓ_u and ℓ_ℓ are the distances in cm or in. as indicated in Figures 9.1 and 9.1a

L_{WL} = is as defined in 2.1

A = the total projected area of rudder in m² or ft²

W = maximum width in cm or in. of the rudder at ℓ

$N = 1.0$; where $\dfrac{\Delta}{(0.01L_{WL})^3} \geq 4304$ SI/metric units

$\dfrac{\Delta}{(0.01L_{WL})^3} \geq 120$ inch ft units

$= \dfrac{0.0265L_{WL}^2}{\sqrt[3]{\Delta^2}}$; where $\dfrac{\Delta}{(0.01L_{WL})^3} < 4304$ SI/metric units

$= \dfrac{0.00243L_{WL}^2}{\sqrt[3]{\Delta^2}}$; where $\dfrac{\Delta}{(0.01L_{WL})^3} < 120$ inch ft units

Δ = maximum estimated displacement, in metric tons or long tons

The required rudder stock diameter at and in the neck bearing is to be obtained from 9.1.1 using M_n and T_n for M and T respectively. Above the neck bearing the required rudder stock diameter is to be obtained using T_n and a value of M reducing linearly from M_n at the top of the neck bearing to zero at the rudder carrier bearing.

Below the neck bearing the required stock diameter may be gradually reduced but at a distance 0.2h from the bottom of the rudder it is to be no less than 0.46 times the required diameter at the neck bearing.

9.1.4 Semi-spade Rudders

The bending moment and torque to be used in 9.1.1 are given by the following equation.

$$M_p = \frac{F_2 h^2_C}{2} \quad \text{N-cm (kgf-cm, lbf-in)}$$

$$M_n = \frac{F_1(h^2_b - h^2_n)\left(\frac{1}{2} + \frac{\bar{x}}{8}\right) + F_2 h^2_C\left(\frac{1}{2} + \frac{h_b}{h_c} - \frac{\bar{x}}{4}\right)}{1 + \bar{x}\left(1 + \frac{h_a}{h_b} \times \frac{I_b}{I_a} \times \frac{E_b}{E_a}\right)}$$

N-cm (kgf-cm, lbf-in)

$$\bar{x} = \frac{h^3_b}{3I_b E_b h_h\left(\frac{\ell^2_h}{G_h J_h} + \frac{h^2_h}{3I_h E_h}\right)}$$

$$F_1 = \frac{P\left(A_1 + \frac{A_2}{2}\right)}{A(h - h_c)}, \quad F_2 = \frac{P\left(A_3 + \frac{A_2}{2}\right)}{A h_c}$$

$$T_n = \frac{P}{A}(A_1\ell_1 + A_2\ell_2 + A_3\ell_3) \quad \text{N-cm (kgf-cm, lbf-in)}$$

$$T_p = \frac{P}{A}(A_2\ell_2 + A_3\ell_3) \quad \text{N-cm (kgf-cm, lbf-in)}$$

where

M_p = the bending moment at the pintle, in N-cm (kgf-cm, lbf-in)

M_n = is the bending moment at the neck bearing in N-cm (kgf-cm, lbf-in)

T_n = the torque at the top of the rudder in N-cm (kgf-cm, lbf-in)

T_p = the torque at the pintle in N-cm (kgf-cm, lbf-in)

For the above locations see Figure 9.4.

ℓ_1 and ℓ_2 = $0.20\ell - x_1$ cm or in. but not to be taken as less than 0.125ℓ

ℓ_3 = $0.33\ell - x_1$ cm or in. but not to be taken as less than 0.125ℓ

ℓ = the horizontal length of the rudder in cm or in. at the centroid of areas A_1, A_2 or A_3 as appropriate and x_1 is the horizontal distance at the same position from the leading edge of the rudder to the centerline of the pintle

h, h_a, h_b, h_c, h_n and ℓ_h are the dimensions in cm or in. as shown on Figure 9.3

P and A are as defined in 9.1.3

A_1, A_2 and A_3 are the areas, in m^2 or ft^2 as shown on Figure 9.3.

I_a = is the mean moment of inertia in cm^4 or $in.^4$ of the upper rudder stock

I_b = is the mean moment of inertia in cm^4 or $in.^4$ of the rudder above the pintle

I_h = is the mean moment of inertia in cm^4 or $in.^4$ of the rudder horn

J_h = is the polar moment of inertia in cm^4 or $in.^4$ of the rudder horn at the support point

$$= \frac{4\,a^2 t}{s} \quad \text{cm}^4 \text{ or in.}^4$$

a = is the mean horizontal area in cm^2 or $in.^2$ enclosed by the outer surface of the rudder horn plating

t = is the mean plate thickness in cm or in. of the rudder horn

s = is the median rudder horn wall circumference in cm or in.

ℓ_h = horizontal distance in cm or in. from center of stock to center of a.

E_a = flexural modulus of elasticity of the upper stock, in N/cm^2 (kgf/cm^2, psi)

E_b = flexural modulus of elasticity of the lower stock or rudder body, in N/cm^2 (kgf/cm^2, psi)

G_h = shear modulus of the horn in N/cm^2 (kgf/cm^2, psi)

E_h = flexural modulus of elasticity of the horn in N/cm^2 (kgf/cm^2, psi)

The required rudder stock diameter at the neck bearing is to be obtained using M_n and T_n. Above the neck bearing, the required rudder stock diameter is to be obtained using T_n and a value of M, reducing linearly from M_n at the neck bearing to zero at the rudder carrier bearing. At the pintle, the required rudder stock diameter is to be obtained using M_p and T_p. Below the pintle, the required stock diameter may be gradually reduced but at a distance $0.2h$ from the bottom of the rudder it is to be no less than 0.46 times the required diameter at the neck bearing.

9.3 Rudder Structure

Where the rudder stocks do not extend to the bottom of the rudder, the rudder structure in way of the axis of the stock is to have bending and torsional strength, and stiffness no less than required for the stock in the same location, as required in 9.1.3 and 9.1.4; below $0.2h$ from the bottom of the rudder, the strength and stiffness may be gradually reduced until at the bottom of the rudder they correspond to that of a stock having a diameter 0.33 times the required stock diameter at the neck bearing. Where rudders are of eliptical profile, the strength and stiffness of the rudder below 0.2h from the bottom of the rudder may be gradually reduced until at a point 0.1h from the bottom of the rudder, they correspond to a stock having a diameter of 0.39 times the required diameter at the neck bearing. Strength and stiffness are to be gradually reduced below from this point to the bottom of the rudder.

Where FRP rudder is unstiffened internally, PVC foam of no less than 64 kg/m³ (4 lbs/ft³) is to be used.

9.5 Rudder Bearings, Pintles and Gudgeons

9.5.1 Rudder Bearings

Rudder bearings are in general to be arranged as shown in Figures 9.1 and 9.3. The neck bearing is to be fitted as near to the top of the rudder as practicable. The bearings are to be adequately supported and effectively attached to the hull.

The bearing pressure on rudder stock and rudder pintle bearings is to be not greater than obtained from the following equation.

$$p = \frac{R}{A_b} \text{ N/cm}^2 \text{ (kgf/cm}^2\text{, psi)}$$

where

p = the allowable bearing pressure in N/cm² (kgf/cm², psi) for steel against steel and for steel against bronze is 1037 N/cm², 105.7 kg/cm² or 1500 psi, and for steel against synthetic material is 677 N/cm², 69 kgf/cm² or 975 psi. Special consideration will be given to roller and similar mechanical bearings.

R for spade rudders
- at the carrier bearing is $R_c = M_n/h_a$ N (kgf, lbf)
- at the neck bearing is $R_n = P + R_c$ N (kgf, lbf)

R for semi-spade rudders
- at the carrier bearing is $R_c = M_n/h_a$ N (kgf, lbf)
- at the neck bearing is

$$R_n = R_c(1 + h_a/h_b) + \frac{F_1}{2h_b}(h_b - h_n)^2 - M_p/h_p \text{ N (kgf, lbf)}$$

at the pintle bearing is $R_p = P + R_c - R_n$ N(kgf, lbf)

A_b = the bearing area, d times the bearing length, in cm² or in.²

d = the actual diameter of the rudder stock or pintle in the bearing, in cm or in.

P = is as defined in 9.1.3
for spade rudders, M_n and h_a are as defined in 9.1.3
for semi-spade rudders M_n, M_p, F_1, h_a, h_b and h_n are as defined in 9.1.4

In general the length of the bearing is to be not less than 1.20d nor more than 1.5d, where d is the diameter of the stock or pintle in the bearing. The bushings are to be effectively secured in the bearings. Roller bearings will be specially considered.

9.5.2 Rudder Pintles

Pintles are in general to be cast or forged steel, other bearing materials will be specially considered. In the housing, the length of the pintle is to be not less than 1.2 times the pintle diameter and in the housing, the pintle is to be tapered about 1 in 6 on the diameter. The pintle nut is to be effectively locked to the pintle.

Where sleeves are fitted, they are to be shrunk onto the pintle; other methods of efficiently securing the sleeves will be specially considered.

9.5.3 Pintles, Gudgeons and Housings

Pintles, gudgeons and housings are to have a depth not less than 1.2 times the diameter of the pintle and a thickness outside the bore of not less than 0.5 times the diameter of the pintle. Compliance with this thickness requirement for tapered pintle housings may be based on the thickness outside the bore at the half depth of the housing.

9.7 Rudder Stock Couplings

9.7.1 Bolts

Where bolted rudder stock couplings are used, each coupling bolt is to be of steel or other approved material and is to have a diameter, d_b, at the bottom of the thread not less than the following equation.

$$d_b = \sqrt{\frac{0.382d^3}{n\,r}} \text{ cm or in.}$$

where

d = the required solid rudder stock diameter in cm or in. obtained from 9.1.1 using the minimum ultimate tensile and minimum yield strengths of the bolt material,

r = the pitch circle radius of the coupling bolts in cm or in.

n = the number of coupling bolts, generally not less than four.

The coupling bolts are to be fitted and coupling bolt nuts are to be effectively locked.

9.7.2 Coupling Flanges

Where bolted rudder stock couplings are used, the flanges are to be of steel or other approved material. Where the flanges are of material having strength properties no less than those of the coupling bolts, the thickness of the coupling flanges is to be not less than d_b in cm or in. and the minimum width of flange material outside the bolt holes is to be not less than ⅔ d_b in cm or in.

9.9 Tillers

Tillers and their connections to the stocks are to have strength equivalent to that required for the rudder stock at the rudder carrier.

Spade Rudder

FIGURE 9.2

FIGURE 9.1

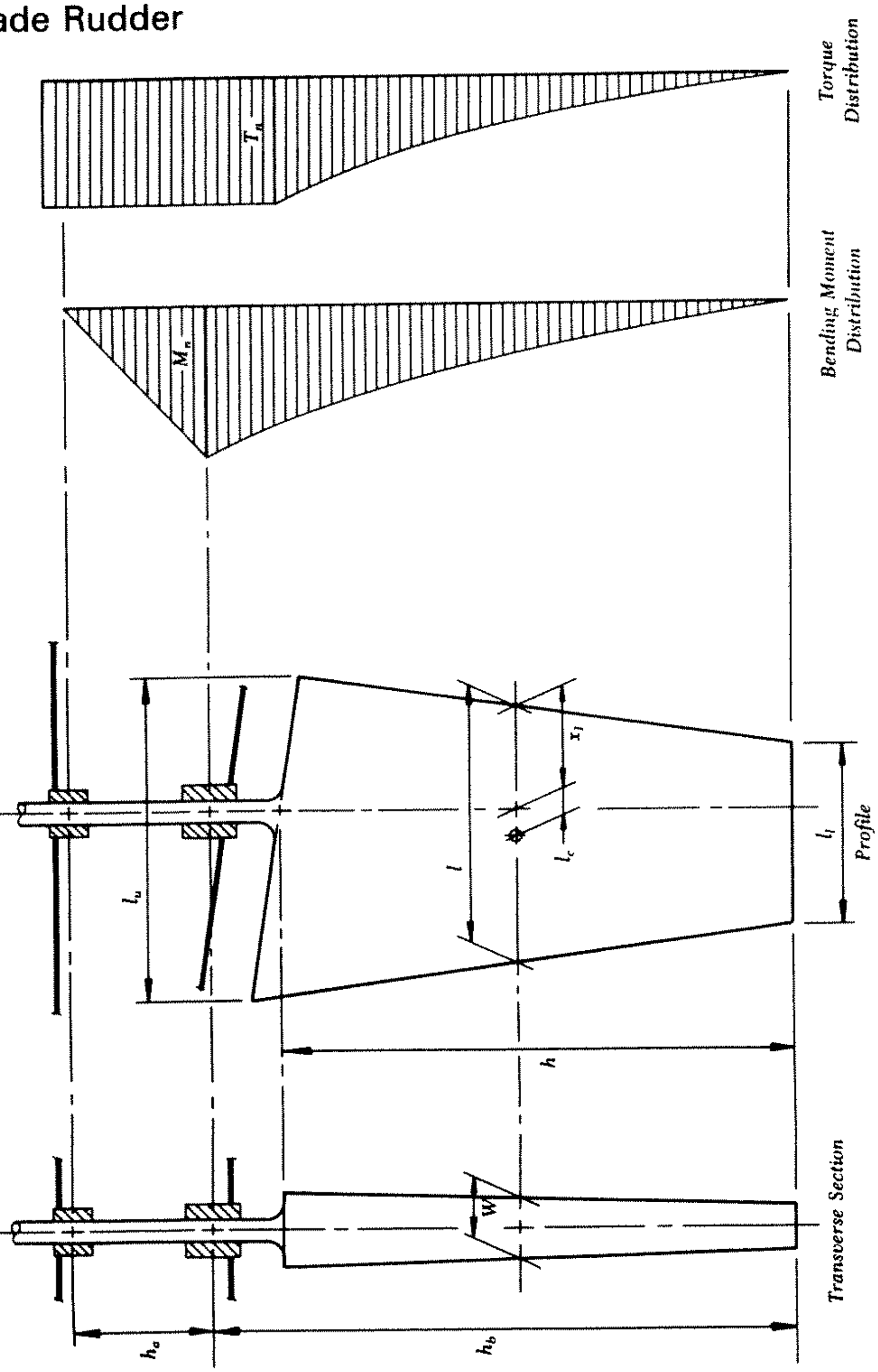
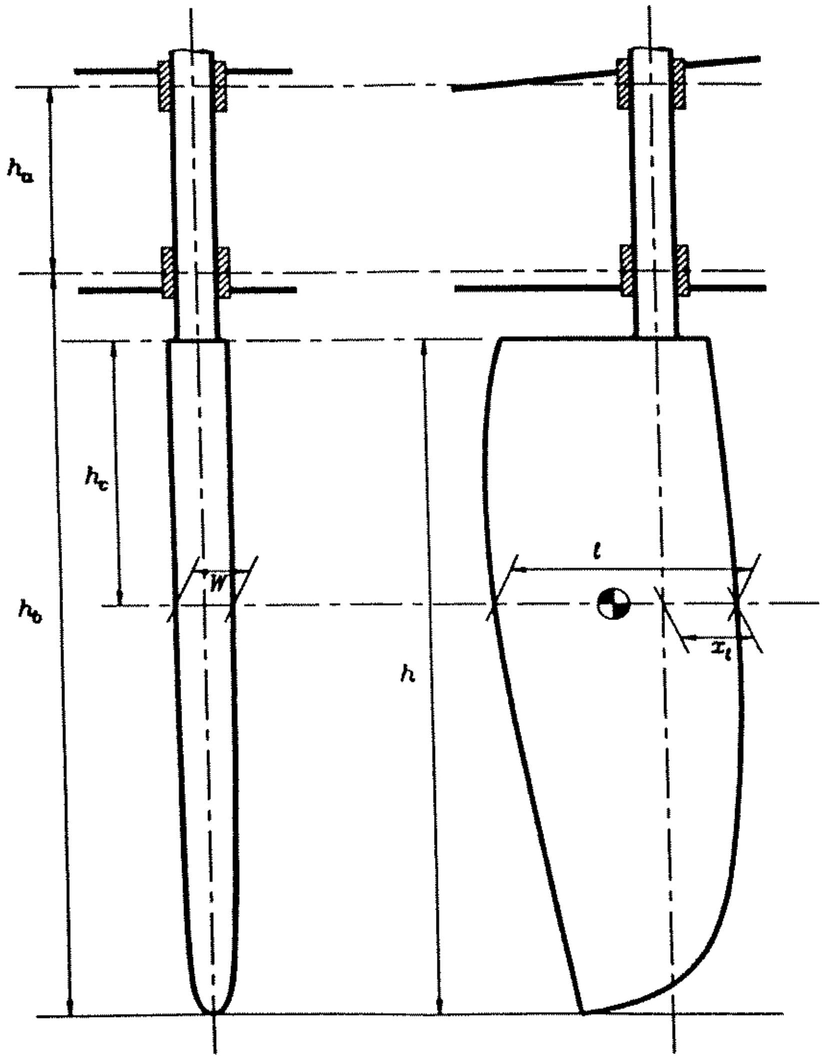


FIGURE 9.1A
Elliptical Profile Spade Rudder



Semi-Spade Rudder

FIGURE 9.4

FIGURE 9.3